The Dynamics of Wetland Water Loss in Churn Creek Protected Area: British Columbia's Semi-Arid Grassland Hydrology

by

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Abstract

Twelve Churn Creek Protected Area wetlands were characterized to gain an understanding of the potential factors affecting their water loss. Monitoring consisted of pond area, depth, and temperature measurements at twelve wetlands, and additional comprehensive monitoring at five wetlands, encompassing (1) randomized quadrat emergent vegetation sampling with canopy climate monitoring and beneath-canopy water property monitoring; (2) permanent radial soil transect sampling through compaction, electrical conductivity, moisture, and temperature measurements. Findings revealed that the rate of water loss at each wetland is dependent on its specific biological, chemical, and physical characteristics. A wetland's elevational position in the landscape, as well as its basin shape and size, and vegetative cover and density, all played a prominent role in determining the rate of water loss. These findings underscored the importance of prioritizing vegetated wetlands in future monitoring efforts and serve as a foundation for comprehensive studies in CCPA and British Columbia grassland ecosystems.

Keywords: closed-basin wetland; wetland hydrology; wetland water loss; pond evapotranspiration; semi-arid grasslands; wetland water balance

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List of Acronyms

SFU	Simon Fraser University
BCIT	British Columbia Institute of Technology
CCPA	Churn Creek Protected Area
BC	British Columbia
BEC	Biogeoclimatic Ecosystem Classification
ET	Evapotranspiration
Ta	Air Temperature
Tw	Water Temperature
RH	Relative Humidity
VPD	Vapor Pressure Deficit
REM	Reference Evaporation Model
SP	Sampling Period
DL	Dry Lake Wetland
IG	Iron Gate Wetland
CP	Coffee Pot Wetland
AG	Aspen Grove Wetland
AP	Airport Wetland
BD	Black Dome Wetland
TY	Typha Wetland
HG	Hog Lake Wetland
GH	Grasshopper Wetland
PL	Perlite Wetland
HL	High Lake Wetland
GL	Grouse Lake Wetland
WS	Weather Station
P	Precipitation
A	Area
D	Depth
V	Volume
p	Basin slope profile
EC	Electrical Conductivity
Ts	Soil Temperature
WQG	Water Quality Guidelines

Glossary

Biological Integrity	The capacity (of a wetland) to support and sustain a balanced, interconnected, and adaptable community of diverse species relative to a region.
Latent Heat of Vaporization	The energy required to transform liquid water into vapor without a change in temperature.
Hydrological Resilience	A wetland's ability to endure its current condition, withstand or assimilate disruptions, and restore itself to its original state following disturbances.
Moist Margin	The wetted area on the outskirts of a wetland pond that is influenced by the pond water balance.
Pond	A continuous body of water central in a wetland that holds connectivity and contracts and expands with water inputs and outputs.
Pond Perimeter	The continuous water's edge that still holds connectivity to the main pond.
Relative Humidity	The amount of water vapor present in the air relative to the maximum amount it can hold at a specific temperature.
Vapor Pressure Deficit	The difference between the actual vapor pressure and the saturation vapor pressure at a given temperature.
Wetland	A fixed area of land that experiences prolonged soil saturation or flooding, permanently or intermittently, and contains wetland soil and vegetation.

1. Introduction

The climate crisis presents a significant threat to wetlands worldwide, altering temperature and precipitation patterns and fundamentally disrupting their hydrology and ecological functions (Coelho, 2008; Erwin, 2009; Londe et al., 2022; Salimi et al., 2021). Current climate predictions suggest that future shifts in weather patterns are unavoidable (Calvin et al., 2023; Ficklin & Novivk, 2017; Londe et al., 2022). Wetlands face heightened radiative pressure and intensified water loss through evapotranspiration (T. Wang et al., 2016), resulting in changes in water availability, impacting wetland water levels, pond recession patterns, and the species dependent on these ecosystems (Erwin, 2009; Londe et al., 2022).

Wetland hydrology is vital for supporting biodiversity and fostering productive ecosystems (Anderson & Davis, 2013; Fay et al., 2016). They serve as essential sources of drinking water, food, shelter, and breeding grounds for a variety of mammals, amphibians, reptiles, birds, and insect species, playing a critical role in their survival (Gopal & Junk, 2000; Steen & Iverson, 2021). In addition, wetlands significantly influence vascular and non-vascular plant species density and richness through factors such as pond duration, recharge and recession timing, and water column depth (Anderson & Davis, 2013; Hayashi et al., 1998).

The importance of wetland water for the health and sustainability of grassland ecosystems, particularly in semi-arid regions like Churn Creek Protected Area (CCPA) in British Columbia (BC), cannot be overstated. In summer, freshwater sources are scarce in these dry interior ecosystems (Coelho, 2008), and the hydrological processes regulating water levels in these ponds are sensitive to changes in climate (Hayashi & van der Kamp, 2007; Londe et al., 2022). They are amongst the most venerable ecosystems to changing precipitation patterns, temperature increases (Calvin et al., 2023), and increases in evaporative pressure (Massmann et al., 2019).

Despite their significance and vulnerability to changing climate conditions, the factors governing water loss in interior wetlands, including those within the CCPA, are not thoroughly understood (Steen & Iverson, 2021). Fortunately, wetland ecosystems have been highlighted as crucial components of the CCPA landscape by BC Parks (2000) and, in response, The Friends of Churn Creek Protected Area Society has initiated long-term hydrological monitoring at 12 CCPA wetlands. My research in CCPA aims to enhance understanding of the wetland water loss dynamics at these 12 wetlands, providing valuable information to support the management and protection efforts of BC Parks, Friends of Churn Creek, Empire Valley Ranch, and the Stswecem'c Xget'tem First Nation Land Guardians.

1.1. Study Area

CCPA is situated in the southern Fraser Plateau within the Fraser River Basin Ecosection of British Columbia's Central Interior (Demarchi, 2011) (Figure 1) on the traditional territory of the Stswecem'c Xget'tem, Tl'esqox, Esk'etemc, Pelltiq't, and Yunesit'in First Nation Peoples. The provincial government established CCPA in July 1995, extending its borders in 1998 with the addition of Empire Valley Ranch, projecting a total area of 36,747 ha (B.C. Parks Division, 2000).

The Fraser River runs along the east border of CCPA. During glaciation, the Fraser River was ice-dammed causing a large lake to form and silt to settle across the landscape (Demarchi, 2011). As the glaciers melted and receded, unique geological features formed, such as kettle ponds, creating the many depressional wetlands that are found in CCPA today (B.C. Parks Division, 2000; Demarchi, 2011).

A series of cliffs and valleys that were created during the downcutting of the Fraser River and its tributaries inform the climatic patterns in CCPA (Demarchi, 2011). Solar radiation heats the topography, warm air is forced upwards, and clouds are pushed to neighbouring plateaus. These climatic events limit precipitation and cloud cover, giving way to CCPAs semi-arid climate, with annual air temperatures ranging between -10 to 24 °C (T. Wang et al., 2016). About half of the annual precipitation in CCPA falls as snow during winter, with the largest amount of rain falling in June and July. Annual reference evaporation (~650 mm) is consistently high and exceeds precipitation (~525 mm) (T. Wang et al., 2016).

Soils in the CCPA are dominantly Brown to Black Chernozemic (B.C. Parks Division, 2000; Church & Ryder, 2010). Chernozems are typically formed under grassland ecosystems (Brady & Weil, 2010), which rings true to CCPA as it hosts some of BC's rarest grassland ecosystems. The Bunchgrass Biogeoclimatic Ecosystem Classification (BEC) is prevalent in the lower and middle elevational grasslands that dominate CCPA, while an Interior Douglas Fir BEC prevails at higher elevations (B.C. Parks Division, 2000).

Wetlands in CCPA span across these BEC zones over an elevational gradient, ranging from approximately 600 m to 1400 m, and covering around 49 ha of CCPA (Steen

& Iverson, 2021). At lower elevations, upland areas are characterized by bunchgrass ecosystems with sparse tree coverage and areas with big sagebrush shrub-steppe. As elevation increases, Douglas fir forest cover becomes more prominent, with ongoing encroachment on established grasslands.

The wetlands occupying these systems are commonly Shallow Open Water and largely Marsh wetland classes (Steen & Iverson, 2021). Eighteen distinct marsh plant communities have been recorded in CCPA, often occurring in complexes of two or more which are frequently found as a fringe around the perimeter of Shallow Open Water wetlands or as mosaic patches within a dominant marsh type (Steen & Iverson, 2021).

1.2. Wetland Hydrology

Approximately 75 wetlands are found across CCPA, the majority of which are closed-basin depressional wetlands with perched water tables that experience varying degrees of inundation, ranging from permanent to intermittent (Steen & Iverson, 2021). These closed-basins, or sometimes wetland complexes, operate as closed systems, meaning they are hydraulicly isolated from persistently inflowing water bodies (Coelho, 2008; Hayashi et al., 2016). Changes in their water storage are determined by their hydrologic inputs and outputs, with wetland water balances exhibiting strong seasonality due to the climate in CCPA. This seasonality is characterized by the quick recharging of wetlands by spring snowmelt from their local watersheds and a consistent net loss of water in summer months.

Water contributions to closed-basin wetlands are inclusive of watershed and direct hydrological inputs, including overland flow, subsurface water, and direct precipitation. Due to CCPA's semi-arid climate, these inputs are minimal during summer months and are primarily through direct precipitation. Rainfall across the watershed is largely used by vegetation or retained in the soil, with few wetlands receiving subsurface flow from neighboring sources with the exception of intense rainfall events due to the high infiltration capacity and evaporated demands of semi-arid landscapes (Hayashi et al., 1998).

Hydrological outputs are primarily terrestrial and aquatic evaporation and transpiration, collectively referred to as evapotranspiration (ET), with marginal and often insignificant, subsurface loss. In summer, outputs are strong. ET rates are driven by the degree of solar radiation, wind speed, air temperature (Ta), and humidity a wetland experiences (El-Dessouky et al., 2002; Harne et al., 2023).

Other biophysical properties such as basin shape, soil and water properties, emergent and riparian vegetation, animals, and disturbances can dynamically interact with a wetland’s water balance, complicating the understanding of the spatiotemporal hydrological losses at each wetland due to the diverse nature of each wetland.

The distinctive characteristics of each wetland's pond basin makes it challenging to precisely ascertain the water volume it contains at any given time. The interplay of basin shape and the area-depth relationship, influenced by land elevation distribution within the depression, largely governs wetland water volumes (Hayashi & van der Kamp, 2000; Minke et al., 2010).

A wetland’s water temperature (Tw) can significantly impact evaporation by influencing the energy level of water molecules. As Tw rises, the molecules gain more kinetic energy, making it easier for them to transition from the liquid phase to the vapor phase (Kadlec, 2006). This process is facilitated by the latent heat of vaporization, which is the energy required to transform liquid water into vapor without a change in temperature (Taiz et al., 2018). As the Tw warms, more molecules acquire the necessary energy to overcome intermolecular forces and evaporate (Kadlec, 2006). As such, warmer wetland surface water may lead to higher rates of evaporation.

The conductivity of wetland water, influenced by dissolved ions like salts, can affect water loss rates (El-Dessouky et al., 2002; Mor et al., 2018). High conductivity increases heat retention (Ogungbe et al., 2015) and may reduce evaporation rates (Mor et al., 2018). Dissolved salt ions lower water activity and vapor pressure, hindering evaporation and creating a complex interaction between conductivity and temperature (Mor et al., 2018).

Emergent vegetation, the moist margin of the pond, and its surrounding upland area, collectively undergoes ET, with the latter two components drawing water from the pond through the soil. Water from the wetland is transported to upland areas through horizontal groundwater flow, facilitated by a zone of high conductivity and a hydraulic pressure gradient that is created by transpiring vegetation (Hayashi et al., 1998). Landcover type, including the species and density of vegetation, across a wetland (Kiniry et al., 2023) and its catchment (Hayashi et al., 1998) plays a substantial role in the rate of ET (Jansen et al., 2023).

Emergent vegetation can also significantly shape the microclimate above a pond’s surface, which in turn influences the evaporative dynamics within the canopy. By intercepting solar radiation and reducing wind exposure to the pond surface, emergent plants modulate Ta and relative humidity (RH) within the canopy (Goulden et al., 2007;

Jansen et al., 2023); RH being the amount of water vapor present in the air relative to the maximum amount it can hold at a specific temperature (ECCC, 2023). The interception of solar radiation by emergent vegetation not only mitigates direct heat transfer to the water but also fosters a cooler microclimate within the canopy (Eichelmann et al., 2018; Goulden et al., 2007). Moreover, by sheltering the water surface from direct wind exposure, emergent plants help maintain higher levels of humidity in the air (Eichelmann et al., 2018). However, the alteration of air movement within the canopy can lead to the accumulation of warmer air, potentially exacerbating the vapor pressure deficit (VPD). As the VPD is the difference between the actual vapor pressure and the saturation vapor pressure at a given temperature (Schönbeck et al., 2022), it is a crucial factor governing the gradient driven evaporative losses from a wetland (Jansen et al., 2023). With reduced air circulation within the canopy, warmer air temperatures prevail, which, in turn, can increase the capacity of the air to hold water vapor. Consequently, the VPD rises, amplifying the driving force for evaporation from the water surface.

Furthermore, the shading effect provided by denser and taller canopies, or canopies with dense litter mulches, further impacts microclimates by reducing the intensity of solar radiation reaching the water surface. This attenuation of light penetration into the water column reduces the heating of the surface water and contributes to the maintenance of cooler temperatures, which can mitigate the rate of evaporation (Goulden et al., 2007; Kadlec, 2006). Moreover, upland vegetation surrounding the wetland, such as trees, may impede airflow and disrupt turbulent transport of vapor within the wetland system. This obstruction to airflow can create pockets of stagnant air, potentially leading to localized increases in temperature. Thus, the combined influence of emergent and upland vegetation on the microclimate above wetlands underscores their significance in modifying evaporation rates and overall water balance within wetland ecosystems.

The interaction of animals, particularly cattle, with CCPA wetlands could significantly impact wetland water balance. Livestock grazing, primarily through activities like treading and herbivory, can greatly accelerate the quantity of water lost, with each mature cow consuming about 40 liters of water daily (Brown, 2006). With the presence of larger herds, this substantial water demand can lead to significant water loss and soil disturbance, essentially leading to the alteration of various wetland hydrological processes (Brown, 2006; Hayashi et al., 2016; Morris & Reich, 2013; Pietola et al., 2005; Pyke & Marty, 2005).

Landscape disturbances have the potential to alter the hydrological regimes of wetlands. In CCPA, primarily used for recreation, hunting, and ranching, anthropogenic alterations and ongoing disturbances are relatively minimal due to its remote location. However, roads and agricultural activities can still interfere with the natural water flow within the watershed, potentially disrupting water courses and affecting soil processes, including erosion occurrence.

Likewise, wildfires on the landscape can alter soil properties and functioning. Fires, especially, high intensity, induce soil hydrophobicity, leading to increased runoff and damage to soil structure, resulting in higher bulk density and impacting soil water movement (Agbeshie et al., 2022). Climate changes, namely rising temperatures and decreased precipitation, may exacerbate these disturbances by promoting more frequent and severe fires due to prolonged drought conditions. The resilience of the grassland ecosystem, wetlands, and their hydrology to wildfire activity are uncertain as we face unknown climatic conditions.

The hydrological dynamics of water loss are complex and multifaceted. The interplay of these factors shapes the water storage and loss patterns in wetlands, with implications for their ecological functioning and water availability for the species that rely on them. Understanding these underlying hydrological processes and what affects them is crucial for effective wetland management, particularly in the face of our changing climate.

1.3. Reference Evaporation Model

The permanence of wetland ponds is crucial for effective rangeland management as they serve as essential water sources for cattle. However, the changing climate contributes to the loss of wetlands in grassland ecosystems, such as those found in the CCPA (Coelho, 2008). Recognizing this challenge, Pantel Environmental has developed a Reference Evaporation Model (REM) to assess the resilience of wetland ponds to water loss. This model has demonstrated success in Saskatchewan, specifically in forecasting water losses in prairie pothole wetlands. Building upon its proven effectiveness, the BC Cattlemen’s Association seeks to expand the application of this model to ranches in the interior grasslands of BC (A. Pantel, personal communication, April 27, 2023).

However, in the Upper Assiniboine River Basin in Saskatchewan, where the model’s volume regression equation was derived, the elevation span ranges from 296 to

877 m (Anis & Sauchyn, 2022), with flat to low-relief terrain (Rannie, 2001). In CCPA, the wetlands have a wider elevation range (~600-1400 meters) and variable topographical traits ranging from flat to mountainous upland areas. Consequently, there are questions about whether evaporative losses in CCPA will be like those in the prairies, despite both being in semi-arid climates. Accordingly, this initiative by Pantel Environmental and the BC Cattlemen's Association aims to evaluate the suitability of the model as a management tool in BC's diverse grassland landscapes, including those found in CCPA.

The model uses data on wetland ponded area and historical monthly meteorological averages in precipitation and reference evaporation to forecast both current and future evaporative losses from wetland ponds. Predictions of monthly area and volume, spanning from springtime pond-full volume to the end of summer, are generated using a regression analysis approach outlined by Wiens (2001) after determining the initial pond area through geographic information system data.

The regression formula, designed for application in hydrological models, was formulated based on a study conducted in the Saskatchewan Upper Assiniboine River Basin by Wiens (2001). This study unveiled a notable correlation between the surface area and volume of ponds measuring under 10 ha, with the most accurate predictive outcomes observed for ponds under 4 ha. A lower limit of 2 ha was established, as smaller ponds were categorized as unreliable water sources for season-long use by cattle.

The majority of the wetlands in CCPA are small kettle ponds measuring below 1 ha in size, primarily due to the distinct watershed topography of the CCPA (Steen & Iverson, 2021). Despite their crucial role in the ecosystem, these small ponds are deemed unreliable water sources. The prevalence and reliance on such small wetlands in the CCPA highlight the necessity for a predictive risk model to assess water resilience for effective wetland conservation. This REM holds value not only for livestock management at Empire Valley Ranch in the CCPA but also has the potential to assist BC Parks in managing and safeguarding wetland ecosystems across BC, thus protecting them from permanent dry out.

1.4. Wetland Assessment

Hydrological resilience refers to a wetland's ability to endure its current condition, withstand or assimilate disruptions, and restore itself to its original state following disturbances (Zhang et al., 2019). Assessing the vulnerability and resilience of wetland ecosystems is crucial for their long-term conservation and management, particularly in the face of our climate crisis. Rising temperatures and shifting precipitation patterns will exacerbate water scarcity, affecting wetland hydrology, biodiversity, and overall ecosystem health (Londe et al., 2022). Wetlands with stable pond permanence are better equipped to adapt to these changes, as they can retain water and support healthier ecosystems despite increased water loss. However, variations in annual water levels are normal, making long-term monitoring and assessment of hydrological conditions essential for tracking permanent changes.

Variables influencing water storage and other chemical, biological, and physical aspects inherent to wetlands can serve as indicators of wetland health and resilience (Adumus et al., 2021; Government of Alberta, 2016; J. Karr et al., 2021). Monitoring pond water quality in accordance with the BC Water Quality Guidelines (2023) enables the tracking of ongoing chemical alterations and potential threats to native terrestrial and aquatic species, as well as cattle. Assessing biological integrity, defined as a wetland's capacity to support and sustain a balanced, interconnected, and adaptable community of diverse species relative to its region (J. R. Karr & Dudley, 1981), through multiple biological matrices, offers a means to evaluate the cumulative impacts of physical and chemical changes in a wetland (J. Karr et al., 2021; J. R. Karr, 1991; U.S. EPA., 2002), and determine a wetland's biological significance to native species. Disturbances ranging from benign to those that entirely modify wetland processes or characteristics. Understanding the differences between these and effectively tracking them, facilitates early detection of issues that could inform wetland management and protection.

Achieving a comprehensive understanding of wetland vulnerability within CCPA necessitates monitoring and establishing baselines for multiple parameters. The insights derived from these assessments will be invaluable for CCPA management stakeholders and First Nation governments, guiding strategic conservation efforts aimed at enhancing the resilience and longevity of wetland ecosystems in the region.

2. Research Goals and Objectives

For my study, 12 CCPA wetlands were monitored from May 18 to August 22, 2023. These wetlands spanned across CCPA and were found in multiple BEC zones. They experience different mesoclimates and have varying watershed sizes, topographical traits, vegetative qualities, and stressors - all which impact their temporal water level and pond recession patterns.

Accordingly, the primary goal of my research was to gain a comprehensive understanding of the potential factors contributing to water loss at these wetlands. I aimed to answer the following questions: What physical, chemical, and biological characteristics do each of the wetlands possess or experience that could contribute to their water loss from May to August? Can a Reference Evaporation Model forecast the change in water storage in CCPA wetlands given their diverse characteristics? Could protective or restorative actions increase the inundation duration specific to each of the wetlands?

My objectives were to: 1) characterize each wetland to gain an understanding of the potential factors that could affect their water loss, including mesoclimatic conditions, pond area, depth and volume, water and soil physical and chemical properties, emergent vegetation characteristics, animal use, and disturbances; 2) verify the predictive accuracy of the Reference Evaporation Model in comparison with the water loss quantified in selected wetlands to gauge its efficacy as a wetland management tool in CCPA; and, 3) assess the condition of the selected wetlands and offer recommendations for the protection and restoration of those that are vulnerable or damaged.

3. Methods

The hydrological fluctuations and seasonal changes of 12 wetlands across CCPA were monitored by measuring a variety of physical, chemical, and biological properties over a 3 month period in 2023, from May 18 to August 22.

The monitoring completed at these 12 wetlands was comprised of pond area and depth measurements, and ongoing Tw monitoring via HOBO thermometer installation. Additional monitoring was completed at five of these wetlands and encompassed both emergent-vegetation and soil sampling, and was inclusive of: within- and above-canopy atmospheric conditions, including Ta, RH, and wind speed; within-canopy water chemical properties, including Tw, electrical conductivity, total dissolved solids, and pH; emergent vegetation height and percent cover; soil compaction, moisture, and pH; and photo monitoring.

The five selected wetlands were sampled 6 times, approximately every 20 days. The remaining 7 wetlands were sampled a minimum of 2 times (at the start and end of the study) to a maximum of 4 times. These sampling dates were determined by my proximity to the location, and available time and resources. Six sampling periods (SP) were consequently outlined: **SP 1** - May 18-20; **SP 2** - May 31-June 6; **SP 3** - June 20-23; **SP 4**- July 10-13; **SP 5** - July 29-August 2; and **SP 6** - August 18-22. A summary of when samples were taken is available in Table 1.

For the purpose of this study, the delineation terms for a wetland and its catchment described by (Hayashi et al., 2016) will be used (Figure 3). A wetland is defined as a fixed area of land that experiences prolonged soil saturation or flooding, permanently or intermittently, and contains wetland soil and vegetation; a wetland pond is a continuous body of water central in a wetland that holds connectivity and contracts and expands with water inputs and outputs; and a wetland's moist margin is the wetted area on the outskirts of the wetland pond that is influenced by the pond's water balance.

3.1. Wetland Selection

The 12 wetlands chosen for my study were Dry Lake (DL), Iron Gate (IG), Coffee Pot (CP), Aspen Grove (AG), Airport (AP), Black Dome (BD), Typha (TY), Hog Lake (HG), Grasshopper (GH), Perlite (PL), High Lake (HL), and Grouse Lake (GL) wetlands. Their classifications were described during a reconnaissance by Steen & Iverson (2021) and are summarized in Table 2. Four of these wetlands were described as 95-100% (IG, AG, AP, BD) Common spike-rush marshes – types Wm04 or Wm04a(Steen & Iverson, 2021). Five of these wetlands were described as 52-90% Shallow open water wetland – types Ww, Wwa, or Wwx (CP, HG, GH, HL, GL). These five had various sized vegetated fringes around their perimeter of the following marsh types: Saltmarsh bulrush – Wm11 (CP), Sharp bulrush – Wm08 with Great bulrush - Wm06 (HG), Common spike-rush – Wm04 (GH), and Baltic rush – Wm07 with either Great bulrush - Wm06 (HL) or Inflated sedge - Wm09 (GL). The final three wetlands were described as a Cattail marsh - Wm05 (TY), a Beaked sedge-Water sedge marsh – Wm01 (PL), and a River bulrush-saltmarsh bulrush hybrid marsh – WmBolbflu (DL). Many of these wetlands, especially BD, have diverse patches of species throughout these dominantly described marsh types. Refer to Appendix A for photos of each wetland.

Of these twelve wetlands, five wetlands were selected for comprehensive monitoring (IG, AP, BD, GH, and HL). These wetlands represented a gradient across the elevational span of CCPA (highlighted in Table 2) and, to reduce variation, they all lacked woody vegetation in their immediate riparian area, had little potential for unknown groundwater inflow, and had a relatively comparable size. Wetlands with grassy riparian areas were desired because it was assumed that nearby woody vegetation could significantly impact their water balances through high and variable rates of ET; therefore, wetlands with a substantial amount of woody vegetation were excluded. Reasons for exclusion included: a burned grove of Aspen trees at AG wetland, a partially wooded riparian area that included confers and willows at TY wetland, an Interior Douglas Fir forest adjacent to PL and GL, and a large section of willow dominated brush along the north-east edge of DL. IG did have a large patch of roses along its north-west edge; however, AP contained emergent roses within its pond and were therefore not considered as a terrestrial woody species for this study. Wetlands that were suspected of continuous groundwater inflow from neighboring sources after initial spring recharge were also omitted. CP, HG, and TY wetlands all have wetlands upland from them, which had potential to contribute to their water volume through groundwater inflow. Lastly, two wetlands, DL and HG, were substantially larger in area than the other wetlands (approximately four to eighty times and three to eighteen times larger, respectively). The large area of the wetlands did not accommodate the sampling design, as the number of samples would have to proportionally increase, impacting data collection timing and consistency, and thus were consequently not selected for comprehensive monitoring.

3.2. Wetland Characterization

3.2.1. Mesoclimate

Climate data was sourced from three weather stations (WS) across CCPA (Figure 2). At the lowest elevation, the Dry Lake WS sits at an elevation of 640 m and has been monitored by Friends of Churn Creek since 2021. At a mid-elevation point, the Coffee Pot WS is located at 885 m, which was installed during this study on June 16, 2023 (Figure 4). Lastly, Dry Farm WS, operated by BC Parks, is at an elevation of 1088 m.

Precipitation (P), Ta, and RH data from May 18 to August 22, 2023, was pulled from Dry Lake WS and Dry Farm WS. Coffee Pot WS data began recording on June 28 when the loggers were initiated. Dry Lake WS and Coffee Pot WS climate data recorded 4 times an hour at 15 minute intervals, whereas Dry Farm WS data recorded every hour. Accordingly, for P, the 4 values associated with each hour (ex. 1:00, 1:15, 1:30, 1:45) at Dry Lake WS and Coffee Pot WS were totaled, and the hourly value (ex. 1:00) was used for Ta and RH, so that all data resembled that of Dry Farm WS.

Dry Farm WS data downloaded with many missing data points. For P and RH, missing values were left blank. Accordingly, Dry Farm WS total values were underreported for these variables. For Ta, where one to three data points were missing concurrently, the mean values between the two given points were averaged to estimate missing values. Where four to five data points were missing concurrently, values that were in the upward or downward diurnal periods were estimated in the same fashion. If missing values included daily high and low peak Ta times, the missing data was not estimated but left blank. Days with missing data included May 23, June 3, 7, 8, 10, 12, 13, 22, and July 10-12. Even with these added estimates, mean Ta was slightly underreported.

The analysis of the WS data included the calculation of total P, and mean, minimum, and maximum Ta and VPD at each WS during the cooler spring period (before June 28) and warmer summer period (after June 28). VPD was calculated using Ta and RH data with the Tetens formula, presented by Schönbeck et al. (2022), and is expressed as:

Equation 1

$$VP_{act} = \frac{RH \times VP_{sat}}{100}$$

Equation 2

$$VP_{sat} = 0.6108 \times e^{17.27 * Ta/237.3 + Ta}$$

Equation 3

$$VPD = VP_{sat} - VP_{act}$$

Where VP_{act} is the actual vapor pressure, and VP_{sat} is the saturated vapor pressure at a given Ta in °C.

3.2.2. Water Storage

The fluctuation of stored pond water was monitored across all 12 wetlands. The total ponded areas (A) and column depths (D) were measured, and then used to estimate wetland water volume from SP 2 (May 31-June 6) to SP 6 (August 18-22). In instances where wetlands dried completely, meaning they had no pond present, dry out dates were estimated using apparent outlying Tw data and wildlife camera observations of pond water.

Ponded Area

To calculate the total ponded area, the pond perimeter was walked with a Garmin GPSmap 62s using the Area Calculate function (Figure 5). In situations where delineating the perimeter proved challenging due to factors such as vegetation causing sight obstruction and blocked access, cattle plugging causing water filled holes, or the natural shape of the basin causing multiple smaller or abnormally shaped pools to form, a best-guess perimeter route was chosen during sampling.

The number of area measurements conducted over the study period varied among the wetlands and depended on the frequency of visits (Table 1). Initial measurements for all wetlands were taken during SP 1, apart from TY, and final measurements were taken during SP 6. The dense woody vegetation on the perimeter of TY wetland restricted sampling, thus its first area measurement occurred during SP2.

For SPs where an area measurement was not obtained, an estimated value was assigned by averaging the change in area between two measured sampling points across the number of days between them. The date in which the nearest wetland was sampled was selected as its sampling date. These estimated values were used in other analyses, such as the water volume estimations and the verification of the REM.

Water Depth

The water column depth was measured with a 4-meter foldable wooden surveying staff at the deepest identified point near the HOBO thermometer location (see 3.2.3. Water Temperature methods), from the basin bottom to the water surface. The initial water depth measurements were conducted during SP 2 and were measured to the nearest 0.5 cm. Water depths were recorded in the same manner at every sampling visit thereafter. These measurements were taken from two to five times for each wetland depending on the frequency of visits (Table 1). In instances where the underwater vegetation did not obstruct the measurement process and the water depth was less than approximately 1 m, a millimeter measuring tape was used instead of the staff to enhance accuracy.

Where a depth measurement was not obtained, the average change in depth was calculated between two measured values for each wetland for use in further analyses, again to assist in volume estimations and the REM verification.

Water Volume

The water volume of the 12 wetlands were estimated using the measured and estimated area and depth data with the full volume-area-depth method created by Hayashi et al. (2000), and reported on by Minke et al. (2010), with a modification that used the simplified method to obtain the *s*-coefficient. This method uses the *A-D* and *V-D* relationships, along with the basin pond slope profile (*p)*, to estimate water storage in depressional wetlands. Water volume (*V*) is estimated based on *p* and is obtained using concurrent *A* and *D* measurements. The larger the *p* value obtained, the steeper the profile slope between two points. The *p*-coefficient was calculated using a power *A-D* line equation specific to each wetland. Its value equals 2 divided by the power exponent. The *V* equation is as follows:

Equation 4

$$V = \frac{s}{(1 + 2/p)} \frac{D^{1+(2/p)}}{{D_o}^{2/p}}$$

Where *s* is the basin size coefficient and equals the area of the pond when *D* = 1 m; *D* is the wetland depth at any given time; and D_o is the unit depth (1 m). The *s*-coefficient was calculated using the following equation:

Equation 5

$$s = A_1 \left(\frac{D_1}{D_0}\right)^{-2/p}$$

Where D_1 is the lowest measured depth above the minimum depth (D_{min} = 0 m), A_1 *is its associated area,* and h_0 is the unit depth (D_0 = 1m).

Where final depth and area measurements equaled zero (D_{min}), their values were removed before plotting the power regression. Outlying values were omitted in the same fashion to achieve the best fit line. Where there were limited data points, like for GH, and the final line equaled D_{min}, a value of 0.1 was given for *A* and *D,* as was done by Minke et al. (2010).

3.2.3. Water Temperature

Wetland Tw was measured with semi-permanently installed HOBO data loggers. Onset HOBO UTBI-001 TidbiT v2 and U22-001 Pro v2 Water Temperature Data Loggers (±0.21 ^{o}C accuracy) were deployed in all 12 wetlands during SP2 (Table 3). To secure logger placement, HOBOs were tethered to a line and anchored to the basin bottom using a brick and float, suspending them 15 cm from the bottom at all wetlands. Where the water column depth allowed, additional HOBOs were suspended at depths of 45 cm and 75 cm. HOBO type was based on availability, but generally Pros were suspended at 15 cm, and TidbiTs at 45 cm and 75 cm.

In 11 of the 12 study wetlands, HOBOs were installed at a single location. At IG, CP, AP, AG, BD, TY, HG, GH, and PL, water depth measurements were taken at multiple spots using a 4-meter foldable wooden measuring staff within a 2 m radius around pre-existing surface water level monitoring well. At the deepest identified point, the appropriate number of loggers were installed on a weighted line. HL and GL had water depths exceeding chest wader height at installation time, as such HOBOs were placed at the deepest accessible location within arm's reach after wading in. Note: HG depth was over chest wader height; however, there was a surface water level monitoring well relatively deep within the wetland, so installation methods mimicked smaller wetlands.

Given the substantial size of DL, two installation locations were chosen based on the location of pre-existing surface water level monitoring wells within the wetland and riparian zone. Areas that were relatively open and minimally vegetated near the surface water level monitoring well locations were measured for depth, with the deepest spots selected for HOBO installation.

It's important to note that most HOBOs were installed relatively centrally within their respective wetlands. However, in the cases of DL, HG, HL, and GL, the HOBOs were notably off-center. HG and both DL HOBOs were situated closer to the perimeter due to the large size of these wetlands and the placement of surface water level monitoring wells. HL and GL HOBOs were approximately a quarter to a third of the way from the center depth.

The HOBO loggers remained in the wetlands until there was no water remaining or until SP6, whatever came first (Table 3). There were two exceptions to this protocol: at AG, a new HOBO had to be deployed on July 10 (SP4) as the first one had gone missing in June, and on July 2 I found that there was potential movement of IG HOBO. Both instances were attributed to bear activity. Data from the HOBOs were downloaded when they were retrieved from their respective wetlands.

The collected data was cleaned by removing the start and end of the time series data when the HOBOs were not in the water. Abrupt changes in Tw assisted in the estimation of dry out dates, as did the comparison between Tw and Ta, and observations from the wildlife cameras. Data collected from the two HOBOs at DL were very similar, so they were averaged to represent the whole wetland.

3.2.4. Water Chemistry

Water samples were collected at the 12 wetlands during SP2 for chemical analysis of ions, dissolved metals, electrical conductivity, pH, and alkalinity. Samples were collected using sanitized sample bottles obtained from ALS laboratory, whereafter they were kept on ice until they were returned to the lab. A second round of sampling was completed during SP6 at the wetlands that still stored water (DL, AP, CP, HG, PL, HL, GL) (Table 1).

For both lab analyses, inorganic anions were analyzed by Ion Chromatography with conductivity and/or UV detection, and to assess for dissolved metals, water samples were filtered (0.45 um), preserved with nitric acid, and analyzed by Collision/Reaction Cell ICPMS. To obtain the ion balance using dissolved metals, the cation sum, anion sum, and ion balance were calculated based on guidance from APHA Standard Methods (1030E Checking Correctness of Analysis). Dissolved species were used where available and minor ions were included where data was present. Electrical conductivity (EC) was measured by immersion of a conductivity cell with platinum electrodes into a water sample. Conductivity measurements were temperature-compensated to 25°C. pH was determined by potentiometric measurement with a pH electrode and was conducted at ambient laboratory temperature (normally 20 ± 5°C). Finally, total alkalinity was determined by potentiometric titration to a pH 4.5 endpoint. Bicarbonate, carbonate, and hydroxide alkalinity were calculated from phenolphthalein alkalinity and total alkalinity values.

The lab results were compared to the British Columbia Approved Water Quality Guidelines (British Columbia Ministry of Environment and Climate Change Strategy, 2023), to assess the normalcy of the results.

3.2.5. Soil Properties

Sampling for soil moisture, soil temperature (Ts), EC, and compaction was conducted at the five selected wetlands (IG, AP, BD, GH, HL). This sampling effort involved establishing four fixed radial transects situated 4 m to the left of each cardinal point and centered around the installed HOBO float at each wetland (Figure 5). Soil sampling activities commenced on the same day as the HOBO installation during SP 2 (Table 3).

The pond perimeter (0 m) at the designated cardinal transects served as reference points for all subsequent sampling throughout the study period (Figure 5). On day one of sampling, the surveying tape was laid up the riparian zone from the 0 m reference point, and one initial riparian measurement was recorded at 0.25 m. Approximately every 20 days thereafter (Table 1) the same riparian measurement was repeated and followed by repositioning the survey tape from the 0 m point down the moist margin towards the HOBO float. All applicable measurements were taken in meter intervals, with the first at -0.25 m and the last at the newly determined receded pond perimeter. In cases where the pond was dry, the transects extended from 0 m all the way to the central HOBO float location.

Moisture (m^3/m^3), Ts (°C), and EC (bulk ds/m) measurements were obtained using a ProCheck Soil Sensor. To capture these measurements, the ProCheck sensor prongs were inserted into the top layer of the mineral soil horizon. When encountering a substantial organic horizon, efforts were made to expose the mineral horizon by separating the organic layer before inserting the prongs. If the soil proved too compacted or hard to penetrate, a hori hori knife was employed to create a slit in the soil to facilitate prong insertion. In instances where the soil remained impervious to both prongs and the hori hori knife, measurements were not feasible. In cases where the EC reading registered as 0 ds/m, and moisture and Ta measurements were still recorded, the prongs were temporarily removed, and approximately 1 tbsp of deionized water was dispensed into the hole before reinserting the prongs to obtain a revised reading.

Soil compaction pressure (psi) and depth (cm) were assessed using a soil penetrometer. Like the ProCheck Sensor, the penetrometer rod was inserted along the radial transects. When taking measurements, the rod was inserted 0.5 m up the riparian zone and down the basin from the 0 m reference point. A ½ inch tip was employed when the soil proved to be more resistant, while a ¾ inch tip was used when the soil was softer.

As the rod was inserted, the compaction needle was monitored, and the prevailing compaction level was recorded. The compaction levels were categorized as follows: 0-200 psi, 200-300 psi, and 300+ psi. Upon removal of the rod, the portion of the inserted rod was measured to determine the total penetration depth. Additionally, any noticeable changes in soil texture and variations in penetration difficulty encountered during the probe's passage through the soil profile were carefully noted.

3.2.6. Vegetation Cover

Emergent vegetation sampling was conducted at the five selected wetlands (IG, AP, BD, GH, HL). There was a diverse abundance and species profile of emergent vegetation across these wetlands which often formed patches across the dominantly vegetated and exposed water areas. To achieve a comprehensive representation of the canopy characteristics, patches of emergent vegetation with areas exceeding 10 m^2 were sampled using a 1x1 meter PVC quadrat. To randomize the sampling process, one side of the quadrat was haphazardly thrown into the patch and then rebuilt in place. In cases where tossing the quadrat was impractical, such as when vegetation was quite tall (above 2 m) or when the area was primarily exposed water, the built quadrat was tossed or walked into place with guidance from a field assistant. Patches smaller than 10 m^2 were deemed inadequate for representing the wetland or were considered too small to have a significant impact on water loss processes.

The number of 1x1 m quadrat samples collected at each wetland equated to 20% of the number of 50 m^2 patches per total ponded area (Equation 6). Patch areas were measured by walking their perimeters with a Garmin GPSmap 62s (Figure 5).

Equation 6

$$n^{total} = \frac{A^{total}}{50\ m^2} \times 20\%$$

where n^{total} was the total number of samples taken at each wetland, and A^{total} was the total wetland area (m^2) during that SP.

To ensure adequate representation of each patch and dominant cover type, the number of quadrats sampled in each patch was based on its size (Table 4). Patches with areas exceeding 10 m^2 but falling under 50 m^2 were sampled with a single quadrat. Patches with areas exceeding 50 m^2 and falling under 100 m^2 were sampled with two quadrats. Once patches exceeded 100 m^2, they were considered more homogenous, requiring fewer samples per 50 m^2. Consequently, for each additional 100 m^2 in patch size, only a single sample was added. Following the sampling of all patches, any remaining samples were collected across the dominant vegetation area. Within each quadrat the following parameters were measured:

Water Depth: Water depth was measured from the basin floor to water surface at the center of the quadrat using a wooden surveying staff.

Vegetation Height: The minimum, maximum, and average height of the vegetation within the quadrat was recorded. These measurements were taken from the same surveying staff which the depth was measured from, with the water height subtracted to obtain accurate vegetation readings.

Percent Cover: Overlapping percent cover of all plant species, exposed water, algae, litter, bare soil, dung, and wood was recorded to the closest percentage.

Within-Canopy and Above-Canopy Atmospheric Conditions: Ta, RH, and wind speed were measured using a Kestrel 4000 Weather Meter. Measurements were taken both within and above the canopy, approximately 10 cm above the water and vegetation, respectively. Due to the dynamic nature of atmospheric conditions, such as wind gusts, readings were taken as quickly as possible to minimize measurement errors. The relative difference between canopy and open air measurements were calculated to remove diurnal and time-related climatic variations between SP readings. When the vegetation exceeded arm's reach, measurements were taken at the highest accessible point. In areas with no vegetation on the water surface, a single reading was taken at a height of 10 cm above the water surface.

Water Parameters: Tw, EC, total dissolved solids, and pH were measured using a Hanna Combo Meter. Measurements were taken approximately 1 inch below the water surface within the quadrat.

Sampling commenced approximately every 40 days or until wetland dry out, with the initial sampling occurring during SP2 (Table 1). Figure 5A is a schematic drawing of BD pond with total pond area and vegetation patches during SP2. Figure 5B shows the changes in the pond area and number of vegetation patches as the wetland dried.

3.2.7. Animal Use

Strike Force HD Pro X Trail Cameras were strategically placed at IG, AG, AP, BD, GH, HL, and GL wetlands to monitor wildlife and cattle activity. In each wetland a single camera was affixed at chest height to the nearest tree that provided a comprehensive view of the entire wetland area. During each visit, the SD cards were replaced, and the captured photos were carefully examined for evidence of animals. The data collected from these images included the identification of species, mainly large mammals, birds, and bats, their count, observed activities, and the duration they spent within the camera's frame. Timeseries photos were also taken at a fixed point at each wetland visit to monitor their physical changes on a larger scale (Appendix A). Both the trail camera photos and timeseries photos played a crucial role in tracking and understanding the causes of any physical changes or disturbances detected within the wetland ecosystems.

With the exception of the Aspen Grove camera, which was installed during SP 4 due to equipment disappearances, all cameras were set up during SP2. Subsequently, all cameras were retrieved during the final visit, conducted during SP 6.

3.2.8. Disturbances

Biological and physical disturbances made by animals, humans, climatic events, and fire were recorded observationally. At every SP, observations were noted as they were seen when present at the wetlands. During the final visit of each wetland, an assessment list was used systematically at each cardinal point to capture the accumulated effects of the season. The final observations of the biological and physical components were recorded, including the characteristics related to the pond, riparian, and upland areas, such as dominant vegetation types, water flow probability, landscape characteristics, and disturbances. They were later analyzed to understand the impacts any of these features or disturbances may have on wetland water loss.

3.3. Reference Evaporation Model

The area data collected in field during SP2 (May 31-June 6) was used as the initial value in the REM. Depth measurements from SP2 to SP6 were used in place of precipitation and reference evaporation inputs and outputs, respectively. The net water loss was calculated by subtracting one SP depth from the other. For SPs that did not have collected depth data, the average change in depth between two collected points was used for the missing sampling dates (as described in section 3.2.2.). These values that were approximately 20 days apart were added to the REM to initiate its forecast. The model predictions were compared to the collected area values to determine if the model was able to predict evaporative losses at each of the 12 CCPA wetlands. The model equations can be found in Table 5, which shows an example scenario produced by Pantel Environmental.

3.4. Wetland Assessment

A wetland assessment was developed, and each study wetland was evaluated using a comprehensive framework and scoring system that evaluated various indicators crucial for understanding wetland vulnerability and resilience (Appendix B). These indicators, including pond permanence, water quality, biological integrity, and natural and anthropogenic disturbances, were selected and informed by factors examined in the study. The factors considered within each indicator category are described below.

Pond Permanence: This category assessed the stability and longevity of wetland ponds, considering mesoclimatic conditions, pond area-depth relationship, mean water temperature, water EC, emergent vegetation presence, emergent vegetation density and litter cover, summer water inputs, presence of riparian vegetation, and moist margin width.

Water Quality: The quality of water within the wetlands was evaluated based on BC Water Quality Guidelines for chemical composition and water EC, providing insights into potential contaminants and overall water nutrient and salt levels.

Biological Integrity: This category focused on the presence and diversity of biological species and their breeding habitats within the wetlands, highlighting the importance of biodiversity and habitat suitability for a wetland's sustainability to support a balanced, interconnected, and adaptable community.

Natural and Anthropogenic Disturbances: The presence and severity of fires, erosion levels, anthropogenic alterations and cattle through plugging and grazing were assessed to understand the extent of disturbances impacting the wetland ecosystems.

Attributes that define these factors were ranked with a point system. A score of 5 represented a low vulnerability ranking, where a score of 1 represented a high vulnerability ranking. A score of 3 could be considered a moderate or neutral ranking. Not all factors had rankings that increased steadily from 1 to 5; instead, some were ranked from 1, 2, or 3 to 4. Moreover, some rankings skipped values, such as 1, 3, and 5 with no 2 or 4. The latter two situations where there are varying factor point ranges that deviate from the normal 1 through 5 ranking, suggest that there was a weak or strong correlation to their indicator, or that the factor was of lesser importance to the indicator.

After the framework was completed, each wetland was assessed. The closest attribute was identified, and points were allocated accordingly. In some cases, certain wetlands experienced unique circumstances not fully captured by the listed attributes. For these cases, an appropriate score was applied to reflect the specific situation. For instance, GH's breeding habitat would have received a low score compared to others if not for its use by the Western Toad. While the Western Toad could potentially breed in other wetlands, it does not appear to do so. Therefore, in this instance, GH was awarded additional points, and Western Toad breeding was not considered for other wetlands. This ranking process was informed by the results from this study, the end-of-study wetland surveys, wetland photos, on-site observations, and literature.

Once each wetland was scored, a grade percent was assigned for each indicator. The results were observed to inform and provide recommendations to CCPA management participants, aiming to guide conservation and management efforts. For further details on the assessment factors, refer to Appendix B.

4. Results

4.1. Wetland Characterization

4.1.1. Mesoclimate

Climate variability was observed at three weather stations situated across CCPA, spanning low, mid, and high elevations. The elevational contiguity of each wetland to their WS aids in comprehending their mesoclimatic patterns in relation to the water losses experienced at each wetland.

Daily minimum and maximum Ta peaks from all WS were relatively similar (Figure 6). Dry Farm WS, at the highest elevation, had the narrowest temperature range, whereas Dry Lake WS had the widest Ta range at the lowest elevation. From May 18 to approximately June 23 fluctuations were more sporadic than the rest of the study days. CCPA experienced more cooler days during this time; from about June 24 onward Ta remained relatively higher and stable. Because there is no data for Coffee Pot WS before June 28 due to installation timing, it will be the boundary date that separates the analysis for the cooler spring period and warmer summer period.

Dry Lake WS had the highest mean Ta both before and after June 28 at 17.5°C and 20.3°C (Table 6). Dry Farm WS had the lowest mean Ta in both periods at 15.0°C and 18.4°C. Coffee Pot WS only recorded the summer period and was at nearly the same mean Ta as Dry Lake (20.2°C) at mid elevation. Ta ranges for the spring period were 2.2-35.3°C and 1.3-29.1°C at Dry Lake WS and Dry Farm WS, respectively. In the summer period, minimum and maximum Ta increased for Dry Lake WS and Dry Farm WS at respective 2.7-35.9°C and 1.3-29.1°C ranges. Coffee Pot minimum Ta was over 4°C warmer than Dry Lake WS minimum Ta but had a lower maximum Ta at 6.9-33.3°C.

In the spring, total P was significantly higher than in summer months, and at higher elevations (Table 7). Dry Lake WS had the lowest P at 62.0 mm before June 28, and 27.0 mm after. Dry Farm WS had the highest P at 85.4 mm before and 33.4 mm after. Again, Coffee Pot WS had a similar value to Dry Lake at 25.8 mm.

RH and Ta were used to calculate the VPD at the three WS (Table 7). Dry Lake WS and Dry Farm WS had spring mean VPD values of 1.3 kPa and 1.1 kPa, respectively. And summer values for Dry Lake, Coffee Pot, and Dry Farm WSs were 1.5 kPa, 1.5 kPa, and 1.3 kPa, respectively; again, Dry Lake and Coffee Pot WS show similar trends.

With regards to water loss, peak daily values are of more interest than mean values, especially maximum VPD, because there is a higher potential for water loss and max Ta gives insight into how VPD may change in the future with increasing Ta. At Dry Lake WS and Dry Farm WS, VPD ranged from 0.03-5.3 kPa and 0.01-4.3 kPa in spring. In summer, Dry Lake, Coffee Pot, and Dry Farm minimum and maximum VPDs were 0.03, 0.02, 0.00 kPa and 5.0, 4.2, 3.8 kPa, respectively. Maximum VPDs show a decreasing trend with higher elevations.

The climatic data from Dry Lake WS and Coffee Pot WS was comparable in many aspects. Average Ta, total P, and average VPD was similar compared to Dry Farm WS which had the lowest VPD, highest P, and lowest mean and maximum Ta by far. These similarities are already highlighted in their BEC. The BEC system uses four classifications that comprises climate, site, vegetation, and seral systems, with climate being a prominent driver in the development of particular ecosystems, including grasslands (Ryan et al., 2022). The expansive Bunchgrass (BGxwm) BEC zone in CCPA houses Dry Lake WS and Coffee Pot WS and half of the 12 wetlands on the lower and middle elevational grasslands, including DL, IG, CP, AG, AP, and HG. The other half are found in the Interior Douglas Fir (IDFxm and IDFdk) BEC zone, usually on upper elevation grasslands, with two on middle grasslands (BD and TY) (Steen & Iverson, 2021).

Wetland elevation is not always aligned with a wetland's proximity to a WS, meaning a wetland could be close to a WS but have a significantly different elevation, such as BD's mid elevation and Dry Lake WS high elevation but relatively close proximity. Assigning a WS to each wetland will help our understanding of the mesoclimate each wetland experiences and its ability to alter wetland hydrology. Because of the clear difference in weather at Dry Farm WS, the IDF BEC classification assisted in assigning IDF upper wetlands to this WS, including HL, GL, PL, and GH. Since precipitation was relatively low throughout the study, and Dry Lake WS and Coffee Pot WS have many similar Ta trends, the determination of the six BG wetlands was determined secondly by elevation. DL and IG are at the lowest elevations and in close proximity to Dry Lake WS, so they were paired. Three others (CP, AG, and AP) had similar elevations to Coffee Pot WS, so they were paired. Surrounding vegetation, including prickly-pear cactus (*Opuntia spp*), at the remaining wetlands (BD, TY, and HG) suggested their allotment with Coffee Pot WS.

4.1.2. Water Storage

Ponded Area

The inundated area of the 12 CCPA wetlands ranged from 591 m^2 to 47,745 m^2 during SP1 (Table 8). Most of the wetlands had initial areas between 1,149 m^2 and 5,409 m^2. Only IG had an area below 1,000 m^2 (0.1 ha), while DI and HG had areas above 10,000 m^2 (1 ha). DL had the largest area through out the entire study, with an initial area of 47,745 m^2; similarly, HG had the second largest area throughout the study with an initial area of 10,967 m^2. By SP2, only 20 days later, two more wetlands had areas below 1,000 m^2 (AG and GH). One of these wetlands, GH, lost over half of its volume at a surprising rate (1276 m^2 to 563 m^2). This is important to note because all other monitoring began during SP2, so for many analysis this is GHs baseline area.

Ponds with similar areas did not recede at the same rate. The initial ponded area of the wetlands shrank from 8 to 100% depending on the wetland. Five wetlands dried completely before SP6. As noted, GH dried very quickly, and had an estimated dry out date of June 12. BD dried next on approximately July 12, then AG and IG around August 4. TY dried only days before SP6, on approximately August 17. Two wetlands were nearly dried during SP6, including AP and PL, with only 4% and 1% of SP1 area left, respectively. The remaining wetlands still had a substantial ponded area, and only lost between 8-35% of their initial area. DL lost 29% of its area from SP1 to SP6, which is a substantial area of land (13,645 m^2) given its comparatively large size. CP lost 35% of its area and HG, HL, and GL only lost 17%, 8%, 16% of their total areas, respectively.

At three wetlands ponded area measurements were larger between SPs at least once. AP and BD both increased in area between SP1 and SP2, from 3,344 m^2 to 3,479 m^2 and 3,621 m^2 to 3,743 m^2, respectively, likely due to continuation of spring discharge. HL gained area twice, from SP2 to SP3 and SP5 to SP6, though it is suspected that there may have been a GPS signal error because wetland size visually decreased. While there was variation in the measured pond area of these wetlands there was still a total net loss.

Water Depth

The water column depth of all wetland ponds varied greatly, from 18 cm to 113 cm on SP2 (Figure 7). Pond depth steadily decreased from SP2 to SP6 at all ponds, despite area gained at AP, BG, and HL.

The deepest wetlands throughout the entire study were HL, GL, and HG, though the maximum depth of these ponds was unknown. Depth measurements were taken at the deepest points in these ponds after wading in, which were respectively 112 cm, 113 cm, and 88 cm, but it is a safe assumption that HG is well over 100 cm in depth as well. These wetlands are not known to dry out completely, so monitoring could be accomplished closer to shore.

The shallowest wetland ponds were GH and BD at 18 cm and 30 cm, respectively, and they were the first two wetlands to dry completely. The remaining wetlands had initial SP2 depths close to either 45 cm or 60 cm. Despite these groupings, the rate of depth lost was variable. Two of the four ponds that started near 45 cm in depth (AG and TY) dried out prior to SP6, one had 1% of its pond remaining with a depth of 11 cm at SP6 (PL), and the other had a 65% of its pond area with almost 15 cm of water left. The 3 wetlands with initial depths near 60 cm showed similar variability; one completely dried before SP6 (IG), one had 4% of its pond left with almost 8 cm depth left (AP), and the final one had 71% of its pond area with approximately 27 cm of its depth remaining (DL).

Water column depth was lost at varying rates. The mean loss in water depth per day across all wetlands was 0.66 cm, the minimum loss was 0.15 cm, and the maximum loss was 2.50 cm. Most wetlands did not lose more that 0.85 cm a day on average. Uniquely, GH lost all of its water before SP3 at an average rate of 1.66 cm per day, much faster than any other wetland during this time. Both AP and AG, which are only 150 m apart, had high rates of depth lost in June and July (0.84 to 1.00 cm). Similarly, TY had a high loss rate in August of 1.05 cm. Finally, one of the lower elevational wetlands, IG, had a prolonged high water loss from SP3 through to SP6 (1.11 cm, 0.89 cm, and 2.50 cm per/day on average).

Water Volume

Water volume was a product of area, depth, and the profile shape of the proportion of the basin water was lost. Water volume was estimated using SP2 depth and area because no depth measurements were taken during SP1.

The estimated ponded water volume of the wetlands ranged from 19349.6 m^3 to 28.5 m^3 (Table 9). Seven ponds lost all or nearly all their water by SP6. The other five ponds lost only 28.3-76.5% of their volume. GL, HL, and HG lost the smallest amounts at 28.3%, 36.1%, and 43.9%, respectively, which aligns with the change in depth of their water columns. DL and CP lost respective 65.5% and 76.5% of their volume. These two wetlands are unique in this study, DL is the largest pond in the study and CP has a distinctive chemical profile with a highly saline water.

The water volume extrapolated from the *A*-*V*-D relationships was highly dependant on the calculated average *p*-coefficients (Table 10) that represent the slope basin between the highest point the water touched and the lowest from SP2 to SP6. Higher *p*-coefficients tended to be assigned to wetlands that lost little area and therefore only a small section of the profile determined their *p*-coefficients (DL, HG, GL, CP); where lower *p*-coefficients (> 2) tended to be assigned to wetlands with relatively shallow basins that dried completely over the summer months and their full basin slopes were exposed (IG, AG, AP, BD, TY, GH, PL). HL had a *p* value of 2.38, close to what Hayashi and van der Kamp (2000) describe as a parabolic slope, though like the wetlands with very high *p*-coefficients HL had little area loss, so this only describes a very small proportion of the basin profile.

Because the *p*-coefficient does have so much strength in the formula, the more area and depth data points available the more accurate the p-value will be because it is determined by the power regression line. Wetlands with a small number of samples due to earlier dry out, such as GH, may have skewed *p*-coefficients. Likewise, power regression lines from wetlands that had few samples taken but values were supplemented by equated average changes will have a more predisposed line with less variation, possibly altering the true line. Furthermore, many, if not all, of the wetlands experience basin shape irregularity, slope unevenness, and diverse vegetative patterns around the pond perimeter which would alter the average *p* value.

4.1.3. Water Temperature

Each wetland had a unique temperature profile (Figures 8A-L). Ta, water quantity, water chemistry, and upland and emergent vegetation look to be influencers of Tw. In most cases, Ta seemed to play the biggest role in determining the daily Tw fluctuations. Besides climate, the above factors influenced shifts away from the standard diurnal cycle and caused a dynamic set of circumstances at each wetland.

At most wetlands, diurnal Tw fluctuations lagged behind fluctuations in Ta. As solar radiation warmed the landscape Ta rose and Tw followed behind. As the sun set, the landscape cooled, as did the wetland water. In general, Ta low and high peaks were between 4:00-6:00 and 13:00-16:00, respectively. Most of the wetlands, including IG, AG, AP, BD, HG, HL, and GL, hit their lowest peak from 6:00-8:00 and their highest from 15:00-

19:00. There were deviations from these patterns; as the study progressed, daily Tw fluxes tended to become more extreme. This was most apparent when ponds reached approximately 30 cm and under, and even more so when the area was nearly depleted. A shift in the stability of the fluxes happened on approximately July 1. Temperatures stabilized at a higher range, before this there were several cool periods where Tw and Ta dropped for several days. This shift aligns with the spring and summer periods defined by the WS data.

Among the wetlands described above, the average Tw was 18.8° C with a range from 10.3° C to 28.4° C. Five of the seven wetlands fell within 0.5° C of this mean; on average BD wetland was 2° C cooler and HG was 1.8° C warmer. BDs Tw steadily increased over SPs from 16.4° C to 16.8° C to 17.7° C, as did its Tw flux ranges. BD started at 30 cm, so this constant increase is in line with the depth pattern described above. HG was consistently one of the warmest wetlands during the entire study period; however, its temperature did not show a steady increase over SPs (Table 11), instead its mean Tw followed Ta patterns throughout the study.

Outliers from the norm include DL, TY, PL CP, and GH. DL was the only wetland with clear patterns of diminishing fluxes from SP3 to SP6 (Figure 8A). It did follow typical fluctuation patterns until later in the season but eventually deviated with longer periods in between peaks. TY and PL showed the same effect as DL but inversely. They began with low to no fluctuations, sometimes for many days (ex. 5 days), before slowly transitioning into following Ta. In addition, they both had unique Tw regimes which were substantially lower than 10 other wetlands. TY's mean Tw was 11.8° C, with a range between 9.2° C to 16.7° C, and PL mean Tw was 10.9° C, with a range between 7.7° C to 14.3° C; respectively 5.2° C and 7.8° C cooler than the average mean Tw of all wetlands (17.0° C).

CP also experienced a period with abnormal fluxes in June and partially into July. Instead of having limited fluxes, CP had many mini fluxes throughout the day. This erratic change in Tw was only found in CP, primarily in June. After July 1, CP began to follow typical fluctuation trends but still maintained some erratic fluxes into July, just not as pronounced. Despite this phenomenon, CPs temperatures were in line with the average Tw across all wetlands, with a mean of 17.3° C and a 10.9° C and 26.3° C range.

Finally, GH did not have a chance to follow typical trends. It had relatively low Tw with a mean of 16.3 and a range of 9.2 to 24, but values spanned only 12 days because it dried out so quickly. Its starting depth was the lowest of all wetlands at 18 cm and it was used by cattle during this time.

4.1.4. Water Chemistry

Wetlands in the southern portion (CP, HG, HL, GL, PL) of CCPA have different water chemistry profiles than wetlands in the northern portion (DL, IG, AG, AP, GH, BD, TY) due to differences in the geochemical composition. The southern wetlands have a high EC, (550-5100 µS/cm), alkalinity (282-2500 mg/L), and pH (8.7-9.53) with exception of PL (Table 12). All of these wetland still had water in them during the final SP; thus, a second sample was collected.

Water quality deteriorated from the first sampling period to the last, with many chemical concentrations increasing over time (Table 12). This is normal occurrence in drying wetlands. EC and alkalinity values increased substantially over the summer, except for CP alkalinity. For these same wetlands, EC ranged from 550-18900 µS/cm and alkalinity ranged between 626-1450 mg/L. CP which had alkalinity of 2500 µS/cm in SP2, had a reported alkalinity of 101 µS/cm in SP6. This value seems low due to the increased and extreme content of dissolved salts (sodium was 1470 mg/L in SP2 and 6000 mg/L in SP6 and sulfate was 618mg/L in SP2 and 2500 mg/L in SP6). The northern wetland's EC levels were between 150-375 µS/cm.

The majority of wetlands had metal and dissolved ion concentrations that were within the suggested water quality guidelines (WQG) (British Columbia Ministry of Environment and Climate Change Strategy, 2023). DL, AP, GH, PL, and CP all had dissolved iron levels above the short-term acute water WQG limits for aquatic life (0.35 mg/L) (Table 12), though there is no limit for livestock or wildlife. Short-term acute WQG are designed to protect aquatic environments from severe, immediate impacts caused by contaminants, focusing on the most vulnerable species and life stages during a brief exposure period, typically around 96 hours. Both DL and AP initially had iron levels below the suggested limit at the beginning of the season, but these levels became concentrated due to water loss over time. GH was only sampled once during SP2 and it already had high iron, suggesting that if GH pond were around longer, its concentration would increase with time. A red-orange soil precipitate was noticed on GH soil surface on July 13 onward and at AP on August 19 to a lesser extent (Figure D1), which could be the oxidization of iron deposited during dry out. Both PL and CP had high dissolved iron levels during both SP.

All other high chemical concentrations were found in PL and CP wetlands. Both ponds contained elevated levels of aluminum during SP6 only. The short-term acute WQG are 5.0 mg/L for wildlife and livestock, where PL and CP had 17.7mg/L and 32.9 mg/L, respectively. They also had high dissolved arsenic concentration throughout the study ranging from 0.029-0.13 mg/L at PL and 0.038-0.15 mg/L at CP. Maximum WQG for dissolve arsenic are 0.025 mg/L.

Lastly, CP had high concentrations of sulfate and dissolved chromium, selenium, and boron. Sulfate levels were 2.5 times the WQG (1000 mg/L) at 2500 mg/L during SP6. Dissolved chromium and selenium concentrations were only high in SP6. Chromium was 0.06 mg/L and selenium was 0.01, while their respective WQG were 0.05 mg/L for livestock and 0.002 mg/L for wildlife (livestock WQG were 0.03 mg/L). Finally, boron was slightly over (5.0 mg/L), and the long-term chronic WQG at 5.9 mg/L. Long-term chronic WQGs aim to safeguard the most vulnerable species from sub-lethal and lethal effects over indefinite exposures, utilizing an averaging period strategy where concentrations can vary around the guideline as long as short-term acute levels are not surpassed.

Wetland water that exceeds any WQG, like found at CP and PL, could have adverse effects on wetland ecology. Further investigation with more active monitoring can help to indicate actual risk.

4.1.5. Soil Properties

Soil Water Content

Of the five wetlands selected for soil monitoring, three dried completely (IG, BD, GH) and one nearly dried by SP6 (AP). GH dried by SP3, and the length of its total basin cardinal transects (established during SP2) were 8 to 14 m long (Figure 9). BD dried before SP5, with total transect lengths of 23 to 43 m (Figure 10). IG dried completely before SP6 and had 11 to 12 m total transect lengths (Figure 11). AP had a small pool remaining, so its transects did not stretch the full radius of the pond. The pond was deepest around the N transect, where most of the pool remained (Figure 12). The S transect reached the central HOBO, and the E and W transects were within 8-5 m of the HOBO. Its E transect lengthened substantially between SP2 and SP3 (from 2 to 17 m) due to the disconnection of the Open Water E Arm patch. However, HL only lost a total of 1 to 2 m of water from its basin transects (Figure 13). Because the HOBOS were placed central in the ponds that dried, the length of the transects gave an indication of which areas of the ponds dried sooner due to things like vegetation presence, differences in soil compaction, textural differences that influence infiltration, such as high rock content, or variation in basin shape.

Moisture levels generally did not decrease smoothly down the profile; instead, there were pockets of wetter and drier soil. Upon observation, sampling points with limited vegetation and more exposure to the sun were typically drier. The presence of vegetation did yield varying results, however. Some vegetated points were wetter than their neighbouring exposed points, where some were much drier. The latter seemed to be accompanied by a dense root mass. Cattle-plugging or other concaved areas tended to be wetter that untrampled or convex areas. Moreover, the longer the soil experienced unsaturated conditions and the further away a point was from the pond perimeter, the drier it tended to become over the season.

The maximum soil moisture found across all five selected wetlands was 0.581 m^3 (water)/m^3 (soil) and the minimum was 0.054 m^3/m^3. Soil moisture levels above 0.3 m^3/m^3 can be considered wet to saturated or at field capacity, and anything below 0.1 m^3/m^3 is dry to oven-dry or at the permanent wilting point (Onset, 2018). From 0.3-0.1 m^3/m^3 the soil is moving toward more extreme drought levels. The moisture margin of the pond in this case can be thought of as the ring around the pond that has moisture levels above 0.3 m^3/m^3. There is active lateral infiltration from the pond through capillary action here. As the soil gets drier down the transect, the hydraulic pressure potential decreases, pulling pond water horizontally through zones of saturation then vertically through unsaturated zones by transpiring vegetation, if there is any (Hayashi et al., 1998; van der Kamp & Hayashi, 2009), or through evaporation from the soil surface. It is important to note that moisture measurements were obtained only in the top two inches of the mineral soil horizon. The moisture content below will increase up a moisture gradient, but to what extent will vary across wetlands. Moreover, many roots will uptake water for transpiration from below the sampled area; however, dry conditions at the top of the soil create a larger hydraulic pressure gradient, influencing water to come to the surface (Brady & Weil, 2010; Hayashi et al., 1998).

During the initial sampling (SP2) all moisture measurements in the single riparian sample were in the moist margin, over 0.4 m^3/m^3, except that of AP's N transect (0.364 m^3/m^3) (Figure 12). From SP3 on, deviations began. GHs moisture dropped to around 0.3 m^3/m^3 at all transects from the riparian reference point to the central HOBO (Figure 9). GH had no remaining surface water at this point. During SP4, GH began to experience consistent drought conditions as most samples were between 0.1 m^3/m^3 and 0.2 m^3/m^3. During SP5 and SP6, GH was too dry to sample, the soil was hard, the sensor could not penetrate the soil in most places, and readings were below 0.1 m^3/m^3. BD, AP, and IG all showed similar decreases with SPs. BDs transects remained in the moist margin until after its dry out (SP4-5), whereafter its range mostly stayed within 0.1-0.3 m^3/m^3 for the N, W, and S transects; the E transect was in the 0.3-0.4 m^3/m^3 from 13m to 41 m before dropping under 0.3 m^3/m^3 again when it reached the central *Carex exsiccate* patch (Figure 10). AP started to exhibited drought conditions around SP4 (Figure 12). Between SP5 and SP6, the pond area dropped significantly along the S and W transects by respective 34 m and 25 m; however, much of the new transect portions remained above 0.3 m^3/m^3 and were actively moist. IG only experienced drought conditions for 2 to 4 m in SP5 and SP6 before rising above 0.3 m^3/m^3 (Figure 11). Though small, IG has a deep basin for its size, likely supporting a longer interaction with the groundwater. HL never reach drought conditions in the sampled transects (Figure 13).

Soil Temperature

Soil temperatures along the cardinal transects were influenced by multiple factors. The extent of incoming solar radiation on any given day affected how warm the soil could become; the shading from vegetation and landforms, and the time of day sampling was completed, potentially contributed to variation at a single site. Ts was also clearly influenced by soil moisture levels. At drier sampling points, Ts tended to be relatively higher, whereas at wet or saturated sampling points, often situated close to the water end of the cardinal transect, Ts was lower. This pattern aligns with Tw being cooler than Ta at any given time. Consequently, wetlands with more variable moisture profiles, such as AP and BD, commonly exhibited large ranges in Ts. GH recorded the warmest mean Ts across its three soil sampling points (27.2°C), consistent with its early dry-out date and drying basin characteristics (Table 13).

Electrical Conductivity

The average EC of four of five of the wetland's soils were 0.22 ds/m across all sampling periods (Table 13). HL had an average EC over five times greater at 1.1 ds/m. Because soil moisture acts as the electrical conductor for ions in the soil, drier soils had a low EC reading. Accordingly, the average values above are inclusive of low EC readings associated with drying wetland basins. A good example of this process was found along the E transect at BD, where at the 10 m sampling point a single abnormally large EC sample was found at 1.1 ds/m. During SP at the same 10 m sample the EC was 0.42 ds/m most likely due to considerable drying.

Compaction Pressure and Depth

The average pressure category (0-200 psi - green, 200-300 psi - yellow, 300+ psi - red) was recorded at every sampling point along the soil transects. HL demonstrated excellent penetration, with 86% of the samples falling into the green category and only 8 in the red. In contrast, 52% and 42% of IG and GH samples, respectively, were categorized as green, while 28% and 27% fell into the red zone. AP and BD exhibited the lowest penetrability, with only 15% and 11% of samples in the green category, and 45% and 31% in the red category, respectively.

The average maximum penetration depth was lowest at GH, AP, and HL wetlands (30.7 cm, 32.8 cm, and 39.6 cm, respectively), whereas BD and IG exhibited higher average penetration depths (52.3 cm and 59.9 cm, respectively) (Table 13). All wetlands had sampling depths reaching the full penetrometer depth of 70 cm, but only BD and AP had sampling points where the penetrometer could not penetrate the soil (0 cm). HL had the smallest penetration range, with its highest depth recorded at 11.8 cm.

Like EC, compaction was correlated with soil moisture levels. When the soil was dry, the penetrometer encountered greater resistance, making it harder to push into the soil and potentially leading to a higher compaction reading. Conversely, when the soil was saturated, the resistance was likely underestimated as the soil behaved more like a liquid. IG serves as a notable example of this. From SP2 to SP5, nearly all penetration depths reached 70 cm. However, after the pond dried out during SP6, the average depth decreased to 52 cm, with only 34% of the samples reaching the full depth of 70 cm. Furthermore, from SP2 to SP4, all samples were below 300 psi, with the majority falling into the green zone. During SP5, 6% of the samples exceeded 300 psi, and this percentage increased tenfold in SP6, with 60% of the samples registering pressures over 300 psi.

Certain transects exhibited greater rockiness than others, which hindered the penetrometer's movement through the soil, either by halting it completely or slowing its progress. In the case of HL, between a third to all the samples encountered rocks at every transect, thereby limiting the penetration depths despite HL's overall good penetration levels. BD's S transect was notably rocky, with moderate rockiness observed along the E transect. AP contained rocky patches, particularly on its E transect, while the N and S transects experienced minimal rockiness. IG and GH both encountered some rocks, although no consistent rocky patches were observed along their transects.

4.1.6. Vegetation Cover

Refer to Table 14 for species names and codes.

Wetland Cover

The relative abundance of emergent vegetation, algae, and organic materials, and the proportion of exposed water in each sampled emergent patch were evaluated during every second SP (SP2, SP4, SP6) (Table 15). Sampling was limited to patches within the ponded area, resulting in exclusion of some patches as ponds receded, and the addition of new patches due to their absence in the previous sampling or small size, <10 m^2. Because of their dry out dates, GH was only sampled during SP2, while BD and IG were sampled during SP2 and SP4, and HL and AP were sampled at all three intervals.

At BD, AP, GH, emergent vegetation covered the entire pond surface with varying degrees of exposed water depending on the SP (see Table 16). In contrast, HL and IG were predominantly open water with vegetative fringes of various widths around their ponds. The percentage of exposed water consistently decreased in BD and AP over the SPs, while at HL, it increased by less than 2% from SP2 to SP3 before dropping by almost 15% by SP4. Conversely, at IG, the percentage of exposed water increased by almost 35% for SP2 to SP4. The extent of water exposure at each site was largely determined by the physical characteristics, species density, and developmental stage of each sampled patch.

In SP2, BD and AP exhibited the highest diversity in terms of species and patch type (Tables 15 and 16). BD displayed a mosaic of patches with six sampled, three of which were dominated by the same species (*Typha latifolia* – Typhlat). Eight species were identified at BD, with *Eleocharis palustris* (Eleopal) being the dominant species surrounding the other distinct patches. Similarly, AP also had eight species with a dominant area of Eleopal, but its distribution was central with six defined patches around the dominant area. Some patches were dominated by terrestrial species like *Rosa woodsia* (Rosawoo), indicating substantial flooding in areas that do not typically flood or flood only briefly.

Similarly, GH and IG both had Eleopal as their dominant species, although it covered the majority of GH's patch, it was only found on the outskirts of IG's pond, gradually moving more centrally as the pond receded. One to two other plants were found in these ponds; however, IG had notable algae covering its surface during SP2 (approximately 29%), substantially reducing the percent of exposed water. Consequently, IG was the only wetland that experienced a considerable increase in exposed water coverage (+35%). BD also had a substantial amount of algae (30%) in SP2 but did not lose exposed water coverage, likely due to a sizable increase in vegetative growth.

HL had four sampled species growing across its pond: *Schoenoplectus tabernaemontani* (Schotab), *Juncus balticus* (Juncbal), *Lemna minor* (Lemnmin), and *Persicaria amphibia* (Persamp). Both Schotab and Juncbal patches grew in a fringe around the pond, while Lemnmin and Persamp grew over the dominant open water portion and within other patches. Consequently, Lemnmin was consistently the dominant vegetation type at HL, despite Schotab and Juncbal being more prominent in terms of canopy structure.

Canopy Structure

The canopy structure over the five selected wetland ponds was defined by the variability in patch height, species growth, and the size of the pond during each SP. Patches that remained in the ponded area over multiple SPs increased in height with time, and the average height range across the pond depended on which patches were present during sampling (Table 17).

HL was sampled three times, with two of its three patches sampled during every SP (Schotab and the dominant open water area). The Schotab patch had a mean height of 119.8 cm with a maximum height of 172.5 cm. Its lowest vegetation (Lemnmin) grew over the dominant open water area at a height of less than 1.0 cm. On the final sampling, Scotabs height grew 76 cm more, Lemnmin stayed the same. During all SPs, HL had the tallest vegetation and widest range.

BD was sampled twice, with only two of its six patches sampled at both SPs (*Carex exsiccate* (Careexs) and the dominant Eleopal area). During SP2, the average height of Careexs was 32.9 cm, and the dominant Eleopal was 30.9 cm, both had a maximum height of 53 cm. These were the two shortest patches during this SP. Three Typhlat patches towered above these patches at an average of 88.4 cm. During SP4, the Careexs patch grew substantially with an additional 26.7 cm average and a total maximum height of 105.8cm.

At AP only the dominant Eleopal area was sampled during all 3 SPs. Its average height changed from 30.1 cm to 52.7 cm to 55.6 cm, with maximum heights of 46.5 cm, 82.3 cm, and 74.5 cm, respectively. The Rosawoo patch was the only other patch sampled more than once (SP2 and SP4) but its area was relatively small, and its health was poor (limited foliage) due to its submergence in water.

IG was sampled twice and only had one patch, the open water dominant area. Eleopal height was recorded for this wetland, but the abundance was sparse, with only 1% cover across the entire wetland. The impact that Eleopal had on water conditions was limited.

GH was only sampled once due to its quick dry out. Eleopal was 33.3 cm at the time with a maximum height of 53.0 cm. It did have an estimated 25% cover, so it could have aided in wetland dry out.

Canopy Atmospheric Conditions

The relative difference between atmospheric conditions within vegetation patch canopies across all wetlands and above them had clear trends. 83% of the wind speed samples and 52% of the RH samples were lower within the canopy. 69% of the Ta samples were higher within the canopy. 10-16% of samples measured for wind, RH, and Ta had no relative difference (x=0). 85% of the equated VPD showed there was a greater evaporative pressure in the canopy air than above.

Both within- and above-canopy VPDs had similar ranges from around 0.54 kPa to 3.3 kPa, though within-canopy had more comparably higher VPDs. The vast majority of the equated VPDs were above 0.7 kPa, which is the lowest approximated VPD for desirable plant growth; however, more than half of these were above 1.5 kPa, delineating optimal VPD from high VPD that promotes rapid water loss through stomatal conductance for many plants (Runkle, 2021). These values are comparable to the equated weather station VPDs on the specific SP dates.

Water properties

Water properties under each vegetation quadrat were sampled to monitor their differences relative to each vegetation patch. EC and total dissolved solids increased over the season under patches that were measured more than once. AP was the exception to this, it experienced highly variable measurements (208-404 µS/cm) with both increasing and decreasing EC levels. pH levels had the inverse response to time, they tended to decrease over the season. There were notable decreases in pH at BD, AP, and IG, but almost no change at HL. There were abnormally high and low EC and pH levels found in AP and BD wetlands. Departures in both occurred when there was a high proportion of algae or, in one case at BD during SP4, within the Persamp patch when EC was substantially lower than the rest of the pond.

4.1.7. Animal Use

Wildlife cameras and on-site observations were employed from SP2 (May 31-June 6) to SP6 (August 18-22) to gain a broad understanding of the types of animals utilizing each wetland during the study and their behavioral patterns. It is improbable that these methods provided comprehensive coverage of animal activity within the wetlands.

At BD, the cameras recorded the presence of 9 black bears (*Ursus americanus*), 10 coyotes (*Canis latrans lestes*), and a single cow (*Bos taurus*). Countless birds using the wetland for shelter, sustenance, and nesting were also recorded and visually observed when on site. Snails were present during sampling as well. Of every species noted, the cow was the only large mammal caught utilizing the pond for watering, and flattened and broken emergent vegetation was noted after this event. It was present for about 2 hours, thus the quantity of water removed through drinking was likely not significant.

AP and AG are adjacent to each other and exhibited similar animal usage patterns. Cattle were observed utilizing both wetlands for extended periods from July 11-15 (Figure D2), July 21, and August 7-15, despite not being part of the 2023 grazing plan. Instead, the cattle accessed the wetlands through burnt fencing from the 2021 fire. The wildlife cameras captured 10-60 cattle in a single photo, suggesting that there was an even larger herd present at the time the photos were taken. Both wetlands experienced considerable damage to vegetation; Eleopal at AP was flattened over a substantial portion of the wetland surface, and extensive soil plugging was observed at both sites (Figure D3). Cattle were observed spending prolonged periods within the ponded area, for watering, grazing, and assumed cooling purposes.

On various occasions, the wildlife cameras captured three black bears at AP and two black bears with one mother and cub at AS. While the black bears at AP were sighted upland from the wetland, tracks indicated their presence at the water's edge. At AS, the black bears were observed in the pond, showing curiosity towards installed surface water level monitoring wells. Additionally, many birds were photographed using the AS wetland, with its neighboring fire-burnt aspen stand providing perching and other habitat qualities. Bats (*Corynorhinus spp*) were also captured in several night photos at AG, and mule deer tracks were observed at AP.

At IG, the wildlife cameras captured the presence of seven black bears, two mule deer (*Odocoileus hemionus*), and numerous birds, primarily waterfowl and black-billed magpies (*Pica hudsonia*). Snails were observed, and what appeared to be horse dung was found floating in the pond. On one occasion, a mule deer visited the wetland at night. Despite the presence of these animals, disturbance to the ecosystem was minimal. The black bears were observed wading through the ponds, resulting in the breakage of a surface water level monitoring well on one occasion and the removal of the HOBO float twice (Figure D4). Waterfowl were present when the pond was full, and black-billed magpies were observed near drying (Figure D5).

Between June 1 and June 12, the pond at GH completely dried up. During this period, it was used by cattle on June 6, 10, and 11, with at least 6-14 individuals observed. Initially, on June 1, the pond contained thousands of Western toad (*Anaxyrus boreas*) tadpoles, and a single toad was spotted (Figure D6). However, by June 12, trampling and grazing were observed, and there were no signs of tadpoles or toads remaining (Figure D7). Coyote visited the upland area of GH five times, once before the drying period. Few birds were observed over this time. Following the drying of the pond, the partial fence surrounding the wetland was replaced, completely enclosing it, and only coyotes were observed within the fenced area thereafter. Although cattle were seen in the upland area on June 26 and July 1-2, they could not access the wetland area (Figure D8).

Due to a lack of animal activity, the HL wildlife camera was relocated at the end of June. From July onwards, the camera recorded black bears visiting the wetland four times, including an instance involving two blond-black bears. At multiple visits bear scat was discovered. Additionally, the cameras captured the presence of three coyotes, five mule deer, and various bird species, including whiskey jacks (*Perisorius canadensis*), grouse (*Tympanuchus phasianellus*), and several types of waterfowl, which frequented the wetland commonly. A garter snake (*Thamnophis spp*) was observed during sampling. Although cattle were not present, evidence of their previous activity, such as plugging and old dung, was observed.

GL was also outfitted with a wildlife camera, which captured images of one black bear, two sandhill cranes (*Antigone canadensis*), three mule deer, six coyotes, and many waterfowl. In-person sightings revealed the presence of over 60 cattle during SP1, along with a black bear and bear scat. The cattle were observed utilizing the pond, resulting in extensive grazing and plugging.

On-site observations at the other five wetlands revealed various findings: a California bighorn sheep carcass (*Ovis canadensis*) and a grater snake was discovered at DL; fresh cattle dung and plugging, along with a mule deer carcass, were observed at TY; at CP, a cow carcass, a black bear sighting, bear scat, and tracks of a mother and cub were documented; and HG exhibited signs of plugging and grazing, along with big cat prints. No signs of large mammal use were observed at PL, although a black bear was spotted within a kilometer of the wetland. In addition, birds and insects were observed utilizing every wetland extensively.

4.1.8. Disturbances

CCPA primarily attracts visitors for recreational camping, hunting, and related activities, while Empire Valley Ranch manages grazing and forage farming activities across the landscape. Public access within CCPA varies, with the southern area restricted to hiking access only, except for researchers, land guardians, ranchers, and residents. Dirt roads within CCPA are high in silt content and maintained by grading and serve as a source of anthropogenic disturbance to the wetlands. While some wetlands like GL, DL, AP, and AG are unaffected by active roads, others such as BD, PL, CP, HG, and IG experience varying degrees of disturbance due to their proximity to roads, disrupting natural watershed flow into the wetlands and promoting erosion and sediment relocation. GH, along with having a minimally used road in its watershed, faces additional human disturbance from cattle corralling and branding activities. Furthermore, wetlands like HG exhibit additional disturbances such as watering troughs, old fencing with fallen barbed wire, and abandoned structures. The introduction of agriculture to CCPA has significantly disrupted wetlands, primarily through altered vegetation communities and cattle use. Alfalfa, an introduced species, and a significant water consumer, appears largely in disturbed areas and its presence is observed upland of most wetlands. In addition to these disturbances, a fire burned the northern portion of CCPA in 2021 (Figure 14). This fire impacted AS, AP, IG, GH, and DL wetlands and their watersheds, and it appeared that hydrological processes could have been altered depending on the severity of the fire, such as increased runoff. AG and AP were severely burned, with signs of damaged soils (Figure D9) leading to hydrophobic conditions in some areas.

4.2. Reference Evaporation Model

The REM predicted volume and area losses of the twelve wetlands (Appendix C) between SPs (approximately every 20 days) reasonably well in five wetlands (AP, BD, GH, TY, PL). The difference between the final forecasted area and actual area at these five wetlands were within 4.2% of each other (Table 18); however, there was timing variability among the predicted dry out dates and actual dry out dates. For instance, AP and PL still had small ponds on the final sampling date (SP6) but the model predicted their dry out was between SP5 and SP6, 1-20 days prior to the sampling date. Similarly, TY's dry out date was underpredicted by 1-2 weeks and, the opposite was true for BD, the model overpredicted its dry out by several weeks. GH's forecasting aligned well with its actual dry out; however, it also dried at an accelerated rate, three times faster than another wetland its size. All five of these ponds have emergent vegetation across their entire area, though at different densities and with varying species.

The predicted dry out for IG and AG was between SP3 and SP4, but both ponds progressed past SP5 with the same observed dry out dates of August 4. IG's initial area was 500 m^2, where AG was 982 m^2, but IG's net depth lost was over two times larger. These wetlands plus GH were the only wetlands below 1000 m^2 in area during SP2, and they are the only wetlands where water loss was predicted early in the season (Table 18). If GH experienced presumably normal dry out rates like those of IG and AG, its water loss might have been underpredicted as well.

The water loss at the five remaining wetlands (DL, CP, HG, HL, and GL) was highly overpredicted, with the difference in the predicted and actual measured area between 30% and 78% (Table 18). DL was the only one of these wetlands that was entirely vegetated. It was also the only wetland over 2 ha, with a starting area of 4.5 ha (4522 m^2). The difference in predicted area to actual measured area was 30% and its predicted volume loss was 62% of its initial predicted volume. The predicted volume lost (62%) could be close to what occurred at DL, as it lost 47% of its measured depth, 29% of its measured area, and had a relatively shallow basin. Conversely, the area, and volume predictions for the other 4 wetlands were incomprehensibly large compared to the actual measured area of water. All of these wetlands have a large open water center, three of them are estimated to be over 2 m deep at their deepest points (HG, HL, GL), the other is highly saline (CP).

Wiens (2001) presented data and various regression equations for small wetlands under 10 ha in Table 2 of his report. Four regression equations were given for wetlands with average areas under 0.55 ha. The first two have R^2 values above 0.9; of those, the first equation (V=2.85A), when substituted for the model's equation (V=2.85A1.22), improved many predictions. These result are not surprising given the greater accuracy for the proposed wetland size; however, the difference was not substantial enough to suggest supplementing this equation, or to come to a new conclusion about which ponds performed best in the REM.

4.3. Wetland Assessment

Each wetland indicator was graded based on its attributes to measure wetland vulnerability (Table 19). It is crucial to note that the grades between categories cannot be directly compared due to differences in their total point counts. For instance, pond permanence had a total of 42 potential points, water quality had 10, biological integrity had 13, and disturbances had 25 potential points. Therefore, a score of 20% in water quality would be considerably less significant than 20% in pond permanence. Moreover, the total grade of all four categories did not necessarily reflect the condition at each wetland accurately. Wetlands with clear risks in pond permanence could score much higher due to their high biodiversity, for example. Therefore, it was essential to evaluate the categories separately to understand the favorable and unfavorable qualities at each wetland for targeted protective and restorative actions.

The pond permanence indicator grade is arguably the most important of the four, as without water, the other categories become irrelevant. Pond permanence grades for the twelve wetlands ranged from 48% to 76%. IG, BD, and GH ranked the lowest at 48%, 52%, and 55%, respectively. DL, AG, and AP all had grades of 57%. HL and HG were ranked highest with grades of 71% and 76%, respectively. The others fell between 62% and 67%.

Rankings for water quality were based on only two factors: optimal chemical composition and electrical conductivity (EC), resulting in a superficially wide grade range. CP had the lowest grade at 20%, followed by PL at 50%, and IG at 60%. HG, HL, and GL received 80%, while the remaining wetlands achieved a perfect grade of 100%.

Biological integrity was based on three variables and had a narrower range than water quality, spanning from 54% to 100%. GH had the lowest ranking at 54%, CP was the second lowest at 62%, followed by AG, AP, and IG, all tied at 69%. DL, BG, and HG were ranked the highest, ranging from 92% to 100%. The remaining wetlands received a grade of 77%.

The widest range in grades was found for disturbances, spanning from 32% to 92%. HG, AP, AG, and CP were ranked the lowest at 32%, 44%, 52%, and 56%, respectively. Alternatively, IG and PL were ranked the highest at 84% and 92%, respectively. All others fell between 60% and 68%.

Looking at these results, several wetlands consistently show up in the lowest rankings across indicators, including IG, CP, GH, AP, and AG. However, CP was not ranked low in pond permanence. Among the 6 ranked lowest in pond permanence, BD and DL did not have any other low rankings. However, IG, AG, and AP had two, and GH had one other low ranking in either water quality, biological integrity, or disturbances indicator categories.

High rankings displayed notable variability. Due to the water quality indicator comprising only two factors and the majority of wetlands meeting optimal WQG, most received high grades for water quality. Beyond water quality, HG was the sole wetland with multiple high rankings, while TY and GL consistently obtained mid-range rankings. Outside of these exceptions, grades varied considerably.

For more detailed information on each ranking, please refer to Appendix B and Figure 19. Further insights into each wetland will be provided in section 5.3, where personal observations and understanding will be discussed.

5. Discussion

5.1. Wetland Characterization

5.1.1. Mesoclimate

Pond permanence is linked to a wetland's position in the landscape due to variability in climate (Hayashi et al., 2016). The mesoclimate of the 12 wetlands was characterized according to the climatic conditions monitored at CCPA weather stations, considering elevation and their corresponding BEC zones. Dry Lake WS was matched with two wetlands at the lowest elevations (635-720 m); Coffee Pot WS was matched with six wetlands at mid elevations (859-1013 m); and Dry Farm WS was matched with four wetlands at high elevations (1040-1249 m). Weather patterns for the Dry Lake WS showed that these ponds experienced the highest mean Ta, VPD, and the lowest precipitation levels; and with increasing elevations, Ta and VPD declined, but precipitation increased. This pattern was even more evident in summer months when a seasonal shift in weather conditions was defined through increased and stabilized Ta trends. During this summer period, wetlands at lower elevations had comparatively more evaporative stress put upon them by their mesoclimates, potentially accelerating water losses.

As climatic patterns are shifting, wetlands are at risk of drying at a faster rate, and projections suggest that semi-arid ecosystems are the most vulnerable ecosystems to variations in weather (Coelho, 2008). Current mid elevation (900 m) CCPA projections from Climate BC (T. Wang et al., 2016) indicate that mean annual Ta will continue to rise, as will reference evaporation. Mean annual precipitation is also projected to increase, with a larger proportion falling in the winter; however, the amount of winter precipitation as snow will decrease. Implications of this will be especially prevalent across CCPA, and its surrounding area, because snowmelt is the main input to these ponds and recharge is determined by the snowpack depth, density, and the timing of melt (Coelho, 2008). ET rates are directly influenced by solar radiation and Ta (Allen et al., 2005), as is VPD (Schönbeck et al., 2022); increases will certainly induce a stronger evaporative pressure on the landscape. Thus, wetlands at lower elevations may be more at risk of drying than wetlands at higher elevations.

It has already been reported that wetlands in interior grasslands are shrinking and that precipitation and ET patterns have altered the hydrology, reducing pond volume and the persistence of surface water into the winter (Coelho, 2008). Moreover, Fey et al. (2016) found that more arid wetlands that already experience water deficits would be extra sensitive to warming and less summer precipitation than wetlands in less arid environments. Their projections suggested that climate would decrease the water depth of historically deep wetlands, suggesting that several of the wetlands in CCPA may be more at risk in the future.

5.1.2. Water Storage

The 12 wetlands within CCPA exhibit diverse area-depth basin shapes, categorized into seven distinct types, including a small area pond with shallow or moderate depth, a moderate area pond with shallow, moderate, or deep depth, and a large pond with moderate or deep depth. In the case of this study, small ponds were classified as being <0.1 ha, while large ponds were >0.50 ha; shallow depths were classified as being <30 cm, while deep depths were >80 cm; moderate areas and depths fell in between but generally within 0.2-0.4 ha and 40-65 cm. Notably, all wetlands that completely dried out during 2023 (through this study and beyond) fit into the first four categories, while those still inundated fell into the last three.

During water storage analysis, a clear drying pattern emerged, with depth initially dictating the process. Shallow ponds dried first, followed by moderate depth ponds, and then deep ponds. Within each depth category, the drying sequence progressed from small to moderate to large area ponds, where large pond drying was assessed. This analysis was conducted from SP2 (May 31-June 6) onward because there was potential rechange happening at some ponds between SP1 and SP2.

Area was expected to influence water loss due to the potential for increased surface water and basin area for respective evaporation and infiltration by groundwater outflow and capillary action from the pond to the moist margin (van der Kamp & Hayashi, 2009). That is, ponds with a smaller area would tend to dry before ponds with a larger area. Hayashi et al. (2016) explained this process with a hypothetical scenario where the smaller pond of two ponds, one with a small area and one with a large area, that had the same depths and a constant evaporation rate, would dry first at a faster non-linear rate due to less seasonal inputs and a larger infiltration outflow per unit area. Their example outlined that pond permanence is related to pond size, which is what we observed in the second half of the pattern observed in CCPA.

Within CCPA, we observed that depth was a bigger indicator of water loss than area. All ponds with similar depths but varying areas consistently dried up before ponds with different depths. The findings revealed that ponds tended to dry more rapidly once their depth reached 30 cm or below, especially as their surface area diminished. Data indicated that Tw did not emerge as the prominent driver of water loss. Larger ponds and smaller ponds that persisted through the study often exhibited higher temperatures compared to ponds that had lower Tw and eventually dried, such as TY.

The presence of emergent vegetation within shallow and moderate depth ponds could be a confounding factor of this accelerated loss, however. As the study progressed, vegetation within and around the ponds experienced growth, leading to increased water demand to support cellular function and transpiration (Taiz et al., 2018). Late growth of vegetation and the development of new patches further intensified this demand. Not only is this happening within the pond by emergent vegetation, but the riparian area and drying basin had substantial new growth by emergent species and terrestrial species, which could increase transpiration and water transmission from the pond (Hayashi et al., 1998). In addition, emergent vegetation within the pond could also contribute to a substantial increase in biomass within the water, which was not accounted for in water storage measurements. In fact, the presence of vegetation meant that water loss rates could be even greater than estimated, as the volume occupied by vegetation replaced that of water.

The depth of the water column is therefore highly dynamic and influenced by the abundance and biomass of vegetation, species-specific water demands, and plant stomatal activity that is influenced by climate. The temporal reduction in water column depth and area correlated with the development of vegetation, potentially contributing to the observed accelerated water loss once depths dropped below 30 cm.

However, it is crucial to acknowledge the study's temporal in extrapolating trends over multiple years or across more ponds within CCPA. Climatic variability, including factors like annual variation in snowpack, frozen soil, snow drift, and the soil water deficit all determine how much water a pond will even receive in spring (Coelho, 2008; Hayashi et al., 1998, 2016; van der Kamp & Hayashi, 2009), underscoring the need for further investigations in the observed area-depth recession trend.

5.1.3. Water Temperature

Different exposure levels to solar radiation have been shown to lead to seasonal differences in Tw responses by wetlands (Semaden-Davies, 2009). In CCPA, solar radiation, reflected in diurnal Ta trends, strongly regulates Tw fluctuations at the majority of the wetlands in CCPA. However, the wetlands exhibited varying responses, several outlying ponds demonstrated trends unlike the ponds with typical regimes that followed Ta trends, suggesting that there are other main factors influencing the Tw at some of these wetlands.

Elevation was anticipated to play a significant role in determining Tw. A trend of decreasing Tw with increasing elevation was expected to emerge to some degree because Ta was cooler at higher elevations than lower elevations, but this is not what was found. HG, GL, and HL are three of the highest elevational wetlands, yet they still had some of the warmest mean Tw. Moreover, BD and TY are neighbouring wetlands, yet they showed extremely different Tw regimes (Figure 15). TY and PL, however, showed remarkably similar regimes and they are 213 m apart. These results suggest that CCPA wetlands have superseding factors over solar radiation that ultimately regulate Tw regimes.

Emergent vegetation looked to have one of the strongest influences on Tw at three wetlands during study. These wetlands all had dense vegetative cover with one dominant species, either *Bolboschoenus fluviatilis* (Bolbflu)*, Typha latifolia, or Carex* exsiccate, that expanded the surface of their pond. All had varying physical traits and growth stages and patterns; the one commonality was that their standing and fallen or partially fallen litter looked to provide mulching during some part of the study. Mulching is often thought of as a ground cover that is used to control evaporation from the soil (Brady & Weil, 2010); however, over or within water it can still act in the same manner, restricting solar radiation from interacting with the water below (Goulden et al., 2007).

Bolbflu, or river bulrush, grew extensively across DL. At the beginning of June, Bolbflu litter was standing and relatively intact, with few emerging shoots. As the season progressed Bolbflu developed, and its litter shed into the pond. Lemnmin also grew across much of the water surface below Bolbflu. The diminishing Tw fluctuations in DL looked to be due to the coupling or individual effects of underwater mulching overtop of the HOBO readers from the deposition of litter and the shading of the tall mature Bolbflu and Lemnmin.

The other two wetlands showed inverse temperature patterns that were more extreme. Careexs, or beaked sedge, grew across the pond at PL. Similar to Bolbflu at DL, new shoots were beginning to grow, and standing litter was intact; however, there was also a mat of deposited litter approximately 1-2 ft thick within the water column surrounding the plant crowns. This deposition looked to be an accumulation from several years due to varying degrees of decomposition found. The litter mat seemingly functioned as insulator from solar energy, maintaining a relatively constant temperature throughout the water column with minimal fluctuations. As the season progressed, the water slowly warmed and small diurnal fluctuations began, which could be attributed to the recession of the pond.

Typhlat, or common cattail, covered almost the entire surface of TY. Again, there were very few new shoots and standing litter remained, but much of the leaves were partially fallen creating an above water intertwined web of senescent leaves that shaded the water from solar radiation. As the Typhlat developed, the litter fell to the basin bottom. The Tw shifted similar to PL (Figure 15), despite presenting quite different canopy structures and litter deposition mechanisms.

A study by Goulden et al. (2007) studied a Typhlat marsh and found that a large amount of standing litter, like that in TY, acted as a mulch layer maintaining lower Tw due to protection from solar radiation. They attributed this to the heating of the top of the litter surface causing the mulch layer to be atmospherically stable. The cool heavy air below suppressed downward movement of warm air, and at night the mulch cooled and promoted convection that facilitated upward heat transfer from the water. Lower Tw were thought to be the result of mulch heat transfer properties. Their results showed similar trends as found at TY and PL, where Tw remained near minimum Ta or below.

Shade effects from live emergent vegetation also has been found to lower wetland Tw (Kiniry et al., 2023). It is well known that all canopies provide some cooling to the ambient air through ET processes (van Westreenen et al., 2020; X. Wang et al., 2023; Zhang & Dai, 2022), but they also provide shade, reducing the temperature of the area they are shading. DL, PL, and TY may experience a degree of cooling not only through their litter cover but also from shade provided by their canopies or riparian vegetation, which both PL and TY had directly at their pond perimeters. This shading effect is likely present in several of the other wetlands due to their prevalence of vegetation cover or vegetation in their riparian zones.

In wetlands that have a high proportion of exposed water, such as HL, GL, and HG, the reverse of this effect could be observed where Ta was consistently high throughout the study. These wetlands also happened to be the deepest wetlands and showed a decreasing temperature gradient with depth, confirming that depth does not play a role in determining surface Tw until wetland depth is much lower, approximately <30 cm.

HG was the warmest pond on average across the entire study period. It also was the only pond that exhibited mixing occurred to a depth exceeding 45 cm below the surface (Figure 8H), contrasting with other ponds that displayed a distinct temperature gradient at that depth until later stages or throughout the season. (Figures 8A, 8K and 8L). The temperature regime observed in HG is particularly intriguing given its status as the second largest wetland in the study. One might not expect it to exhibit the highest temperatures among all the wetlands surveyed. Its largely non-vegetated surface could partially account for its high temperature, as could its seemingly high degree of mixing. HG is a long oval shape and situated directly between two hillsides on its east and west (Figure 8A). Its topography could indeed act as a wind tunnel, channeling prevailing winds through the landscape and potentially influencing water movement within the wetland.

Moreover, HG (and three other wetlands) had a high EC, indicating its potential to effectively retain heat (Ogungbe et al., 2015). It's plausible that due to its size, depth, and heat retention qualities, it experiences less cooling over the winter months, potentially leading to a quicker warming in the spring. High EC can contribute to the resistance of temperature changes within a body of water. The abnormal fluxes observed in CP during June (Figure 8C) could be attributed to its high conductivity, which may contribute to its resistance to temperature changes. Further investigation into the EC levels of these wetlands is needed to fully understand the Tw dynamics at play.

The outlying wetlands that do not follow air temperature trends can offer valuable insights into the potential factors influencing temperature regimes in CCPA wetlands. Lower temperatures, resulting from any of the factors discussed, can lead to reduced rates of evaporation from the water surface (Goulden et al., 2007; Mor et al., 2018).

5.1.4. Water Chemistry

Wetlands with high EC, mainly those with a high proportion of dissolved ions, exhibit reduced rates of evaporation (El-Dessouky et al., 2002; Mor et al., 2018), and CP could represent an extreme example of this due to its enormous conductance. A comparison with AP underscores this potential. It has been established that CCPA wetlands with a high degree of open water generally have higher temperature regimes compared to vegetated ones, and wetlands with smaller areas lost water more quickly. CP is an open water wetland with practically no emergent vegetation and, during SP2, despite being categorized in the same A-D classification as AP, CP was considerably smaller in area after the completion of spring recharge. Both wetlands shared similar elevations and initial areas and depths; however, by SP6, AP was nearly dry with only 4% of its area remaining, while CP retained 14 cm of water with 65% of its area still intact. Furthermore, AP had undergone a significant fire, likely resulting in hydrophobic soil conditions, and cattle had visited AP twice for extended periods, utilizing the wetland for watering. All indications suggested that CP would lose a similar or a greater amount of water compared to AP, yet this was not the case, prompting speculation that conductance may play a significant role in controlling evaporative loss.

Moreover, it is important to consider that AP and CP may have different rates of subsurface losses and gains. CP had a wetland directly upland from it, approximately 25 meters away, which could have been contributing to its pond volume. In contrast, AP had an established large wet margin that was vegetated, likely contributing to higher soil conductance and transpiration from the moist margin vegetation compared to CP's minimally vegetated riparian and saline moist margin. However, ET in the moist margin at CP was apparent by the formation of salts on its moist margin surface and plants (Figure D10) and considering the larger perimeter-area ratio at CP, ET could potentially have a more significant effect on pond water loss compared to AP, which had a smaller ratio (see 5.1.5. for more details on moist margin ET).

HG, HL, and GL also exhibit elevated levels of EC, although not to the extreme extent seen in CP. As reported, these wetlands were the deepest and had the most water left in them at the end of the study. Despite this, it is plausible that they exhibit resistance to evaporation given their high conductance and associated heat retention properties. More research is needed to understand the mechanisms influencing water loss in these wetlands, to confirm that high EC is a contributing factor to lower evaporation rates.

5.1.5. Soil Properties

Lateral water movement from wetland ponds can account for a significant portion of water leaving the pond (Hayashi et al., 1998; Millar, 1971; van der Kamp & Hayashi, 2009).

Hydraulic conductivity decreases quickly with depth (Brady & Weil, 2010; van der Kamp & Hayashi, 2009), normally within 4–5 m of the surface because it has much lower pressure potential than the zone below (T. Winter, 2003). This is vitally important to the lateral groundwater exchange between a pond and its moist margin (Hayashi et al., 2016), because it suggests that ET losses are a major water balance component (Hayashi et al., 1998; T. C. Winter & Rosenberry, 1998).

IG and BD had significant moist margin widths before their final dry out, as did AP the entire study (Figure 10-12). Because of this, ET losses from the basin's moist margin was expectedly exceedingly high. Millar (1971) found a strong linear correlation between the ratio of the pond perimeter to area and the rate of depth loss, meaning that smaller ponds have much higher recession rates due to their infiltration into the moist margin through hydraulic pressure differences (Hayashi et al., 2016). Hayashi and van der Kamp (2009) found that the ET loss from a 8-10 m moist margin would be 0.04 m^3 per day. Given that the average moist margin was approximately 13 m at AP on SP6 that could mean significant losses. IG only had an average 8 m moist margin on SP5 before its dry out but, given the area-perimeter ratio, that could double its total ET rates since moist margin ET rates are similar to that of pond ET (Shjeflo, 1968).

Dense vegetation in the moist margin promotes higher hydraulic movements into the moist margin (Hayashi et al., 1998; Meyboom, 1966; Rosenberry & Winter, 1997), so wetlands with woody vegetation in their immediate riparian areas or densely emergent vegetation can induce substantial water loss through ET in moist margins, such as at TY and PL. Additionally, dense root masses were observed at BD in some patches, and due to the mosaic patch growth patterns across the wetland, areas containing these were both submerged and eventually outside the pond boundary. Given the likelihood that the large root development translates to heavy water uptake (Brady & Weil, 2010), substantial water loss from the wetlands could be loss through moist margin capillary action.

Soil temperatures were observed to be cooler at wet sampling points across all wetlands, with the most significant differences noted at AP and BD due to their longer transects and uneven basin profiles. The latent heat of vaporization occurs more readily at warmer Tw because less energy is needed for the phase change from water to vapour (Kadlec, 2006). On the other hand, the potential for evaporative losses are greater when water supply is not limited (Brady & Weil, 2010; Penman, 1948) due to a higher pressure gradient with ambient air (Brady & Weil, 2010; Kadlec, 2006). The two processes occur in unison and may be particularly prominent around the perimeter of the moist margin where soil is warming but water is not limited, likely resulting in high evaporation rates. Similarly, numerous pools disconnected from the main pond, observed at AP and BD, can create areas with higher Tw and sufficient moisture, facilitating rapid evaporation. The significant removal of water from the main pond by these pools decreases pond volume, potentially accelerating warming and enhancing evaporation rates.

In addition, soil moisture readings at BD and AP revealed extreme fluctuations along the transect, with wet conditions at some surface points and drought conditions only meters away (Figures 10 and 12). Loose, dry soils, as observed in non-trampled areas, have a lower heat capacity and are poor conductors of heat (Brady & Weil, 2010). This means they require less energy to increase in temperature, and the heat does not disperse as easily. In contrast, wet, compacted soils, observed in trampled areas, have a high heat capacity and are excellent conductors of heat (Brady & Weil, 2010). As a result, soils do not heat as quickly but can transfer the heat below. The disconnection of pools may lead to rapid soil heating in their surrounding margin and warming effects on the water. GH is a good example; although its initial maximum water level was 18 cm, the water depths under the quadrat samples were much lower, ranging from 3 to 5 cm. This suggests that the average depth of the pond was much shallower than the measured points. GH's pond dried quickly over 12 days; its shallow basin slope likely promoted high disconnection from the main pond, allowing for some of the described processes to occur, especially considering cattle were present at GH over these 12 days.

The amount of water loss from the basin soil will determine the recharge demand for the following year or more, depending on the severity of drought. After drying, GH experienced continuous land evaporation under drought conditions (<0.01 m^3/m^3) from June 12 on. By the end of the study, the soil had formed deep surface cracks that extended feet below the surface due to its prolonged drying (Figure D11). These cracks accelerate evaporation from the soil surface further, as their surface area expands along the crack surfaces and deep levels. Extensive and continuous drying, as observed at GH, into the winter will certainly present recharging challenges for subsequent years. Groundwater replacement will need to take place before the pond is recharged, and depending on its water table depth, dry ponds can absorb a large amount of the runoff from snowmelt before a surface pond forms (Hayashi et al., 2016). Thus, a wetland's potential to recharge is reliant on its winter snowpack. Unfortunately, the winter of 2023-2024 was relatively dry, so in the case of GH, pond persistence into 2024 is questionable.

5.1.6. Vegetation Cover

Energy availability and the exchange efficiency from liquid water to water vapor both have a hand in driving evaporative losses (Jansen et al., 2023). Energy availability considers the degree of solar radiation hitting a surface, vegetated or water, to make the transformation and drive photosynthesis, and exchange efficiency considers both the vapor pressure gradient and the wind speed because they simultaneously control the exchange process.

In this study, VPD tended to be higher within the canopy relative to its ambient VPD. This suggested a stronger evaporative pull from the water surface and stomatal conductance in the shorter vegetation within the canopy. However, this only highlights one part of the exchange efficiency factor, leaving out wind speed. The data showed that on average emergent vegetation canopies block wind, so while the VPD is lower in the ambient air around the canopy, wind is higher, meaning saturated air around the canopy is continuously being transported away, increasing the pressure gradient (Jansen et al., 2022; Taiz et al., 2018). Moreover, radiative exposure is lower within the canopy due to shading by taller stems, so there is less energy for vaporization and photosynthesis. Jansen et al. (2023) found that energy availability was a bigger driver of evaporative losses than exchange efficiency on vegetated surfaces, such as on peatland swamps and grasslands, than over open water. Open water ponds had a high exchange efficiency with a small direct response to incoming radiation, allowing for a dominant response to atmospheric water demand and wind. Thus, even though the VPD tended to be higher in the canopy, the biophysical factors of plant species (Du et al., 2021; Mohamed et al., 2012), and the proportion of vegetation and its capacity to create shade and block wind must be taken into account before confidently determining that higher VPD is an indication of higher evaporation within the canopy.

Because the abundance and diversity of emergent vegetation growth is site-specific, each wetland will have varying degrees of evaporative pressure that changes throughout the season. However, with increasing temperatures, VPD is likely to increase (Ficklin & Novivk, 2017). Both weather station data and plant sampling data showed that the VPD already experienced in CCPA is above well above 1.5 kPa most days, indicating high atmospheric evaporative pressure. If VPD trends continue to increase worldwide as they have been (Ficklin & Novivk, 2017), higher evaporative stress will not only speed up open water evaporation that has been confirmed to be strongly driven by the exchange efficiency (Jansen et al., 2023), but plants may need to alter their stomatal conductance strategies to accommodate the increased pressure deficit (Grossiord et al., 2020; López et al., 2021; Massmann et al., 2019; Taiz et al., 2018).

The presence of emergent plants in a wetland pond complicates our understanding of water loss. Ponds with vegetation may or may not have a bigger risk of drying completely, more attention to these wetlands is critical for their understanding.

5.1.7. Animal Use

Livestock grazing exerts multifaceted effects on wetland ecosystems, primarily through processes such as treading and herbivory (Morris & Reich, 2013). These activities alter various aspects of the hydrological cycle; however, their impacts can vary across regions (Renton et al., 2015).

In CCPA, over 400 cattle are cycled through the landscape who rely on the wetlands, lakes, and provided troughs for watering. The extended use of the wetlands can lead to cows utilizing an extensive amount of water as a single individual can consume around 40 liters of water a day (Brown, 2006). Accelerated water loss correlated with cattle presence, as might have been seen at GH, could be detrimental to its sustained persistence, especially given our climate crisis.

Riparian and upland areas across CCPA experience various levels of grazing, which in part can increase or decrease the amount of water reaching a wetland. Grazed vegetation often undergoes reduced ET, as suggested by a decrease of 6.1%, conserving soil water in the top 30 cm of the soil. (Renton et al., 2015). It has also been reported that grazing can lead to more runoff through cattle-induced soil compaction and loss of infiltration, prolonging pond inundation periods and pond holding capacity (Hayashi et al., 2016; Morris & Reich, 2013; Pyke & Marty, 2005). Moderately grazed pastures may lose up to 25% infiltration, or up to 50% under heavy grazing (Morris & Reich, 2013). Moreover, improved infiltration by the exclusion of cattle from grasslands caused faster soil water loss due to heightened transpiration (Hayashi et al., 2016). Although grazing can induce more runoff, and in turn lead to more water in wetland systems, it can also heavily impact soil structure and mechanical strength leading to erosion and sediment filling, and reduce vegetative growth (Brady & Weil, 2010; Pietola et al., 2005).

Despite the negative aspects, grazing has been associated with beneficial shifts in wetland vegetation composition and diversity (Pyke & Marty, 2005). Vegetation surveys indicate differences between grazed and ungrazed wetlands, with long-protected areas showing reduced floristic quality, fewer rare and specialist species, and more woody plant encroachment compared to recently abandoned areas (Bart, 2021). Similarly, semi-natural grassland wetlands exhibited lower vegetation diversity and quality compared to those in intensively managed pastures (Boughton et al., 2016). Moreover, the removal of grazing negatively impacts the edge and upland zones of wetland pools, leading to declines in native species richness and cover (Marty, 2005).

The multifaceted effects of livestock grazing on wetland ecosystems significantly influence hydrological processes and water loss dynamics. While grazing can lead to accelerated water loss through compaction and altered vegetation structure, it also plays a complex role in shaping wetland hydrology. Understanding these interactions is crucial for effective wetland management and conservation efforts in CCPA, highlighting the need for balanced grazing practices that consider both ecological and hydrological implications to sustain these valuable ecosystems.

5.1.8. Disturbances

Anthropogenic

Due to the rural nature of CCPA and its safeguard to development by its designation as a protected area, anthropogenic disturbances are relatively low. Ranching related activities are the largest source of change in land use and disturbance to the natural ecosystems in CCPA, including wetlands. Fortunately, ranching practices in CCPA are not as intensive as in some areas. A two-year rotation is in place and a planned annual grazing schedule is in play. The ranchers are dedicated to managing the landscape in a sustainable manner to encourage grassland regrowth and cattle distribution away from water sites and riparian areas (Holmes, 2023). Maintained commitment to sustaining ranching practices needs to remain a priority for the persistence of wetlands in CCPA.

Unfortunately, the introduction of species by historical farming practices prevails across CCPA and they will stay that way. Cattle, wildlife, and humans use maintained pathways and roads where many of these species are in abundance, distributing seeds throughout CCPA.

Fire

Five wetlands were fully or partially burned by a fire in 2021 (Figure 14), with varying degrees of severity. Fire in a wetland's watershed can significantly alter the conditions of the soil, thereby impacting hydrological processes and altering pond water balances. Evidence suggests that such alterations occurred in the AP and AG wetlands, where ponds expanded beyond established terrestrial plant communities, such as the *Rosa woodsia* patch at AP.

Fires facilitate higher overland flow by affecting soil bulk density and inducing hydrophobicity. The destruction of soil aggregates and organic matter increases soil bulk density, leading to the collapse of pore spaces and deterioration of soil structure (Agbeshie et al., 2022). Aggregates can completely disintegrate under high severity fires, exceeding 200°C, resulting in reduced water holding capacity and slower infiltration (Agbeshie et al., 2022; Brady & Weil, 2010). At lower temperatures (30-60°C), aggregate quality may improve, enhancing stability but also forming a hydrophobic layer, hindering infiltration and increasing runoff in areas affected by severe fires (Agbeshie et al., 2022), potentially observed at AP.

Fire also impacts the composition of upland vegetation communities. While woody vegetation, including smaller trees and shrubs, may die, there is often an increase in graminoids and forbs in subsequent years (Ducherer et al., 2009). Loss of woody vegetation can enhance throughfall of precipitation and reduce subsurface water removal. However, burning of trees and shrubs affects the amount of radiation reaching the land surface, as well as soil and air temperatures (Ducherer et al., 2009), ultimately influencing the evaporative capacity of upland areas.

The effect of forest fires on wetland water quantity largely hinges on the duration and intensity of the fire. While fires might extend hydroperiods at CCPA wetlands, the shifting climate, characterized by rising temperatures and prolonged droughts, poses an increased risk of forest fires in CCPA, potentially offsetting any positive hydrological impacts to wetland water balances.

5.2. Reference Evaporation Model

The predictive accuracy of the REM varied across the 12 wetlands in CCPA. The model adequately predicted water loss at four wetlands (AP, BD, TY, PL); at another wetland (GH), accurate predictions were thought to be confounded by external forces that rapidly reduced pond water levels, suggesting that at a comparable water loss rate to other wetlands water loss would have been overestimated. Early-season dry-outs were predicted at two small wetlands when their ponds actually persisted to the end of summer; and water losses at the final five wetlands were significantly overestimated compared to observed losses.

The discrepancies in model performance are likely attributed to the combination of factors, including diverse topographical traits and elevational patterns. In CCPA, the study wetlands spanned an elevational range of 630-1250 m and had variable topographical traits that ranged from flat to mountainous upland areas. Climate variation was evident across elevation, the three monitored weather stations showed that higher elevations experienced cooler temperatures and higher rainfall amounts than low elevations.

Three wetlands that were well predicted by the model were situated at moderate elevations and were in close proximity to each other, suggesting similar Ta. However, the fourth wetland (PL) stands out with the highest elevation, approximately 300-400 m above the other three. Interestingly, the areas of another two wetlands (HL and GL) that are closest in proximity to this wetland were grossly overestimated by the model. This observation suggests that elevation may not always exert a strong influence on water loss.

Climatic variation alone does not influence water loss, as evidenced by the mixed results observed across wetlands of varying elevations. Basin depth and profile slope could be missing variables in the model, however. The model assumes uniform wetland depths and basin slopes, but model performance was poorer for deeper wetlands. Wetlands with depths less than 60 cm were more accurately forecasted by the model; however, depth variations among wetlands these resulted in skewed initial volume predictions. Ultimately, wetlands of the same size but with different depths had similar REM volume forecasts, ultimately leading to inaccurate predictions.

AP and BD provide a notable example of this because they had similar initial areas (0.35 ha for AP and 0.37 ha for BD) but BD had half the depth of AP during SP2, meaning that BD had less water volume than AP, but the model assigned a larger volume to BD due to its slightly larger area. Both wetlands had similar net losses of water from SP2 to

SP4 (-29 cm), so BD predictions remained greater than AP until SP5, even though BD was already dry and AP progressed past the end of the study.

The model performed most accurately for moderate-sized vegetated wetland ponds with moderate depths between 30-60 cm, all of which were entirely vegetated, though there was differences in vegetative growth patterns among these wetlands.

For instance, AP and BD both had dominant Eleopal areas with various other patch types and were similar in initial area. Conversely, TY and PL are densely vegetated wetlands with Typhlat and Careutr species, respectively, along with woody vegetation in their riparian areas. Despite having the same initial area (0.12 ha), TY and PL exhibit unique Tw regimes compared to the other 10 wetlands, displaying remarkably similar fluctuation patterns and lower temperatures. The variability observed within these wetlands suggests that they experience different rates of water loss due to varying atmospheric demands and Tw regimes influenced by the presence of vegetation compared to the other ten wetlands.

The presence of plants within the water column contributes to the overall volume of ponds. Ponds that were accurately forecasted typically contained a significant amount of live and decomposing plant tissues within their water, which added to their volume. For instance, in the cases of AP, BD, TY, and PL, removing all plants would result in a notable decrease in both depth and area for each wetland. The interaction between vegetation dynamics and water loss becomes apparent here. Vegetation can either mitigate or exacerbate evapotranspiration (ET) through various mechanisms such as shading, mulching, wind blocking, and transpiration. Consequently, each wetland exhibits a unique ET loss pattern influenced by its specific vegetation characteristics, adding complexity to the determination of the impact of plant volume in a pond. The model's sensitivity to vegetation volume might already be inherently incorporated, as its development could have been based on wetlands with moderate to extensive vegetative cover. Alternatively, its suitability for vegetated CCPA wetlands might rely on a specific size-depth relationship, considering that other heavily vegetated ponds were either smaller than 0.1 hectares or larger than 2 hectares. However, it is also plausible that these inclusions were incidental.

Primarily open water ponds, including the three deepest wetlands in the study, were not accurately predicted. Four of these ponds also displayed significantly different water chemistry characteristics, with high Electrical Conductivity (EC) levels ranging from 1330-5100 μS/cm in SP2 and 1690-18900 μS/cm in SP6. These ponds were predicted to experience much higher water loss than observed. The water chemistry could potentially alter evaporation rates. Water with high EC levels evaporates slower due to decreased saturation vapor pressure caused by salinity, which hampers the water's ability to release molecules into the air. Although higher salinity may initially elevate surface temperature, the overall effect is a reduction in evaporation due to the dominant influence of salinity over temperature (Mor et al., 2018).

For instance, CP exhibited the most extreme EC levels. Despite its smaller area and depth compared to AP (with low EC) and being at a similar elevation, CP retained 74% of its actual area (or 15% of its predicted area), while AP's area approached zero. Although unconfirmed, CP's connectivity to an upland pond raises questions. There was a potential for this pond to receive water from an upland source until it dried out. Therefore, it remains unclear whether wetlands with high salinity would display resistance to evaporation, or if other factors such as depth and pond connectivity exert greater control over their water loss dynamics.

In summary, the model generally overestimated water loss forecasts for small ponds below 0.1 hectares. Midsized ponds with vegetation were forecasted more accurately, while non-vegetated and deep ponds tended to have poorer predictions. A deeper understanding of the ponds monitored to develop this model's volume regression equation would help elucidate the factors contributing to the discrepancies observed in water loss projections.

It is important to note that the analysis has only addressed the initial and final values of area and volume thus far. This limitation arises from the discrepancy between the timing of losses in the model and the actual circumstances observed. Specifically, the model's area predictions declined much earlier in the season compared to what was observed in reality.

For instance, consider the case of AP, which performed relatively well in the model with acceptable final area and volume predictions. AP experienced an actual loss of approximately 42% of its area between SP5 and SP6, while the model indicated less than 3% of the remaining area left at SP5. Interestingly, the model predicted that 62% of the area would be lost between SP3 and SP4, demonstrating a notable disparity.

The original model is intended to forecast monthly, while the data for this study was collected every 20 days. This difference in data collection intervals could potentially skew the mid-season predictions. However, considering that the initial and final sampling points were just over 2.5 months apart, it is unlikely that this difference significantly altered the results, especially given the earlier loss in area. To confirm this, an examination of the predictions at SP5 was conducted, considering that SP2 and SP5 are two months apart. However, this additional analysis did not yield any new conclusions.

5.3. Wetland Assessment

The wetland assessment developed in this study served to quantify the findings and establish a structured approach for identifying the shortcomings or weaknesses present at each wetland. These findings generally corroborated on-site observations and individual opinions regarding the state of the wetlands. Below, each wetland will be discussed to outline the findings and provide insight into their respective grades.

DL received a low ranking in pond permanence at 57% but ranked moderate to high in the other three indicator categories. As the largest wetland in the study with a moderate depth, DL did not dry out in 2023 but has experienced drying in past years, such as 2022. Given its lower elevation, DL may face an increased risk of drying in the future due to climate changes. The wetland is fully vegetated across its water surface, with high density and canopy cover, particularly later in the season. There was a correlated decline in Tw fluctuations with vegetation growth and litter deposition, suggesting that high transpiration rates could be somewhat mitigated by cooler midday Tw, which slows evaporative loss, although the stomatal responses to increasing Ta are uncertain.
DL scored low for substantial summer inputs; earlier in the season, there were signs of water inflow, but these diminished by the last sampling period. Despite this, due to its size, DL maintains high biological integrity. It provides ample breeding potential within its dominant Bolbflu cover and riparian vegetation, displaying unmatched biodiversity. While long-term grazing impacts and erosion were present in some upland areas, these disturbances likely have minimal impact on DL due to its large size and surface area to edge ratio.

IG received low grades in pond permanence, water quality, and biological integrity. It did not score higher than 3 points in any of the pond permanence factors. Situated at one of the lowest elevations and being one of the smallest wetlands, IG lacked substantial summer water inputs. Being a primarily open water wetland with a moderately sloped basin, its moist margin did not significantly expand until later in the season, thereby limiting its soil ET. Moreover, its chemical composition returned the lowest values, with some measurements falling below optimal levels. Despite its observational health being one of the best due to limited animal and disturbance pressure, IG's small size does not attract animals for breeding or extended visits, consequently lowering its biological integrity grade. Overall, IG appears to be a seemingly healthy wetland; however, its small size renders it vulnerable to environmental pressures.

CP ranked low in water quality, biological integrity, and disturbances, but was granted either 3 or 4 points for every pond permanence factor except emergent vegetation density and litter cover, resulting in a moderately high grade in this category. Being an open water wetland with limited shade cover, CP exhibited resistance to water loss over the study period relative to its size and depth. Additionally, CP potentially benefits from a neighboring wetland that could feed into it, and it could have some evaporative resistance due to its remarkably high dissolved salt content. However, CP's water chemistry was the primary reason for its low ranking in water quality and biodiversity integrity. The saline conditions restricted the presence of many species, and the low plant density offered limited breeding grounds. While CP's chemical composition is largely influenced by its natural geochemistry, increasing evaporative pressures may exacerbate its saline levels. This could further deteriorate water quality and potentially become lethal to some species if not addressed. Furthermore, cattle used CP during the study, leading to plugging and grazing issues. While earlier season watering may not pose immediate problems, prolonged evaporation could lead to extreme chemical compositions, presenting challenges for both cattle and wildlife. Overall, CP's permanence appears relatively stable for now, but protective measures may be necessary to safeguard both cattle and wildlife.

AG ranked low to moderately for pond permanence due to its area-depth relationship and the lack of inputs over the summer. Throughout most of the study it exhibited relatively sparse emergent vegetation over a sizable portion of its surface, which may or may not be associated with accelerated water loss. Compared to other wetlands, AG showed relatively low species richness. Although AG completely burned in the 2021 fire, the remnants of its burnt riparian Aspen stand remains. Despite this loss, riparian vegetation is regenerating, and the Aspen stand continues to be used by many species, particularly birds. The impact of the fire on the upland grasslands and open forest surrounding AG was significant, with many burned areas showing limited regeneration and possible hydrophobicity. Interestingly, AG appeared to have more water than usual, as terrestrial species were emerged at the beginning of the season. With a small to moderate area-depth relationship, AG could be at risk; however, the fire may have facilitated increased discharge into its basin, potentially mitigating some of this risk.

AP, situated in close proximity to AG, shares similar mesoclimates, nearly identical elevation, and neighboring watersheds. Despite these similarities, there were variations in their assessment results. AP exhibited a higher diversity of emergent plants, including some terrestrial species like Rosawoo. Additionally, AP had greater plant cover as compared to AG, especially evident in the later season when Eleopal was fully developed. This abundant cover, combined with AP's larger size and relatively shallow sloped basin, facilitated the development of an extensive moist margin. Interestingly, AP's size in 2023 was over three times larger than in previous years, while AG's area remained relatively consistent. This disparity could be attributed to changes in AP's catchment following the fire, or possibly due to increased snowfall in AP's catchment area. The crucial question arises whether AP will continue to receive larger amounts of discharge, and if so, what factors contribute to this trend.

BD ranked second lowest in terms of pond permanence, being the second pond to dry due to its shallow depth. However, it boasted a notably long moist margin throughout its flooding period, with abundant vegetation in most of its riparian area and basin. Despite its vulnerability in terms of water permanence, BD scored second highest in biological integrity, attributed to its rich diversity of wetland species and frequent wildlife visits. The wetland hosted multiple bird nests and numerous invertebrates. While moderate disturbance was observed at BD, it did not significantly affect its functionality. Instances of erosion near the road, plugging, and low regrowth of grasses in some areas were noted, likely exacerbated by its proximity to agricultural fields, where many non-native terrestrial plants were observed.

TY received a moderate grade for pond permanence, with a score of 62%. Its only low score was in vegetative emergent and riparian density, which could potentially impact transpiration rates. However, TY maintained cool waters throughout the entire study period and showed signs of potential inflow of water from an upland wetland. The wetland exhibited high biological integrity, with abundant wildlife signs and ample breeding habitat. In terms of disturbance, TY experienced similar levels as BD, given their close proximity. However, TY had fewer spots of erosion near the wetland compared to BD, likely due to the road being farther away from TY.

HG achieved high scores in all categories except for disturbances. As the second-largest wetland in the study with considerable depth, HG benefits from an inflow of subsurface water during at least part of the summer. However, it exhibits limited vegetation cover outside its fringe, resulting in minimal wind blocking and transpiration. Despite its size, HG had a relatively small moist margin. Nevertheless, its expansive size allowed numerous species to use the wetland concurrently, and its mixed fringe offered diverse breeding grounds. However, HG faces significant disturbance issues, with extreme plugging and cattle use. Its large pool and watering trough likely attract numerous cattle for extended periods, contributing to an elevated level of disturbance. Additionally, the proximity of the road and its intersection with the watershed flow further exacerbate these disturbances. Although old anthropogenic remnants, such as a structure and a fallen barbed wire fence, were present, they do not appear to impact the wetland's hydrological function or deter wildlife. Despite its high electrical conductivity (EC), HG's chemical composition adheres to water quality guidelines.

GH wetland received low grades in two indicator categories, pond permanence and biological integrity, which are highly interconnected at GH. The early drying out of GH indicated a lack of substantial inflow, and biological integrity suffered due to its small size and shallow depth. Although GH initially harbored thousands of Western Toad tadpoles, their survival was likely compromised due to the drying conditions, impacting the wetland's biodiversity. Additionally, the absence of water availability hindered the diversity of emergent plant species and wildlife utilization. During the study period, GH was completely fenced off after the pond dried out. While this fencing will keep the wetland protected from cattle in coming years, climatic pressure will persist; with increasing temperatures and reductions in snowpack, GH may not have enough water to persist into the future.

PL is situated in a somewhat secluded area of CCPA, surrounded by forest and experiencing less human traffic. Despite its secluded location, PL exhibited high pond permanence, although it did dry out over the summer, which was somewhat unexpected. However, being at a high elevation and adjacent to a steep forested mountain slope suggests that its potential for snow recharge remains favorable. While a road cuts between the mountain and its basin, limiting runoff from that direction, it serves as the primary source of disturbance, with minimal signs of large mammals. During the final sampling period, a few Water Quality Guidelines (WQG) were exceeded at PL when the pond was nearly depleted, resulting in a lower score in the water quality category. However, the measured levels are not overly concerning. Subsequent end-of-summer sampling is recommended to monitor changes over time and ensure the continued health of PL.

HL demonstrated moderate to high grades across all categories. While pond permanence at HL remained relatively stable, complete drying has been observed in the past, although it is not a regular occurrence. Throughout the study period, water levels at

HL remained high, with minimal moist margin indicating that most evapotranspiration occurs from its large open water surface, which is populated by mobile floating Lemnmin and bordered by a tall and dense fringe of Schotab. Notable wind blocking was observed behind the Schotab patch, providing partial shelter to the open water area from wind. While the Schotab patch offers breeding grounds and shelter for birds, there are limited opportunities for long-term dwellers. HL received a moderate disturbance grade primarily due to its roadside location. However, as the road is minimally used, its impact on HL is low. It is important to note that this aspect is not fully considered in the current assessment.

GL shared many similarities with HL, although its pond permanence score is 11% lower due to its large partial moist margin and the presence of a neighboring forest that may be drawing water from its pond. The only other notable difference lied in the disturbance category. Unlike HL, GL is secluded and inaccessible by car. However, cattle can easily reach GL through a large grassland area, and grazing activity was observed during the study period, resulting in moderate to high plugging in areas with grazed upland grassland. Both GL and HL wetlands are likely to persist with ongoing changes in climate. Their high elevation and largely open water surface may be contributing factors.

A key finding derived from this assessment process was the considerable influence of wetland area on its ranking. Larger ponds tended to exhibit greater biological stability and are less susceptible to disturbance impacts. Moreover, their water availability appeared more stable due to their larger surface area, providing a buffer against rapid water loss compared to smaller wetlands. However, the reduction in size of these large wetlands could lead to alterations in their functions within the landscape. There exists a threshold where a wetland community may become so degraded that it is no longer sustainable (U.S. EPA., 2002). This underscores the importance of preserving and managing wetlands, especially larger ones, to maintain their ecological integrity and functionality over time (U.S. EPA., 2002).

There are also limitations associated with this assessment. Given the challenging nature of continuous monitoring of these wetlands, sampling intervals were spaced weeks apart. However, the dynamic nature of these ecosystems means that biological and physical changes can occur rapidly and may be missed between sampling periods. For instance, GH hosted tadpoles for only 2-3 weeks, highlighting that if a study site was not visited during this critical biological period, the presence of tadpoles might have been entirely overlooked. In such a scenario, the grade for biological integrity at GH would have likely been lower. These limitations underscore the need for more frequent monitoring or the implementation of alternative monitoring techniques to capture the full spectrum of changes occurring within these wetland ecosystems.

While this assessment approach facilitated the comprehension of various aspects of wetland condition for comparison, it is evident that the pond permanence category received greater attention and development compared to the other three categories. This discrepancy can be attributed to the primary focus of this study on pond permanence. Consequently, the other three categories yielded relatively simplistic results that may not have added extensive value to the overall assessment. With refinement and further development of this assessment framework, there is a need to ensure a more balanced and comprehensive approach across all categories to enhance the effectiveness and robustness of the assessment process.

6. Conclusions and Recommendations

6.1. Wetland Characteristics

This study delved into the characteristics that could potentially influence water loss in CCPA wetlands. My findings strongly advocate for prioritizing vegetated wetlands in future long-term monitoring efforts, owing to their intricate nature. Marsh wetlands appeared to exhibit more pronounced water losses compared to primarily open water wetlands. While data indicated the presence of stronger VPD within emergent canopies, these canopies also provided a degree of wind sheltering. Moreover, factors such as vegetation height and density of plants and litter seemed to contribute to lower Tw by obstructing radiative heat. However, the complexity of these dynamics is underscored by the potential for extensive vegetation cover to correspond to higher transpiration rates, underscoring that the effect of vegetation on wetland water loss is variable and not yet fully understood, but suggests that vegetated wetlands may need more focused conservation and protective measures.

Wetlands characterized by open water typically exhibited a tendency not to dry completely, whereas vegetated wetlands frequently experienced dry out. While depth appeared to be a confounding factor in vegetated growth, it nonetheless played a pivotal role in the drying process. The significance of depth was underscored by its influence surpassing that of area, as indicated by the area-depth relationship observed among CCPA wetlands. Interestingly, wetlands with similar depths did not dry out at the same rate, implying that area also played a crucial role. Consequently, wetlands situated lower on the area-depth drying gradient are more susceptible to permanent drying as a result of climate changes.

Moreover, emergent and riparian vegetation play a significant role in driving moisture margin ET. Wetlands characterized by large vegetated moist margins may experience a considerable water withdraw from their ponds, primarily propelled by transpiration. Consequently, wetlands devoid of vegetation or with limited vegetation coverage might exhibit lower total ET. This underscores the critical importance of prioritizing long-term monitoring efforts at wetlands with full vegetation cover, particularly those with extensive vegetated moist margin areas that are particularly prevalent in wetlands with shallow basins.

Climate is a clear driver of wetland water loss in CCPA. Evaporative losses are a main output for these wetlands and increasing temperatures due to climate change will likely accelerate them. Wetlands at lower elevations may face greater risks compared to those at higher elevations. Low to mid elevational wetlands often experience higher air temperatures, lower precipitation, and higher VPD, indicating increased water stress within their watersheds compared to higher elevations. Despite this, higher elevational wetlands may also encounter heightened water stress due to anticipated changes in climatic conditions. However, they may benefit from greater tree cover within their watersheds, which can help mitigate temperatures through shading and enhance precipitation through transpiration. The hydrological regimes of these wetlands need to be studied continuously to identify hydrological trends across wetlands with similar characteristics for their conservation.

Understanding air temperature trends is crucial for comprehending Tw regimes in wetlands, as many wetlands exhibit diurnal temperature fluctuations. The temperature of water significantly influences evaporation rates, especially when pond volume is dwindling. These observations underscore the vulnerability of wetlands to climate variability and highlight the importance of considering elevation and vegetation dynamics in water resource management strategies.

There were signs that cattle may have the potential to induce rapid water loss in CCPA wetlands with prolonged use. Shallow wetlands that cattle can wade into are more at risk than deeper wetlands due to an increased risk of vegetation damage and wildlife disturbance. Cattle management strategies are important for the longevity of these wetlands.

This study has provided valuable insights into the characteristics of twelve CCPA wetlands, which can serve as a basis for understanding other wetlands with similar traits. However, it is important to acknowledge the limitations of this research. The study was confined to a three-month period, from May 18 to August 22, 2023, with some variables not being monitored until the first week of June. Additionally, the wetlands were visited 3 to 6 times, resulting in limited samples and observations, and in some cases, missing entire summer months when water loss rates were significant. Spring snowmelt recharging was also missed so the full picture of the wetlands' hydrology were not achieved.

Moreover, this study captured data specific to the hydrological regime of 2023. Wetland hydrology in CCPA is largely driven by spring snowmelt recharging. Because snowfall patterns vary from year to year and are changing with climate, many aspects of this study need further monitoring to confidently recognize annual hydrological patterns.

Despite these constraints, the data collected offered a broad overview of the functioning and characteristics of each wetland, providing insights into factors potentially controlling water loss. Moving forward, these initial findings can serve as a foundation for more comprehensive studies in CCPA and other grassland ecosystems in BC and provide baseline data for long-term monitoring efforts.

6.2. Reference Evaporation Model

The current efficacy of the REM for application in CCPA appears to be relatively limited. The model lacks consideration for seemingly critical factors such as depth and vegetation cover. Volume is a product of both depth and area. The omission of depth from the model leads to inaccurate initial volume predictions, particularly problematic in CCPA wetlands characterized by diverse basin shapes. Additionally, the presence of vegetation in the water can significantly influence the ratio of water in a pond to the total pond volume.

The characteristics of the wetlands in the Upper Assiniboine River Basin, Saskatchewan, where the model’s volume regression equation was derived, may be representative of adequately forecasted CCPA wetlands, particularly those characterized by fully vegetated moderate depth ponds (40-60 cm). However, comprehensive long-term monitoring is essential to fully understand how a range of factors, including depth and vegetation, influence water loss and affect the model's output in BC's grassland ecosystems. Collecting data over multiple years in CCPA would enable tracking of natural changes in initial area, depth, and volume, thus confirming insights gained from this study.

While the REM may not be suitable as a management tool in the interior grasslands of BC at present, there is optimism that further research could lead to more accurate predictions of wetland water losses in specific wetlands with suitable attributes. Continued investigation and refinement of the model holds the potential to enhance its predictive capabilities and improve its utility in managing wetland ecosystems in BC.

6.3. Wetland Assessment

Assessment Framework

The wetland assessment presented in this study draws upon evidence gathered during the research process and insights obtained from relevant literature on wetland characterization. While this forms a robust foundation for the assessment, it is important to acknowledge its inherent limitations. The subjective nature of my perspective on the ranking of these wetlands reflects the constraints of the study, including the relatively short duration of the research period and the broad scope of the findings. Assumptions were made, and grading criteria were selected based solely on details discussed within this study.

Nevertheless, the contribution of this assessment framework to the ongoing management and monitoring of CCPA wetlands can be significant, particularly if the results are used as a baseline for subsequent assessments. The inherent limitations of my study underscore the need for further refinement of the assessment as more insights are gained about CCPA wetlands. By expanding and refining the assessment framework, it has the potential to become an invaluable tool for tracking annual changes across CCPA wetlands and informing targeted conservation and management efforts.

Conservation and Restoration

Protected areas in British Columbia are protected under the Environmental and Land Use Act, that limits activities from an area and ensures that all aspects concerning the preservation and maintenance of the natural environment are considered (BC Parks, 2023). Specific provisions and any special conditions are outlined during the establishment of the area (BC Parks, 2023), so there many be limitations in what protective measures or restorative actions will be approved for the management of CCPA wetlands. As such, long-term monitoring is essential to identify clear indications of wetland loss and its underlying drivers.

Even in good health, wetland ecosystems are relatively fragile, susceptible to alteration or damage from extensive management activities. Hence, management activities must be relatively non-invasive. Wetlands with small water volumes, at higher risk of drying, or facing biological threats may be fully or partially protected from cattle use. A representative case is GH, where complete fencing was implemented after its 2023 dry-out event. Replacement fencing damaged by fire was installed, now encompassing the entire wetland with a gate allowing controlled access. Cattle exclusion, either year-round or periodically during biologically important periods or critical water loss levels, can be enforced.

However, protecting these wetlands presents challenges. Their utilization by wildlife and cattle is crucial, and exclusion methods may adversely affect certain populations or pose ranch management issues. Conversely, lack of protection could jeopardize the wetlands' existence. Resourceful management techniques, like installing additional cattle watering troughs coupled with fencing, may mitigate some of these challenges.

Thinning vegetation may offer a viable management approach to regulating water levels in densely vegetated wetlands. However, this strategy comes with challenges such as environmental disruption and resource constraints. Thinning vegetation is a labor-intensive process that requires ongoing maintenance for sustained effectiveness. In implementing vegetation management techniques, there may be an opportunity to engage First Nation groups to oversee these projects, fostering collaboration and leveraging traditional ecological knowledge in wetland conservation efforts.

As previously mentioned, conducting long-term monitoring of CCPA wetlands is crucial for comprehensively understanding their water balances. However, additional insights can be gained from monitoring and studies conducted at identified wet meadows, as documented by Steen and Iverson in the 2021 CCPA wetland inventory. These wet meadows can serve as valuable reference sites for understanding the characteristics of wetlands that no longer persist. By analyzing specific vegetative qualities, soil conditions, basin sizes, and watershed sizes in these areas, informed decisions can be made regarding which wetlands may be at risk in the future. This integrated approach provides a holistic understanding of wetland dynamics and aids in proactive conservation and management strategies.

Projections indicate that ongoing climate changes will exert increasing pressure on wetland ecosystems. In the event of clear evidence of wetland loss, BC Parks may be required to take significant intervention measures. This could involve directly restoring the function of existing wetlands or creating new wetlands altogether. Options for intervention may include deepening or expanding existing wetlands; however, these approaches may prove ineffective due to water scarcity in the wetland. Alternatively, constructing new wetlands could be considered as a viable alternative. However, it is crucial to thoroughly understand the factors that contribute to the resilience of wetlands in CCPA before implementing such measures. This understanding is essential for ensuring the effectiveness and sustainability of wetland conservation efforts in the face of ongoing climate challenges.

Proposed strategies for constructing wetlands entail meticulous site selection, prioritizing high elevational or shaded areas. Wetland complexes with interconnected basins of varying sizes and depths should be created to accommodate diverse native wildlife habitats. It is essential to recognize that deeper and relatively steep basins are likely to retain water more effectively. Careful selection of plant species is crucial to mimic wetlands that have adapted to climate stressors.

However, numerous challenges and risks are associated with wetland construction. Appropriate site selection is paramount to minimize degradation from equipment and ensure the effectiveness of restoration efforts. Moreover, there is a risk of future drying if construction is not executed correctly or if unexpected climatic conditions occur. Therefore, thorough planning, careful execution, and ongoing monitoring are essential to mitigate these challenges and ensure the success of wetland construction projects.

Wetland conservation was identified as a principal management objective in the 2000 CCPA management plan (B.C. Parks Division, 2000). The findings of this study underscore the imperative for continuous monitoring to gain a comprehensive understanding of wetland hydrology and the potential ramifications of the ongoing climate crisis on these ecosystems. Moving forward, adaptive management strategies are essential to effectively address the evolving challenges faced by these ecosystems.

The insights garnered from this study can serve as valuable guidance for Regional BC Parks staff, aiding in the identification of wetlands most vulnerable to loss or significant impacts due to climate change. By integrating this information into management practices, BC Parks can enhance their capacity to preserve and safeguard the ecological integrity of wetland ecosystems within the CCPA.

Tables

Table 1. **Sampling completed for area (A), depth (D), vegetation quadrats (V), soil transects (S), and water chemistry (W) at each wetland from May 18 to August 22, 2023 - (SP1) to (SP6). Note: nd means no pond data was collected due to dry out, and * indicates that there was equipment related issues and data could not be collected.**

Wetland	SP1 May 18-20	SP2 May 31- Jun 6	SP3 Jun 20-23	SP4 Jul 10-13	SP5 Jul 29 - Aug 2	SP6 Aug 18-22
Dry Lake	A	*, D, W	-	-	-	A, D, W
Iron Gate	A	A, D, V, S, W	A, D, S	A, D, V, S	A, D, S	nd, S
Coffee Pot	A	A, D, W	-	-	-	A, D, W
Aspen Grove	A	A, D, W	D	D	-	nd
Airport	A	A, D, V, S, W	A, D, S	A, D, V, S	A, D, S	A, D, V, S, W
Black Dome	A	A, D, V, S, W	A, D, S	A, D, V, S	nd, S	nd, S*
Typha	*	A, D, W	D	-	D	nd, D
Hog Lake	A	A, D, W	-	-	-	A, D, W
Grasshopper	A	A, D, V, S, W	nd, S	nd, S	nd, S	nd
Perlite	A	A, D, W	-	-	D	A, D, W
High Lake	A	A, D, V, S, W	A, D, S	A, D, V, S	A, D, S	A, D, V, S*, W
Grouse Lake	A	A, D, W	-	-	-	A, D, W

Table 2. **Wetland elevation and classification types of the 12 Churn Creek Protected Area wetlands. The five wetlands with grey text were monitored more comprehensively than the seven with black text.**

Wetland	Elevation (m)	Dominant Wetland Type	Fringe Type
Dry Lake	635	95% WmBolbflu	5% Wm04
Iron Gate	720	95% Wm04	5% Wm07
Coffee Pot	859	90% Wwa	10% Wm11
Aspen Grove	872	100% Wm04a	-
Airport	877	100% Wm04a	-
Black Dome	903	Wm04a	Mosaic Wm01, Wm05
Typha	915	100% Wm05	-
Hog Lake	1013	81% Ww	18% Wm08, 1% Wm06
Grasshopper	1040	65% Wwx	35% Wm04
Perlite	1128	100% Wm01	-
High Lake	1215	70% Wwx	22% Wm07, 8% Wm06
Grouse Lake	1247	52% Ww	47% Wm07, 1% Wm09

Table 3. HOBO locations, data collection start and end dates, and the estimated day out date. (*) Aspen Grove HOBO was lost and reinstalled on July 10, 2023

Wetland	HOBO Coordinates	Installation Date	Removal Date	Estimated Dry Date
Black Dome	51.42027, -122.29054	31-May	31-Jul	21-Jul
Grasshopper	51.44549, -122.34612	1-Jun	15-Jun	12-Jun
Airport	51.46049, -122.29878	2-Jun	19-Aug	-
Aspen Grove	51.45869, -122.29801	10-Jul*	19-Aug	4-Aug
Perlite	51.35880, -122.34576	3-Jun	20-Aug	-
Typha	51.42412, -122.29608	3-Jun	20-Aug	17-Aug
Coffee Pot	51.35439, -122.27696	3-Jun	22-Aug	-
Hog Lake	51.34502, -122.28348	3-Jun	21-Aug	-
Dry Lake South	51.50284, -122.32928	4-Jun	18-Aug	-
Dry Lake West	51.50338, -122.33086	4-Jun	18-Aug	-
Iron Gate	51.49606, -122.32645	4-Jun	18-Aug	4-Aug
Grouse Lake	51.35721, -122.32449	5-Jun	21-Aug	-
High Lake	51.35197, -122.30462	6-Jun	21-Aug	-

Table 4. The number of samples taken in each vegetation patch size category.

Patch Area (m2)	Number of Quadrats Sampled
10.00 – 49.99	1
50.00 – 99.99	2
100.00 – 199.99	3
200.00 – 299.99	4
300.00 – 399.99	5

Table 5. **Example of a Reference Evaporation Model scenario with equations of Wetland X, produced by Pantel Environmental.**

Equation	Calculation	Climate Scenario	Month	Totals
	Pond Full Area (A_{May})			4.44 ha
1	Pond Full Volume (V_{May})	$2.85 * A^{1.22}_{May}$		17576 m^3
	Precipitation $_{May}$	1990-2009	May	37 mm
	Reference Evaporation ($Eref_{May}$)	1990-2009	May	91 mm
2	*Net water balance $_{May}$*	$Eref_{May}$-Precipiation $_{May}$		*-54 mm*
3	*Lake Evaporation ($Evap_{May}$)*	(A_{May})* Net Water Balance $_{May}$		*2399* m^3
4	*Remaining Volume (V_{June})*	(V_{May}) - $Evap_{May}$		*15177* m^3
5	*Remaining Area(A_{June})*	$(0.350877 * V_{June})^{0.819672}$		*3.94 ha*
	Pond Full Volume (A_{June})			*3.94 ha*
	Precipitation ($Precip_{June}$)	1990-2009	June	53 mm
	Reference Evaporation ($Eref_{June}$)	1990-2009	June	109 mm
2	*Net water balance $_{June}$*	$Eref_{June}$-Precipitation $_{June}$		*-56 mm*
3	*Lake Evaporation ($Evap_{June}$)*	$(A_{June\ 1st})$* Net Water Balance $_{June}$		*2206* m^3
4	*Remaining Volume (V_{July})*	*(V_{June})* - $Evap_{June}$		*12972* m^3
5	*Remaining Area (A_{July})*	$(0.350877 * V_{July\ 1})^{0.819672}$		*3.46 ha*

Table 6. **Spring (May 18 to June 27) and summer (June 20 to August 22) average, minimum, and maximum air temperature at Dry Lake, Coffee Pot, and Dry Farm weather stations from May 18 to August 22, 2023. Coffee Pot weather station was not set up in spring (n/a).**

Season	Average Ta (°C)			Minimum Ta (°C)			Maximum Ta (°C)		
	Dry Lake	Coffee Pot	Dry Farm	Dry Lake	Coffee Pot	Dry Farm	Dry Lake	Coffee Pot	Dry Farm
Spring	17.5	n/a	15.0	2.2	n/a	1.3	35.3	n/a	29.1
Summer	20.3	20.2	18.4	2.7	6.9	5.5	35.9	33.3	31.0

Table 7. **Spring (May 18 to June 27) and summer (June 20 to August 22) total precipitation (P), and average and maximum vapor pressure deficit (VPD) at Dry Lake, Coffee Pot, and Dry Farm weather stations from May 18 to August 22, 2023.**

Season	Total P (mm)			Average VPD (kPa)			Maximum VPD (kPa)		
	Dry Lake	Coffee Pot	Dry Farm	Dry Lake	Coffee Pot	Dry Farm	Dry Lake	Coffee Pot	Dry Farm
Spring	62.0	n/a	85.4	1.28	n/a	1.13	5.27	N/A	4.27
Summer	27.0	25.8	33.4	1.51	1.55	1.39	5.03	4.2	3.82

Table 8. **Measured area of 12 Churn Creek Protected Area wetlands from SP1 through SP6, and the total change in area in 2023. Grey-bolded values are estimations, they were not measured on site. Typha SP1 area (*) was not measured.**

Wetland	Area (m2)						
	SP1 May 18-20	SP2 May 31- Jun 6	SP3 Jun 20-23	SP4 Jul 10-13	SP5 Jul 29 - Aug 2	SP6 Aug 18-22	Total ∆
Dry Lake	47745.00	**45221.97**	**42847.36**	**39879.10**	**37059.26**	34091.00	-13654.00
Iron Gate	591.18	500.01	377.79	327.63	73.56	0.00	-591.18
Coffee Pot	3185.00	2778.90	**2619.06**	**2432.58**	**2254.98**	2068.50	-1116.50
Aspen Grove	1149.10	982.25	**701.60**	**389.78**	**77.95**	0.00	-1149.10
Airport	3344.00	3479.40	2806.50	2409.40	1542.50	146.70	-3197.30
Black Dome	3620.80	3743.30	2953.00	948.23	0.00	0.00	-3620.80
Typha	*	1178.10	**911.06**	**581.20**	**267.04**	0.00	-1178.10
Hog Lake	10967.00	9744.00	**9605.24**	**9443.35**	**9289.18**	9135.00	-1832.00
Grasshopper	1276.20	563.02	0.00	0.00	0.00	0.00	-1276.20
Perlite	1370.90	1239.60	**971.06**	**639.34**	**323.41**	7.48	-1363.42
High Lake	2928.00	2352.90	2612.90	2492.80	2177.30	2681.00	-247.00
Grouse Lake	5409.40	4804.70	4752.92	4684.95	4620.23	4555.50	-853.90

Table 9. **Extrapolated volume of 12 Churn Creek Protected Area wetlands from SP2 (May 31-June 6, 2023) to SP6 (August 18-22, 2023), and the total volume lost.**

Wetland	Volume (m3)					
	SP2 May 31- Jun 6	SP3 Jun 20-23	SP4 Jul 10-13	SP5 Jul 29 - Aug 2	SP6 Aug 18-22	Total Loss
Dry Lake	19349.6	16363.4	12841.9	9711.1	6675.4	12674.2
Iron Gate	119.4	90.7	27.3	4.8	0.0	119.4
Coffee Pot	1040.1	833.6	624.5	431.2	244.0	796.1
Aspen Grove	182.2	159.7	42.5	1.6	0.0	182.2
Airport	849.0	562.1	158.9	106.7	4.3	844.6
Black Dome	576.2	286.3	35.3	0.0	0.0	576.2
Typha	192.4	130.4	53.8	20.0	0.0	192.4
Hog Lake	7335.8	6687.0	6009.4	5342.7	4687.8	2647.9
Grasshopper	28.5	0.0	0.0	0.0	0.0	28.5
Perlite	127.3	77.1	38.9	20.2	0.2	127.1
High Lake	1611.5	1543.3	1443.5	1048.9	903.6	707.9
Grouse Lake	4556.3	4264.7	3929.3	3593.8	3267.9	1288.5

Table 10. **Wetland basin pond slope profile or p-coefficient (p), as described by Hayashi et al. (2000) and Minke et al. (2010). The p-coefficient was calculated using a power area-depth line equation specific to each wetland. Its value equals 2 divided by the power line exponent.**

Wetland	*p*-coefficient	Wetland	*p*-coefficient
Dry Lake	5.54	Typha	1.11
Iron Gate	1.55	Hog Lake	11.82
Coffee Pot	7.85	Grasshopper	0.78
Aspen Grove	1.94	Perlite	0.53
Airport	1.30	High Lake	2.38
Black Dome	1.97	Grouse Lake	10.42

Table 11. **Mean, maximum, and minimum, water temperatures between sampling periods (SP) from May 31 to August 22, 2023. 'Dry' indicates that the wetland pond was dry at the time of sampling. N/A denotes the missing HOBO data at AG wetland.**

Wetland	SP2 to SP3 (May 31-Jun 6 to Jun 20-23)			SP3 to SP4 (Jun 20-23 to Jul 10-13)		
	Mean T (°C)	Max T (°C)	Min T (°C)	Mean T (°C)	Max T (°C)	Min T (°C)
Dry Lake	15.16	19.41	11.22	16.93	20.69	10.69
Iron Gate	16.30	20.44	11.64	18.57	22.71	10.83
Aspen Grove	N/A	N/A	N/A	N/A	N/A	N/A
Airport	19.22	25.82	13.02	19.39	25.53	12.36
Perlite	8.93	11.81	7.70	10.11	11.69	8.42
Typha	10.27	11.20	9.46	11.11	12.75	9.29
Grasshopper	16.35	24.05	9.24	Dry	Dry	Dry
Hog Lake	18.72	25.82	11.95	21.29	26.52	13.11
Black Dome	16.36	21.53	10.54	16.75	23.14	10.03
Coffee Pot	15.29	21.18	10.88	17.31	22.97	12.82
High Lake	17.36	23.40	11.18	19.49	23.14	12.29
Grouse Lake	16.60	21.53	10.74	19.89	24.58	12.29
Wetland	**SP4-SP5 (Jul 10-13 to July 29-Aug 2)**			**SP5-SP6 (July 29-Aug 2 to Aug 18-22)**		
	Mean T (°C)	**Max T (°C)**	**Min T (°C)**	**Mean T (°C)**	**Max T (°C)**	**Min T (°C)**
Dry Lake	16.67	19.67	13.61	15.03	16.75	12.07
Iron Gate	19.62	26.74	13.76	18.26	30.93	10.08
Aspen Grove	19.25	26.18	15.10	Dry	Dry	Dry
Airport	19.57	31.23	13.19	16.99	24.90	3.49
Perlite	11.88	12.68	11.25	12.44	14.43	9.36
Typha	12.61	13.40	11.30	13.05	16.68	10.27
Grasshopper	Dry	Dry	Dry	Dry	Dry	Dry
Hog Lake	20.92	25.45	15.20	21.13	27.48	14.34
Black Dome	17.64	33.52	9.58	Dry	Dry	Dry
Coffee Pot	17.91	24.58	13.06	18.36	26.26	10.93
High Lake	19.16	23.33	14.46	18.67	22.66	13.93
Grouse Lake	19.91	25.48	14.70	19.87	25.74	14.46

Table 12. Water chemical lab analysis results for SP2 (May 31-June 6, 2023) and SP6 (August 18-22, 2023). Bolded-underlined concentrations are over the suggested water quality guidelines.

Chemical Parameters	Lowest Detection Limit	Units	Dry Lake		Iron Gate	Coffee Pot	
			SP2	SP6	SP2	SP2	SP6
Conductivity	2.0	µS/cm	235	347	146	**<u>5100</u>**	**<u>18900</u>**
Alkalinity, total (as CaCO3)	1.0	mg/L	100	156	63.3	**<u>2500</u>**	101
pH	0.10	pH units	7.37	7.85	7.05	9.18	9.53
Chloride	0.50	mg/L	12.7	9.23	3.67	37.9	1.44
Fluoride	0.020	mg/L	0.060	0.082	0.025	<0.400	<2.00
Nitrate (as N)	0.0050	mg/L	<0.0050	<0.0050	<0.0050	<0.100	<0.500
Nitrite (as N)	0.0010	mg/L	<0.0010	<0.0010	<0.0010	0.168	<0.100
Sulfate (as SO4)	0.30	mg/L	<0.30	<0.30	<0.30	618	**<u>2500</u>**
Aluminum, dissolved	0.0010	mg/L	0.0099	0.174	0.0070	0.651	**<u>32.9</u>**
Antimony, dissolved	0.00010	mg/L	<0.00010	<0.00050	<0.00010	0.00064	<0.00200
Arsenic, dissolved	0.00010	mg/L	0.00107	0.00152	0.00050	**<u>0.0379</u>**	**<u>0.15</u>**
Barium, dissolved	0.00010	mg/L	0.00599	0.03	0.0158	0.0331	0.47
Boron, dissolved	0.010	mg/L	0.052	<0.100	0.036	1.28	**<u>5.91</u>**
Cadmium, dissolved	0.0000050	mg/L	<0.000005	<0.00200	<0.000005	<0.000040	0.001
Calcium, dissolved	0.050	mg/L	7.34	8.06	11.5	8.69	77.6
Chromium, dissolved	0.00050	mg/L	<0.00050	<0.00200	<0.00050	0.00131	**<u>0.0566</u>**
Copper, dissolved	0.00020	mg/L	0.00100	0.00118	0.00052	0.00658	0.0525
Iron, dissolved	0.010	mg/L	0.248	**<u>1.40</u>**	0.240	**<u>0.751</u>**	**<u>46.00</u>**
Lead, dissolved	0.000050	mg/L	<0.000050	<0.000050	<0.000050	<0.000250	0.0094
Magnesium, dissolved	0.0050	mg/L	4.78	5.55	5.85	6.54	52.2
Manganese, dissolved	0.00010	mg/L	0.0159	0.48	0.0453	0.0394	1.48
Potassium, dissolved	0.050	mg/L	22.0	13.90	20.2	12.5	56.50
Selenium, dissolved	0.000050	mg/L	0.000088	<0.00010	0.000138	0.00190	**<u>0.01</u>**
Sodium, dissolved	0.050	mg/L	29.2	60.8	2.30	1470	6000
Uranium, dissolved	0.000010	mg/L	<0.000010	<0.000010	<0.000010	0.0184	0.08
Zinc, dissolved	0.0010	mg/L	0.0076	<0.0050	0.0122	<0.0050	0.15

Table 12. (continued)

Chemical Parameters	Lowest Detection Limit	Units	Aspen Grove	Airport		Grass-hopper	Black Dome
			SP2	SP2	SP6	SP2	SP2
Conductivity	2.0	µS/cm	302	238	302	375	268
Alkalinity, total (as CaCO3)	1.0	mg/L	162	122	158	159	135
pH	0.10	pH units	7.94	7.73	8.07	7.39	7.58
Chloride	0.50	mg/L	2.45	2.09	<0.050	13.5	3.02
Fluoride	0.020	mg/L	0.075	0.038	0.056	0.096	0.050
Nitrate (as N)	0.0050	mg/L	<0.0050	<0.0050	<0.0050	<0.0050	<0.0050
Nitrite (as N)	0.0010	mg/L	<0.0010	<0.0010	<0.0010	0.0049	<0.0010
Sulfate (as SO4)	0.30	mg/L	<0.30	<0.30	<0.30	7.58	<0.30
Aluminum, dissolved	0.0010	mg/L	0.0020	<0.0010	3.21	0.0079	0.0014
Antimony, dissolved	0.00010	mg/L	<0.00010	<0.00010	<0.00050	0.00017	<0.00010
Arsenic, dissolved	0.00010	mg/L	0.00285	0.00158	0.00149	0.00508	0.00077
Barium, dissolved	0.00010	mg/L	0.00422	0.00446	0.10	0.0128	0.0217
Boron, dissolved	0.010	mg/L	0.080	0.194	0.26	0.196	0.157
Cadmium, dissolved	0.0000050	mg/L	<0.000005	<0.000005	<0.000000	<0.000005	<0.000005
Calcium, dissolved	0.050	mg/L	18.6	13.9	16.8	15.9	18.5
Chromium, dissolved	0.00050	mg/L	<0.00050	<0.00050	0.00459	0.00086	<0.00050
Copper, dissolved	0.00020	mg/L	0.00100	0.00087	0.00553	0.00385	0.00040
Iron, dissolved	0.010	mg/L	0.105	0.032	**6.10**	**0.964**	0.057
Lead, dissolved	0.000050	mg/L	<0.000050	<0.000050	0.000704	<0.000050	<0.000050
Magnesium, dissolved	0.0050	mg/L	11.8	9.25	12.4	13.2	8.54
Manganese, dissolved	0.00010	mg/L	0.00099	0.00100	0.96	0.00175	0.00066
Potassium, dissolved	0.050	mg/L	21.3	19.4	21.2	48.6	22.4
Selenium, dissolved	0.000050	mg/L	0.000277	0.000306	<0.00010	0.000385	0.000227
Sodium, dissolved	0.050	mg/L	26.5	17.7	23.7	23.0	20.1
Uranium, dissolved	0.000010	mg/L	0.000179	0.000031	0.00	0.000157	<0.000010
Zinc, dissolved	0.0010	mg/L	0.0018	0.0084	<0.0050	<0.0010	0.0110

Table 12. (continued)

Chemical Parameters	Lowest Detection Limit	Units	Typha	Hog Lake		Perlite	
			SP2	SP2	SP6	SP2	SP6
Conductivity	2.0	µS/cm	266	**1600**	**2230**	550	**1210**
Alkalinity, total (as CaCO3)	1.0	mg/L	130	**1080**	**1450.00**	282	626.00
pH	0.10	pH units	7.35	9.29	9.1	7.54	7.52
Chloride	0.50	mg/L	4.20	6.74	10.60	2.30	5.66
Fluoride	0.020	mg/L	0.021	<0.200	<0.400	0.342	<0.159
Nitrate (as N)	0.0050	mg/L	<0.0050	<0.0500	<0.100	<0.0050	<0.0250
Nitrite (as N)	0.0010	mg/L	<0.0010	<0.0100	<0.0200	<0.0010	<0.0050
Sulfate (as SO4)	0.30	mg/L	<0.30	10.6	8.36	15.0	3.72
Aluminum, dissolved	0.0010	mg/L	0.0121	0.0072	0.0353	0.0095	**17.70**
Antimony, dissolved	0.00010	mg/L	<0.00010	0.00020	<0.00050	0.00033	0.00
Arsenic, dissolved	0.00010	mg/L	0.00159	0.00273	0.0033	**0.0285**	**0.13**
Barium, dissolved	0.00010	mg/L	0.00798	0.0186	0.08	0.0419	0.47
Boron, dissolved	0.010	mg/L	0.117	0.106	0.158	<0.010	0.25
Cadmium, dissolved	0.0000050	mg/L	0.0000052	<0.000005	<0.00200	<0.000005	0.00
Calcium, dissolved	0.050	mg/L	21.1	20.8	11.1	25.0	152.00
Chromium, dissolved	0.00050	mg/L	<0.00050	<0.00050	<0.00200	0.00148	0.04
Copper, dissolved	0.00020	mg/L	0.00116	<0.00020	<0.00100	0.00161	0.09
Iron, dissolved	0.010	mg/L	0.264	<0.010	0.05	**0.569**	**20.60**
Lead, dissolved	0.000050	mg/L	<0.000050	<0.000050	<0.000050	<0.000050	0.01
Magnesium, dissolved	0.0050	mg/L	8.04	113	135	8.73	27.60
Manganese, dissolved	0.00010	mg/L	0.00126	0.00186	0.09	0.00554	1.80
Potassium, dissolved	0.050	mg/L	26.1	22.3	32.50	21.5	32.20
Selenium, dissolved	0.000050	mg/L	0.000258	0.000181	<0.00100	0.000469	0.00
Sodium, dissolved	0.050	mg/L	17.2	307	398	97.8	179.00
Uranium, dissolved	0.000010	mg/L	0.000015	0.000809	0.00	0.00230	0.06
Zinc, dissolved	0.0010	mg/L	0.0250	0.0025	<0.0500	0.0214	0.28

Table 12. (continued)

Chemical Parameters	Lowest Detection Limit	Units	High Lake		Grouse Lake	
			SP2	SP6	SP2	SP6
Conductivity	2.0	µS/cm	**1590**	**2100**	**1330**	**1690**
Alkalinity, total (as CaCO3)	1.0	mg/L	938	**1240.00**	835	**1060.00**
pH	0.10	pH units	8.70	8.86	8.78	8.96
Chloride	0.50	mg/L	19.5	25.80	10.5	15.00
Fluoride	0.020	mg/L	<0.200	<0.400	0.116	<0.200
Nitrate (as N)	0.0050	mg/L	<0.0500	<0.100	<0.0250	<0.0500
Nitrite (as N)	0.0010	mg/L	<0.0100	<0.0200	<0.0050	<0.0010
Sulfate (as SO4)	0.30	mg/L	20.1	16.40	11.4	9.11
Aluminum, dissolved	0.0010	mg/L	0.0012	0.0324	<0.0010	<0.0010
Antimony, dissolved	0.00010	mg/L	0.00012	<0.00050	0.00010	<0.00050
Arsenic, dissolved	0.00010	mg/L	0.00279	0.00266	0.00129	0.00172
Barium, dissolved	0.00010	mg/L	0.0569	0.07	0.0340	0.0487
Boron, dissolved	0.010	mg/L	0.012	<0.100	0.012	<0.100
Cadmium, dissolved	0.0000050	mg/L	<0.000005	<0.000200	<0.000005	<0.000200
Calcium, dissolved	0.050	mg/L	28.8	26.7	30.7	26.2
Chromium, dissolved	0.00050	mg/L	<0.00050	<0.00200	<0.00050	<0.000200
Copper, dissolved	0.00020	mg/L	<0.00020	<0.00100	<0.00020	<0.00100
Iron, dissolved	0.010	mg/L	<0.010	0.04	<0.010	<0.030
Lead, dissolved	0.000050	mg/L	<0.000050	<0.000050	<0.000050	<0.000500
Magnesium, dissolved	0.0050	mg/L	73.5	95	115	138
Manganese, dissolved	0.00010	mg/L	0.0168	0.21	0.00753	0.137
Potassium, dissolved	0.050	mg/L	33.2	41.00	35.1	47.7
Selenium, dissolved	0.000050	mg/L	0.000069	<0.00100	0.000110	<0.00100
Sodium, dissolved	0.050	mg/L	296	374	165	205
Uranium, dissolved	0.000010	mg/L	0.000868	0.00	0.00325	0.00655
Zinc, dissolved	0.0010	mg/L	0.0027	<0.0500	0.0032	<0.0500

Table 13. Mean, maximum, and minimum soil temperature, electrical conductivity (EC), and compaction depth for the five selected wetlands (GH-Grasshopper, BD-Black Dome, AP-Airport, IG-Iron Gate, and HL-High Lake)

Soil Temperature (°C)	GH	BD	AP	IG	HL	Mean
Mean	27.2	22.7	24.7	19.2	22.9	23.4
Max	34.0	37.5	37.3	28.8	32.2	34.0
Min	17.2	12.9	13.9	14.6	16.2	15.0
EC (ds/m)	**GH**	**BD**	**AP**	**IG**	**HL**	**Mean**
Mean	0.2	0.3	0.2	0.3	1.1	0.4
Max	0.6	1.1	1.1	0.8	2.0	1.1
Min	0.0	0.0	0.0	0.0	0.5	0.1
Compaction Depth (cm)	**GH**	**BD**	**AP**	**IG**	**HL**	**Mean**
Mean	30.7	52.3	32.8	59.9	39.6	43.0
Max	70.0	70.0	70.0	70.0	70.0	70.0
Min	0.4	0.0	0.0	1.8	11.8	2.8

Table 14. Scientific names, common names, and species codes of the emergent vegetation species found in the 12 Churn Creek Protected Area wetlands.

Species Name	Species Code	Common Name
Eleocharis palustris	Eleopal	Common spike-rush
Typha latifolia	Typhlat	Common cattail
Persicaria amphibia	Persiamp	Water smartweed
Mentha canadensis	Mentcan	Canada mint
Carex exsiccata	Careexs	Inflated sedge
Carex utriculata	Careutr	Beaked sedge
Beckmannia syzigachne	Becksyz	American sloughgrass
Rumex crispus	Rumecri	Curled dock
Juncus balticus	Juncbal	Baltic rush
Hordeum jubatum	Hordjub	Foxtail barley
Elymus repens	Elymrep	Quackgrass
Rosa woodsii	Rosawoo	Wood's rose
Lemna minor	Lemnmin	Common duckweed
Schoenoplectus tabernaemontani	Schotab	Soft-stemmed bulrush
Bolboschoenus fluviatilis	Bolbflu	River Bulrush

Table 15. Percent cover for the five selected wetlands during SP2 (May 31-June 6), SP 4 (July 10-13), and SP 6 (August 18-22).

Wetlands	Cover Type	Relative Abundance (%)		
		SP2	SP4	SP6
Black Dome	Water	63.12	55.27	N/A
	Eleocharis palustris	7.28	13.45	
	Typha latifolia	0.60	-	
	Persicaria amphibia	0.71	6.82	
	Mentha canadensis	1.21	-	
	Carex exsiccata	0.27	2.29	
	Carex utriculata	0.31		
	Beckmannia syzigachne	0.15	0.61	
	Rumex crispus	0.07	-	
	Moss	-	2.45	
	Algae	29.57	-	
	Litter	1.58	26.75	
Airport	Water	91.47	80.99	35.00
	Eleocharis palustris	5.69	16.80	55.00
	Persicaria amphibia	-	0.27	-
	Mentha canadensis	0.01	0.03	-
	Juncus balticus	0.49	-	-
	Hordeum jubatum	0.005	0.01	-
	Elymus repens	0.05	0.01	-
	Rosa woodsii	0.15	0.13	-
	exposed water coverage	-	0.01	-
	Unidentified forb	-	0.02	-
	Wood	0.41	-	-
	Bare Ground	-	-	10.00
	Algae	4.60	7.58	-
	Litter	1.21	1.70	1.00
High Lake	Water	83.07	84.81	70.13
	Persicaria amphibia	0.27	2.45	1.83
	Juncus balticus	0.79	-	-
	Schoenoplectus tabernaemontani	1.06	0.92	2.20
	Lemna minor	10.11	8.56	24.78
	Algae	1.76	2.73	1.38
	Litter	2.25	1.76	0.84
Iron Gate	Water	61.67	96.50	N/A
	Eleocharis palustris	0.50	0.75	
	Persicaria amphibia	0.17	-	
	Manure	-	2.00	
	Algae	29.00	-	
	Litter	9.33	1.50	

Table 15. (continued)

Grasshopper	Water	70.33	N/A	N/A
	Eleocharis palustris	25.00		
	Beckmannia syzigachne	0.17		
	Unidentified forb	0.17		
	Bare Ground	8.33		

Table 16. Patch ponded cover over the entire wetland for SP2 (May 31-June 6), SP 4 (July 10-13), and SP 6 (August 18-22) at the five selected wetlands.

Wetlands	Vegetation Patch	Patch Codes	Ponded Area Cover (%)		
			SP2	SP4	SP6
Black Dome	Eleocharis palustris Dominant	Eleopal Dom	89.32	81.57	N/A
	Typha latifolia NE 1	Typhlat NE1	1.52	-	
	Typha latifolia NE 2	Typhlat NE2	0.26	-	
	Typha latifolia SE	Typhlat SE	1.94	-	
	Carex exsiccata Central	Careexs Cen	5.94	13.45	
	Carex utriculata NW	Careutr NW	1.03	-	
	Persicaria amphibia NW	Persamp NW	-	4.98	
Airport	Eleocharis palustris Dominant	Eleopal Dom	81.32	93.88	100.00
	Juncus balticus SE	Juncbal SE	5.70	-	-
	Open Water - Hordeum jubatum SW	OWHordjub SW	1.03	-	-
	Elymus repens SW	Elymrep SW	0.92	-	-
	Rosa woodsii SW	Rosawoo SW	1.02	2.28	-
	Juncus balticus SW	Juncbal SW	4.21	-	-
	Open Water E Arm	OW E Arm	5.79	-	-
	Open Water - Eleocharis palustris NW	OWEelopal NW	-	3.84	-
High Lake	Open Water Dominant	OW Dom	80.98	87.92	88.10
	Schoenoplectus tabernaemontani NE	Schotab NE	8.14	12.08	11.90
	Juncus balticus Fringe	Juncbal Fringe	10.88	-	-
Iron Gate	Open Water Dominant	OW Dom	100.00	100.00	N/A
Grasshopper	Eleocharis palustris Dominant	Eleopal Dom	100.00	N/A	N/A

Table 17. Average, maximum, and minimum emergent vegetation height at the 5 selected wetlands in each of their sampled patches.

Wetland	Date	Patch	Mean Height	Max Height	Min Height
Black Dome	1-Jun	Typhlat NE1	87.3	143.0	45.0
		Typhlat NE2	85.3	111.0	54.0
		Typhlat SE	92.7	144.0	48.0
		Careexs Cen	32.9	53.0	17.0
		Careutr NW	52.5	74.5	36.5
		Eleopal Dom	30.9	53.0	8.0
	11-Jul	Careexs Cen	59.6	105.8	30.8
		Persamp NW	3.9	6.0	2.0
		Eleopal Dom	64.3	86.3	41.3
Airport	2-Jun	Juncbal SE	32.1	48.0	15.0
		OW Hjub SW	21.0	25.0	15.0
		Elymrep SW	28.2	39.5	13.5
		Rosawoo SW	48.3	72.0	15.0
		Juncbal SW	35.3	50.0	23.0
		Eleopal Dom	30.1	46.5	14.0
		OW E Arm	17.3	24.0	13.0
	10-Jul	Rosawoo SW	56.1	130.0	2.3
		Eleopal Dom	52.7	82.3	24.8
		OW Epal NW	40.5	65.5	16.3
	19-Aug	Eleopal Dom	55.6	74.5	33.7
High Lake	6-Jun	Schotab NE	119.9	172.5	45.0
		Juncbal Fringe	46.7	77.5	27.0
		OW Dom	0.4	3.0	0.0
	12-Jul	Schotab NE	153.8	216.0	93.5
		OW Dom	0.4	3.0	0.0
	21-Aug	Schotab NE	209.8	248.5	168.5
		OW Dom	3.8	7.5	0.0
Iron Gate	4-Jun	OW Dom	11.8	41.0	0.0
	10-Jul	OW Dom	20.5	49.3	2.9
Grasshopper	1-Jun	Eleopal Dom	33.3	53.0	19.0

Table 18. Summarized Reference Evaporation Model area (A) and volume (V) forecasts, measured initial and final areas, and the predicted and actual percent area and volume lost at 12 Churn Creek protected Area wetlands.

Wetland	Measured Initial A (m^2)	Predicted Final A (m^2)	Measured Final A (m^2)	Predicted A lost (%)	Actual A lost (%)	Predicted Initial V (m^3)	Predicted Final V (m^3)	Predicted V lost (%)
Dry Lake	45222.0	20697.2	34091.0	54.2	24.6	17962.7	6922.4	61.5
Iron Gate	500.0	NULL*	0.0	100.0	100.0	73.7	NULL*	100.0
Coffee Pot	2778.9	428.1	2068.5	84.6	25.6	597.5	61.0	89.8
Aspen Grove	982.3	NULL*	0.0	100.0	100.0	168.0	NULL*	100.0
Airport	3479.4	0.0	146.7	100.0	95.8	786.1	-7.6	101.0
Black Dome	3743.3	92.1	0.0	97.5	100.0	859.4	9.4	98.9
Typha	1178.1	0.0	0.0	100.0	100.0	209.7	-13.5	106.5
Hog Lake	9744.0	3498.2	9135.0	64.1	6.3	3352.2	1068.7	68.1
Grasshopper	563.0	0.0	0.0	100.0	100.0	85.2	-16.1	118.9
Perlite	1239.6	0.0	7.5	100.0	99.4	223.2	-21.2	109.5
High Lake	2352.9	346.9	2177.3	85.3	7.5	487.8	23.3	95.2
Grouse Lake	4804.7	1356.6	4555.5	71.8	5.2	1165.4	249.1	78.6

Table 19. **Wetland assessment rankings for 12 Churn Creek Protected Area wetlands. Data and observations for the assessment were gathered from May 18 to August 22, 2023.**

Factors	Potential Points	Dry Lake	Iron Gate	Coffee Pot	Aspen Grove	Airport	Black Dome
mesoclimatic conditions	5	1	1	3	3	3	3
pond area-depth relationship	5	4	2	3	2	3	1
mean water temperature	4	3	3	3	3	3	3
water EC for pond permanence	4	3	3	4	3	3	3
emergent vegetation presence	4	1	3	3	4	3	3
emergent vegetation density & litter cover	5	5	1	1	2	3	4
substantial summer subsurface inputs	5	1	1	3	1	1	1
presence of riparian vegetation	5	3	3	4	3	4	3
moist margin width	5	3	3	3	3	1	1
Total Points	42	24	20	27	24	24	22
Grade (%)	**100**	**57**	**48**	**64**	**57**	**57**	**52**
chemical composition	5	5	3	1	5	5	5
water EC for water quality	5	5	2	1	5	5	5
Total Points	10	10	5	2	10	10	10
Grade (%)	**100**	**100**	**50**	**20**	**100**	**100**	**100**
wetland species richness	4	3	3	2	2	3	4
wildlife diversity	4	4	4	4	4	4	4
breeding habitat	5	5	2	2	3	2	5
Total Points	13	12	9	8	9	9	13
Grade (%)	**100**	**92**	**69**	**62**	**69**	**69**	**100**
severity of fires	5	5	3	3	2	2	3
erosion levels	5	3	5	1	5	3	3
anthropogenic alterations	5	5	3	5	3	3	3
plugging intensity	5	2	5	2	1	1	3
grazing impacts	5	2	5	3	2	2	3
Total Points	25	17	21	14	13	11	15
Grade (%)	**100**	**68**	**84**	**56**	**52**	**44**	**60**

Table 19. (continued)

Factors	Potential Points	Typha	Hog Lake	Grasshopper	Perlite	High Lake	Grouse Lake
mesoclimatic conditions	5	3	4	4	5	5	5
pond area-depth relationship	5	3	5	1	3	4	4
mean water temperature	4	4	2	3	4	3	3
water EC for pond permanence	4	3	4	3	4	4	4
emergent vegetation presence	4	1	3	3	2	3	3
emergent vegetation density & litter cover	5	5	1	1	5	2	1
substantial summer subsurface inputs	5	3	5	1	3	1	1
presence of riparian vegetation	5	1	4	3	1	4	2
moist margin width	5	3	4	4	1	4	3
Total Points	42	26	32	23	28	30	26
Grade (%)	**100**	**62**	**76**	**55**	**67**	**71**	**62**
chemical composition	5	5	5	5	1	5	5
water EC for water quality	5	5	3	5	5	3	3
Total Points	10	10	8	10	6	8	8
Grade (%)	**100**	**100**	**80**	**100**	**60**	**80**	**80**
wetland species richness	4	2	4	2	2	3	3
wildlife diversity	4	3	4	2	3	4	4
breeding habitat	5	5	5	3	5	3	3
Total Points	13	10	13	7	10	10	10
Grade (%)	**100**	**77**	**100**	**54**	**77**	**77**	**77**
severity of fires	5	3	3	5	3	3	3
erosion levels	5	5	1	5	5	5	5
anthropogenic alterations	5	3	1	1	5	3	5
plugging intensity	5	2	1	1	5	2	1
grazing impacts	5	3	2	3	5	2	2
Total Points	25	16	8	15	23	15	16
Grade (%)	**100**	**64**	**32**	**60**	**92**	**60**	**64**

Figures

Figure 1. **Location of Churn Creek Protected Area. Map obtained from Steen and Iverson (2021).**

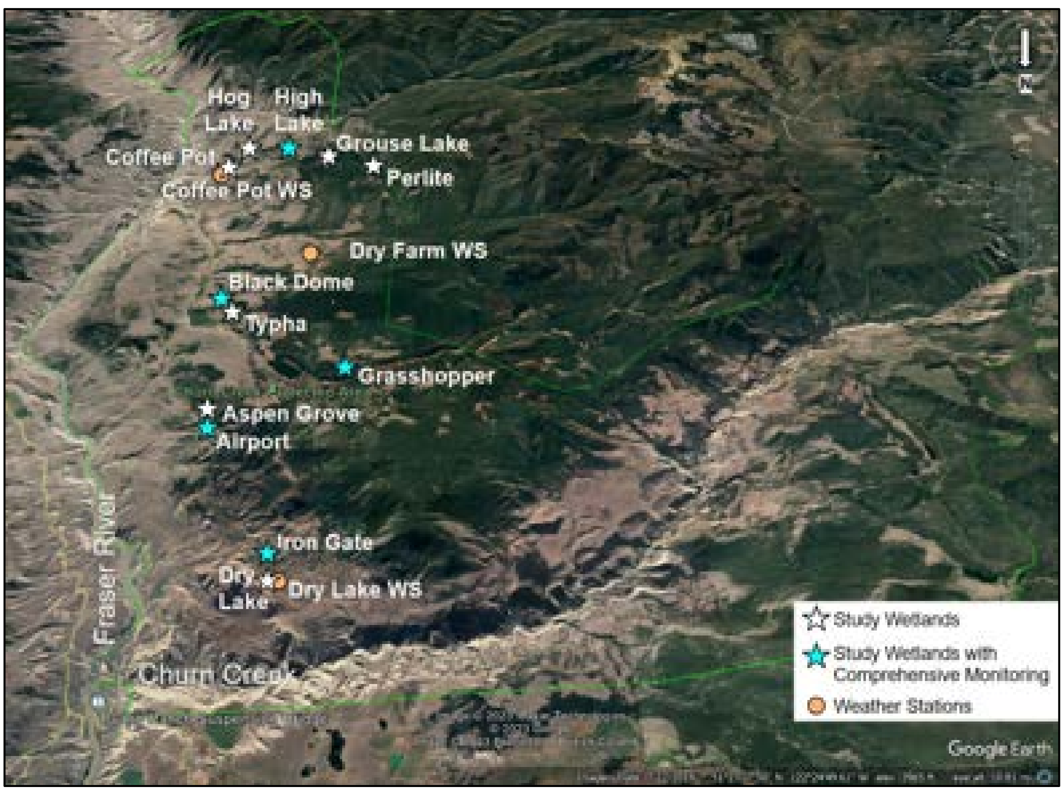

Figure 2. **Google Earth Map of Churn Creek Protected Area with wetland study sites and weather station locations. The five turquoise sites represent wetlands where comprehensive monitoring was completed.**

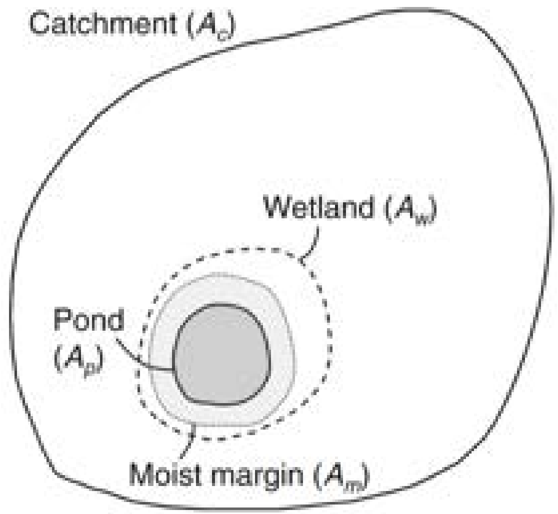

Figure 3. **A delineation illustration of a wetland's area, and its catchment area, moist margin area, and ponded area. Obtained from Hayashi et al. (2016).**

Figure 4. **Coffee Pot weather station, located at a latitude and longitude of 51.358470, -122.274987.**

Figure 5. **(A) Black Dome wetland on May 31 (sampling period 2) and (B) July 11 (sampling period 4) with estimated pond and patch perimeters. The orange dots on the perimeter of the wetland on May 31 (A) are the initial 0 m permanent transect markers for every sampling period. Additionally, all orange dots represent the final soil sampling points on the cardinal transects. The central turquoise dot is the HOBO location and the final sampling point on the transects when the pond is dry. Legends show the percent cover of all vegetation patches sampled.**

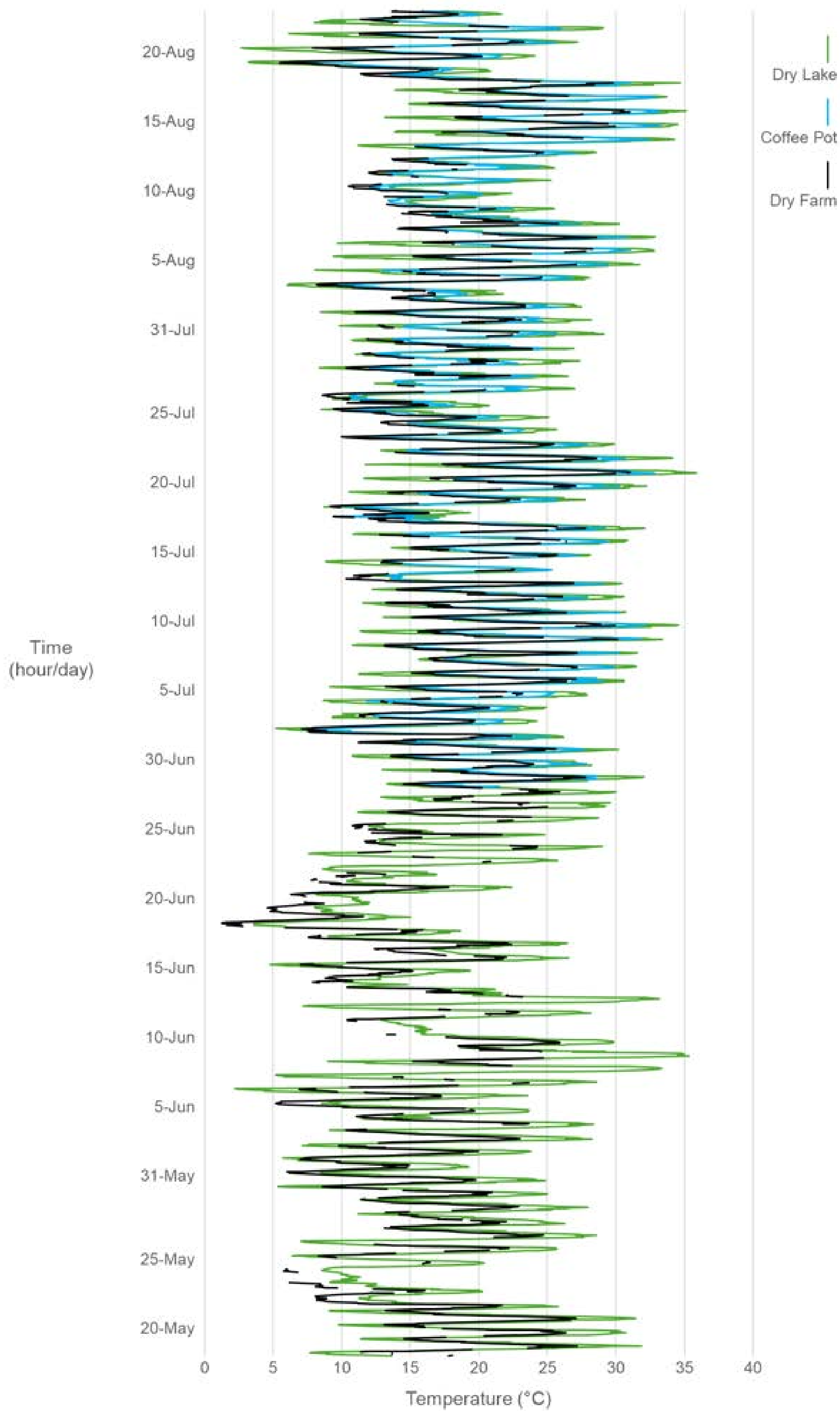

Figure 6. **Hourly temperature at Dry Lake weather station, Coffee Pot weather station, and Dry Farm weather station from May 18 to August 22, 2023.**

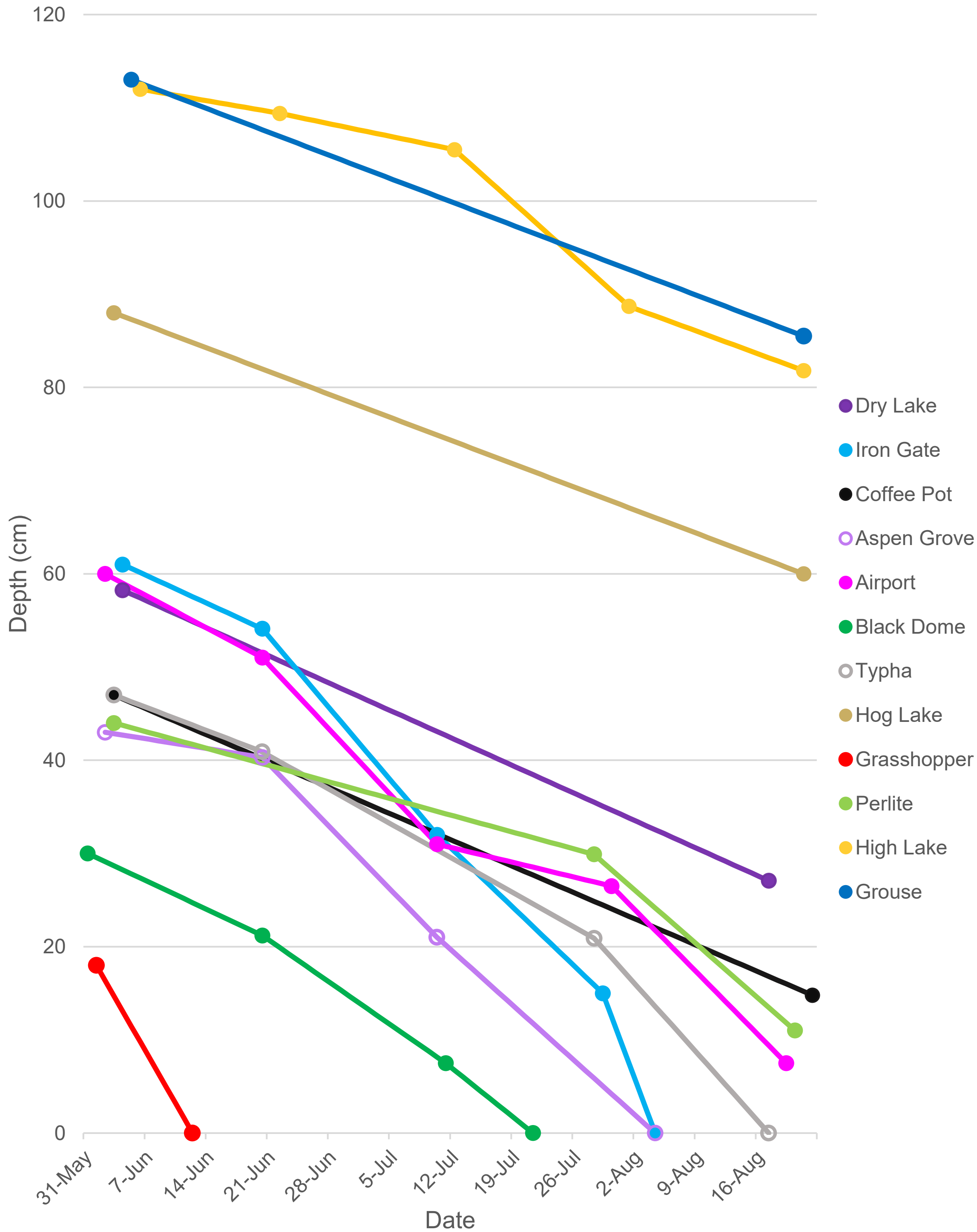

Figure 7. **Water column depth fluctuations over time at all study wetlands. Markers represent depth measurements taken from May 31 to August 22, 2023. Lines are the calculated daily average water loss between measured values.**

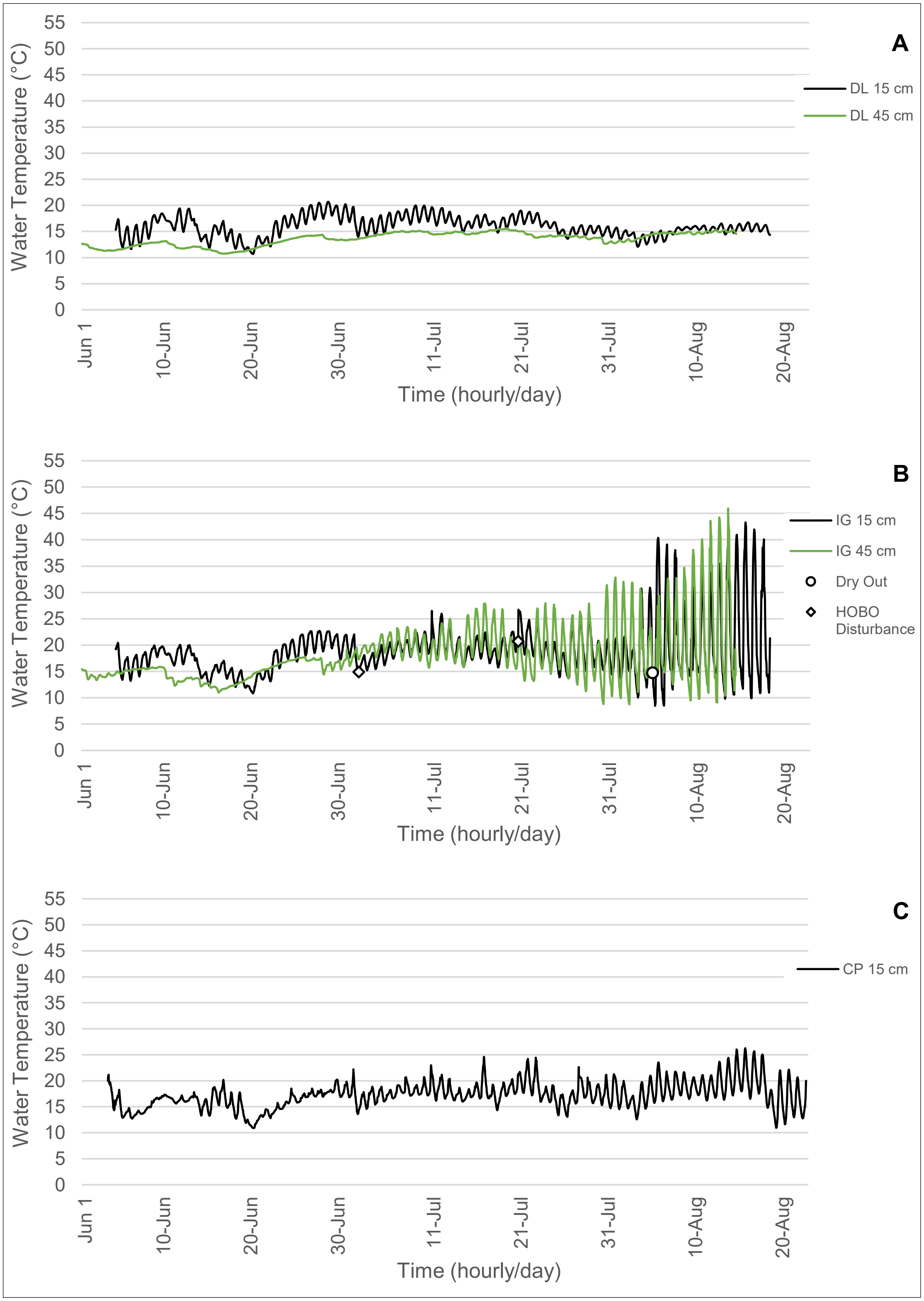

Figure 8. **Water temperature HOBO timeseries from May 31 to August 22, 2023, for (A) DL - Dry Lake, (B) IG - Iron Gate, (C) CP - Coffee Pot. Each axis date represents 00:00 hours.**

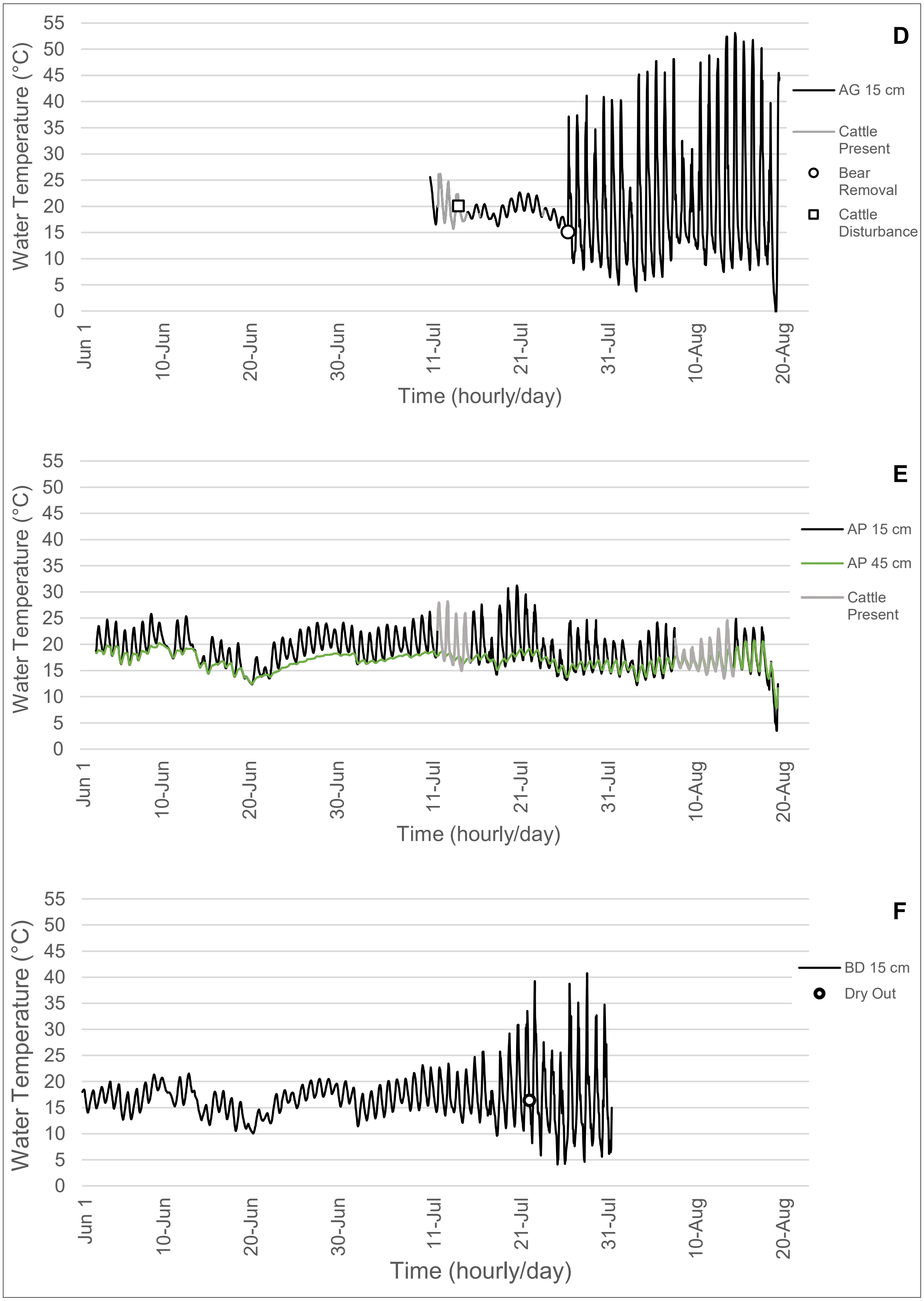

Figure 8. (continued) (D) AG - Aspen Grove, (E) AP - Airport, (F) BD - Black Dome.

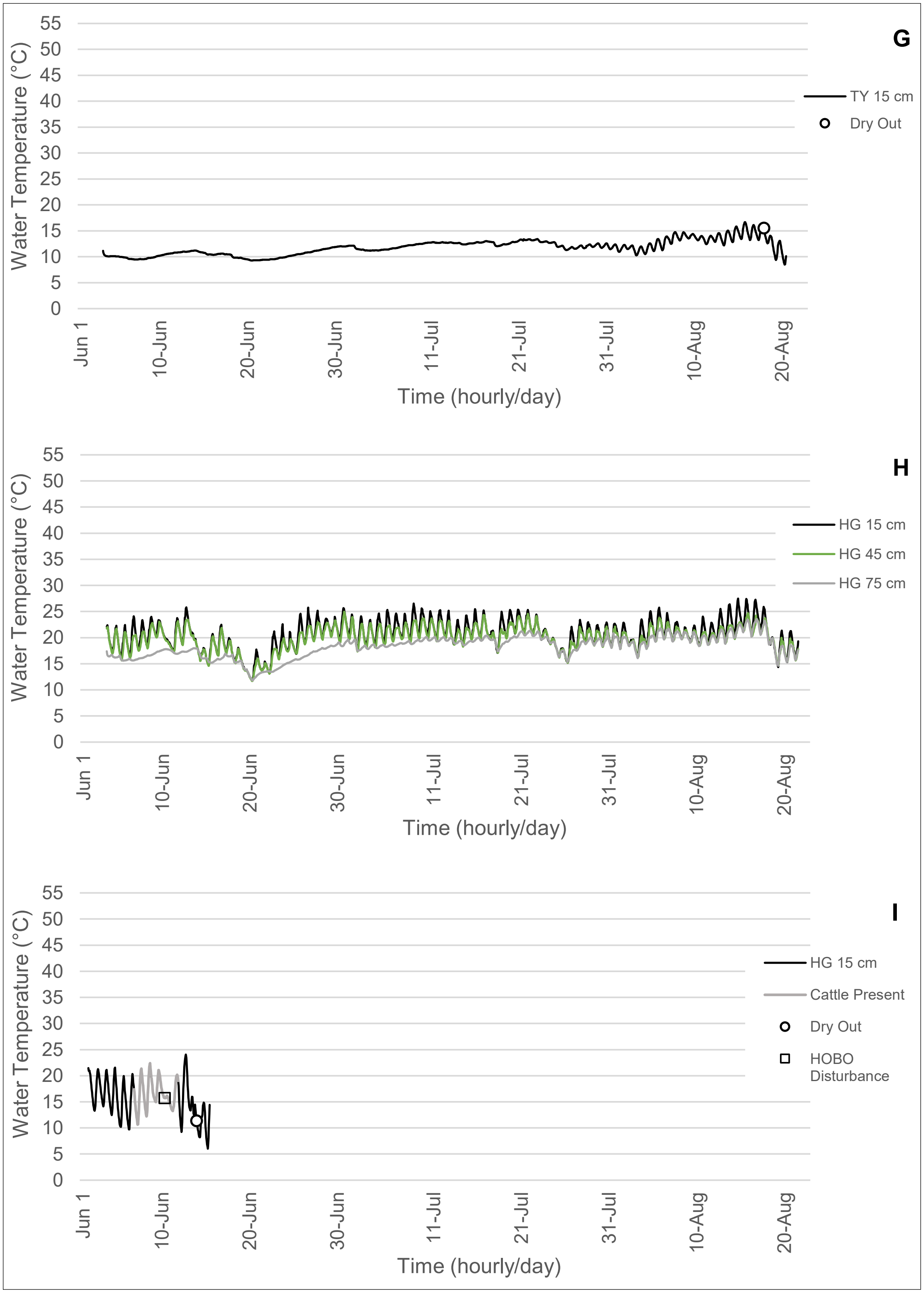

Figure 8. **(continued) (G) TY - Typha, (H) HL - Hog Lake, (I) GH - Grasshopper.**

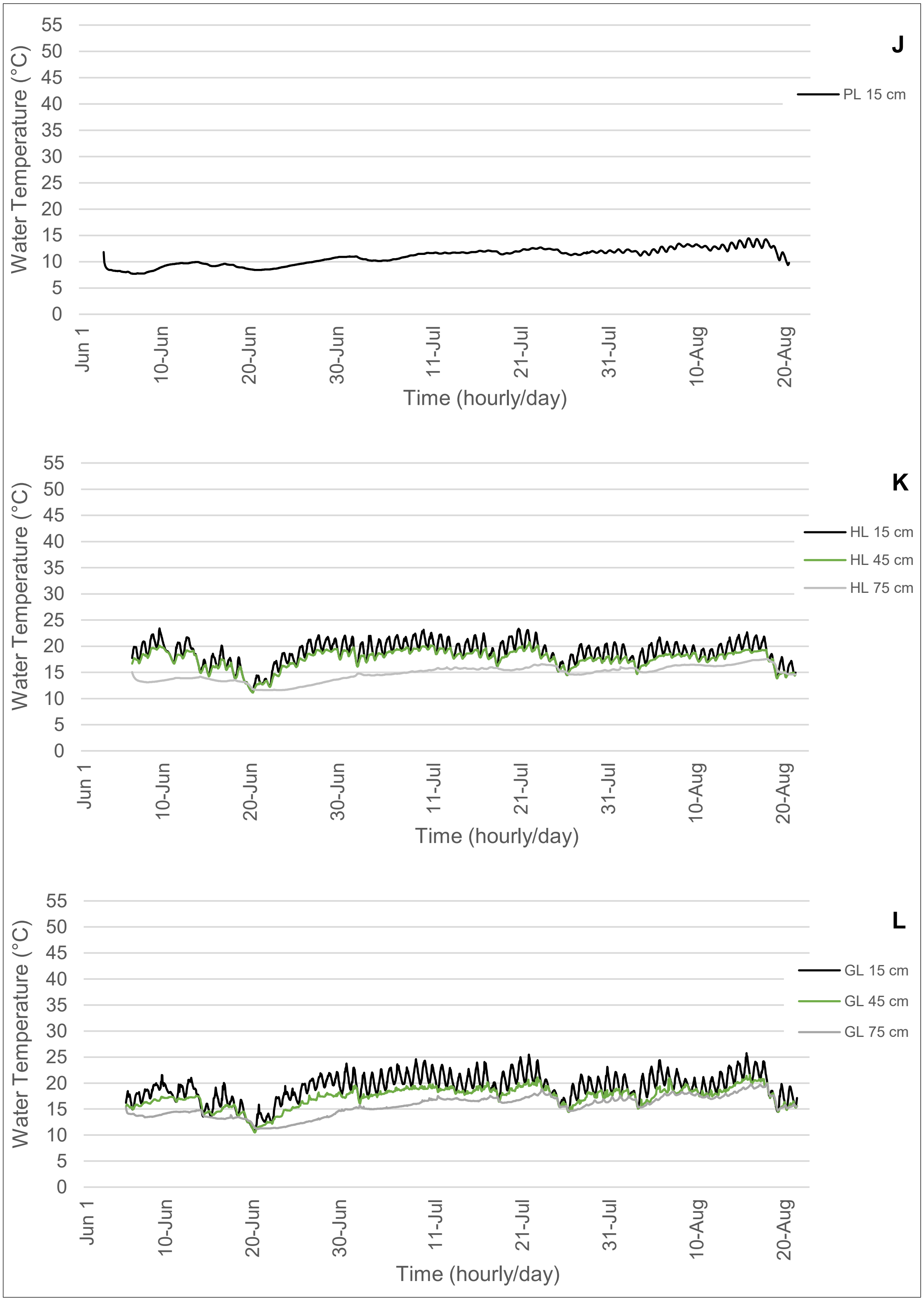

Figure 8. **(continued) (J) PL - Perlite, (K) HL - High Lake, and (L) GL - Grouse Lake.**

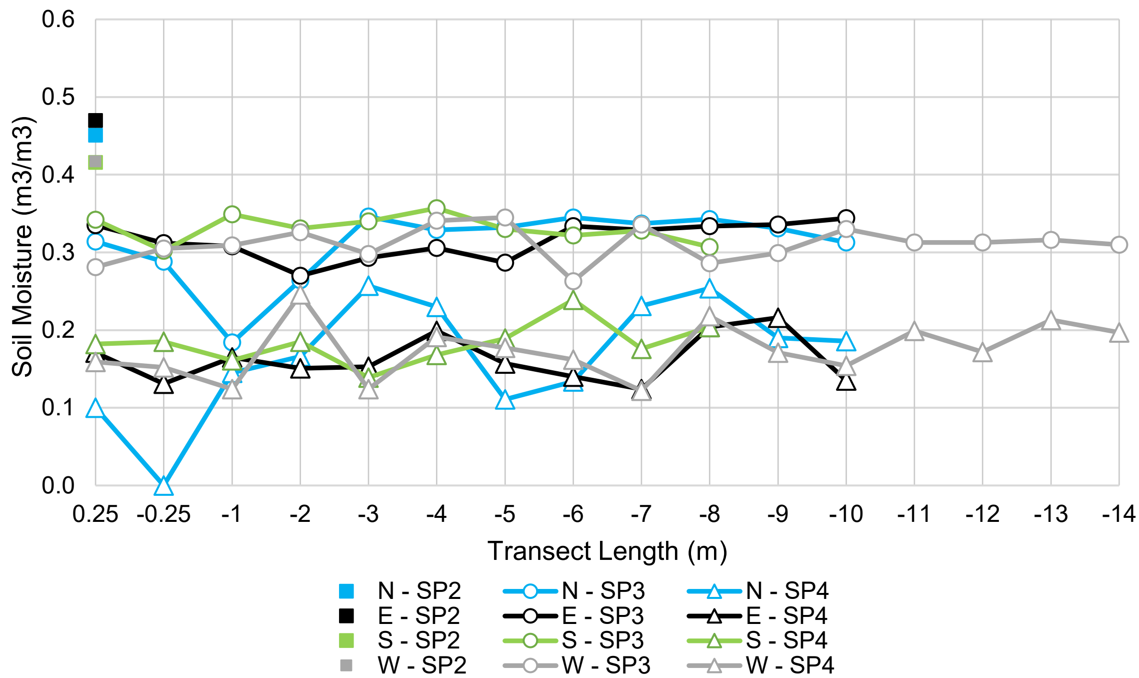

Figure 9. **Grasshopper wetland soil moisture readings along its carinal transects on SP2 (June 1), SP3 (June 23), and SP4 (July 13). Sampling was conducted 0.25 m up the riparian zone then down every meter to the pond perimeter.**

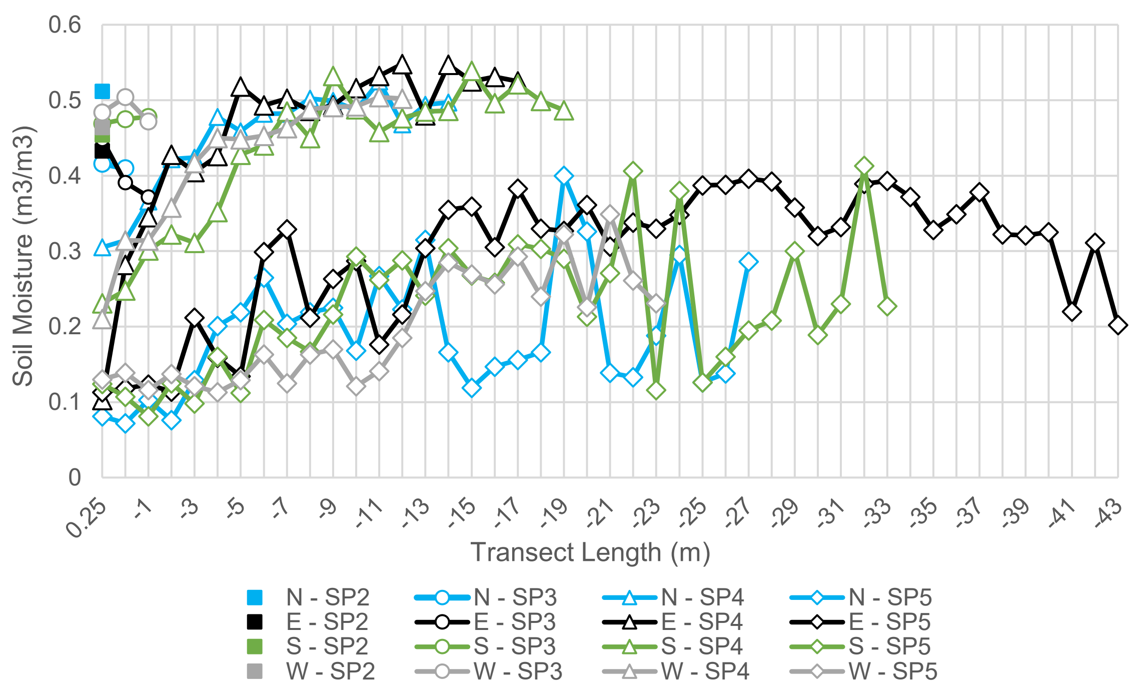

Figure 10. **Black Dome wetland soil moisture readings along its carinal transects on SP2 (May 31), SP3 (June 20), SP4 (July 11), and SP5 (July 31). Sampling was conducted 0.25 m up the riparian zone then down every meter to the pond perimeter.**

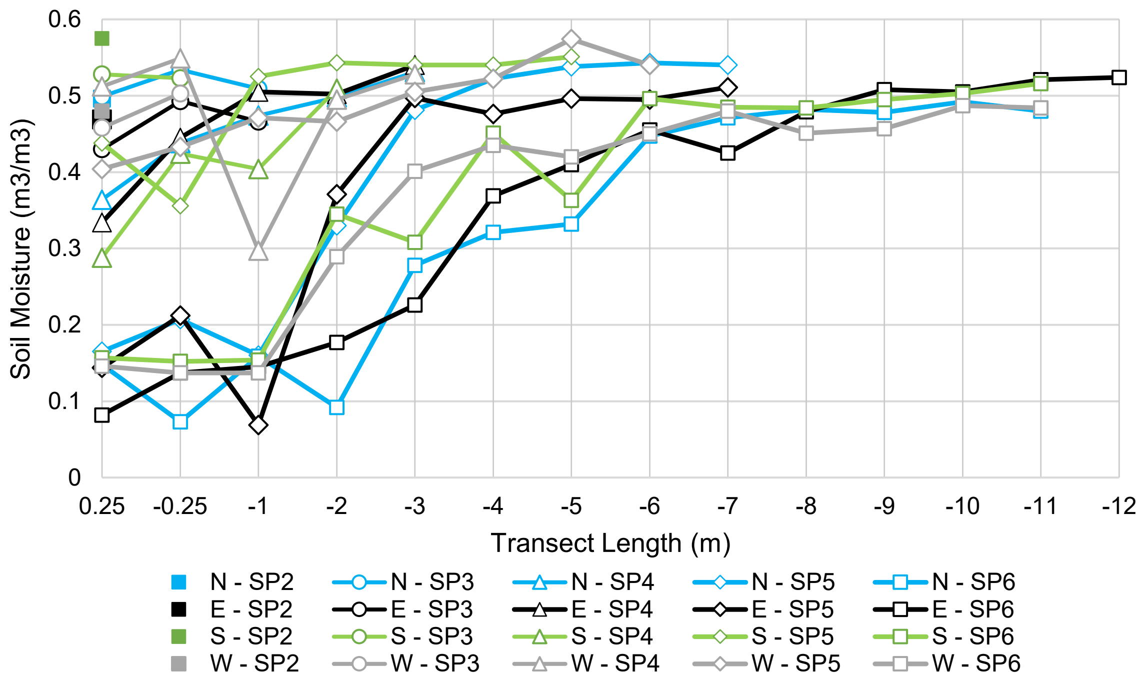

Figure 11. **Iron Gate wetland soil moisture readings along its carinal transects on SP2 (June 4), SP3 (June 20), SP4 (July 10), SP5 (July 29), and SP6 (August 18). Sampling was conducted 0.25 m up the riparian zone then down every meter to the pond perimeter.**

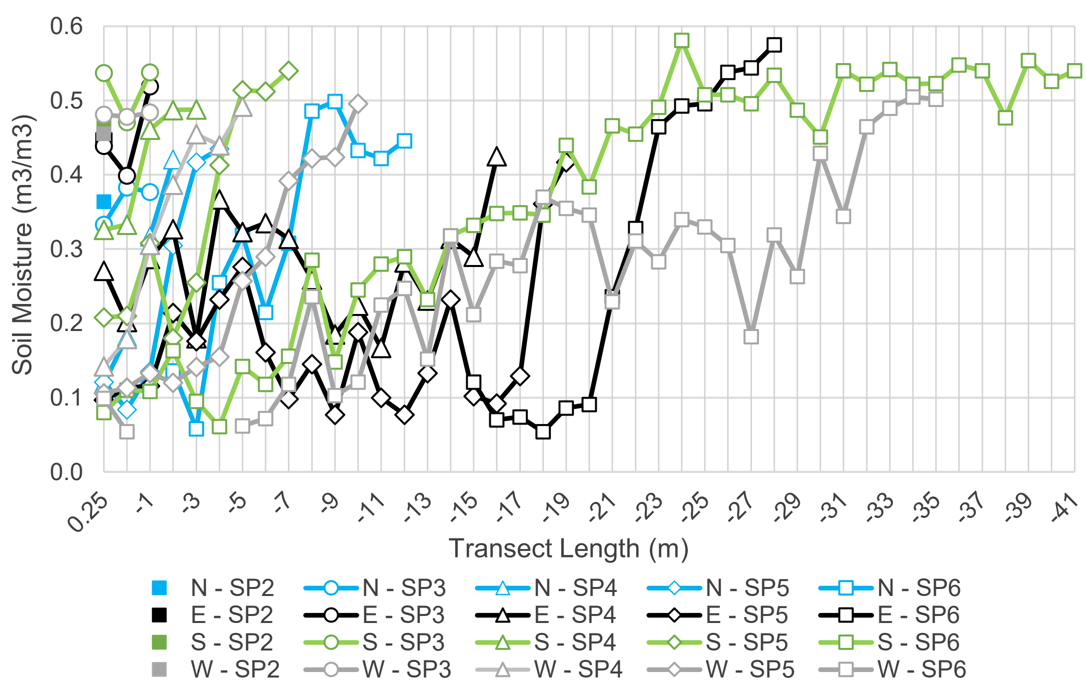

Figure 12. **Airport wetland soil moisture readings along its carinal transects on SP2 (June 2), SP3 (June 20), SP4 (July 10), SP5 (July 30), and SP6 (August 19). Sampling was conducted 0.25 m up the riparian zone then down every meter to the pond perimeter.**

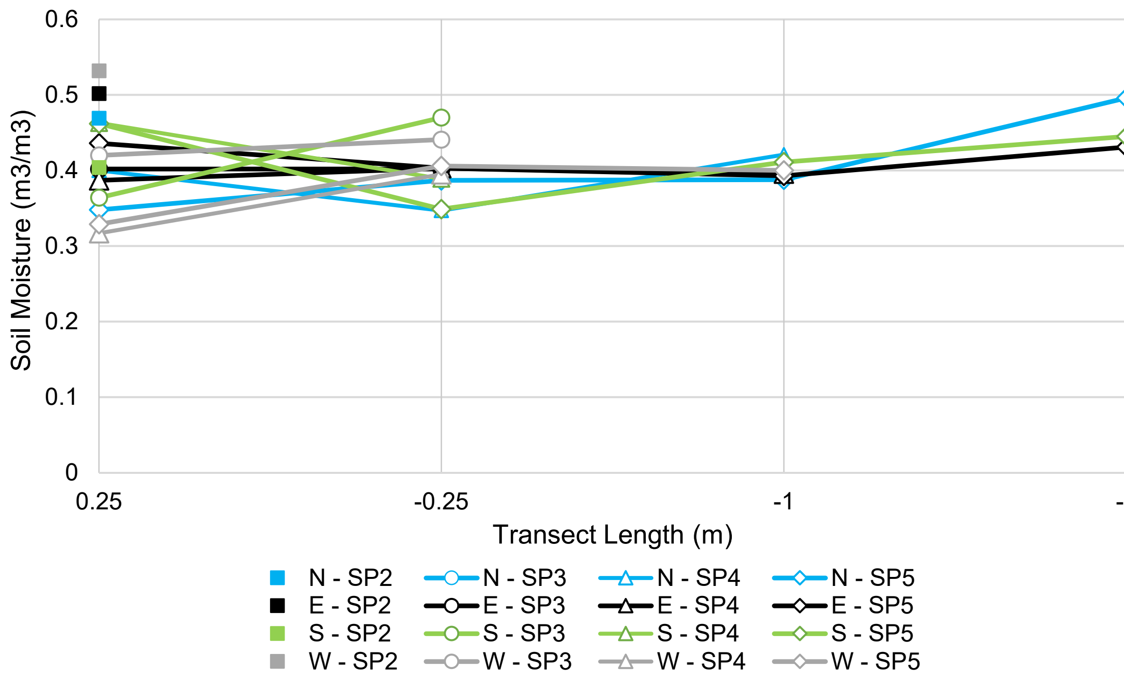

Figure 13. **High Lake wetland soil moisture readings along its carinal transects on SP2 (June 6), SP3 (June 21), SP4 (July 12), and SP5 (August 1). Sampling was conducted 0.25 m up the riparian zone then down every meter to the pond perimeter.**

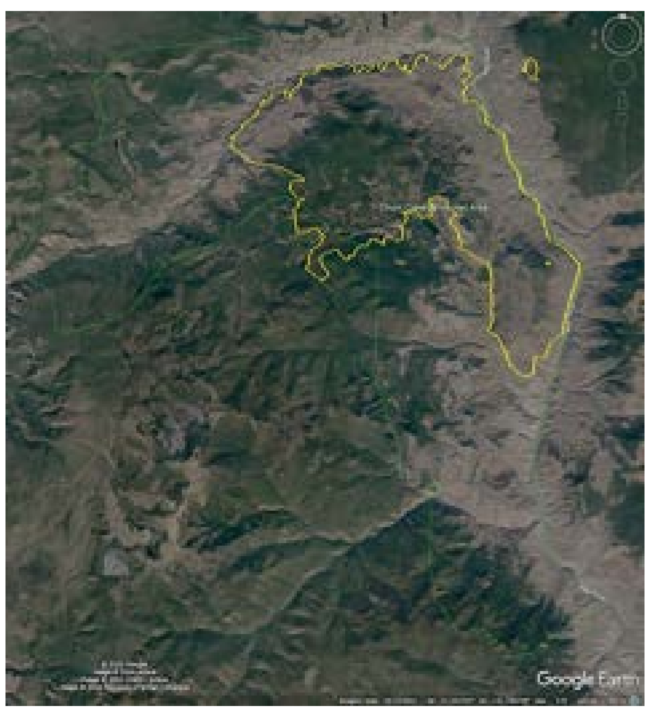

Figure 14. **Fire perimeter and ignition point (yellow) from June 2, 2021, fire within Churn Creek Protected Area's border (green). Five wetlands were burned, including Dry Lake, Iron Gate, Grasshopper, Airport, and Aspen Grove (red).**

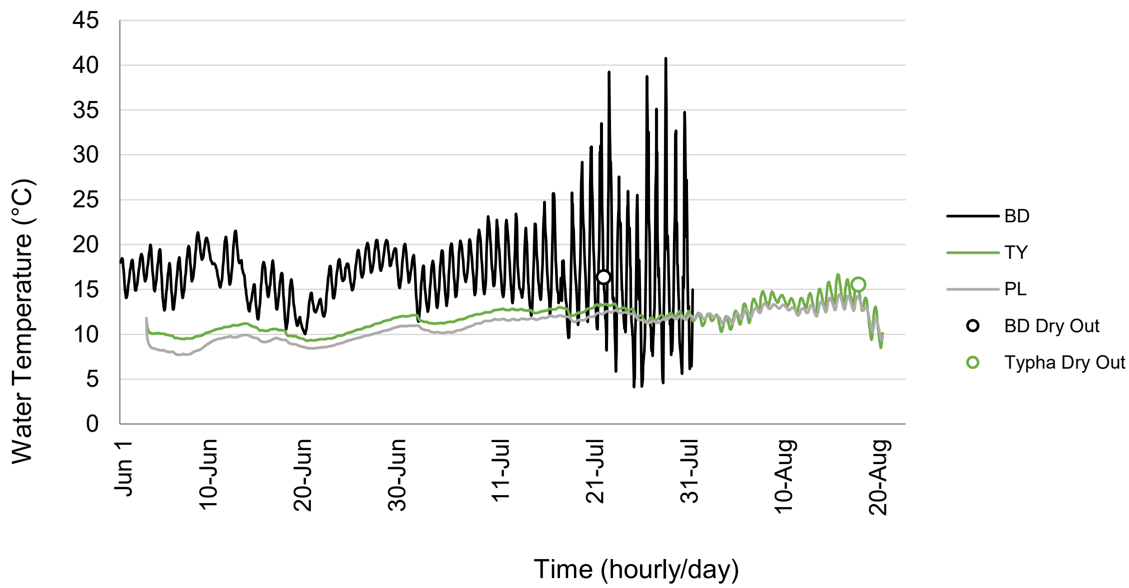

Figure 15. **Water temperature timeseries at Black Dome (BD), Typha (TY), and Perlite (PL) from May 31 to August 22, 2023.**

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Appendix A. Wetland Time Series Photos

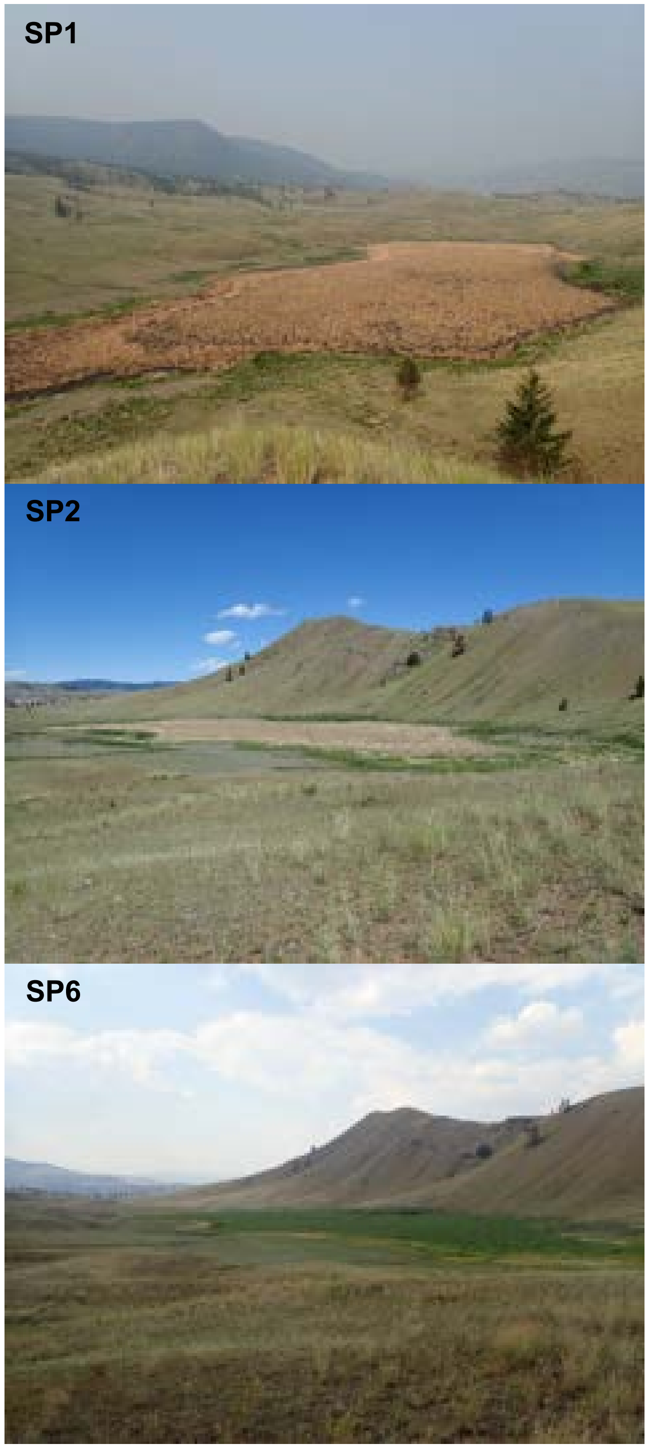

Figure A1. **Dry Lake, 2023. This photo time series depicts Dry Lake on May 18 (SP1) (looking Northwest), and on June 4 (SP2) and August 18 (SP6) (looking Southwest). Vegetation was covering the entire marsh. The pond did not dry up by August 18, 2023.**

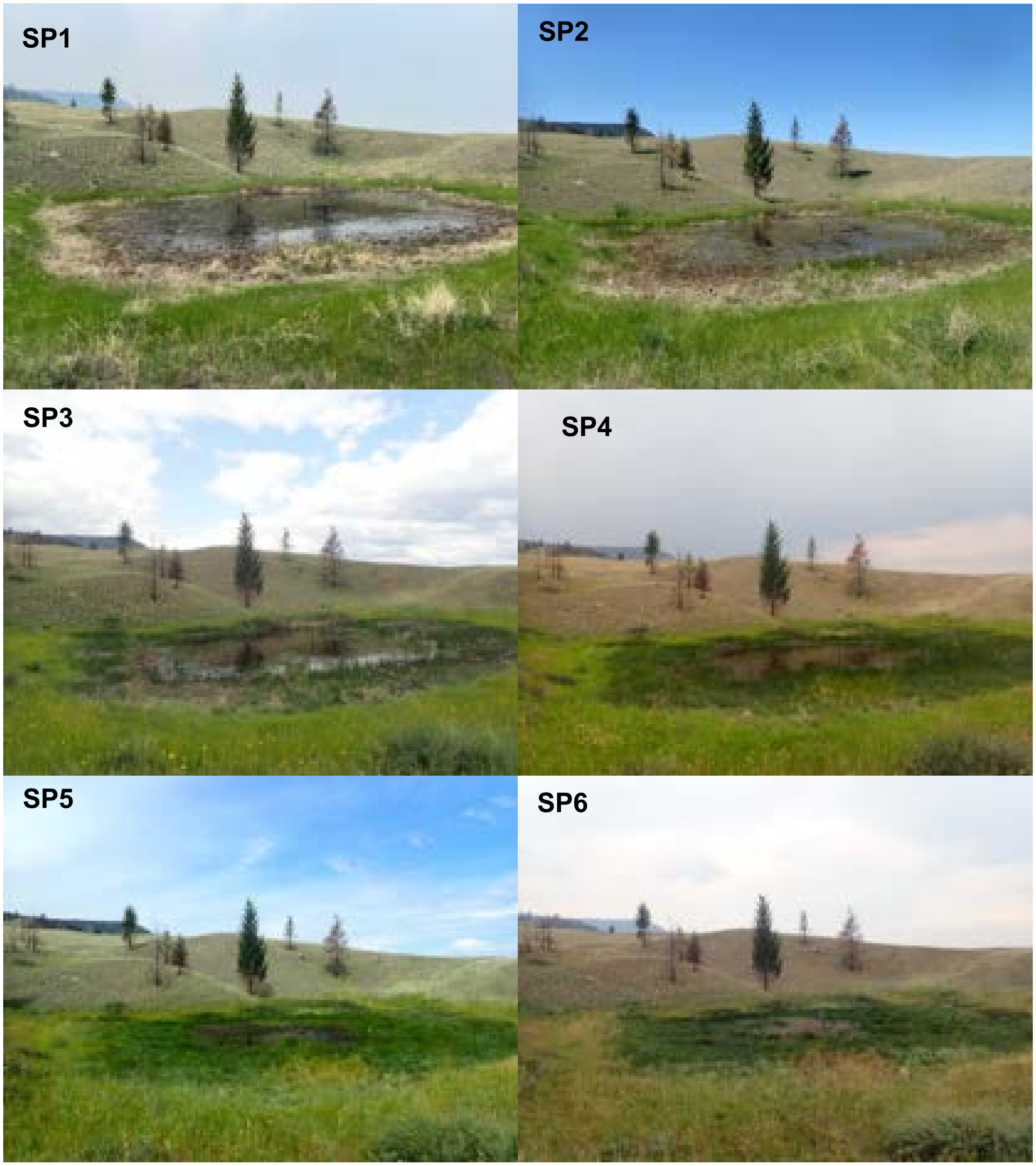

Figure A2. **Iron Gate, 2023. This photo time series depicts Iron Gate on May 18 (SP1,) June 4 (SP2), June 20 (SP3), July 10 (SP4), July 29 (SP5), and August 18 (SP6). Iron Gate was primarily open water with a vegetated marsh fringe. The pond dried completely around August 4, 2023.**

Figure A3. **Coffee Pot, 2023. This photo time series depicts Coffee Pot on May 20 (SP1), June 3 (SP2), and August 22 (SP6). Coffee Pot is a shallow open water wetland. The pond did not dry up by August 22, 2023.**

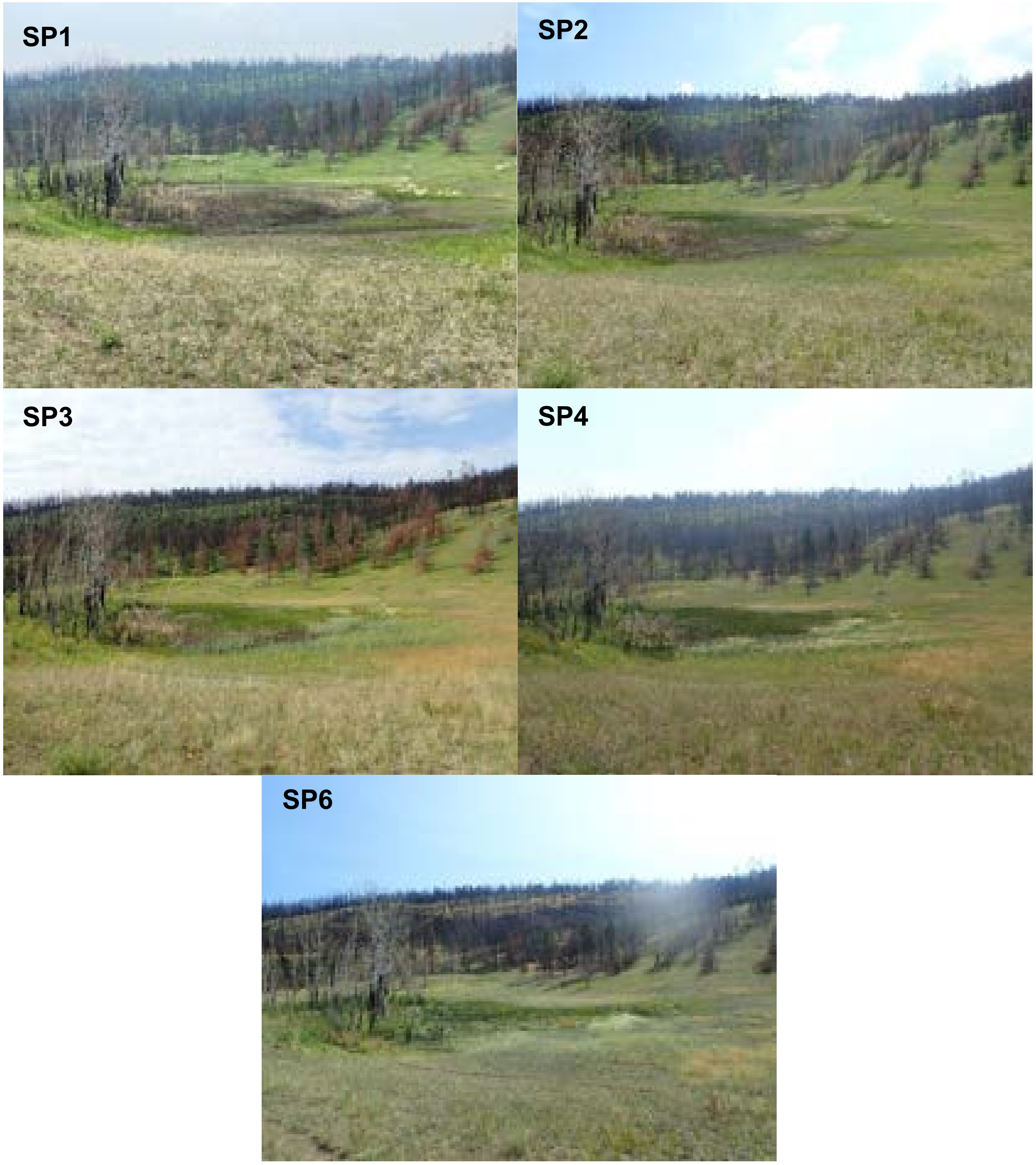

Figure A4. **Aspen Grove, 2023. This photo time series depicts Aspen Grove on May 18 (SP1), June 2 (SP2), June 20 (SP3), July 10 (SP4), and August 19 (SP6). Vegetation was covering the entire marsh. The pond dried completely around August 4, 2023.**

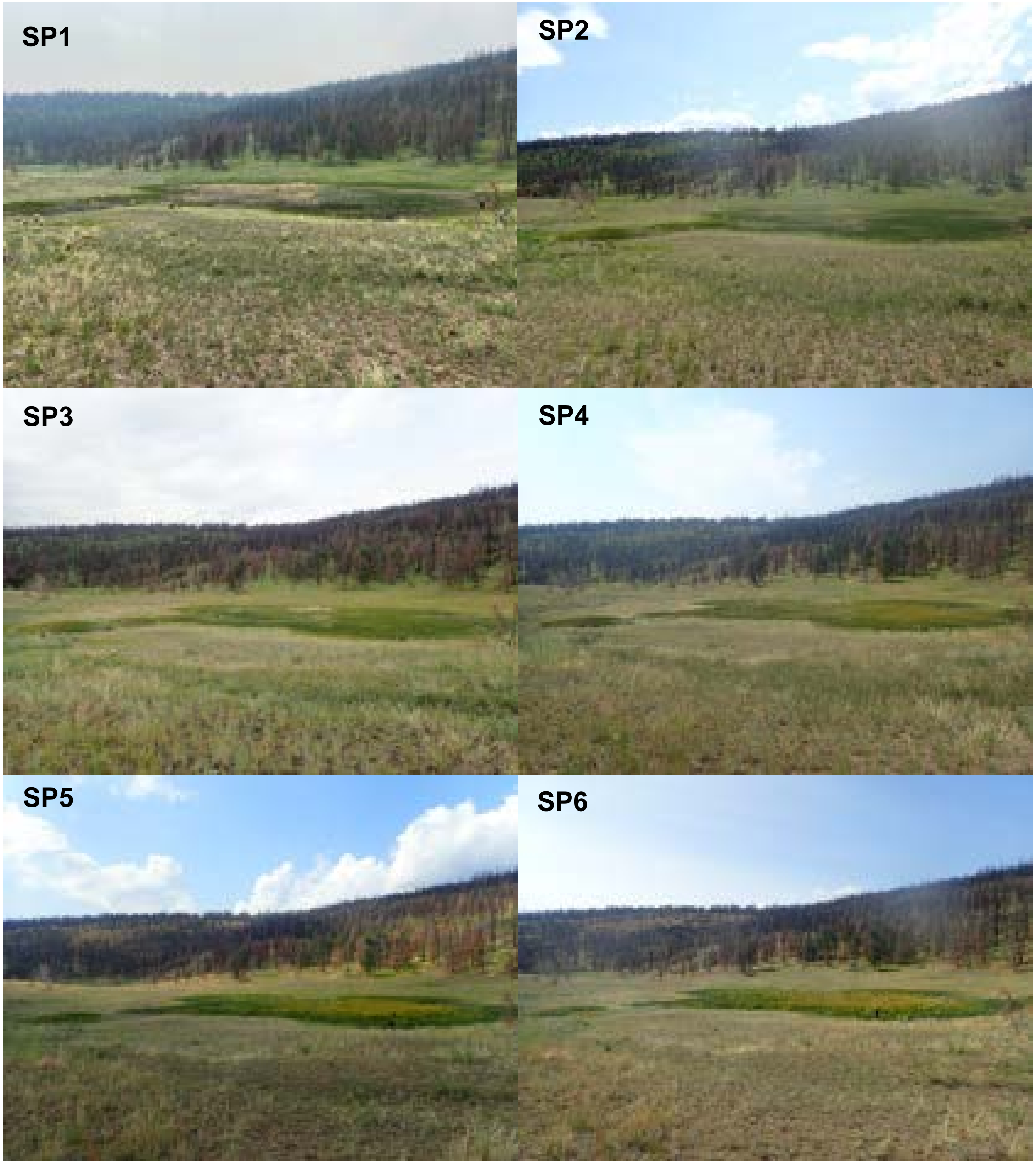

Figure A5. **Airport, 2023. This photo time series depicts Airport on May 18 (SP1), June 2 (SP2), June 20 (SP3), July 10 (SP4), July 30 (SP5), and August 19 (SP6). Vegetation was covering the entire marsh. The pond was nearly dry on August 19, 2023.**

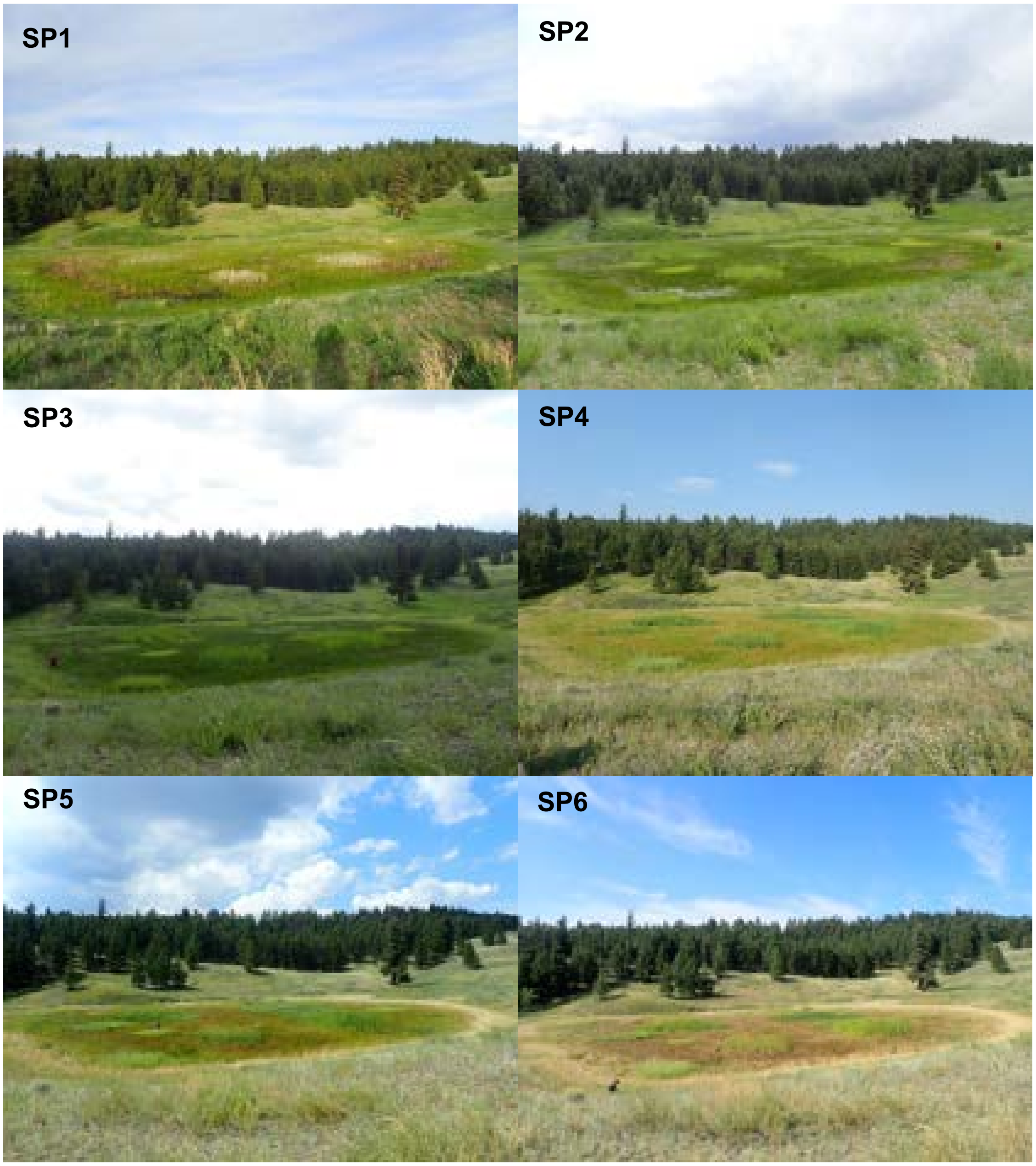

Figure A6. **Black Dome, 2023. This photo time series depicts Black Dome on May 20 (SP1), May 31 (SP2), June 20 (SP3), July 11 (SP4), July 31 (SP5), and August 20 (SP6). Vegetation was covering the entire marsh. The pond dried completely around July 21, 2023.**

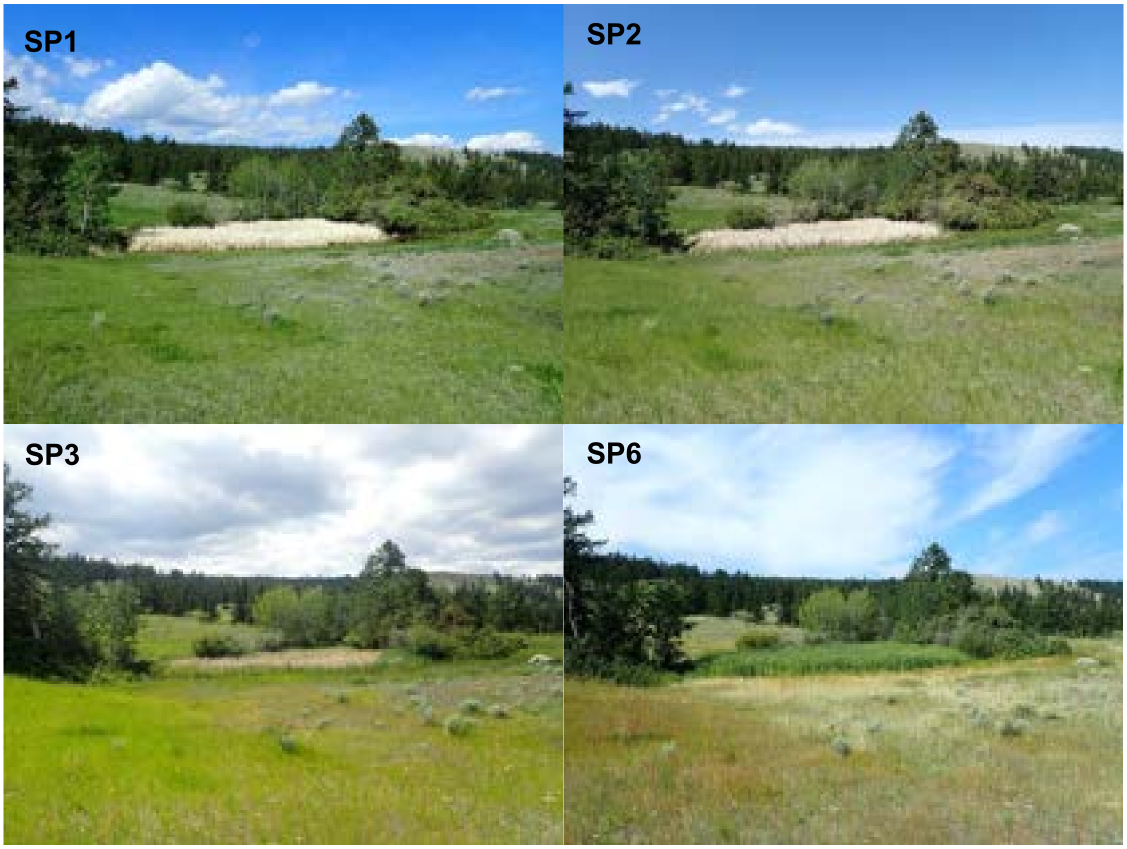

Figure A7. **Typha, 2023. This photo time series depicts Typha on May 19 (SP1), June 3 (SP2), June 20 (SP3), and August 20 (SP6). Vegetation was covering the entire marsh. The pond dried completely around August 17, 2023.**

Figure A8. **Hog Lake, 2023. This photo time series depicts Hog Lake on May 19 (SP1), June 3 (SP2), and August 21 (SP6). Hog Lake is primarily open water with a vegetated marsh fringe. The pond did not dry up by August 21, 2023.**

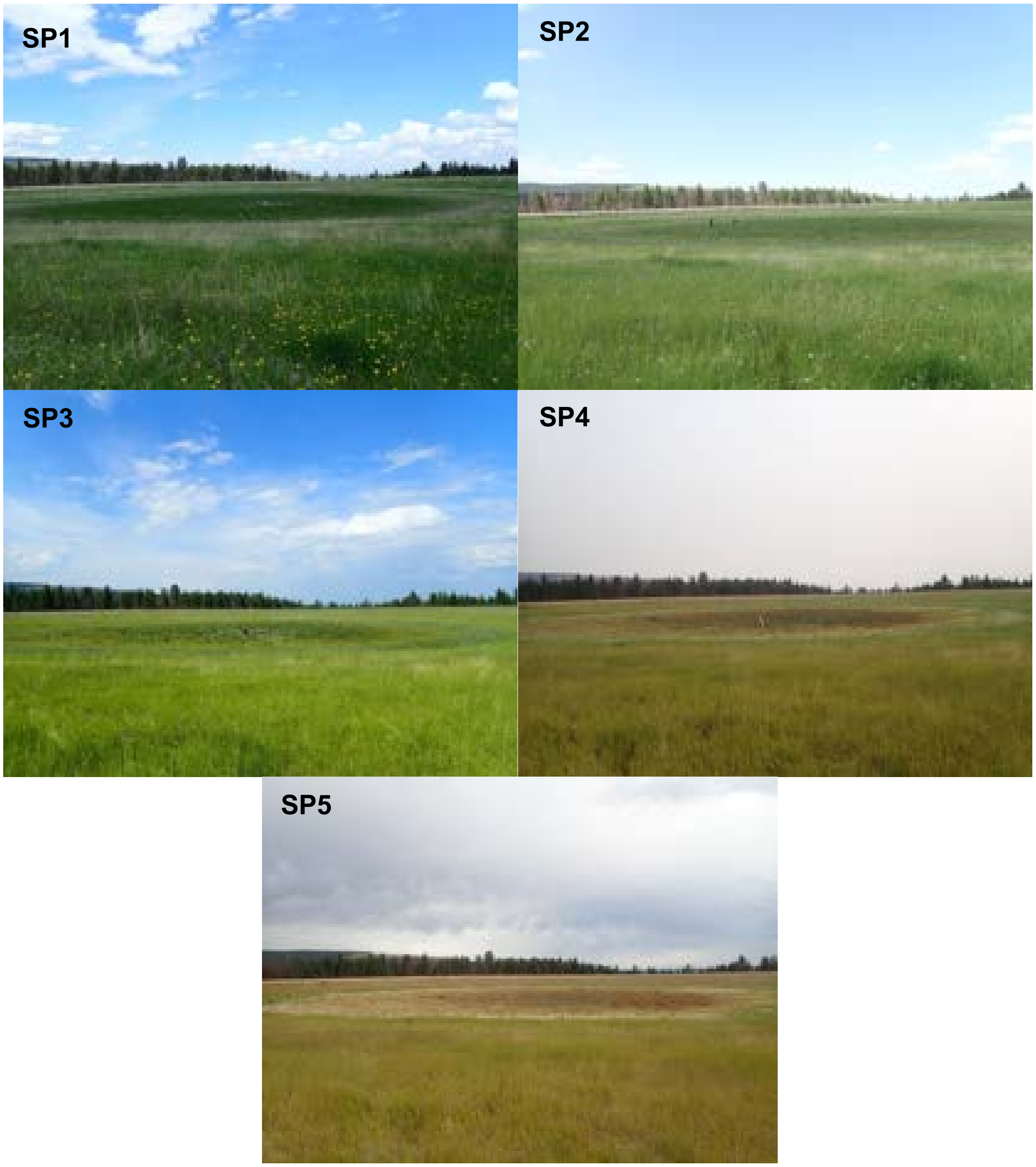

Figure A9. **Grasshopper, 2023. This photo time series depicts Grasshopper on May 20 (SP1), June 1 (SP2), June 23 (SP3), July 13 (SP4), and August 2 (SP5). Vegetation was covering the entire marsh. The pond dried completely around June 12, 2023.**

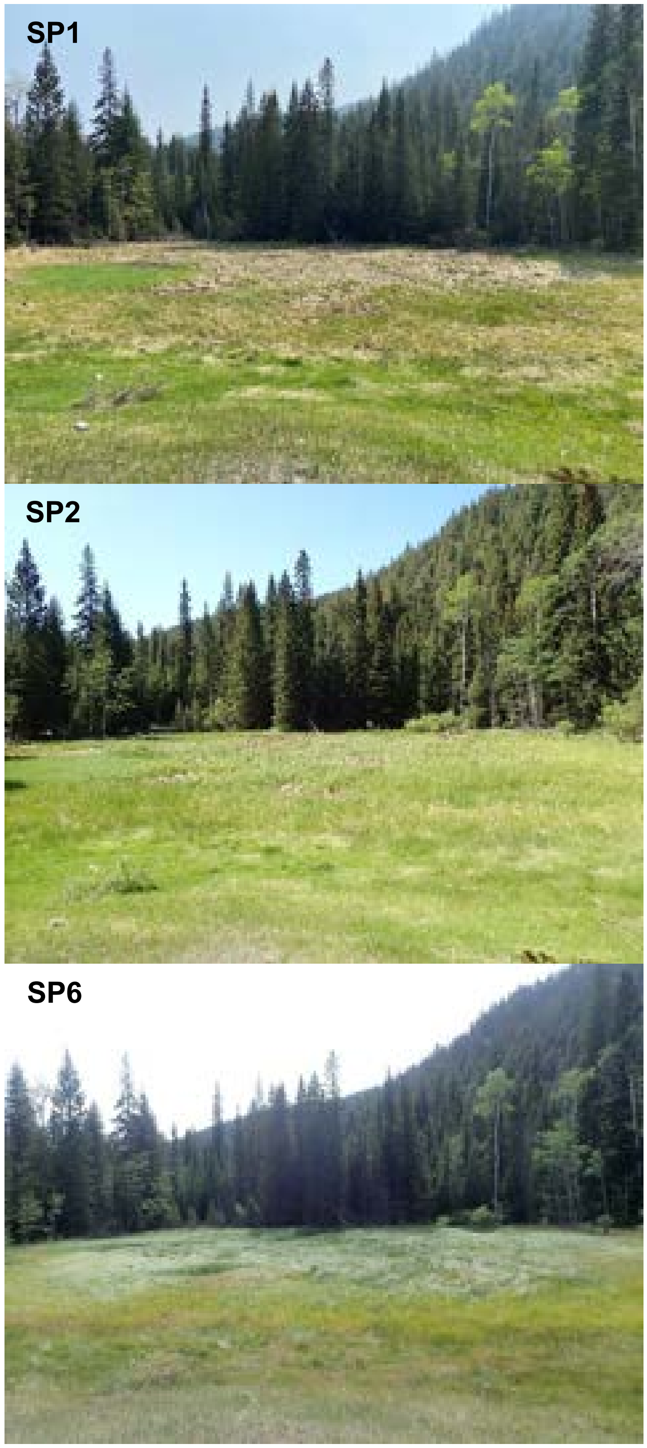

Figure A10. **Perlite, 2023. This photo time series depicts Perlite on May 18 (SP1), June 3 (SP2), and August 20 (SP6). Vegetation was covering the entire marsh. The pond was nearly dry by August 20, 2023.**

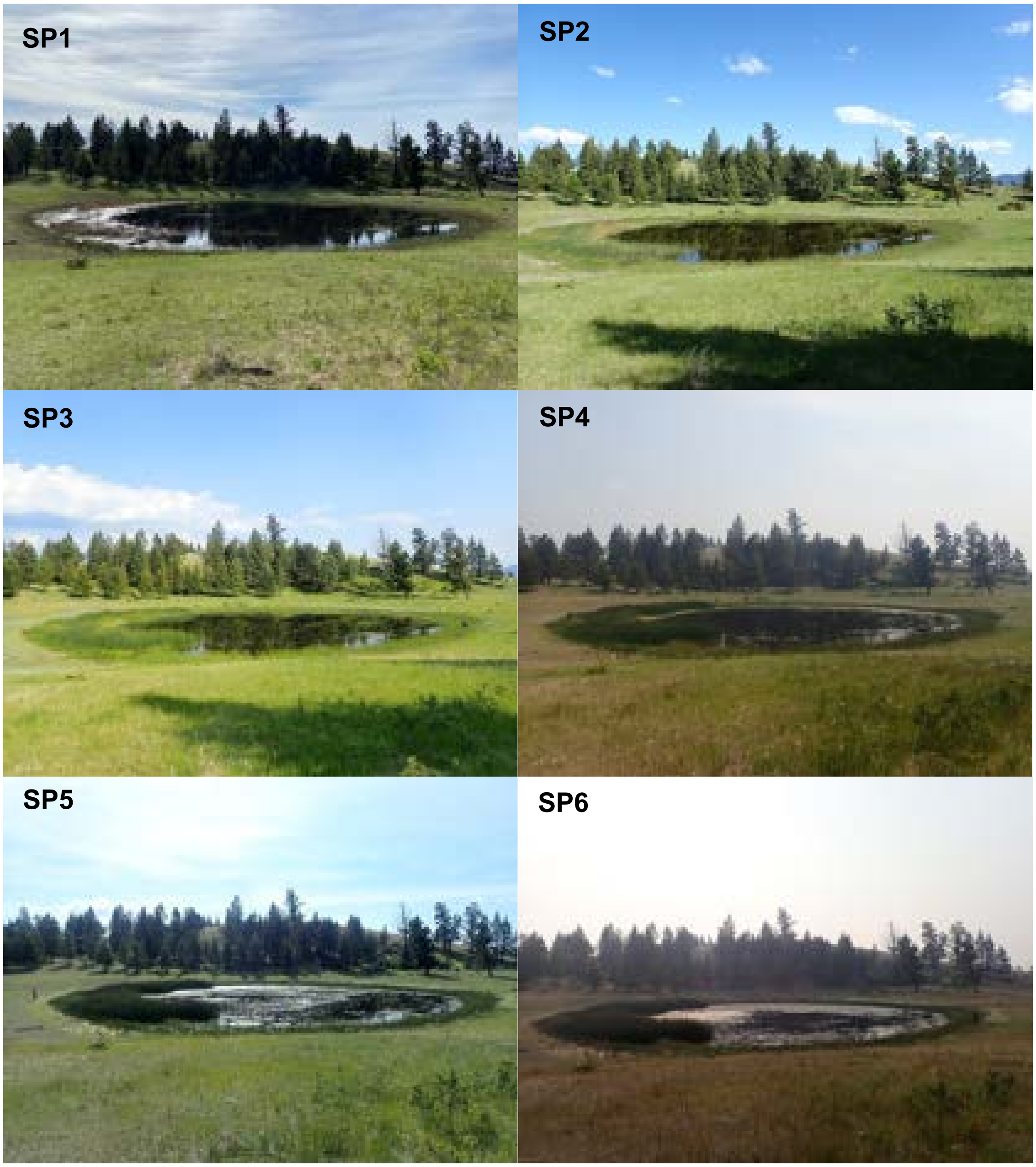

Figure A11. **High Lake, 2023. This photo time series depicts High Lake on May 20 (SP1,) June 6 (SP2), June 22 (SP3), July 12 (SP4), August 1 (SP5), and August 21 (SP6). High Lake was primarily open water with a vegetated marsh fringe. The pond did not dry by August 21, 2023.**

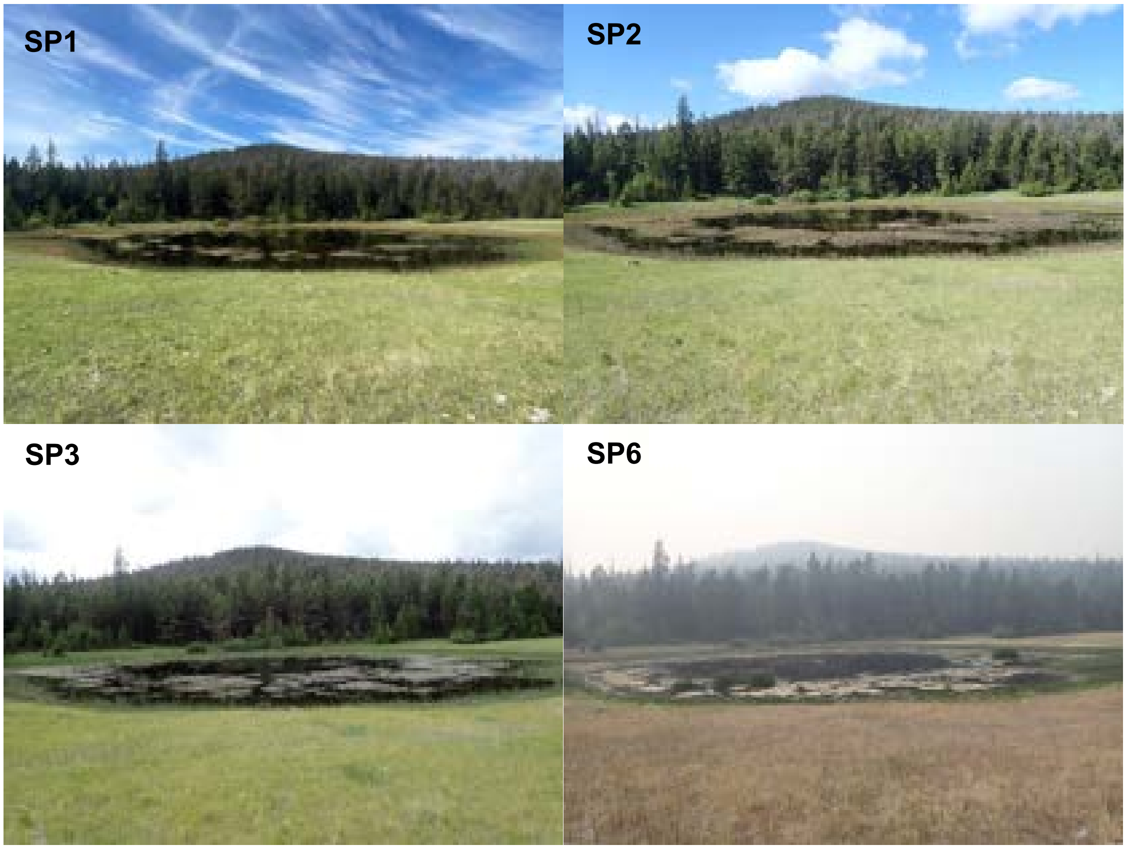

Figure A12. **Grouse Lake, 2023. This photo time series depicts Grouse Lake on May 20 (SP1,) June 5 (SP2), June 17 (SP3), and August 21 (SP6). Grouse Lake was primarily open water with a vegetated marsh fringe. The pond did not dry by August 21, 2023.**

Appendix B. Assessment Framework

Table B1. Wetland assessment framework for the evaluation of indicators of wetland vaurability and reiliance. Factors contributing to pond permanence and stability, water quality, biological integretity, and natural and anthropogenic disturbance were scored through their associated attributes. Varying factor point ranges that deviate from the normal 1 through 5 ranking suggest that there was a weak or strong correlation to their indicator, or that the factor was of lesser importance to the indicator.

Indicator	Factor	Description	Attribute	Points
Pond Permanence	mesoclimatic conditions	Wetlands are found over an elevational gradient in CCPA. Higher elevational wetlands should experience lower Ta and higher P, potentially contributing to higher water inputs and a weaker VPD. Lower elevational wetlands should experience higher Ta and lower P, potentially contributing to lower water inputs and a stronger VPD.	low elevation (<725 m)	1
			low-mid elevation (725-850 m)	2
			mid elevation (850-975 m)	3
			mid-high elevation (975-1100 m)	4
			high elevation (>1100 m)	5
	pond area-depth relationship	An area-depth relationship relating to the speed at which wetlands dry was found in CCPA. Larger and deeper ponds, determined at pond-full volume, have a higher resilience to dry out, where small shallow ponds tend to dry every year. Shallow ponds are more at risk of permanently drying with ongoing changes in climate. Larger ponds likely have a bigger watershed, so even when they are shallow, they are ranked higher than their small and medium counterparts.	small-shallow (<0.1 ha, <0.3 m)	1
			medium-shallow (0.2-0.4 ha, <0.3 m)	1
			large-shallow (>0.5 ha, <0.3 m)	2
			small-moderate (<0.1 ha, 0.4-0.7 m)	2
			medium-moderate (0.2-0.4 ha, 0.4-0.7 m)	3
			large-moderate (>0.5 ha, 0.4-0.7 m)	4
			small-deep (<0.1 ha, >0.8 m)	4
			medium-deep (0.2-0.4 ha, >0.8 m)	4
			large-deep (>0.5 ha, >0.8 m)	5
	mean water temperature	Consistently lower Tw promotes a slower rate of evaporation. Higher Tw promotes faster rate of evaporation. The strength of Tw in determining evaporative loss in CCPA wetlands does not appear to be strong across all wetlands.	<14°C	4
			14-20°C	3
			>20°C	2
	water electrical conductivity	Elevated EC promotes heat retention in Tw and salt ions lower water activity, decreasing vapor pressure.	low-moderate (<1000 µS/cm)	3
			high-very high/saline (>1000 µS/cm)	4

Table B1. (continued)

Pond Permanence (continued)	emergent vegetation presence	Plants can add to water loss through transpiration. The more vegetation there is, the higher the total transpiration. Wetlands with large proportions of open water and little emergent transpiration can experience higher evaporation rates due to limited wind protection.	<20%	3
			20-30%	4
			30-50%	3
			50-80%	2
			>80%	1
	emergent vegetation density & litter cover	Dense plant cover can provide a mulch layer with litter and/or shade from solar radiation, potentially lowering Tw, Ta, and wind, and altering RH, which drives ET. Some wetlands have dense vegetation throughout, some have dense patches, the total cover and response to climate must be considered.	<20%	1
			20-30%	2
			30-50%	3
			50-80%	4
			>80%	5
	summer subsurface water inputs	Inputs from other water sources throughout the summer months would help lower the rate of water loss.	confirmed	5
			unconfirmed	3
			unlikely	1
	presence of riparian vegetation	Plants around a wetland can use pond water for photosynthesis. Dense woody plants may use more water than grazed grassland. Similarly, less plant bimass could equate to more pond discard in spring and during rain events.	primarily unvegetated	5
			grazed grassland	4
			grazed grassland with sparse woody vegetation	3
			ungrazed grassland	3
			ungrazed grassland with sparse woody vegetation	2
			grassland with dense woody vegetation	1
	moist margin width	The moist margin of a pond contracts with pond inputs and output and is thus connected hydrologically. The larger the moist margin, the more potential for water loss as the soil interacts with the pond's water. Larger moist margins expand the pond's evaporative surface.	<1 m	5
			1-3 m	4
			3-7 m	3
			7-10 m	2
			>10 m	1

Table B1. (continued)

Water Quality	chemical composition	Organisms rely on wetland water. Wetlands with high ion and metal concentrations can be detrimental for some species, low concentrations can cause deficiencies.	contains multiple low values	3
			optimal levels	5
			contains multiple high values	1
	water electrical conductivity	EC is a measure of the quantity of dissolved ions. Low EC may signify reduced productivity, while high EC levels suggest elevated salt concentrations, and extreme EC values can indicate potentially harmful water conditions.	low (<200 µS/cm)	2
			optimal (200-1000 µS/cm)	5
			high (1000-10000 µS/cm)	3
			extreme (>10000 µS/cm)	1
Biological Integrity	wetland species richness	High biological diversity of emergent plants, wetland biota, algae, etc. is a sign of a stable and resilient ecosystem.	low (<5)	2
			moderate (5-10)	3
			high (>10)	4
	wildlife diversity	The number of terrestrial species that use and rely on the wetland is an indication of its function and role in the landscape.	low (<5)	2
			moderate (5-10)	3
			high (>10)	4
	breeding habitat	High breeding habitat in wetland and riparian should be protected. Low or no signs could indicate environmental limitations.	low (<10%)	2
			moderate (10-20%)	3
			high (>20%)	5
Natural & Anthropogenic Disturbances	severity of fires	Low severity fires in a watershed can improve ecosystem productivity, high severity fires are associated with soil degradation and biological loss.	none	3
			low intensity	5
			medium intensity	3
			high intensity	2
	erosion levels	High erosion can cause sediment transport into wetlands.	low (little to none)	5
			medium (multiple spots with low intensity)	3
			high (multiple spots of high intensity)	1
	anthropogenic alterations	Human alterations may disturb wildlife and plants, water regimes, produce pollutants, or change other physical or chemical processes in a wetland. Some activities are benign.	none (natural system)	5
			low (present no impact)	3
			high (ongoing)	1

Table B1. (continued)

Natural & Anthropogenic Disturbances (continued)	plugging intensity	Plugging can indicate soil degradation, with high levels indicating a both recent and long-standing signs, while low levels would suggest minimal indications of degradation.	none	5
			low (<10%)	3
			medium (10-30%)	2
			high (>30%)	1
	grazing impacts	Severe grazing has little regeneration, where low grazing can promote regeneration of plants	none	5
			low-moderate	3
			moderate-high	2
			severe	1

Appendix C. Reference Evaporation Model

Table C1. Forecasted area and volume for all wetlands compared to measured area. Initial modelled area (SP2 – May 31 to June 6) is the first measured value from each wetland. Net loss is the difference between measured depths from each sampling period (SP). Any bolded values were estimated based on the calculated daily average water loss between measured values (Figure 9).

Parameters	Dry Lake		Iron Gate		Coffee Pot	
	Modeled	Measured	Modeled	Measured	Modeled	Measured
Area (ha) - SP2	4.52220	4.52220	0.05000	0.05000	0.27789	0.27789
Area (m2) - SP2	**45222.0**	**45222.0**	500.0	500.0	2778.9	2778.9
Volume (m3)	17962.70		73.72		597.54	
Volume (L)	17962698		73720		597544	
Volume (decaL)	17.9627		0.0737		0.5975	
SP3 depth (mm)	**515**		541		**394**	
SP2 depth (mm)	583		610		470	
net (mm)	-68		-69		-76	
Lake Evaporation (L)	3075096		34500		211196	
Remaining Volume (decaL)	14.89		0.0392		0.3863	
Remaining Area (ha)	3.87711		0.02981		0.19437	
Remaining Area (m2) - SP3	38771.1	N/A	298.1	377.8	1943.7	N/A
SP4 depth (mm)	**431**		320		**313**	
SP3 depth (mm)	**515**		541		**394**	
net (mm)	-84		-221		-81	
Lake Evaporation (L)	3256770		65873		157441	
Remaining Volume (decaL)	11.63		-0.0267		0.2289	
Remaining Area (ha)	3.16685		NULL		0.12656	
Remaining Area (m2) - SP4	31668.5	N/A	NULL	327.6	1265.6	N/A
SP5 depth (mm)	**351**		150		**233**	
SP4 depth (mm)	**431**		320		**313**	
net (mm)	-80		-170		-80	
Lake Evaporation (L)	2533480		NULL		101250	
Remaining Volume (decaL)	9.10		NULL		0.1277	
Remaining Area (ha)	2.58924		NULL		0.07842	
Remaining Area (m2) - SP5	25892.4	N/A	NULL	73.6	784.2	N/A
SP6 depth (mm)	267		0		148	
SP5 depth (mm)	**351**		150		**233**	
net (mm)	-84		-150		-85	
Lake Evaporation (L)	2174960		NULL		66656	
Remaining Volume (decaL)	6.92		NULL		0.0610	
Remaining Area (ha)	2.06972		NULL		0.04	
Remaining Area (m2) - SP6	20697.2	34091.0	NULL	0.0	428.1	2068.5

Table C1. (continued)

Parameters	Aspen Grove		Airport		Black Dome	
	Modeled	Measured	Modeled	Measured	Modeled	Measured
Area (ha) - SP2	0.09823	0.09823	0.34794	0.34794	0.37433	0.37433
Area (m2) - SP2	982.3	982.3	3479.4	3479.4	3743.3	3743.3
Volume (m3)	168.03		786.10		859.44	
Volume (L)	168028		786104		859440	
Volume (decaL)	0.1680		0.7861		0.8594	
SP3 depth (mm)	403		510		210	
SP2 depth (mm)	430		600		300	
net (mm)	-27		-90		-90	
Lake Evaporation (L)	26522		313146		336897	
Remaining Volume (decaL)	0.1415		0.4730		0.5225	
Remaining Area (ha)	0.08533		0.22942		0.24896	
Remaining Area (m2) - SP3	853.3	N/A	2294.2	2806.5	2489.59	2953.0
SP4 depth (mm)	210		310		75	
SP3 depth (mm)	403		510		210	
net (mm)	-193		-200		-200	
Lake Evaporation (L)	164683		458847		497919	
Remaining Volume (decaL)	-0.0232		0.0141		0.0246	
Remaining Area (ha)	NULL		0.01290		0.02035	
Remaining Area (m2) - SP4	NULL	N/A	129.0	2409.4	203.5	948.2
SP5 depth (mm)	**42**		265		0	
SP4 depth (mm)	210		310		75	
net (mm)	-168		-45		-75	
Lake Evaporation (L)	NULL		5803		15264	
Remaining Volume (decaL)	NULL		0.0083		0.0094	
Remaining Area (ha)	NULL		0.00835		0.00921	
Remaining Area (m2) - SP5	NULL	N/A	83.5	1542.5	92.1	0.0
SP6 depth (mm)	0		75			
SP5 depth (mm)	**42**		265			
net (mm)	-42		-190			
Lake Evaporation (L)	NULL		15872			
Remaining Volume (decaL)	NULL		-0.0076			
Remaining Area (ha)	NULL		NULL			
Remaining Area (m2) - SP6	NULL	0.0	NULL	146.7		

Table C1. (continued)

Parameters	Typha		Hog Lake		Grasshopper	
	Modeled	Measured	Modeled	Measured	Modeled	Measured
Area (ha) - SP2	0.11781	0.11781	0.97440	0.97440	0.05630	0.05630
Area (m2) - SP2	1178.1	1178.1	9744.0	9744.0	563.0	563.0
Volume (m3)	209.74		3352.24		85.21	
Volume (L)	209743		3352244		85205	
Volume (decaL)	0.2097		3.3522		0.0852	
SP3 depth (mm)	409		**813**		0	
SP2 depth (mm)	470		880		180	
net (mm)	-61		-67		-180	
Lake Evaporation (L)	71864		652848		101340	
Remaining Volume (decaL)	0.14		2.70		-0.0161	
Remaining Area (ha)	0.08353		0.95647		NULL	
Remaining Area (m2) - SP3	835.3	N/A	9564.7	N/A	NULL	0.00
SP4 depth (mm)	**298**		**742**			
SP3 depth (mm)	409		**813**			
net (mm)	-111		-71			
Lake Evaporation (L)	92719		679097			
Remaining Volume (decaL)	0.05		2.02			
Remaining Area (ha)	0.03346		0.75425			
Remaining Area (m2) - SP4	334.6	N/A	7542.5	N/A		
SP5 depth (mm)	209		**671**			
SP4 depth (mm)	**298**		**742**			
net (mm)	-89		-71			
Lake Evaporation (L)	29778		535519			
Remaining Volume (decaL)	0.02		1.48			
Remaining Area (ha)	0.01384		0.58598			
Remaining Area (m2) - SP5	138.4	N/A	5859.8	N/A		
SP6 depth (mm)	0		600			
SP5 depth (mm)	209		**671**			
net (mm)	-209		-71			
Lake Evaporation (L)	28923		416046			
Remaining Volume (decaL)	-0.0135		1.07			
Remaining Area (ha)	NULL		0.45			
Remaining Area (m2) - SP6	NULL	0.0	4475.5	9135.0		

Table C1. (continued)

Parameters	Perlite		High Lake		Grouse Lake	
	Modeled	Measured	Modeled	Measured	Modeled	Measured
Area (ha) - SP2	0.12396	0.12396	0.23529	0.23529	0.48047	0.48047
Area (m2) - SP2	1239.6	1239.6	2352.9	2352.9	4804.7	4804.7
Volume (m3)	223.18		487.75		1165.41	
Volume (L)	223176		487754		1165407	
Volume (decaL)	0.2232		0.4878		1.1654	
SP3 depth (mm)	**396**		1094		**1069**	
SP2 depth (mm)	440		1120		1130	
net (mm)	-44		-26		-61	
Lake Evaporation (L)	54542		61175		293087	
Remaining Volume (decaL)	0.1686		0.4266		0.8723	
Remaining Area (ha)	0.09852		0.21081		0.37892	
Remaining Area (m2) - SP3	985.2	N/A	2108.1	2612.9	3789.2	N/A
SP4 depth (mm)	**343**		1055		**998**	
SP3 depth (mm)	**396**		1094		**1069**	
net (mm)	-53		-39		-71	
Lake Evaporation (L)	52216		82217		269035	
Remaining Volume (decaL)	0.1164		0.3444		0.6033	
Remaining Area (ha)	0.07271		0.17688		0.28008	
Remaining Area (m2) - SP4	727.1	N/A	1768.8	24928.0	2800.8	N/A
SP5 depth (mm)	299		887		**926**	
SP4 depth (mm)	**343**		1055		**998**	
net (mm)	-44		-168		-72	
Lake Evaporation (L)	31994		297160		201655	
Remaining Volume (decaL)	0.0844		0.0472		0.4016	
Remaining Area (ha)	0.05588		0.03469		0.20065	
Remaining Area (m2) - SP5	558.8	N/A	346.9	2177.3	2006.5	N/A
SP6 depth (mm)	110		818		850	
SP5 depth (mm)	299		887		**926**	
net (mm)	-189		-69		-76	
Lake Evaporation (L)	105607		23939		152496	
Remaining Volume (decaL)	-0.0212		0.0233		0.2491	
Remaining Area (ha)	NULL		0.02		0.14	
Remaining Area (m2) - SP6	NULL	7.5	194.3	2681.0	1356.6	4555.5

Appendix D. Site Photos

Figure D1. **Red-orange precipitate on Grasshopper (A) wetland's soil after about one month of drying (July 13), and at Airport (B) wetland during the last sampling period (August 19) when the pond was nearly dry.**

Figure D2. **Cattle use at Airport (A) and Aspen Grove (B) wetlands in Churn Creek Protected Area on July 11, 2023 at 17:43 and July 13, 2023 at 12:19, respectively.**

Figure D3. **Airport (A) and Aspen Grove (B) wetland basin condition on August 19, 2023. Cattle plugging and vegetation disturbance is evident.**

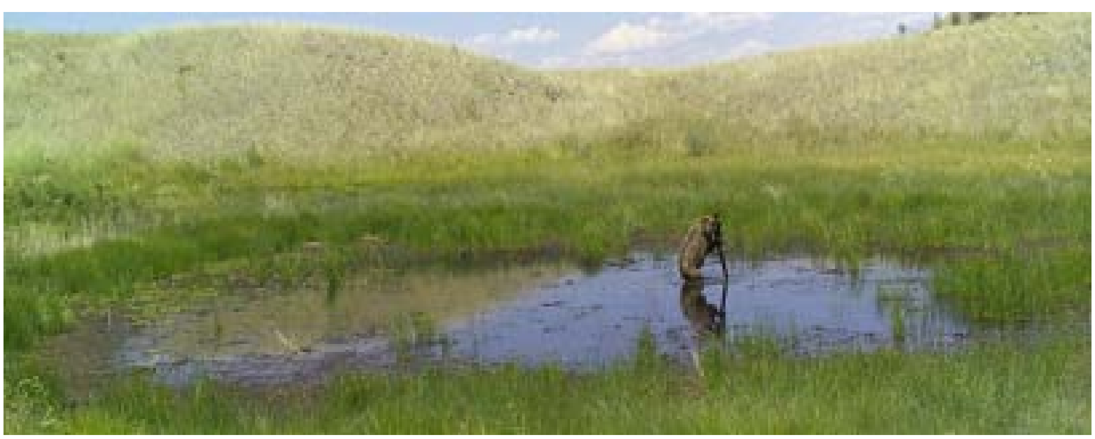

Figure D4. **Black bear removing surface water level monitoring well from Iron Gate wetland on July 20, 2023, in Churn Creek Protected Area at 14:15.**

Figure D5. **Black-billed magpies utilizing Iron Gate wetland on August 3, 2023, in Churn Creek Protected Area at 07:50.**

Figure D6. **Western toad tadpoles (A) and toad (B) at Grasshopper wetland in Churn Creek Protected Area on June 1, 2023.**

Figure D7. **Grasshopper wetland in Churn Creek Protected Area on June 23, 2023, approximately 11 days after its dry out and 23 days after Western Toad tadpole sighting.**

Figure D8. **Grasshopper wetland in Churn Creek Protected Area on June 26 at 19:28. Cattle that were recently excluded from the wetland by a fence surrounding the wetland; coyote could still enter the exclusion zone.**

Figure D9. **Fire damaged soil on August 19, 2023 in the Aspen Grove and Airport wetland area where a high intensity fire burned the Churn Creek Protected Area landscape on June 2, 2021.**

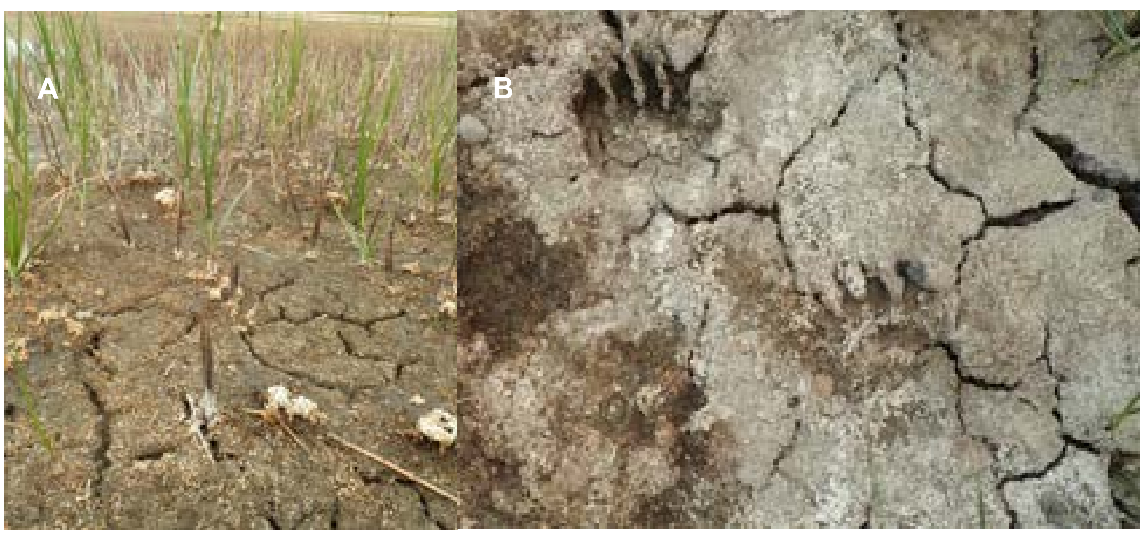

Figure D10. **Precipitated salts on the soil surface (A-B) and vegetation (A) at Coffee Pot wetland in Churn Creek Protected Area on August 22, 2023. Bear tracks were found imprinted in the soil (B).**

Figure D11. The formation of deep surface cracks due to prolonged drying at Grasshopper wetland on August 20, 2023, in Churn Creek Protected Area. Cracks covered the entire wetland basin (A). With depth, soil moisture increased (B).