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Hydrological Vulnerability of the Columbia Wetlands British Columbia to Climate Change

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1 Executive Summary

Wetlands are important ecosystems that provide several critical hydrological functions, including flood and drought mitigation through water storage, infiltration, and groundwater recharge. However, due to their dependency on the hydrologic cycle, wetlands are highly sensitive to changes in local hydrology caused by a changing climate and studies have found that North America could lose 10% of its wetland area because of climate change. Within the Upper Columbia River Valley there are approximately 26,000 ha of floodplain wetlands, recognized as being of international importance under the RAMSAR Treaty. These wetlands have already experienced drying and loss of their wetted area, which is of great concern given their importance ecologically.

Snow accumulation and melt play an important role in shaping the Columbia River and the Columbia Wetlands as the Columbia River is a nival (snowmelt driven) system. The Columbia Wetlands are dependent on spring snowmelt to create a freshwater pulse that overtops levees and refills the wetlands. Wetland recharge from groundwater is also driven by snowmelt, where water sources are below the surface. Climate change is predicted to cause an increase in air temperatures, leading to a reduction in snow accumulation and an advancement of melt across the region.

Monitoring data from the Columbia Wetlands were used in this study investigated the relationship between snow water equivalent (the amount of water in the snowpack) and average wetland water level over the period from 2020 to 2025. We found that maximum winter snow water equivalent was significantly related to average wetland water levels, with a very strong relationship. Snow water equivalent predicted average water levels even better than maximum annual streamflow, suggesting seasonal snowpack is critical for providing source water to the Columbia Wetlands.

Snowpack was simulated in this study using the Raven Hydrological Modelling Framework, where long-term snow simulations from 1985 to 2099 were conducted on a daily time step. Daily snow water equivalent was subsequently used as an input to a statistical model to evaluate change in average water level for the Columbia Wetlands. The analysis suggests the Columbia Wetlands have been drying in recent decades and that this drying trend is expected to continue under modest greenhouse gas emissions and more extreme emissions. Furthermore, results from this study suggest average wetland water levels could approach zero in the later part of the century, indicating the maintenance and enhancement of this important area is critical to preserve ecological functioning.

2 Introduction

Wetlands are important ecosystems that aid in a watershed's hydrological function by tempering peak flows and increasing low flows through water storage, infiltration, and groundwater recharge (Ferreira et al., 2023; Ferreira et al., 2020; Wu et al., 2023). With concerns surrounding the effects of climate change on hydrologic systems rising, wetlands can help buffer these effects by reducing the duration and intensity of droughts (Ferreira et al., 2023) and mitigating floods (Wu et al., 2023). However, as wetlands are dependent on the surrounding surface-water and groundwater hydrology (Hathaway et al., 2022; Wang et al., 2016; Wang et al., 2018) they are projected to be susceptible to the effects of a changing climate. Climate change is projected to increase air temperatures, reduce snowpacks, increase evapotranspiration, and extend droughts, resulting in an increased probability of montane wetlands drying out (Lee et al., 2015). Across North America, climate change driven changes in hydrology may result in a 10% reduction in wetland area by the end of the century under a higher emission (SSP585) scenario (Xu et al., 2024). However, regional impacts vary, underlying the importance of a strong understanding of the local impacts that climate change may have on an area and the potential downstream effects it may have on the regional wetlands.

The Columbia Wetlands are a series of floodplain wetlands within the Upper Columbia River Basin, located in the Rocky Mountain Trench between the Rocky Mountains to the east and the Purcells to the west. They occur as far south as Canal Flats, British Columbia, and continue north to Donald, BC, and contain 26,000 ha of Ramsar Wetlands of International Importance. As this section of the Columbia River is the only undammed section of the Columbia River, the natural hydrology is governed largely by seasonal flood pulses that occur around June and are driven by snowmelt and rainfall (MacDonald Hydrology Consultants Ltd. 2020; Carli and Bayley 2015; Makaske et al., 2009). The seasonal pulses have shaped the Columbia Wetlands, where the combination of high and low flows of the Columbia River has resulted in an aggradation of sediments forming and maintaining levees that then withhold water after flood waters have receding into the late summer and fall (Filgueira-Rivera et al., 2007).

Over the past several decades, many hydroclimatic changes have occurred in the region, including increased air temperatures and evapotranspiration, precipitation shifts, and changes in flow timing, duration, and magnitude (Stewart, 2004; Utzig 2021; Rood et al. 2016; Brahney et al. 2017). The increase in air temperatures has already begun causing a shift in precipitation type with more precipitation occurring as rain and instead of snow (Zhang et al., 2000; Schnorbus et al., 2014; and Vincent et al., 2015). This is in turn driving a decrease in snow accumulation and duration, particularly at low to mid elevations (Stewart, 2009; Valeo et al., 2007; Whitfield, 2014), resulting in earlier onset and more rapid snowmelt during the spring freshet period and an earlier and longer low flow period in the summer and fall (DeBeer et al., 2021; Foster et al., 2016; Leppi et al., 2012) with overall reduced flows in the Columbia River (Rood et al. 2016; Brahney et al. 2017). These hydroclimatic shifts have already resulted in a discernable reduction in open water in the Columbia Wetlands (Hopkinson et al., 2020) and a change in landcover, with wetlands drying out and shifting from marshes and open water towards woody shrub landcover (Rodrigues et al., 2023). These shifts are projected to continue, with the changes in precipitation patterns and seasonal temperatures driving a transition from a snow-dominated streamflow hydrologic regime to a hybrid or rainfall dominated regime by the end of the century (Arora et al., 2025).

Increasing air temperatures are predicted to alter snow accumulation and ablation within the upper Columbia River Basin (Carver, 2017). This is due partly to less precipitation falling as snow (Han et al.,

2025) and as a higher fraction of winter precipitation falling as rain from warmer winter air temperatures (Dierauer, et al., 2021; Berghuijs and Hale, 2025). Winter air temperatures over the past 70 years have risen in cold regions above critical thresholds (- 3°C for snowpack and 0°C for streamflow) due to persistent warming, changing streamflow patterns due to changes in winter snow dynamics (Liu et al., 2025). It has generally been found that a lower fraction of precipitation falling as snow results in a shift towards earlier streamflow, particularly in snowier watersheds (Berghuijs and Hale, 2025; Han et al., 2024). With less snowfall there is less seasonal variability in discharge and a lower annual total discharge, but more interannual variability due to variability in precipitation (Hans et al., 2025b).

This study assesses the relationship between seasonal snowpack and wetland water levels using a combination of hydrological modelling, regional meteorological data, and field observations from the Columbia Wetlands. We evaluate future climate scenarios to assess floodplain wetland vulnerability. The combined modelling and data analysis approach provides a robust framework for evaluating potential future changes for these important wetlands and to help guide priorities to adapt to climate change.

3 Study Area

The Columbia Wetland Complex extends from Canal Flats BC to Donald, BC in the Rocky Mountain Trench, approximately 180 km in length and 260 km^2 in area (Environment and Climate Change Canada, 2018). The wetlands examined in the current project fall within this reach, extending just north of Wilmer to Parsons, BC, spanning approximately 75 km and covering nearly 24 km^2 of area, a little under 10% of the overall Columbia Wetland Complex (Figure 1). The wetlands exist along the Columbia River floodplain, which is restricted laterally in a 1.5 km wide valley between the Rocky Mountain Range and the Purcell Mountain Range, with an average slope of 11.5 cm/km (Makaske et al., 2009). The regional climate and hydrologic model were developed using data from several gauging stations located throughout the watershed; therefore, a larger Regional Study Area was used to develop the hydrologic model, whereas a smaller Local Study Area encompasses the area directly affecting the study wetlands (Figure 1).

3.1 Regional Study Area

The Regional Study Area consists of the drainage area upstream of the gauging station at Donald, BC, which drains an area of 15, 193 km^2. The study area for the models focused on the mountain ranges on each side of the Rocky Mountain Trench, including the headwaters of the Columbia River and Kootenay River. The area extends from below 800 m.a.s.l. at Donald, BC to over 3500 m.a.s.l. at the highest peaks along the Continental Divide and in the Purcell Mountains. Land cover consists primarily of forests below 2200 m, with biogeoclimatic zones of Interior Cedar Hemlock (ICH) in wetter low elevation areas, Montane Spruce (MS) at mid-elevations, and Engelmann Spruce Subalpine Fir (ESSF) at higher elevations. The Columbia River valley bottom consists of large lakes and wetlands. Above treeline, large areas of Alpine characterize most mountain tops, with several glaciers and icefields located at the highest elevations in both mountain ranges; these include the Wapta and Waputik Icefields, located in Yoho National Park, and the Conrad Glacier located in the Columbia Mountains.

The gauging station on the Columbia River at Nicholson, BC (a few km south of Golden, BC) is downstream of the wetlands used in the field study. There are several major tributaries that flow into the Regional Study Area; most of these flow into the Local Study Area and are covered in the following section, but downstream of these the Blaeberry and Kicking Horse Rivers drain the northeast corner of the regional study area from the Rocky Mountains.

Soils within the study area include various types with textures including silt, sand, sandy loams, loamy sands, and loams (BC Ministry of Environment, 1990). Soils are imperfectly, well and rapidly drained. Depositional modes include glacial tills (especially within the valley bottoms), glaciofluvial, fluvial, and colluvial processes (BC Ministry of Environment, 1990). The regions to the western portion of the study area in the headwaters are predominantly undifferentiated bedrock, while silt is notably more present in the river bottoms of tributaries and the Columbia River floodplain, as is loam, sandy loam, and loamy sand.

The study area is made up primarily of sedimentary rocks from the Proterozoic to Paleozoic Eras, including the following (taken from the BC Data Catalogue):

- Coarse clastic sedimentary rocks from the Neoproterozoic associated with the Horsethief Creek Group,

- Conglomerate coarse clastic sedimentary rocks from the Neoproterozoic associated with the Toby Formation,
- Quartzite, quartz, arenite sedimentary rocks found throughout the study area from the Mesoproterozoic that are associated with the Mount Nelson Formation, as well as slivers in the north from the Neoproterozoic to Lower Cambrian associated with the Cranbrook Formation
- Undivided sedimentary rocks from the Mesoproterozoic associated with the Dutch Creek Formation, from the Ordovician associated with the Mount Wilson, Skoki, Tipperary, Glenogle, Survey Peak and Lyell Formations, and; Upper Ordovician to Middle Silurian associated with the Beaverfoot and Mount Wilson Formations
- Dolomitic carbonate rocks from the Mesoproterozoic in the southern portion of the study area that are associated with the Kitchener Formation and from the Middle Silurian to Upper Ordovician that are associated with the Beaverfoot Formation in the north
- Limestone, marble, calcareous sedimentary rocks from the Middle to Upper Cambrian that are associated with the Lyell, Sullivan, Jubilee, or Chancellor Formations
- Mudstone, siltstone, shale fine clastic sedimentary rocks from the Cambrian to Ordovician associated with the McKay group.

3.2 Local Study Area

The Local Study Area is the drainage area upstream of the Columbia River at the same location as the outflow of the most downstream study wetland, consisting of a total of 6,152 km^2 with an elevation range between 782 m.a.s.l. and 3489 m.a.s.l. (Figure 1). The main tributaries to the Columbia River within the Local Study Area are the Spillimacheen River and Bugaboo, Horsethief, and Toby Creeks, all originating in the Purcell Mountains. In addition, there are also Dutch, Sinclair, and Windermere Creeks that flow into the Columbia River, all of which are 6th order streams.

Glaciers cover 2.7% of the Local Study Area and exist in the headwaters of many of the major tributaries, such as Conrad Glacier in Spillimacheen River Watershed, Malloy Glacier, Vowell Glacier, Crescent Glacier, and Bugaboo Glacier in the Bugaboo Watershed, and Jumbo and Toby Glaciers in the Toby Creek Watershed.

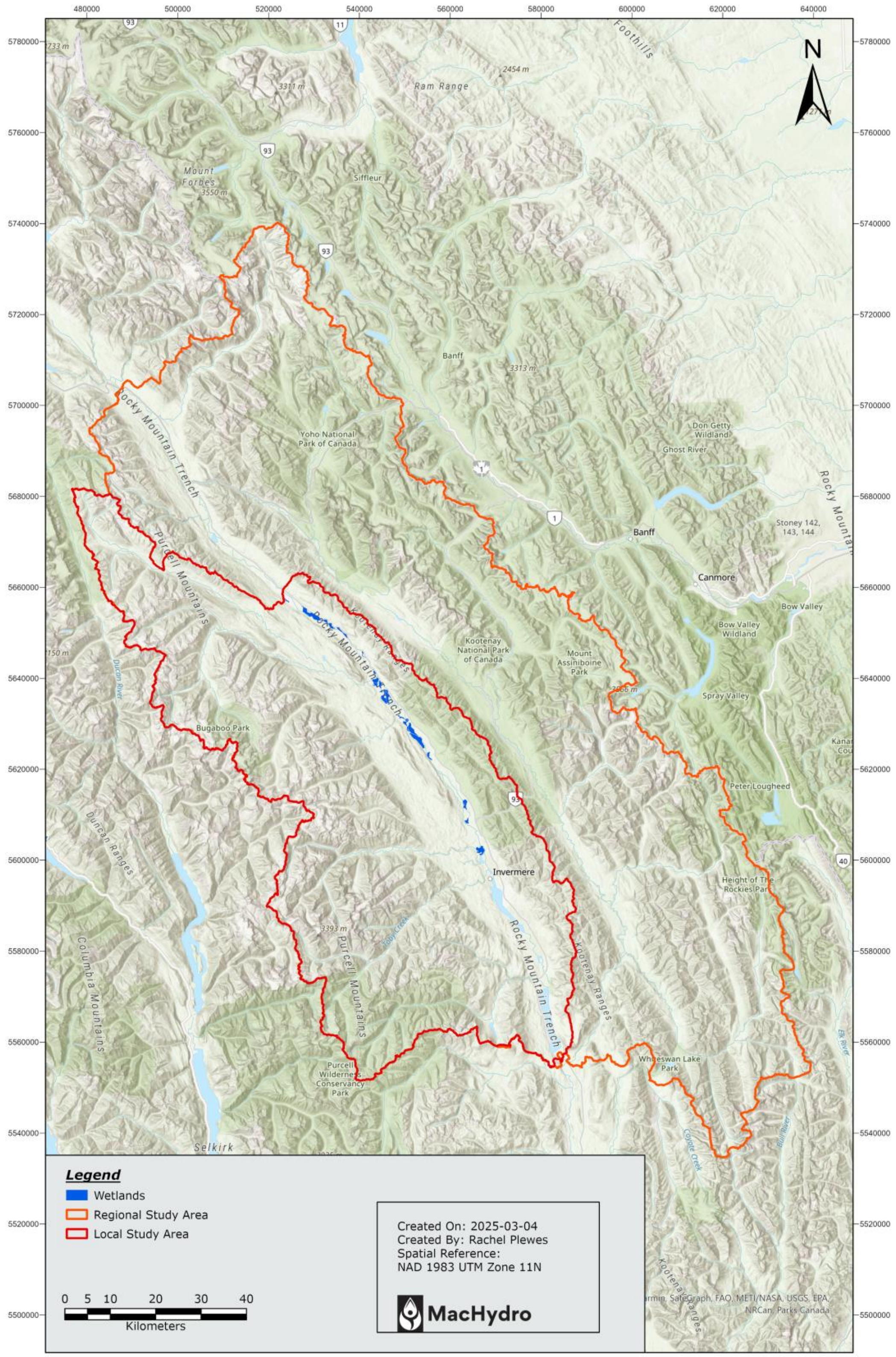


Figure 1. The floodplain wetlands examined within the local (red) and regional (orange) study areas within the Upper Columbia River Watershed.

4 Methods

4.1 Field Methods

Stilling wells constructed out of PVC pipe were installed in a total of 38 wetlands throughout the Columbia Wetland Complex, though not all sites have data for all six years of data collection. Wetland sites were selected to represent different types of wetlands present in the valley based on local knowledge. Water-level loggers (Onset HOBO pressure transducers; Model U20–001–01, 4 m range with a 0.4 cm accuracy or 9 m range with 0.5 cm accuracy) were placed in each stilling well, along with two loggers in the Columbia (with one at Spillimacheen, BC, and the other at Brisco, BC). An additional logger was used to collect barometric pressure and placed in a central location within the study reach. As the deepest location within the wetland could not always be reached, the difference between the height of the logger in the stilling well and deepest location within the wetland was recorded. Loggers were deployed each year in late April or early May and collected data until October and were set to collect water pressure (kpa) and temperature (◦C) at four-hour intervals. Water pressure was converted to water level (m) using the HOBOware Pro 3.7.26 barometric compensation tools. Water levels for all years of monitoring are provided in Appendix A .

4.2 Hydrological Modelling

A semi-distributed hydrological model was used to simulate Snow Water Equivalent (SWE; mm) across the Regional Study Area. The model used a regional parameter set to simulate historical and future SWE under different fossil-fuel scenarios. The semi-distributed hydrological model is an adapted version of the HBV-EC model, emulated within the Raven Hydrological Modelling Framework version 4.0 (Craig et al., 2023). The model spatially distributes daily minimum and maximum air temperature (°C), precipitation (mm/day), and relative humidity (%) from all weather stations across the study region.

Model input data were obtained from DayMet (Thornton et al., 2018) using the Single Pixel Extraction Tool for the period 1980-2023 at a 1/10th degree resolution over the study area. Reference elevations were obtained for each data point and used to correct model inputs using specified lapse rates within the hydrological model. Daily SWE data were obtained from the Floe Lake Snow Pillow (Figure 2), operated by BC Hydro, for the period 2010-2025.

The SWE simulations were conducted spatially using hydrological response units (HRUs) based on the unique overlay of elevation bands, hillshade (i.e. slope-aspect), land cover, forest disturbance history, and sub-basin. The HRU corresponding to the Floe Lake Snow Pillow was used for analysis in this study.

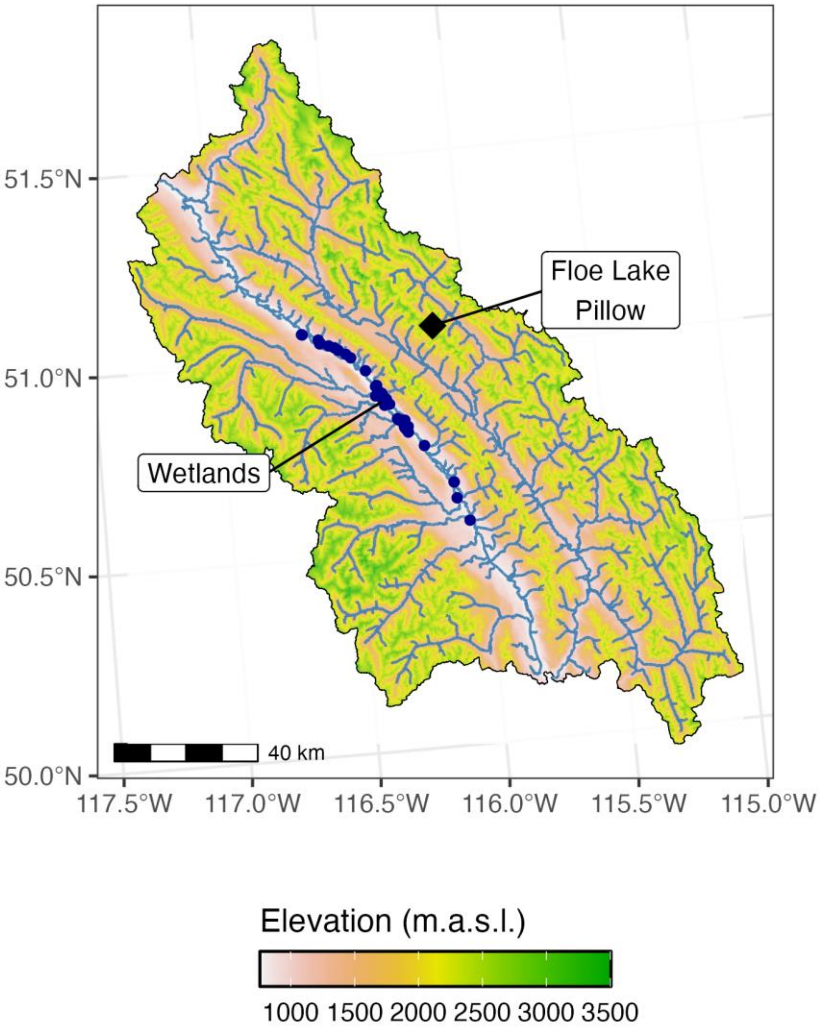


Figure 2 Location of the Floe Lake Snow Pillow relative to the Columbia Wetlands.

4.2.1 Bias Correction

Simulated historical and future SWE were bias-corrected using the “delta” method that uses the mean difference between observed past and simulated present-day climate to present-day simulated climate. This method assumes the local model biases are constant over time (Maraun and Widmann, 2018). Typically, this method adds the mean observed bias to the simulated climate variable. However, for precipitation, which is bounded by zeros and covers multiple orders of magnitude across different ranges, a multiplicative factor is typically used instead of the additive bias correction, corresponding to applying the simulated relative change to the observations (Beyer et al., 2020; Maraun and Widmann, 2018). Where present bias is multiplied to the historical simulated SWE for time t and is estimated as:

$$SWE_{cor}^{hist} = SWE_{sim}^{hist}(x,t)\frac{SWE_{sim}^{hist}(x,0)}{SWE_{obs}\,(x,0)} \tag{1}$$

$$SWE_{cor}^{hist} = SWE_{sim}^{fut}(x,t)\,\frac{SWE_{sim}^{hist}(x,0)}{SWE_{obs}\,(x,0)}$$

The multiplicative correction was then applied to both historical and future daily simulated SWE at the Floe Lake Pillow.

4.2.2 Climate Change Scenarios

The hydrological model was run under several future climate scenarios representing varying Shared Socio-economic Pathways (SSPs):

- **Historical**: Historical observations for 1980-2023.
- **SSP1-2.6 (“Sustainable”):** A future climate change scenario (2021-2100) for Shared Socioeconomic Pathway (SSP) 1-2.6, which represents a “sustainable” scenario whereby the global emissions decline.
- **SSP2-4.5 (“Middle of the Road”):** A future climate change scenario (2021-2100) for Shared Socioeconomic Pathway (SSP) 2-4.5, which represents a “middle of the road” scenario whereby the global emissions do not decline but stay consistent with historical patterns.
- **SSP3-7.0 (“Regional Rivalry”):** A future where with higher aerosol emissions and high global emissions and low-to-absent climate policies.

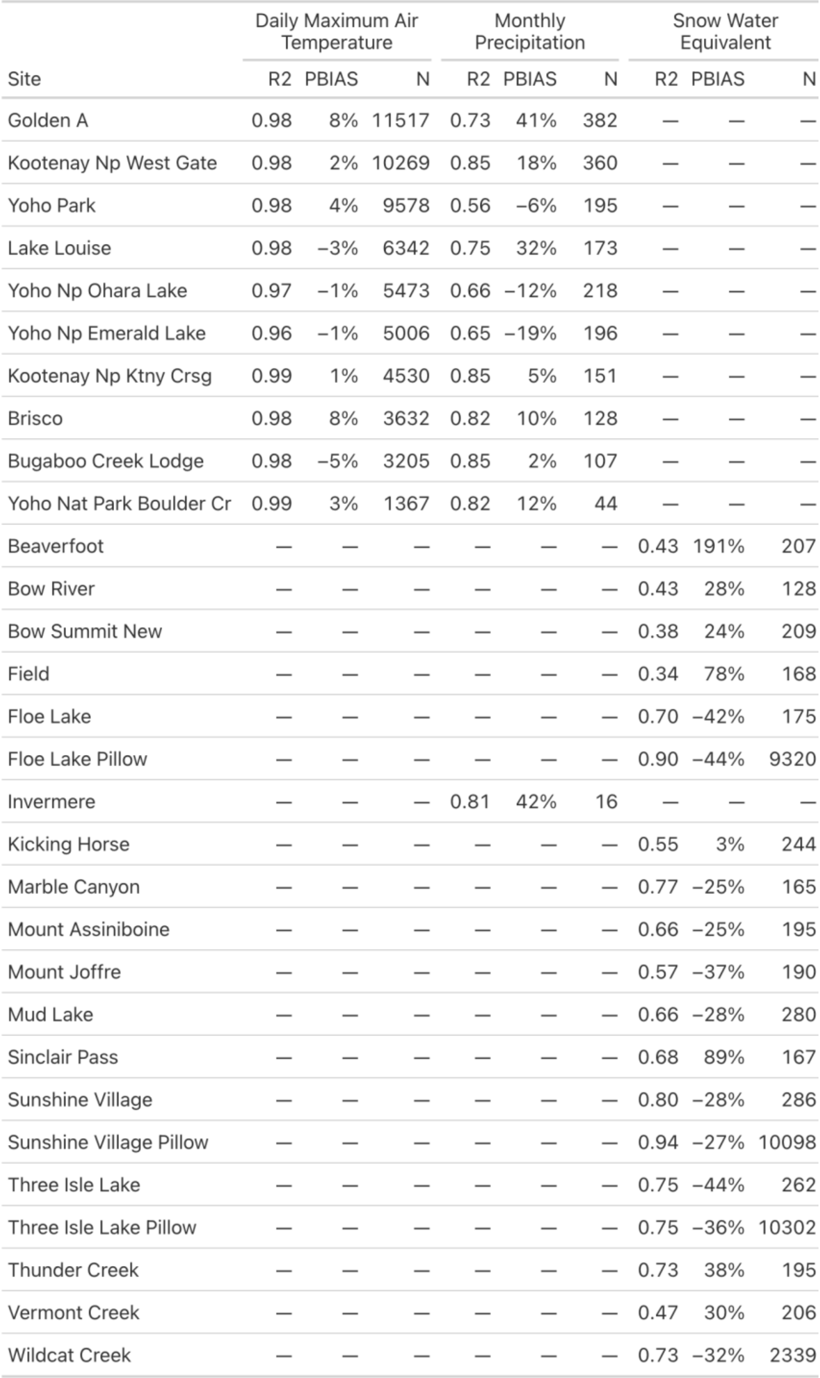
  SSP5-8.5 (“Fossil Fuel Development”): A future climate change scenario (2021-2100) that has a high emissions future with lots of human development with rapid economic growth driven by fossil fuel. This scenario represents a “worst-case” scenario.

5 Results

5.1 Hydrological Model Performance

Hydroclimatic variables including air temperature, precipitation, and SWE were evaluated at independent regional weather and snow pillow/survey stations (**Error! Reference source not found.**).

Table 1 Model performance for regional air temperature, precipitation, and snow datasets.



	Daily Maximum Air Temperature			Monthly Precipitation			Snow Water Equivalent		
Site	R2	PBIAS	N	R2	PBIAS	N	R2	PBIAS	N
Golden A	0.98	8%	11517	0.73	41%	382	—	—	—
Kootenay Np West Gate	0.98	2%	10269	0.85	18%	360	—	—	—
Yoho Park	0.98	4%	9578	0.56	−6%	195	—	—	—
Lake Louise	0.98	−3%	6342	0.75	32%	173	—	—	—
Yoho Np Ohara Lake	0.97	−1%	5473	0.66	−12%	218	—	—	—
Yoho Np Emerald Lake	0.96	−1%	5006	0.65	−19%	196	—	—	—
Kootenay Np Ktny Crsg	0.99	1%	4530	0.85	5%	151	—	—	—
Brisco	0.98	8%	3632	0.82	10%	128	—	—	—
Bugaboo Creek Lodge	0.98	−5%	3205	0.85	2%	107	—	—	—
Yoho Nat Park Boulder Cr	0.99	3%	1367	0.82	12%	44	—	—	—
Beaverfoot	—	—	—	—	—	—	0.43	191%	207
Bow River	—	—	—	—	—	—	0.43	28%	128
Bow Summit New	—	—	—	—	—	—	0.38	24%	209
Field	—	—	—	—	—	—	0.34	78%	168
Floe Lake	—	—	—	—	—	—	0.70	−42%	175
Floe Lake Pillow	—	—	—	—	—	—	0.90	−44%	9320
Invermere	—	—	—	0.81	42%	16	—	—	—
Kicking Horse	—	—	—	—	—	—	0.55	3%	244
Marble Canyon	—	—	—	—	—	—	0.77	−25%	165
Mount Assiniboine	—	—	—	—	—	—	0.66	−25%	195
Mount Joffre	—	—	—	—	—	—	0.57	−37%	190
Mud Lake	—	—	—	—	—	—	0.66	−28%	280
Sinclair Pass	—	—	—	—	—	—	0.68	89%	167
Sunshine Village	—	—	—	—	—	—	0.80	−28%	286
Sunshine Village Pillow	—	—	—	—	—	—	0.94	−27%	10098
Three Isle Lake	—	—	—	—	—	—	0.75	−44%	262
Three Isle Lake Pillow	—	—	—	—	—	—	0.75	−36%	10302
Thunder Creek	—	—	—	—	—	—	0.73	38%	195
Vermont Creek	—	—	—	—	—	—	0.47	30%	206
Wildcat Creek	—	—	—	—	—	—	0.73	−32%	2339

Results demonstrate that the model had strong performance at distributing air temperatures (r^2 ranged from 0.96 to 0.99) and minimal bias. Monthly precipitation showed good performance (r^2 = 0.56 – 0.85) with a notable positive bias at Golden, Lake Louise, and Kootenay NP West Gate, and a negative bias at Yoho NP Emerald Lake and Yoho NP Ohara Lake. Snow Water Equivalent showed strong performance at snow pillows (r^2 = 0.86 - 0.93), and good performance at snow survey sites (r^2 = 0.39 - 0.82). Outliers included Beaverfoot, Field, Sinclair Pass, and Thunder Creek, where there is a considerable positive bias, and Floe Lake, where there is a moderate negative bias.

Daily bias-corrected historical SWE performed better than the original simulation, with a small bias of -3.5% as opposed to the historical uncorrected SWE at this site by 44% (Figure 3). The bias-corrected simulation was used for all remaining work.

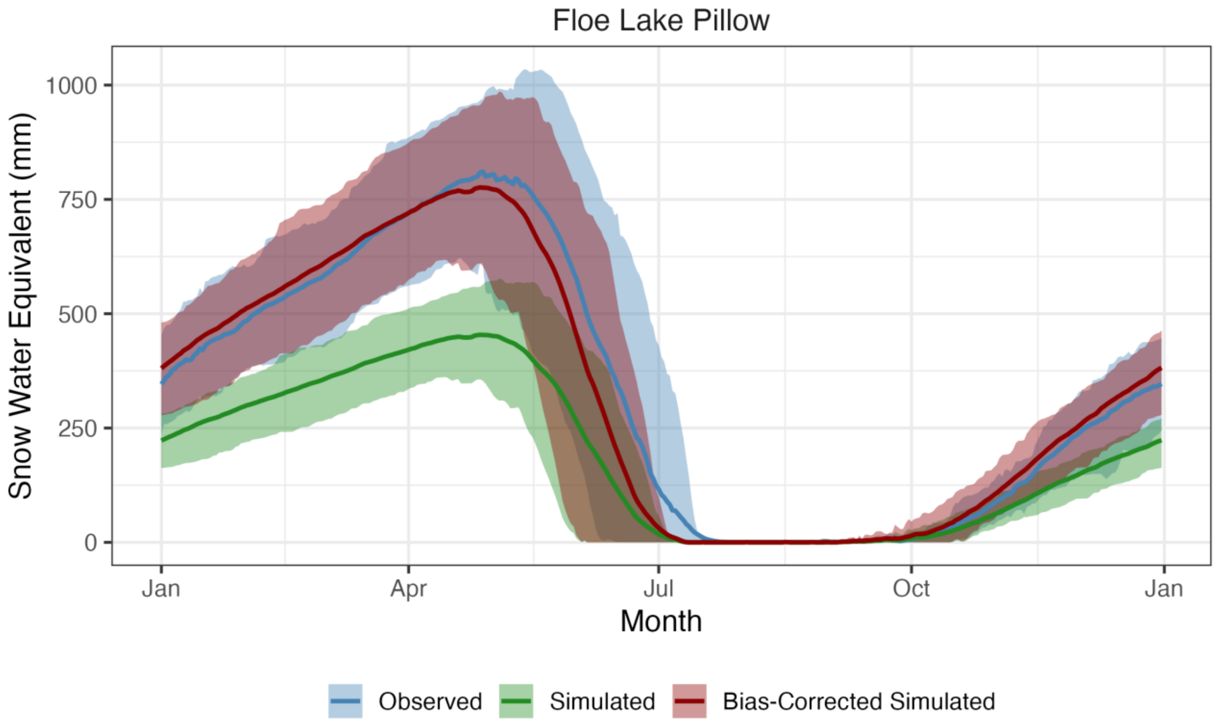


Figure 3 Daily annual for observed (SWE^obs), historically simulated (SWE^sim) snow water equivalent and the bias-corrected simulated (SWE^corr) from 1980 to 2023. The shaded region represents the upper 95% quantile, while the lower bound represents the 10% quantile.

5.2 Effect of SWE on Mean Water Level

An empirical relationship between observed SWE and annual wetland water levels was developed (Figure 4). The relationship between peak SWE and mean water level across all wetlands was statistically significant ($P < 0.05$, $R^2 = 0.94$), indicating a strong association. This relationship is positive, indicating that higher peak SWE corresponds to higher mean water levels across all floodplain wetlands.

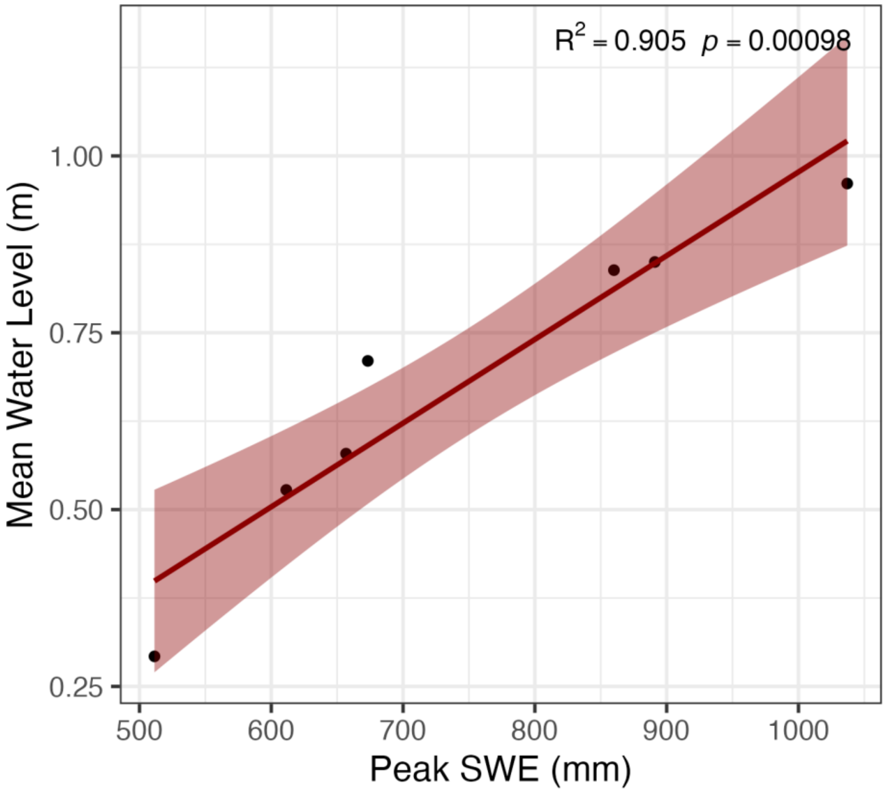


Figure 4 Linear regression and relationship between annual peak SWE from Floe Lake Snow pillow and annual mean water level from all wetlands.

5.3 Potential Trends in Observed Wetland Levels

Figure 5 shows the aggregated annual observed maximum and mean wetland water levels from 2020 to 2025. Both the observations water levels show a negative sloping trend indicating a decline in maximum and mean water levels from 2020 to 2025. The observed maximum experiences a slightly more dramatic shift in water levels decline than the mean. It is important to note that a full trend analysis was not completed given that there is a relatively short dataset. However, observed decreases in water level do suggest at least some drying is occurring.

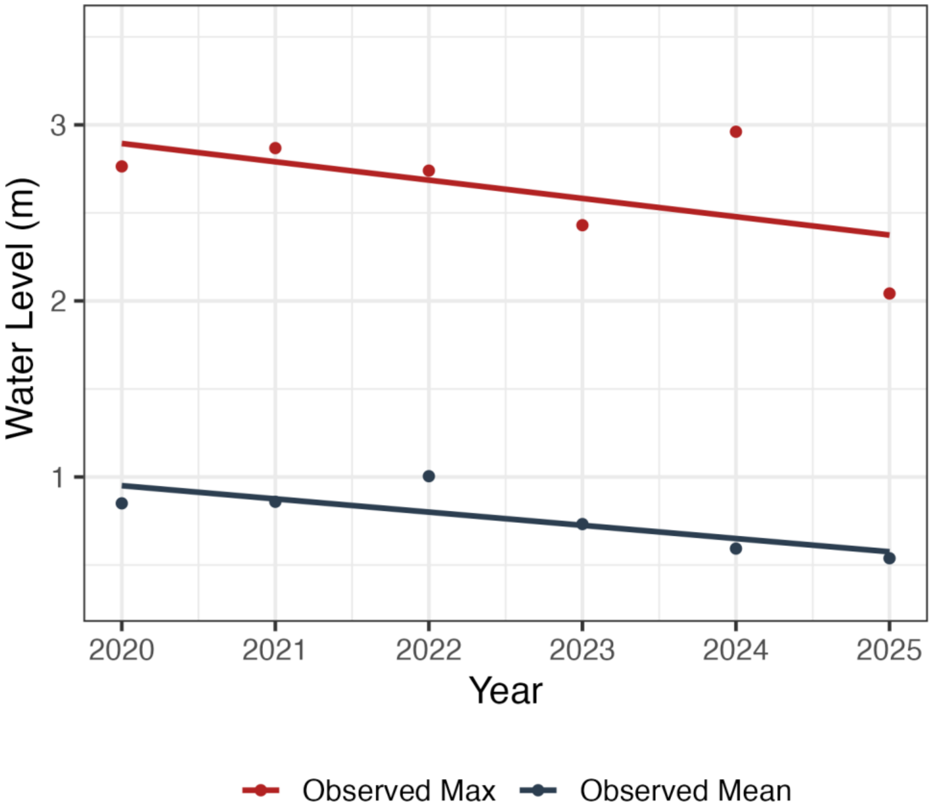


Figure 5 Annual mean and maximum observed water levels for all wetlands monitored in this study.

Figure 6 shows peak annual SWE for the Floe Lake snow pillow, demonstrating reduction in peak SWE over the same period as wetland monitoring from 2020 to 2025. A trend line is shown on the figure; however, a trend is not calculated given that there is a short record shown. These data do suggest there is a reduction in SWE over this period and assessing Figure 5 there is a relationship between mean floodplain wetland levels and SWE at Floe Lake.

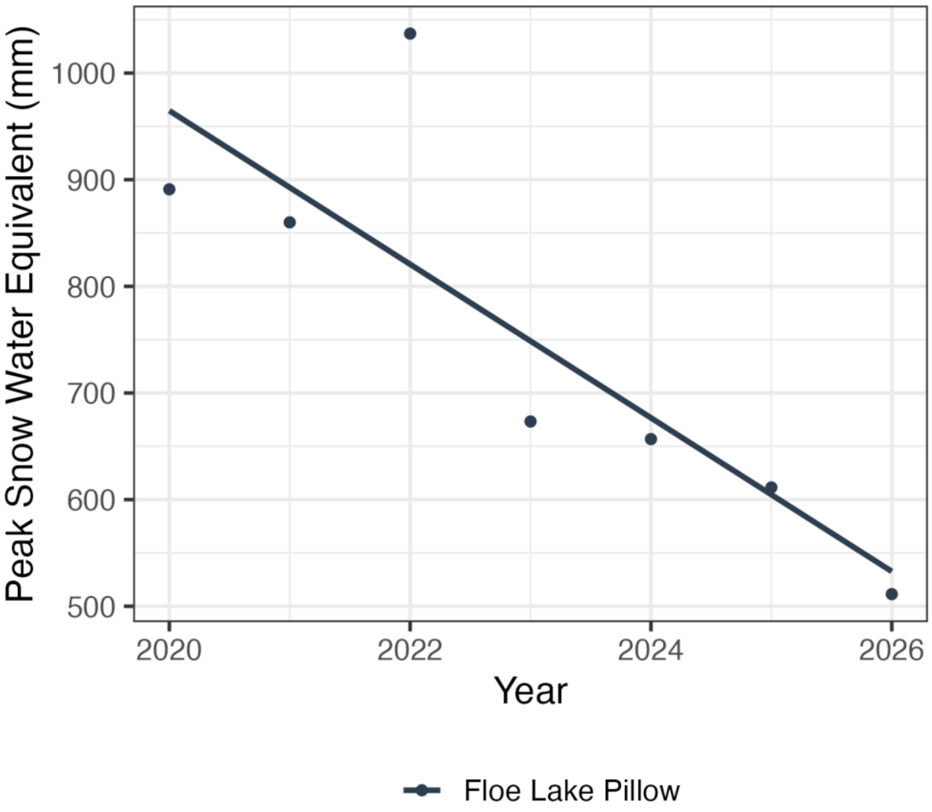


Figure 6 Annual peak SWE for the period from 2020 to 2026.

5.4 Effects of Climate Change

The climate change scenarios have higher precipitation in late fall and over the winter months until early spring from 2021-2050 (Figure 7). November, December and January are expected to have the most extreme increase of precipitation of over 15 mm per month. In the summer months, precipitation is expected to decrease in June and July. However, it becomes more variable in late fall as it's expected to increase in some scenarios (SSP1-2.6 and SSP3-7.0). During the future period of 2051-2080 precipitation is expected to increase until June showcasing a change in timing and extremes of precipitation with July and August expecting less precipitation than historical totals, while the winter precipitation total trends are still increasing albeit more extremely. Maximum air temperatures in all months are expected to increase by around 1°C in the spring and winter and upwards of 2°C in the growing season in 2021-2050. This trend continues in the 2051-2080 period under both climate scenarios where SSP5-8.5 has almost a degree warmer air temperature than SSP2-4.5 and SSP1-2.6 in the growing season.

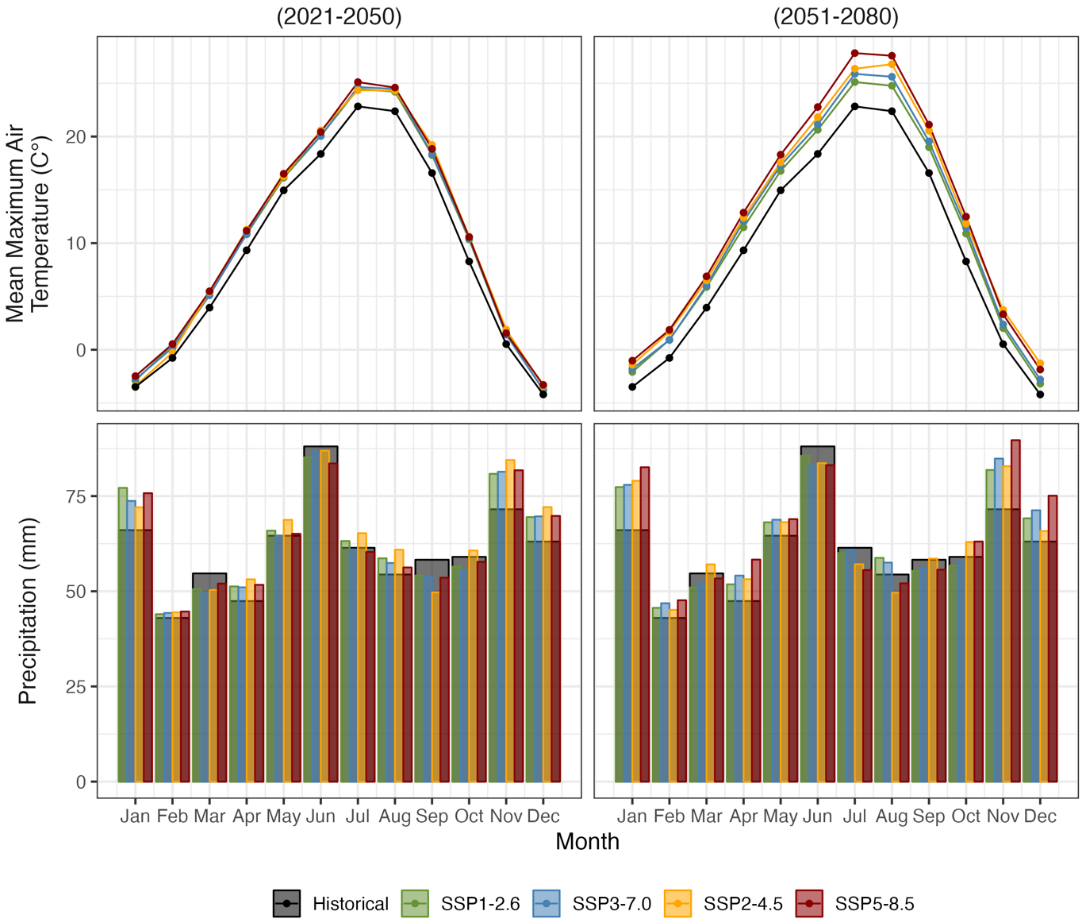


Figure 7 Monthly mean air temperature and precipitation for the historical, SSP1-2.6, SSP3-7.0, SSP2-4.5, and SSP5-8.5 climate scenarios used in the hydrological model.

Future SWE is expected to decrease under all future climate scenarios, with an advancement of snowmelt and a decrease in peak SWE on average (Figure 8). Reductions in SWE are more notable in the 2051-2080 period, with all scenarios showing marked decreases in maximum SWE and a substantial reduction in melt timing relative to the historical period.

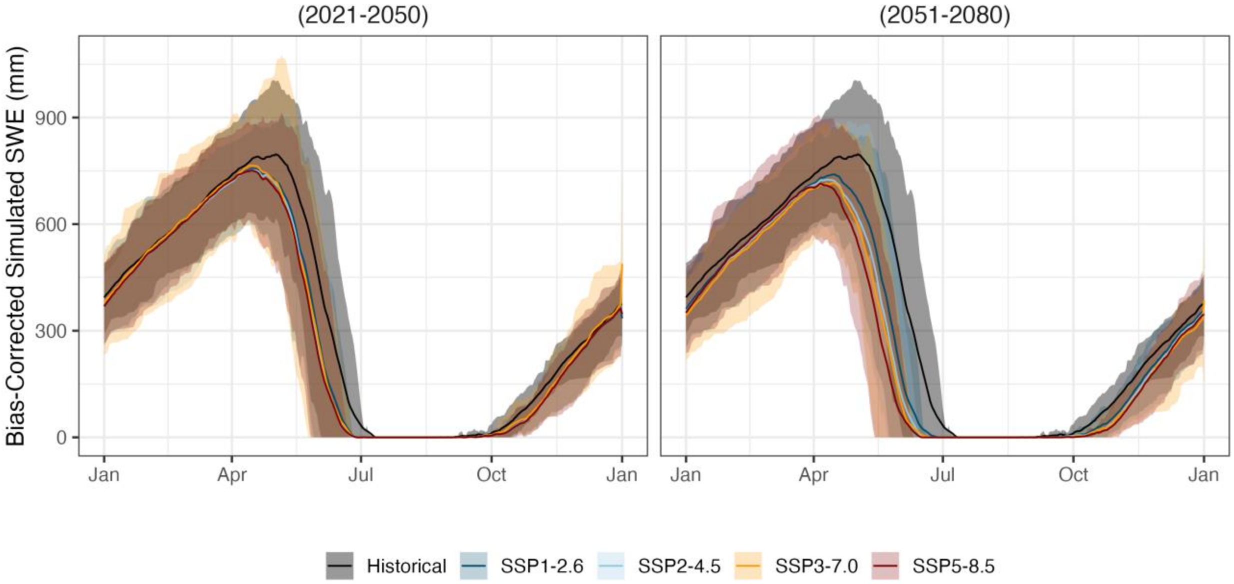


Figure 8 Simulated SWE at the Floe Lake snow pillow under historical, SSP1-2.6, SSP3-7.0, SSP2-4.5, and SSP5-8.5 climate scenarios used in the hydrological model.

Figure 9 shows the annual mean water levels predicted for future climate scenarios from 2020 to 2080 using the linear regression from observed peak SWE and annual mean water levels. Historically wetland water levels fluctuated from 1 to 0.6 m, trending towards smaller water levels from 2000 to 2020. In the future, under all scenarios the annual mean water level is predicted to decrease and become more variable over time. Both high emission scenarios (SSP3-7.0 and SSP5-8.5) have the most extreme variability, oscillating between extreme minimums of 0.4 m and maximums of 0.9 m. Precipitation is expected to increase in this region while the peak SWE is expected to decrease. Warmer temperatures are shifting precipitation in the winter months from snow to rainfall which reduces snow accumulation overall. Wetland storage and mean water levels are expected to decline. Additionally, summer air temperatures are projected to increase by up to 2.5 °C under the “worst-case” climate scenario, this is likely to further enhance evapotranspiration and contribute to additional reductions in wetland water levels and storage.

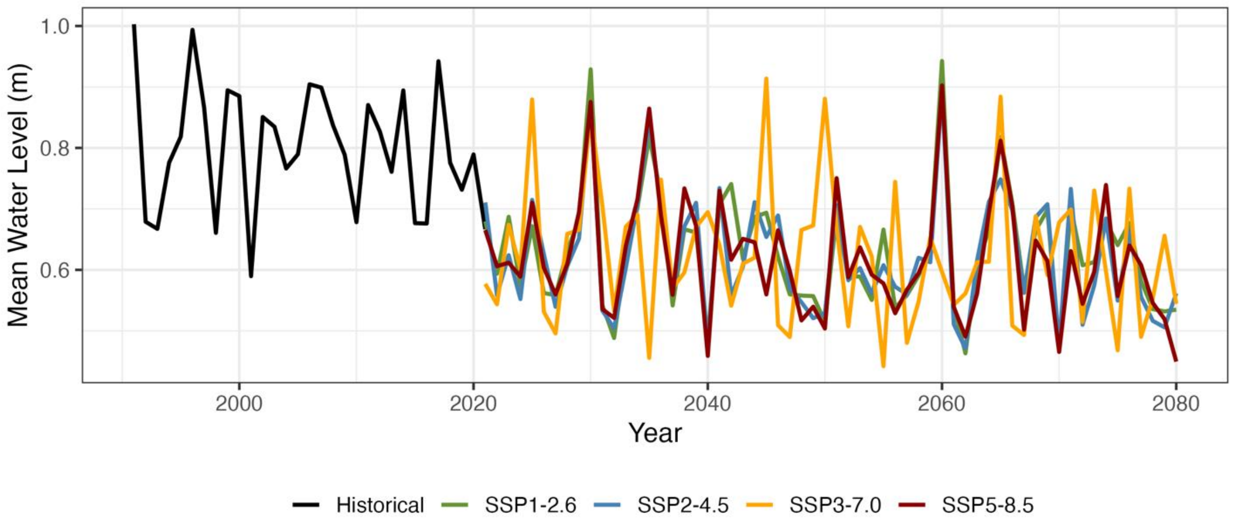


Figure 9 Predicted mean floodplain wetland water level using the empirical relationship and hydrological model SWE outputs for the historical, SSP1-2.6, SSP3-7.0, SSP2-4.5, and SSP5-8.5 climate scenarios.

6 Discussion

The results of this study suggest that the floodplain wetlands within the Upper Columbia River Valley are highly vulnerable to changes in hydrologic conditions resulting from climate change. Observed water levels from this study and spatial analysis from Rodrigues et al., 2023 suggest the floodplain wetlands in this valley are drying. It is important to consider this historical change and recognize that water levels are coupled with streamflow and groundwater. These hydrologic features are highly tied to snowpack in terms of magnitude of seasonal snow accumulation as well as the timing of snowmelt.

Snow plays a critical role in shaping the hydrograph of the Columbia River and the Columbia Wetlands, both due to the large flood pulse that results in the late spring due to melting snow and rain on snow events, but also due to groundwater recharge. Remmer et al. 2023 found that alpine snowmelt is a major contributor to river and groundwater contributions in the Columbia Wetlands, and that snow-fed groundwater is an important source of water for many wetlands later in the season. This is in keeping with previous research that has found that snowmelt dominated watersheds tend to have a higher percentage of snowmelt contributing to groundwater recharge (Earman et al., 2006; Ajami et al., 2012), and that snowmelt is better able to infiltrate deeper into soils than rainwater (Earman et al., 2006).

Analysis presented in this report suggest seasonal snowpack (peak SWE) is highly correlated with average floodplain wetland water level. The mechanism of providing water was not evaluated; however, strong a strong correlation and similar inter-annual variation suggest water supply from snow is important for maintaining overall water supply for the wetlands along the Columbia River.

This is the first study in the region that has applied hydrological modelling and field monitoring to evaluate how floodplain water levels may change into the future. The analysis presented here suggests that on average, the floodplain wetlands of the upper Columbia River Basin are likely to dry substantially in the future. The later part of the century could see near-dry conditions year over year, with limited recharge from snowpack. Historical analyses suggest this drying is likely to result in the encroachment of woody/shrub cover (Liu et al., 2022; Rodrigues et al., 2023). This suggests a fundamental ecosystem shift could occur under future climates and efforts should be made to increase storage at the individual wetland scale.

7 Limitations

While this work provides valuable insight into how wetlands may respond to climate change in the Upper Columbia River Basin, several limitations must be considered when contextualizing these results. This analysis was constrained by the data availability of historical observed snow water equivalent (SWE) and wetland water levels. Only 5 years of observed wetland water levels were available, although a strong statistical relationship was identified, a longer continuous record would have strengthened the analysis and facilitated trend analysis.

8 Closing

The Upper Columbia River floodplain wetlands are experiencing climatic pressures and are vulnerable to the effects of climate change. The Columbia River (supplied by snow) supplies most of the water to the water balance of each wetland, with minimal input occurring in the form of precipitation later in the season. Under climate change projections, snowpacks within the region will likely decrease resulting in wetland water levels decreasing. The drying period will likely begin earlier in the year and last longer, creating a greater seasonal water deficit. Increasing water storage potential can improve climate change resilience in floodplain wetlands in the Upper Columbia Valley.

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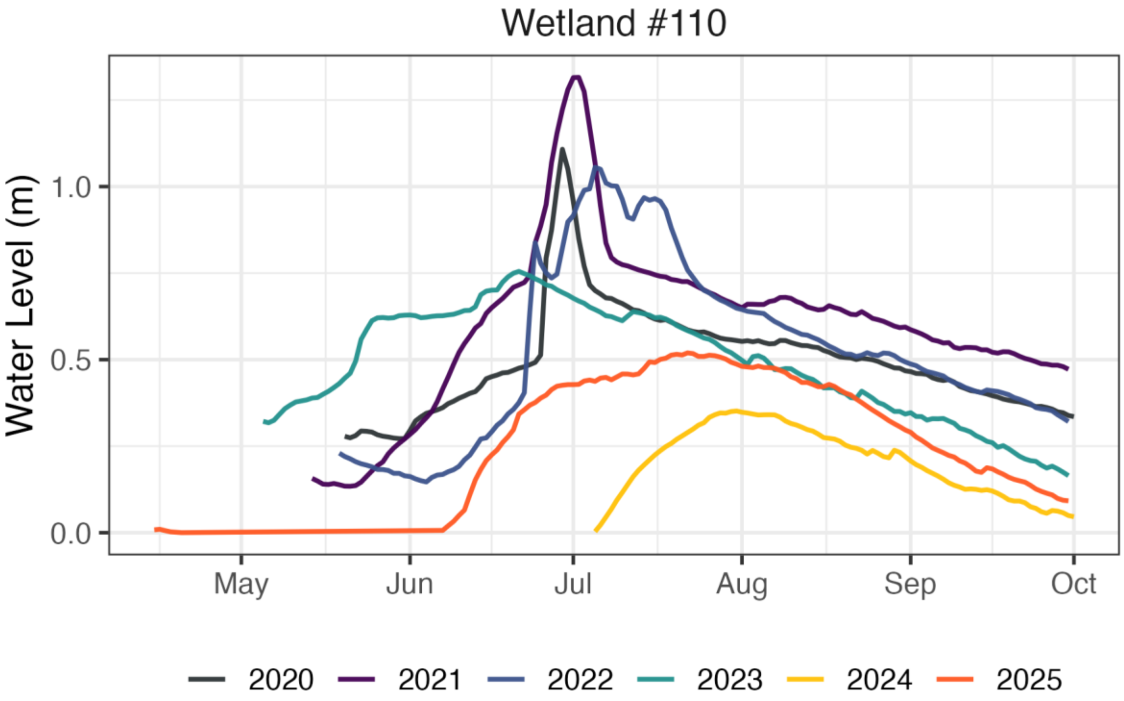
10 Appendix A

The following figures represent daily mean water levels from 2020 to 2025 for monitored wetland sites.



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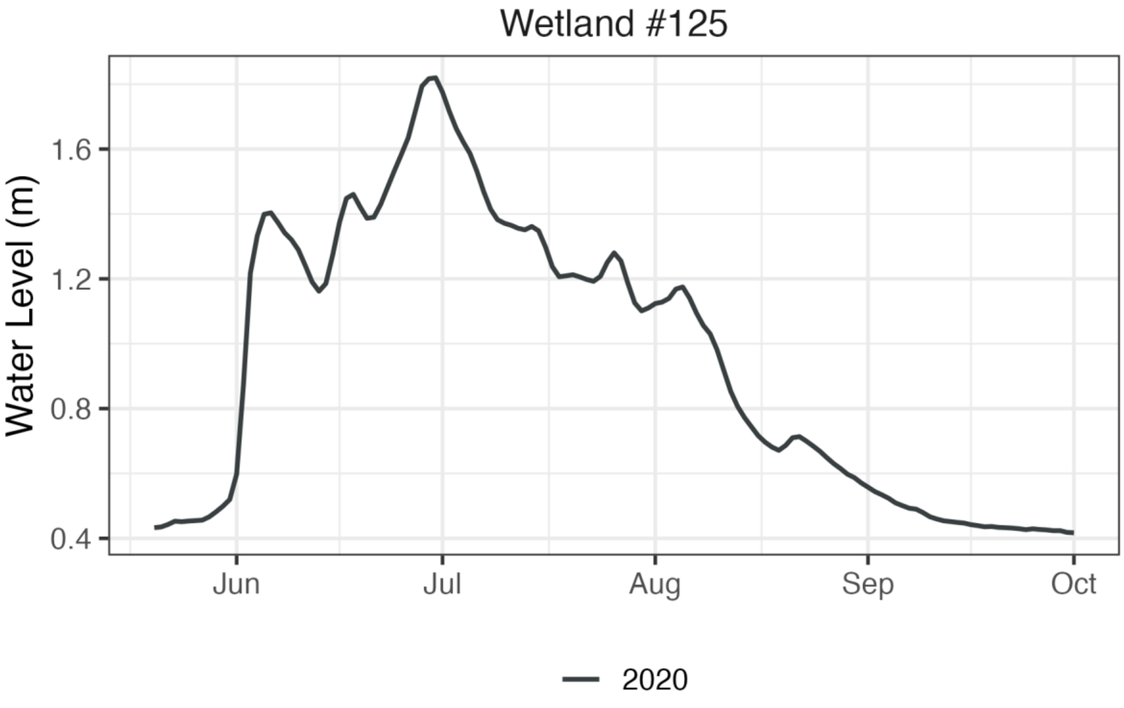

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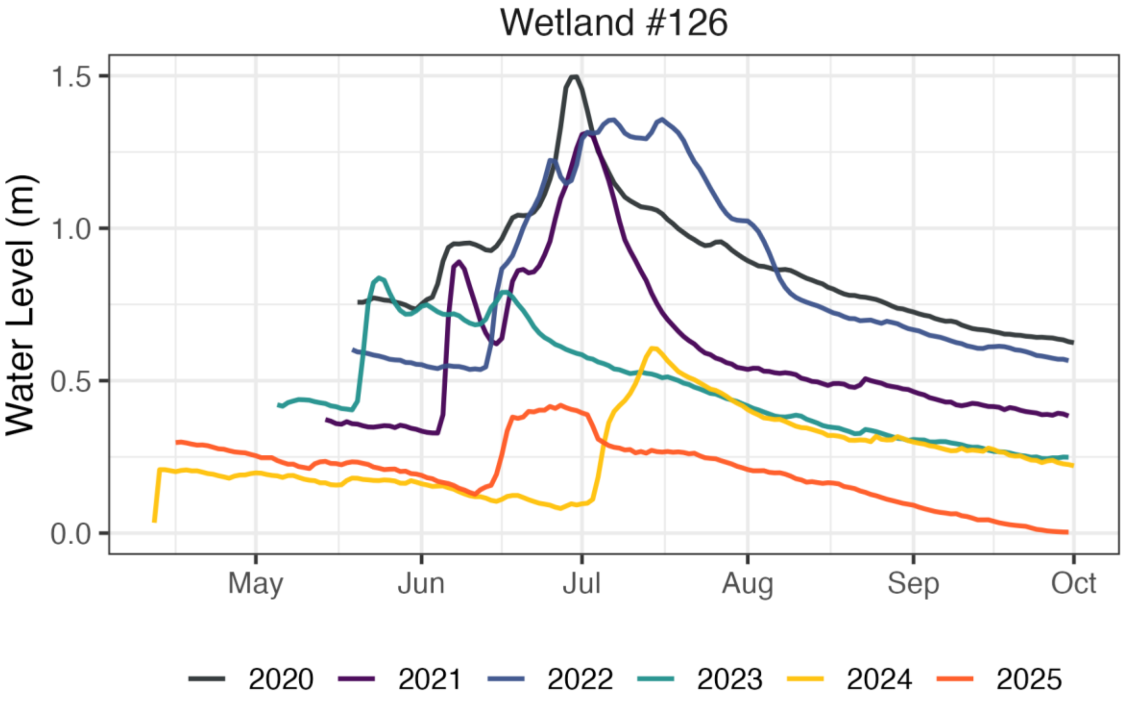

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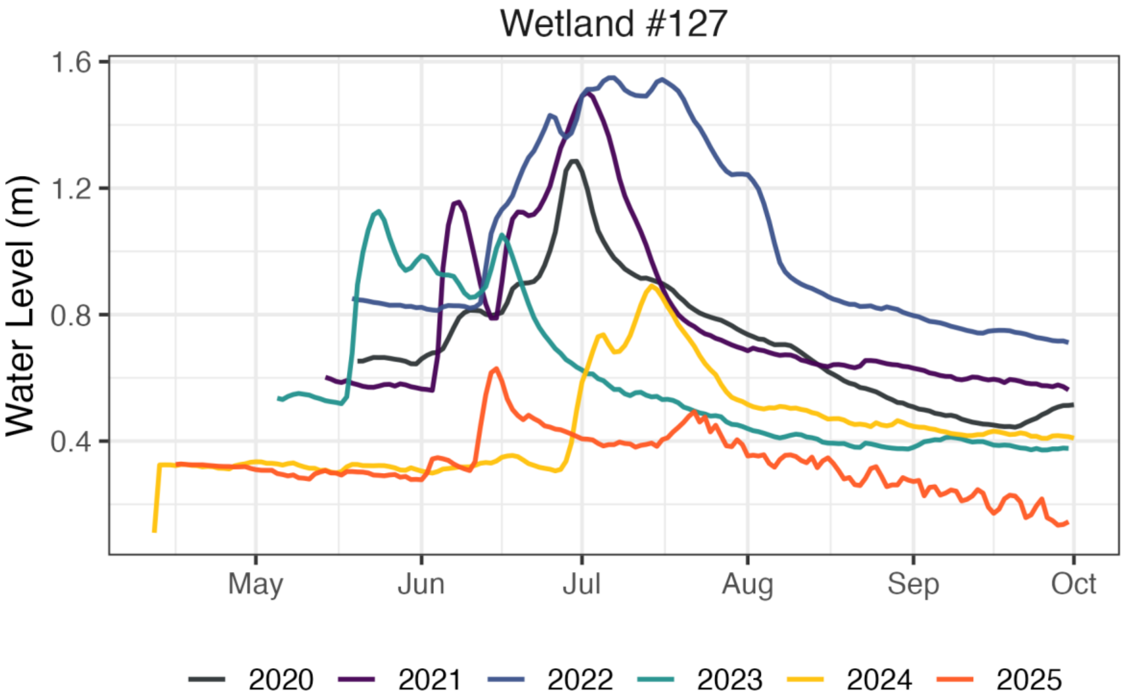

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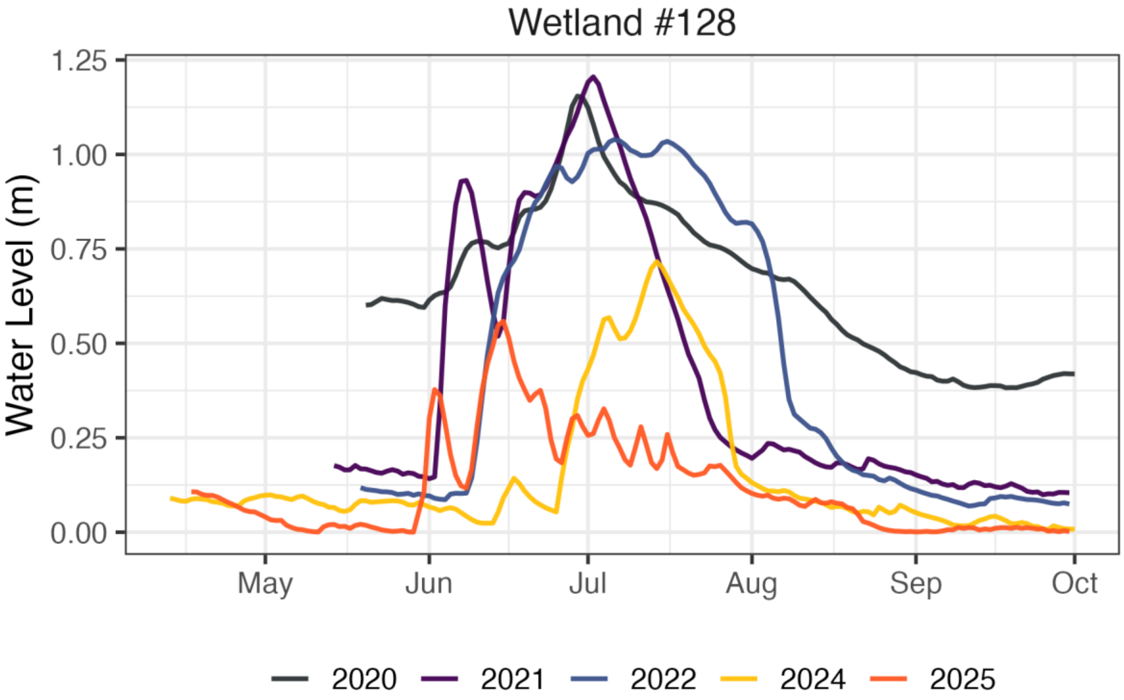

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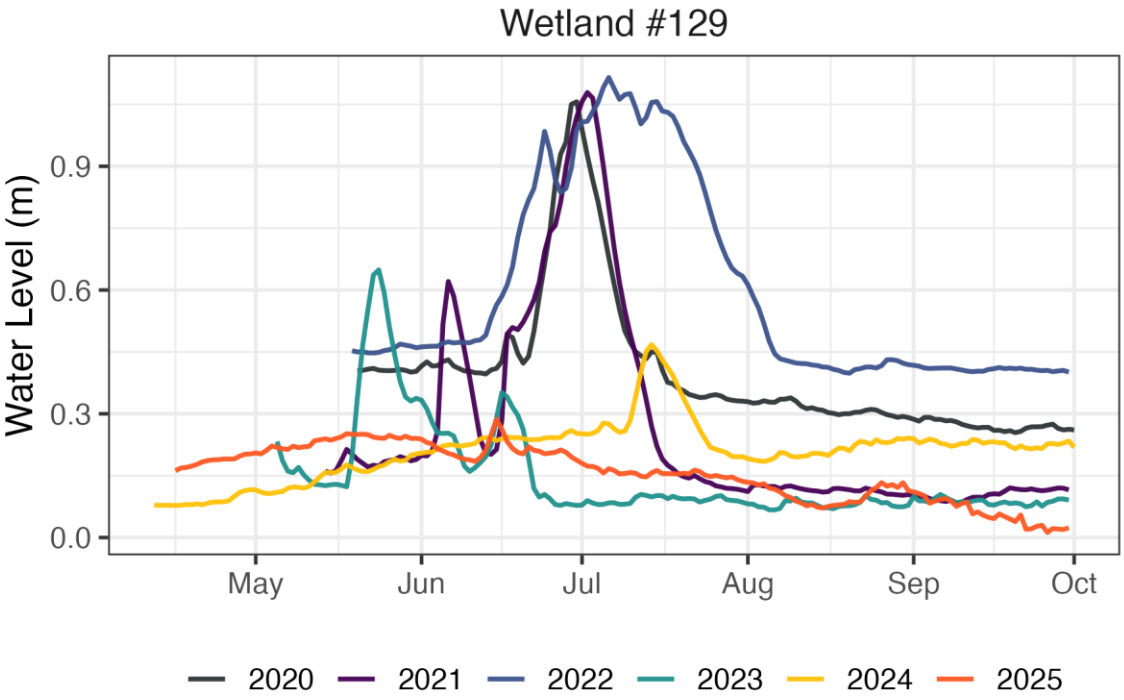

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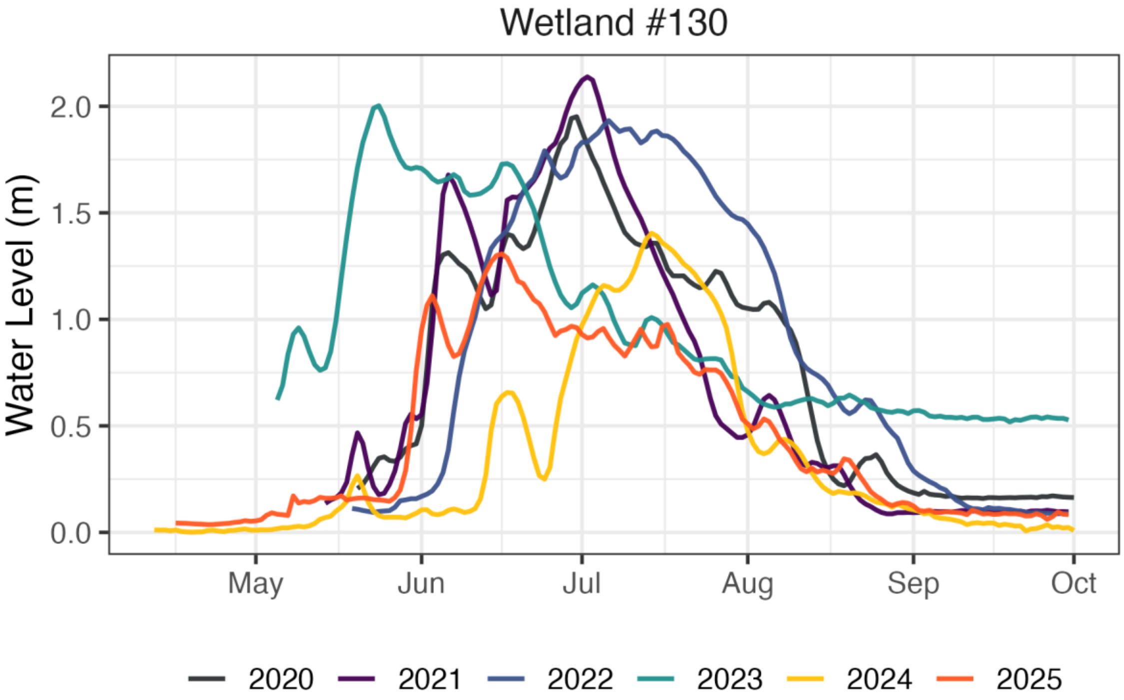

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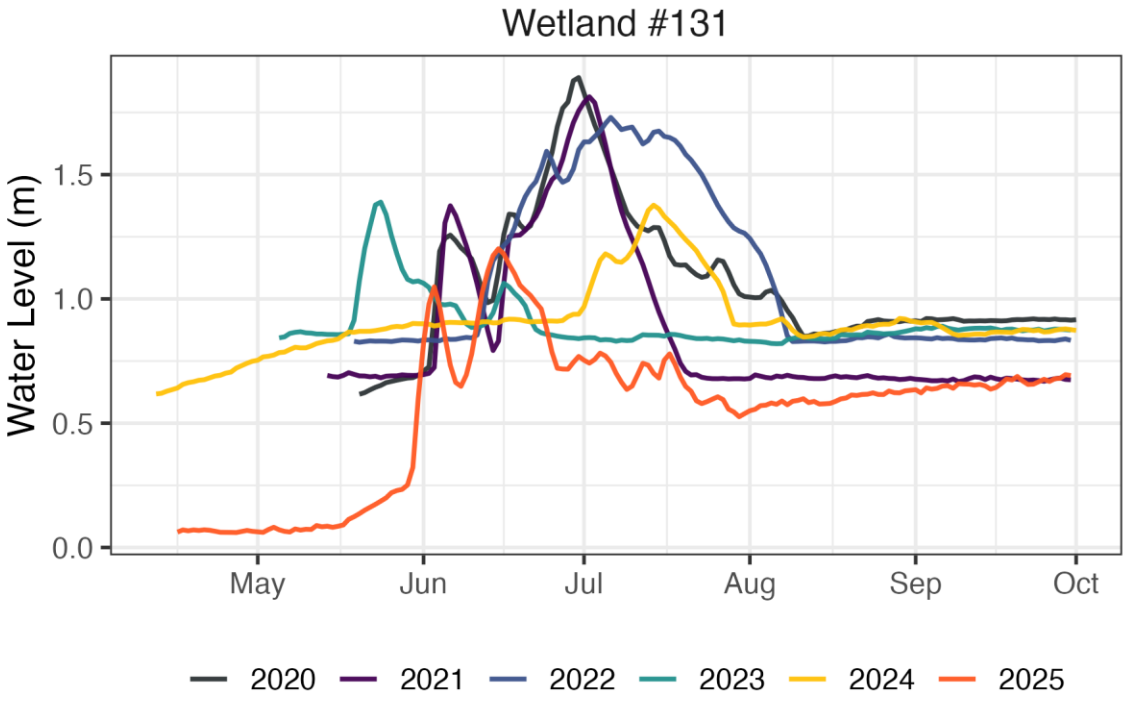

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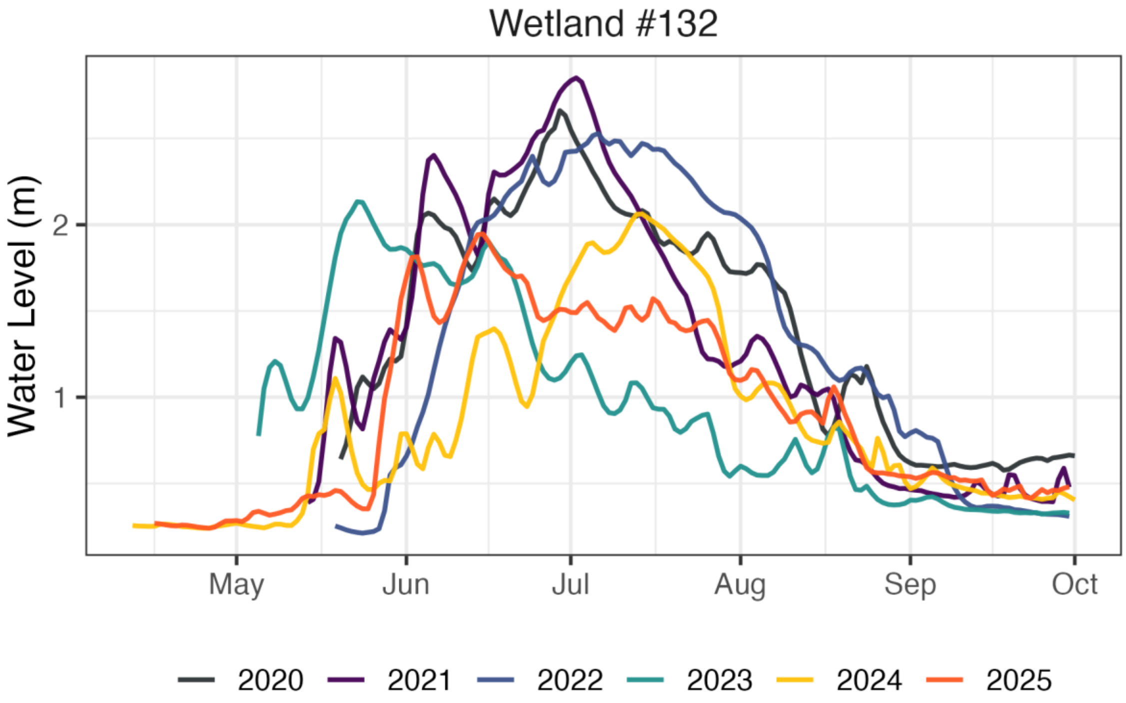

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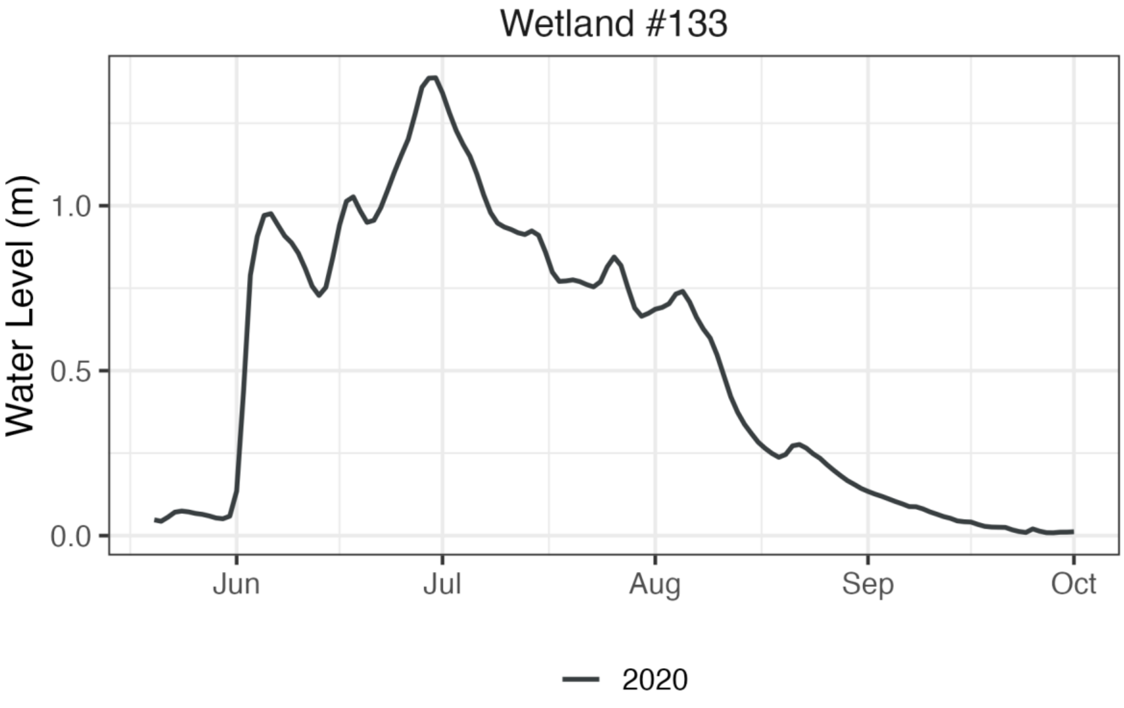

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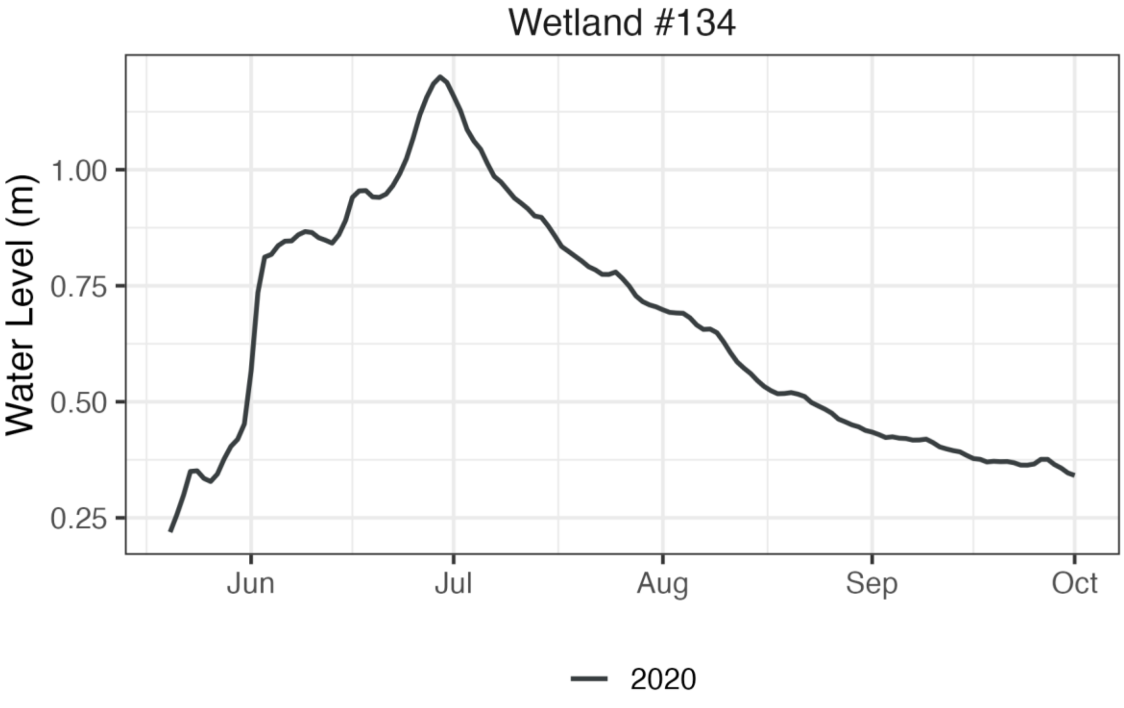

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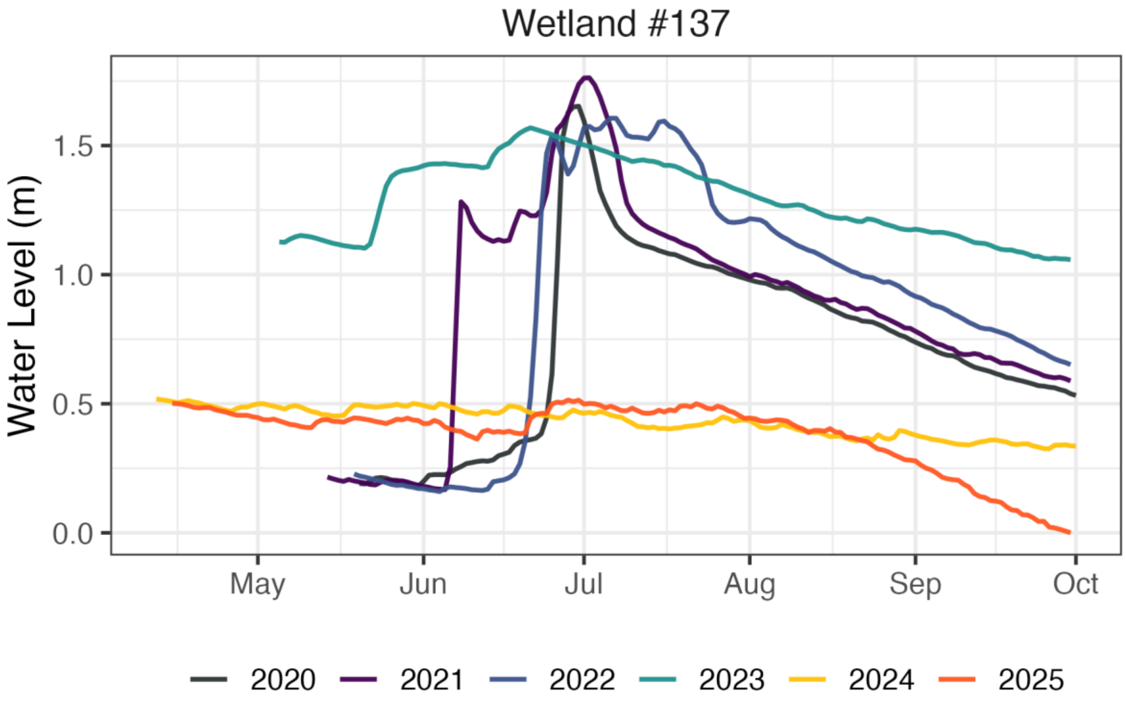

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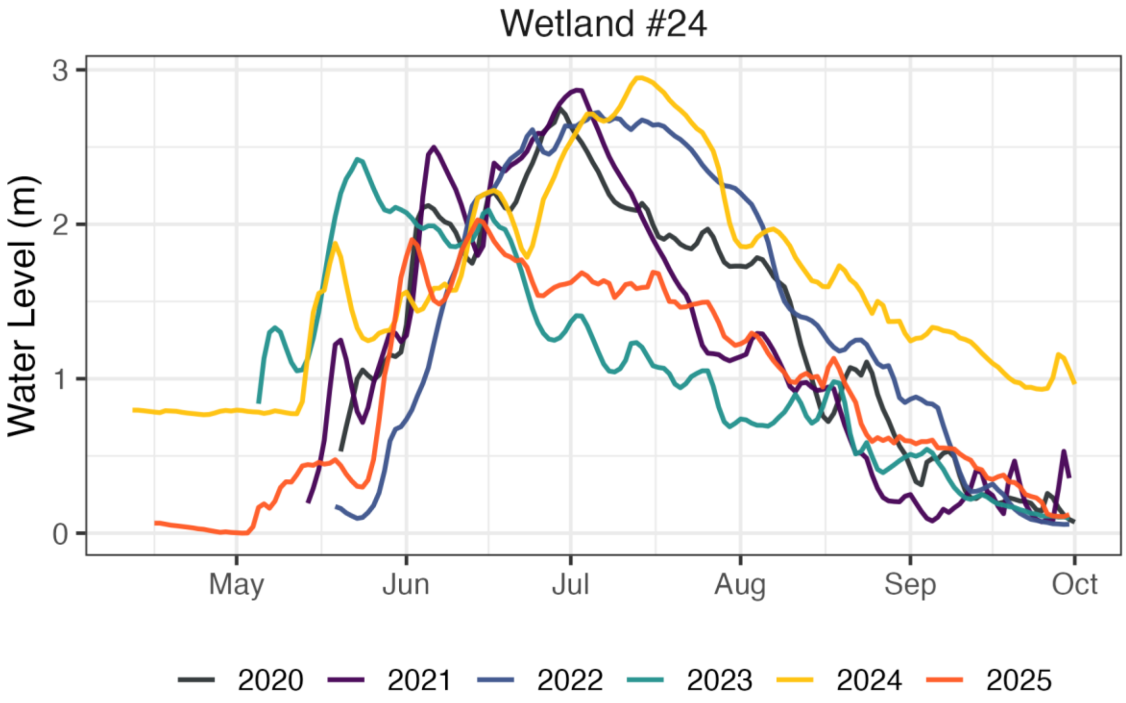

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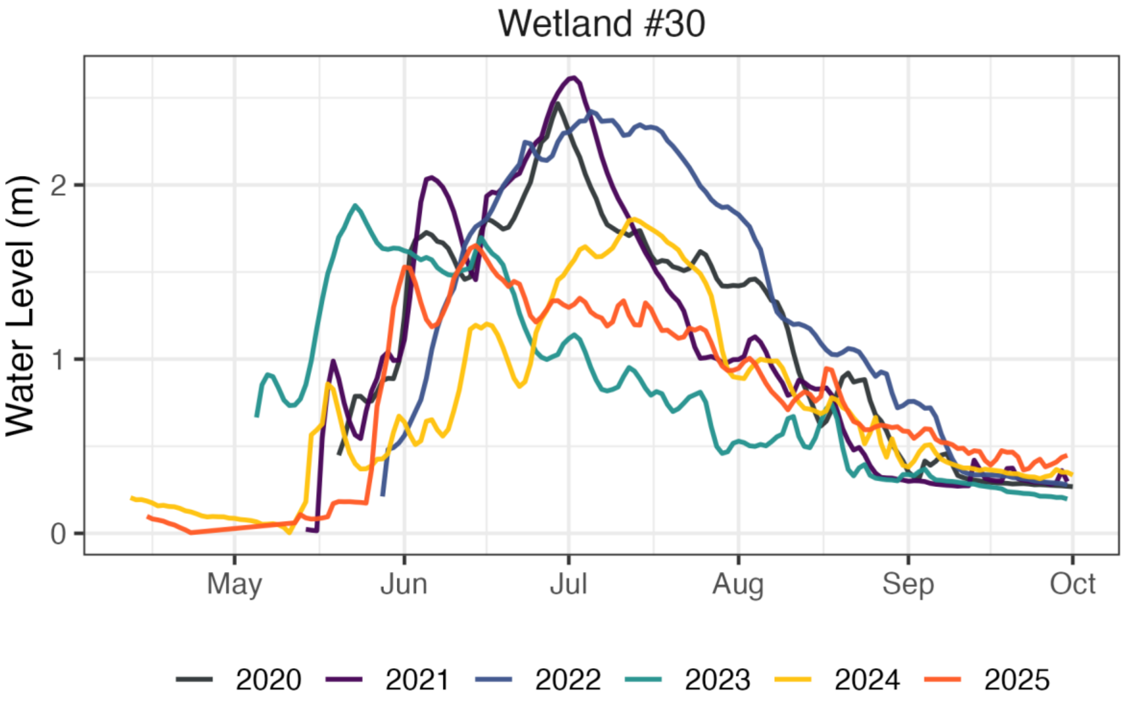

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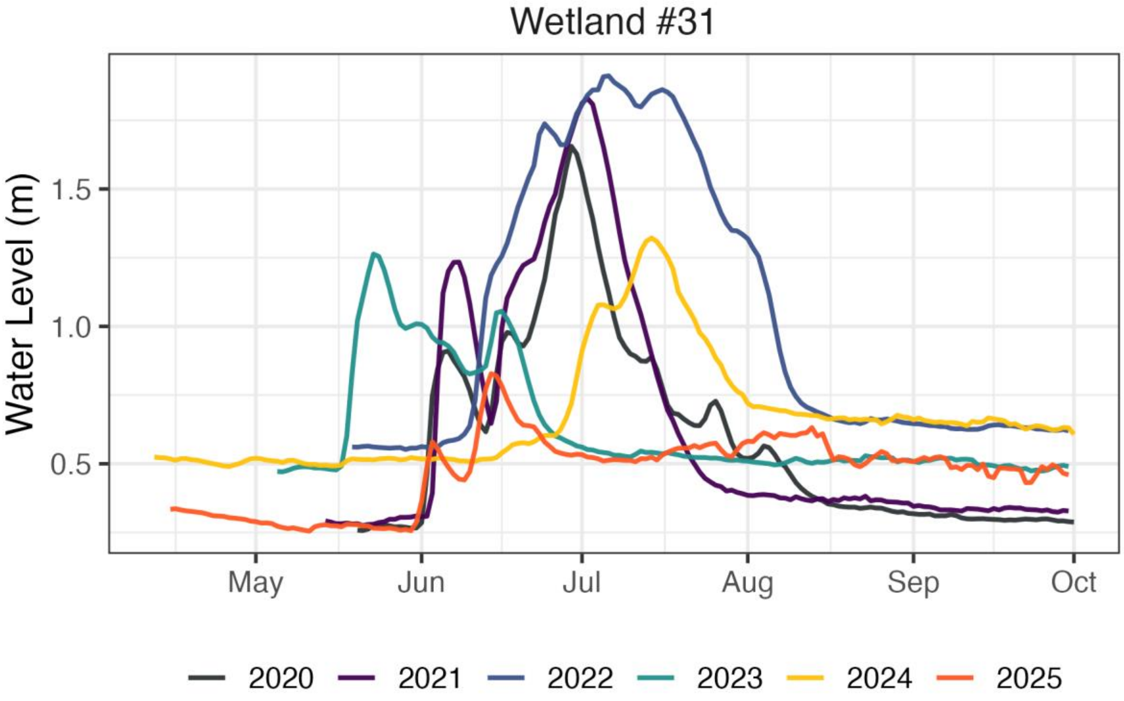

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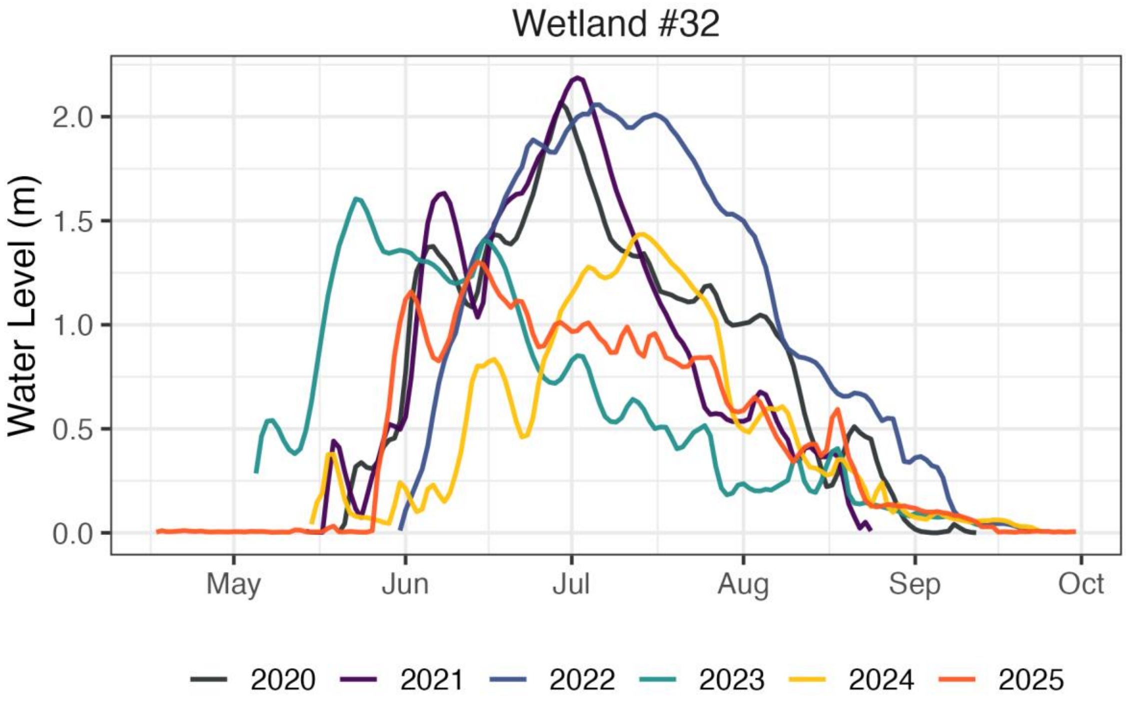

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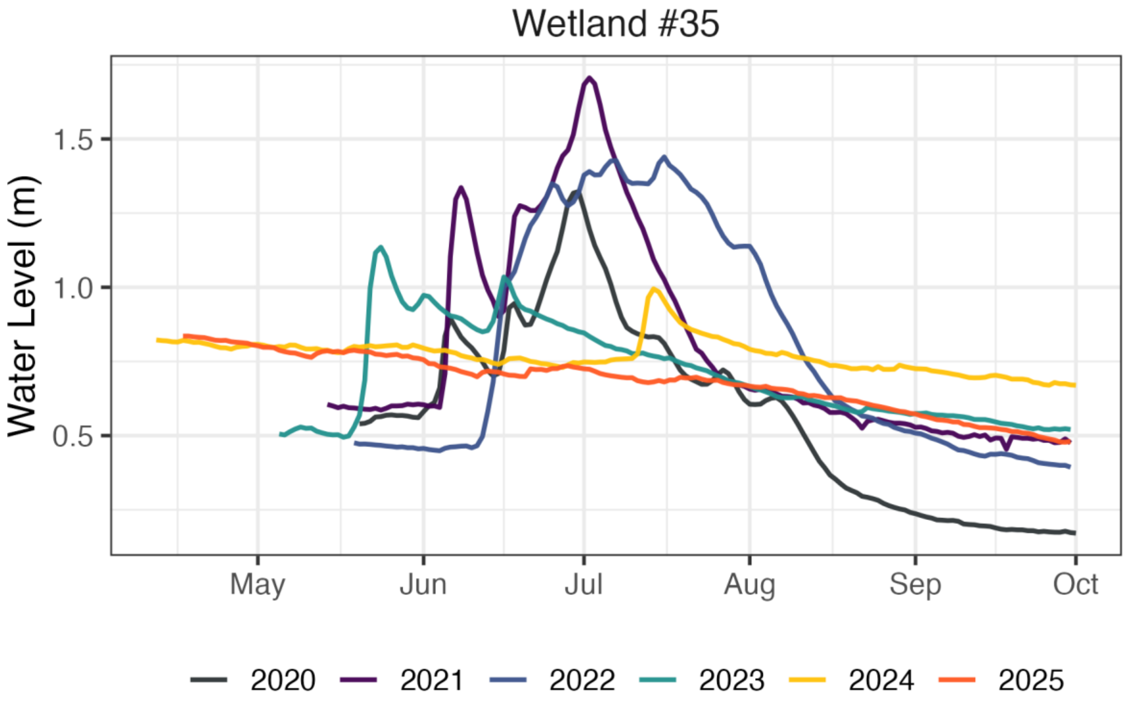

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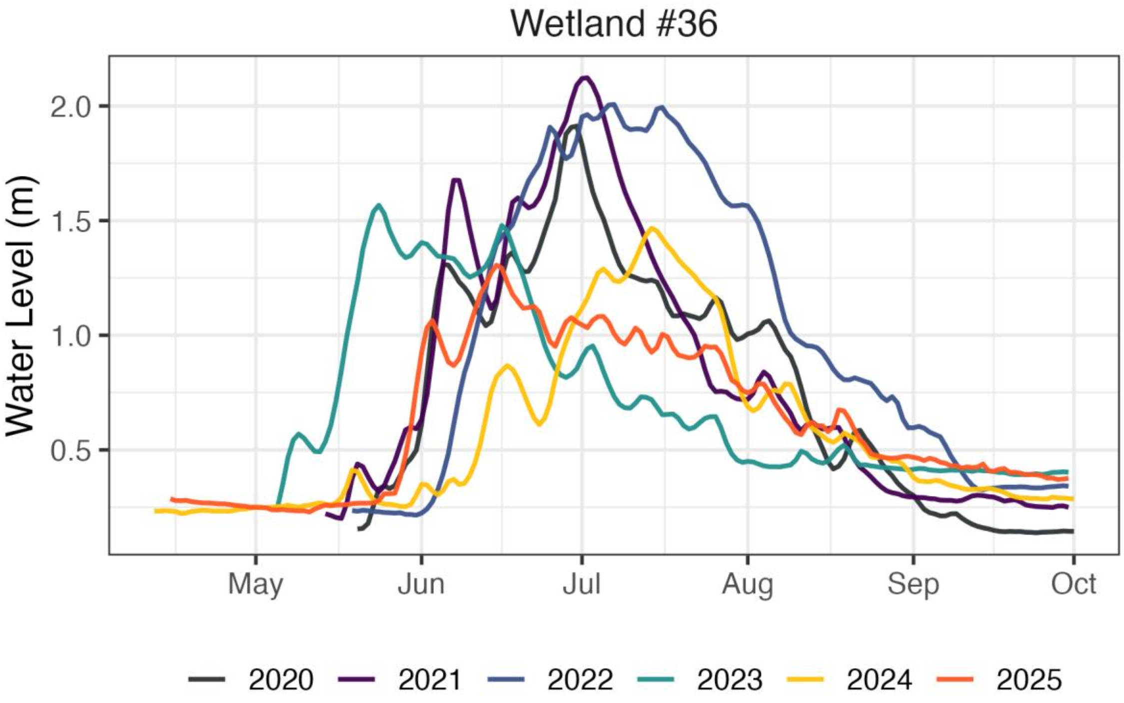

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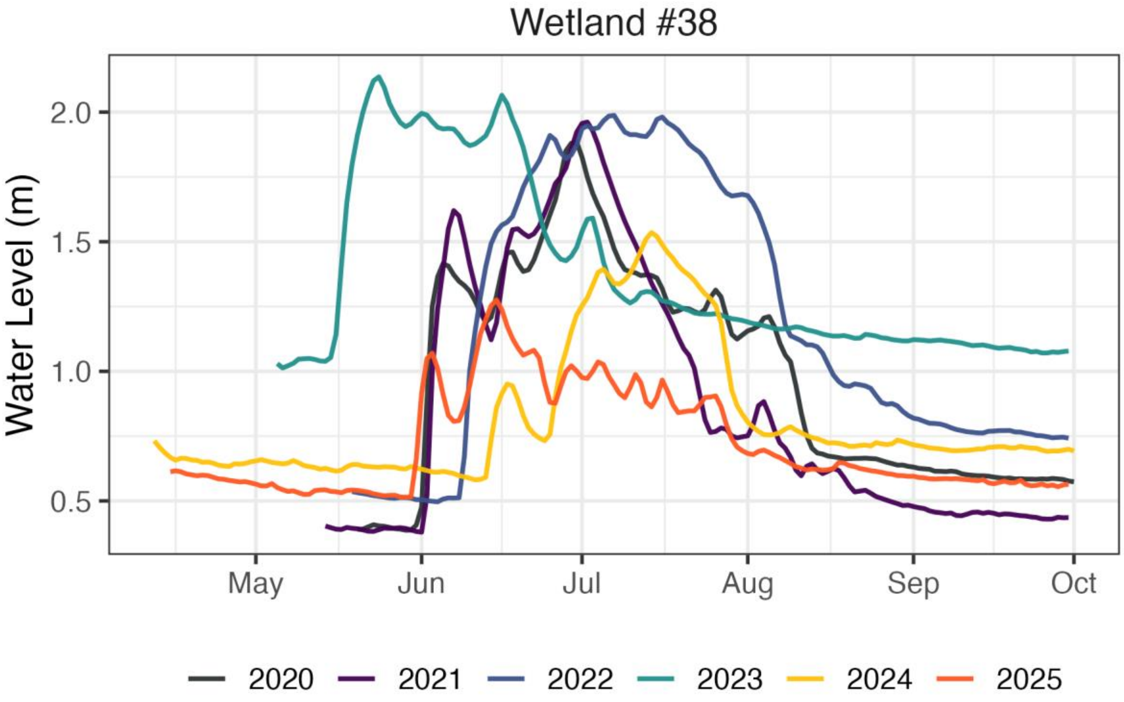

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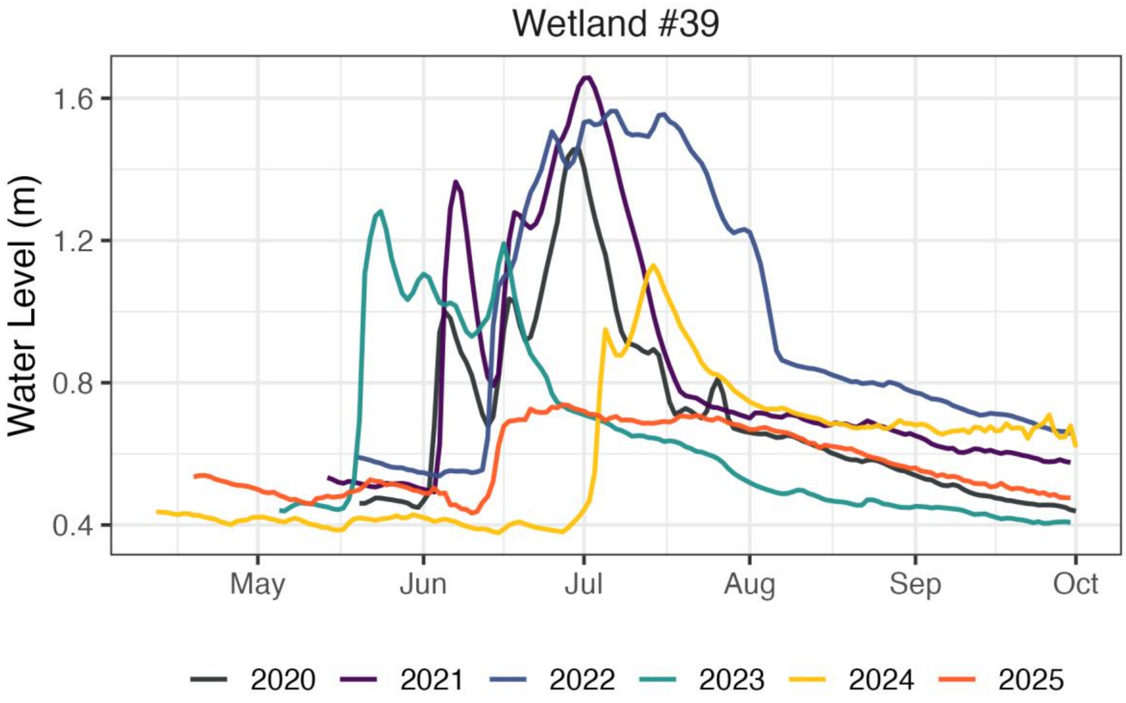

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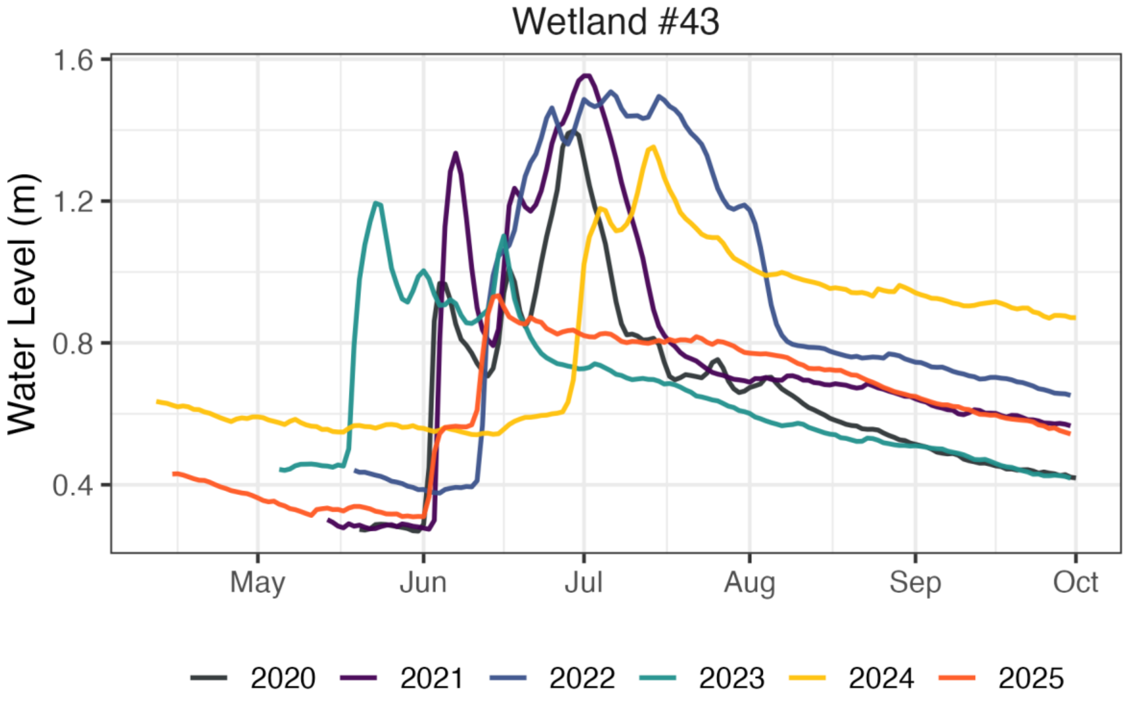

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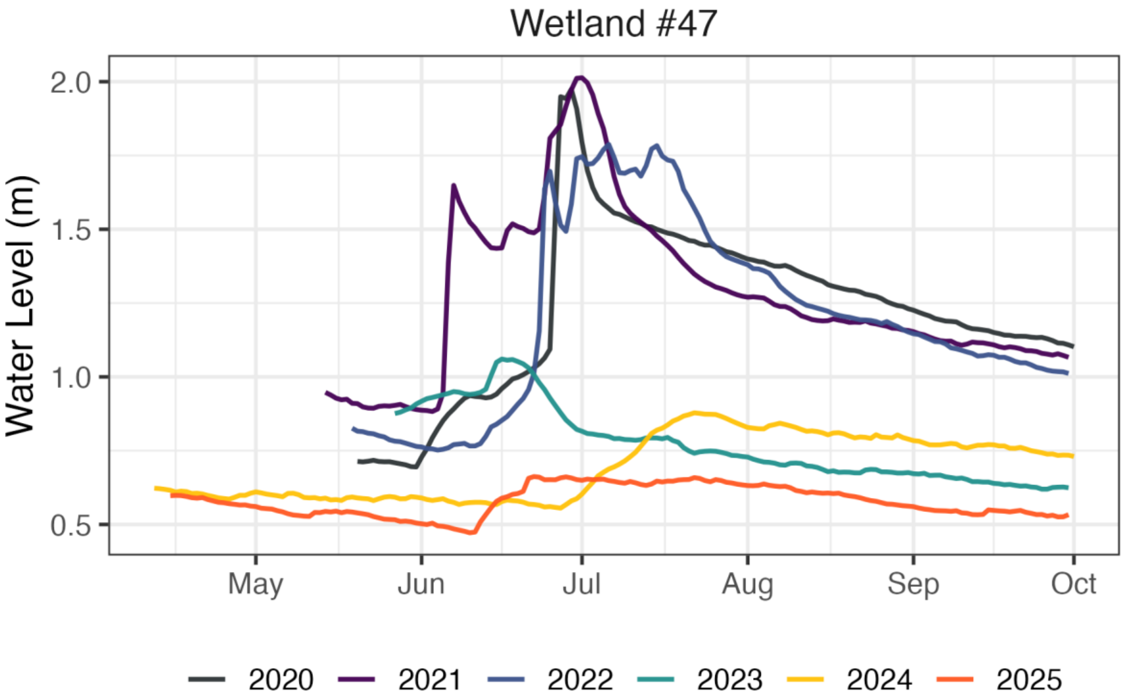

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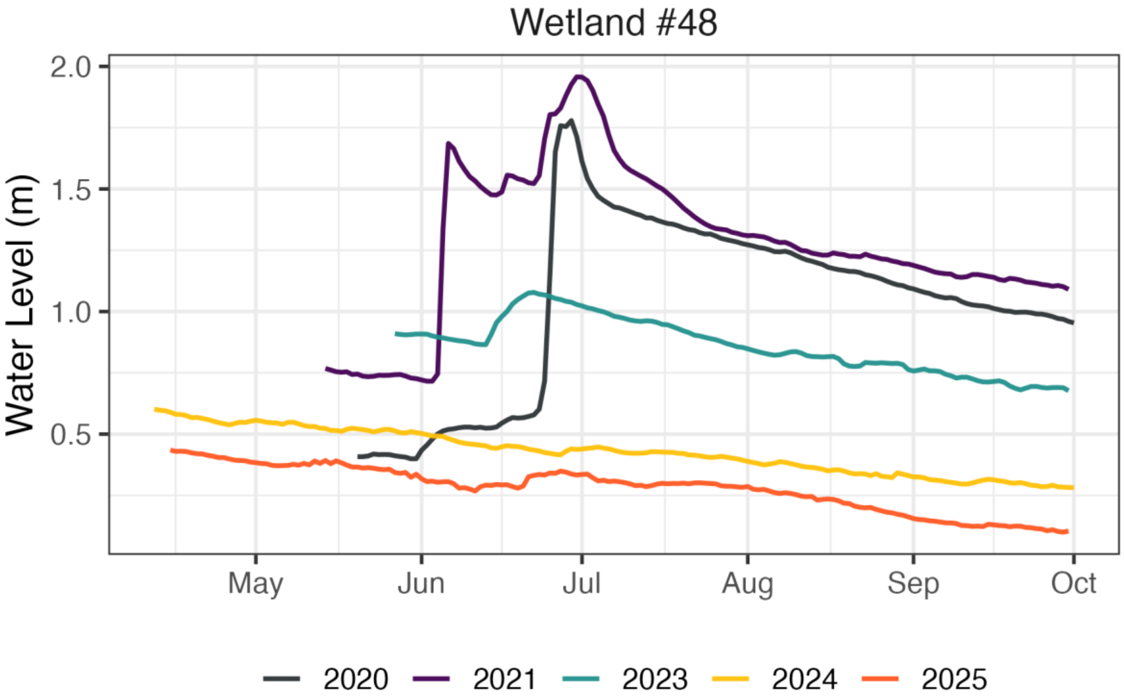

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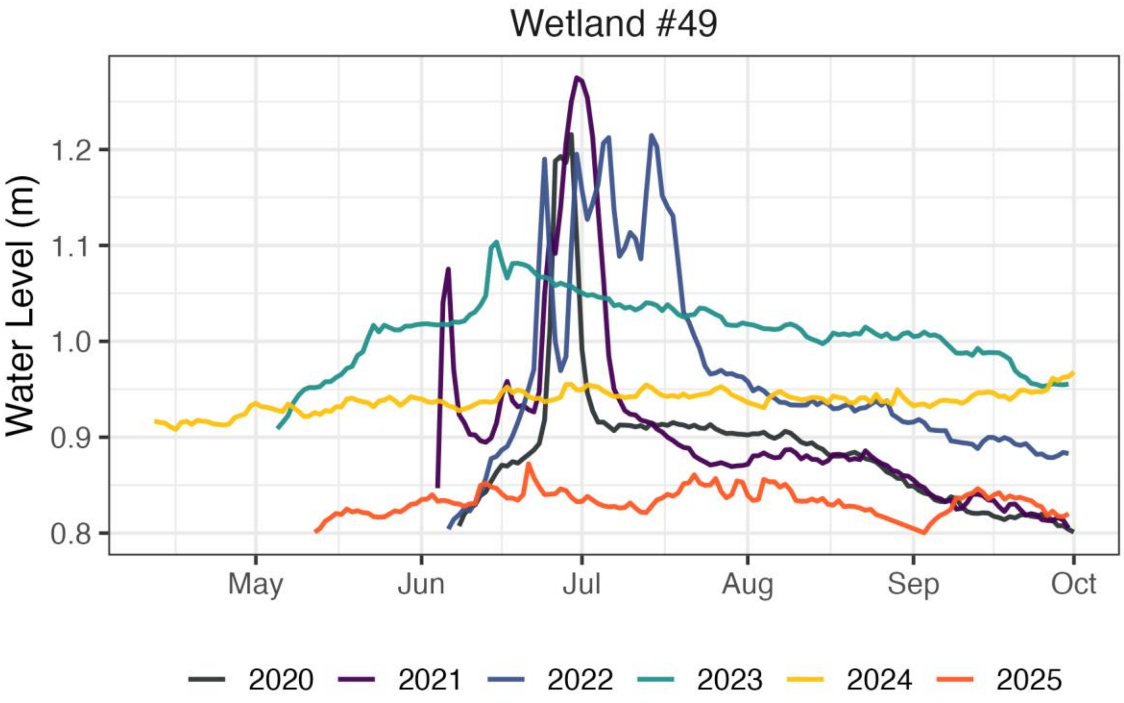

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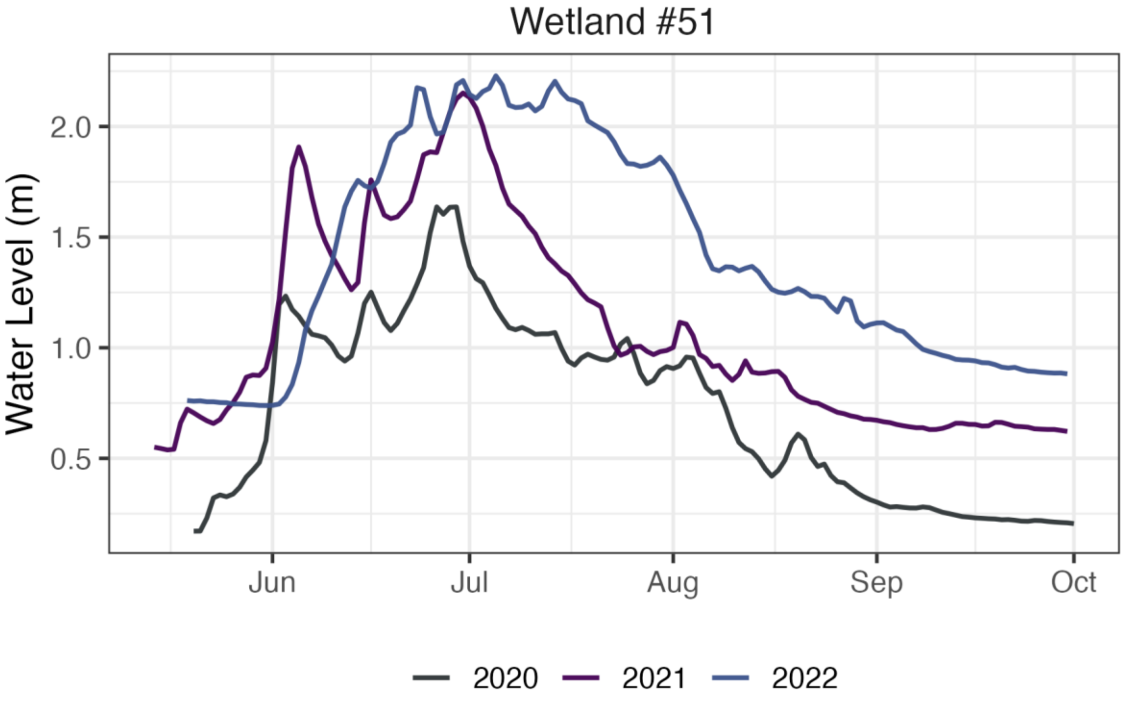

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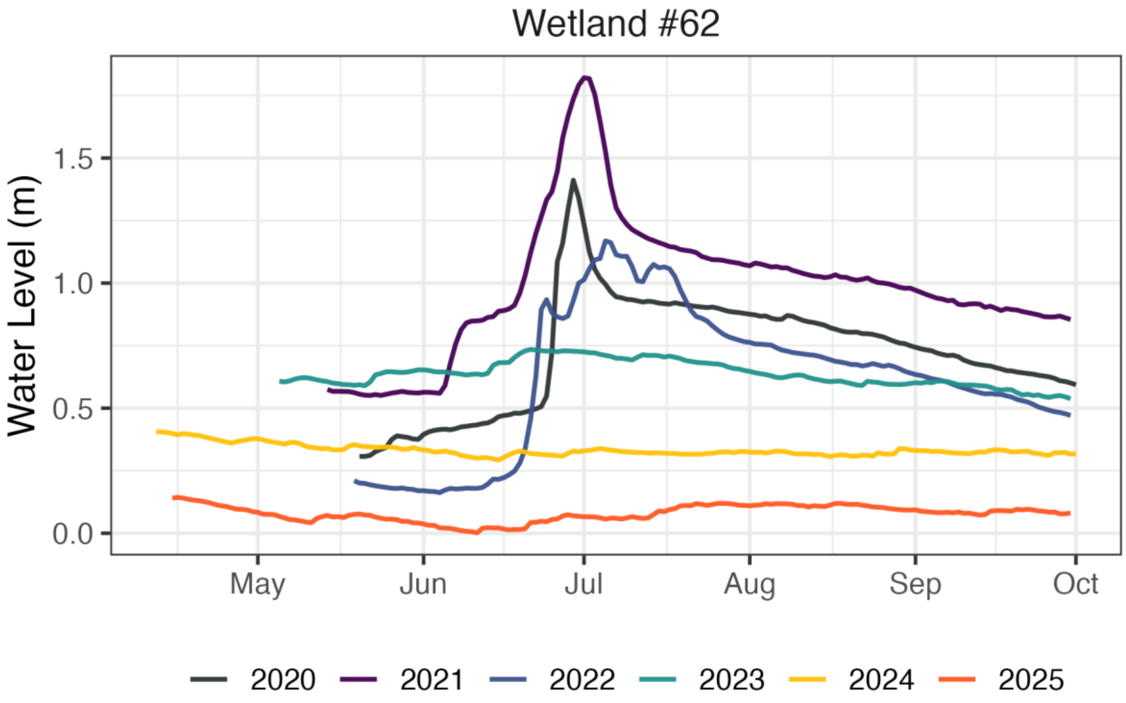

Figure A-26: Wetland #62

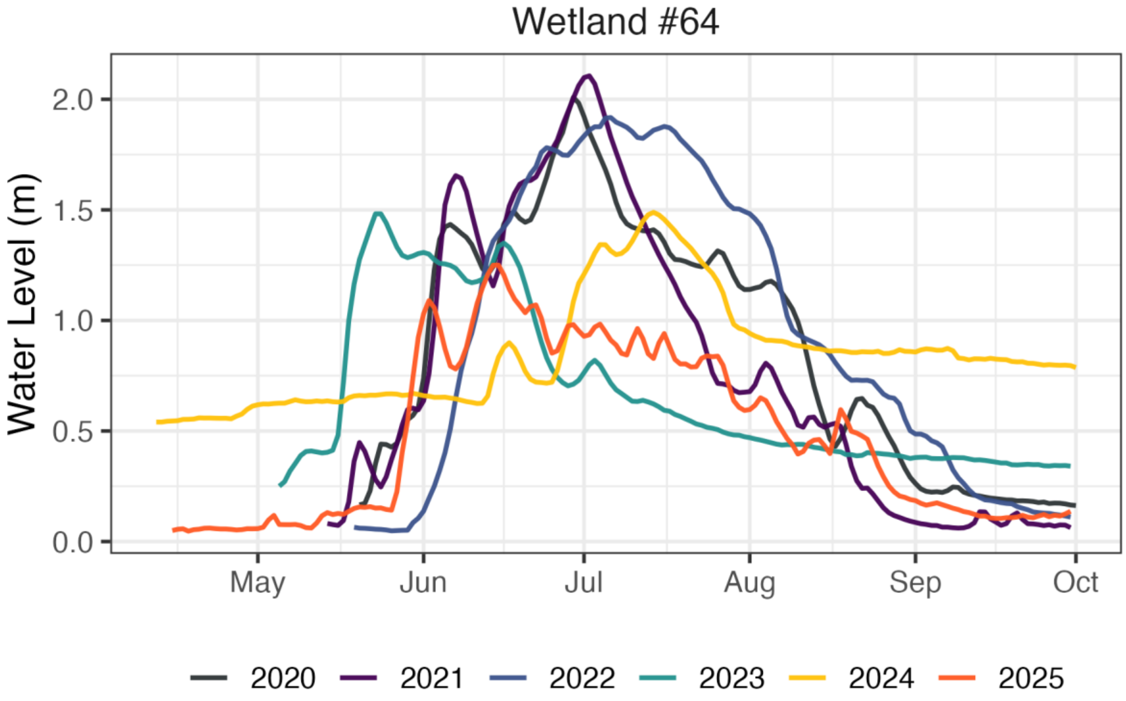

Figure A-27: Wetland #64

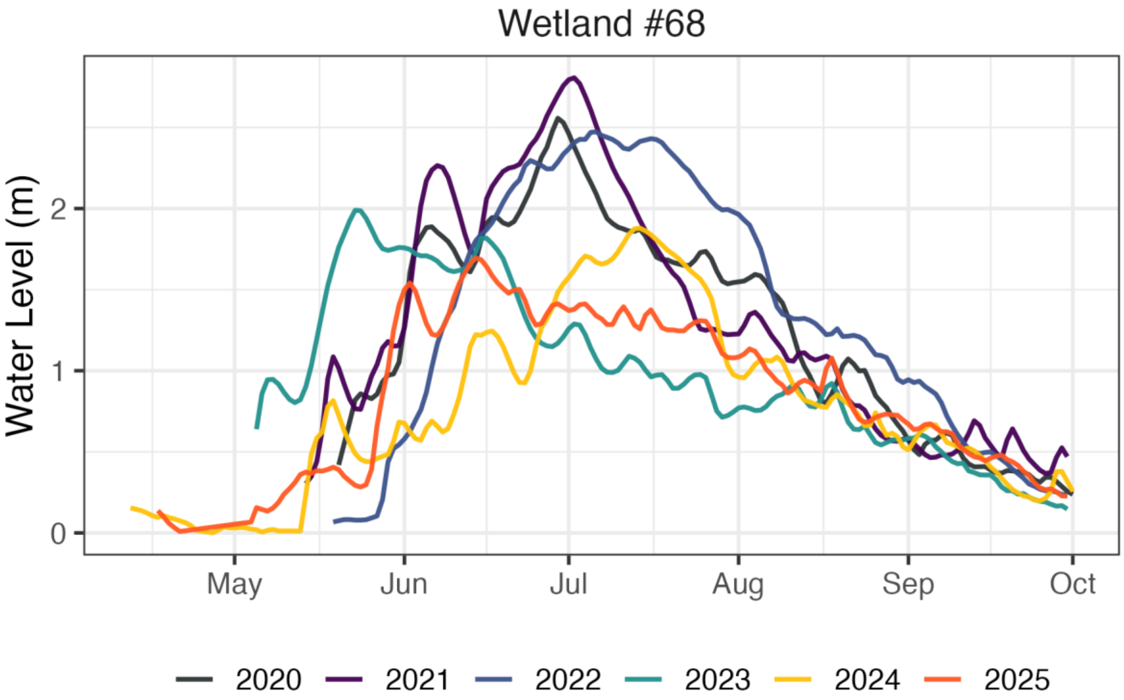

Figure A-28: Wetland #68

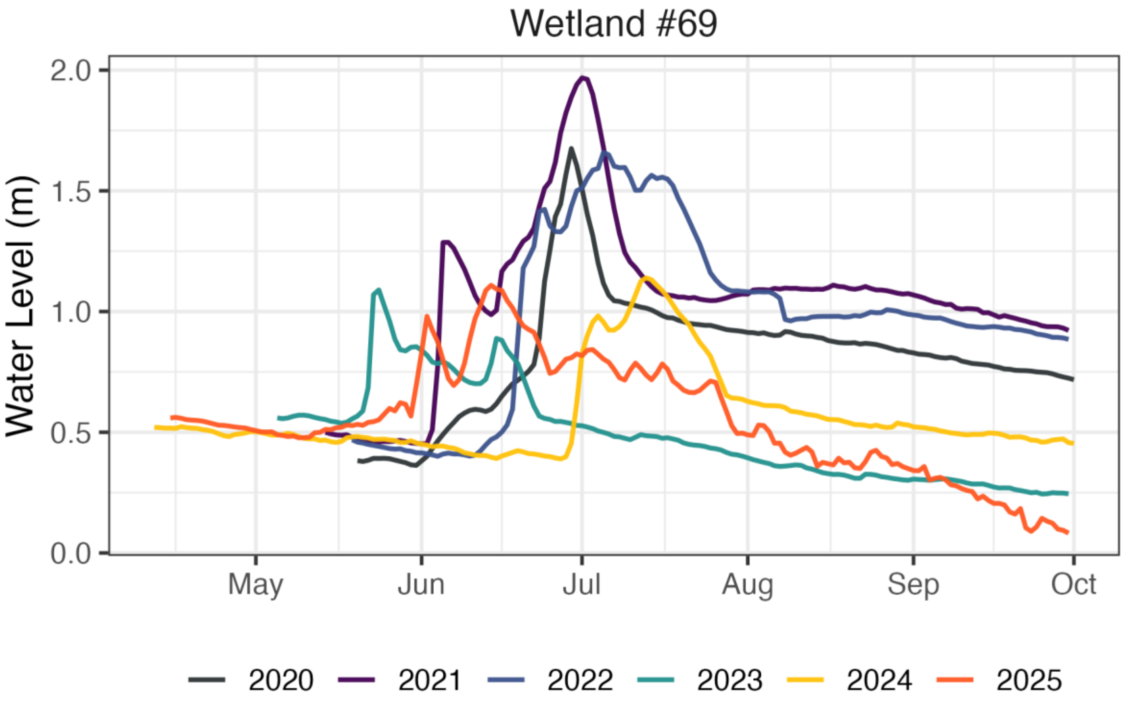

Figure A-29: Wetland #69

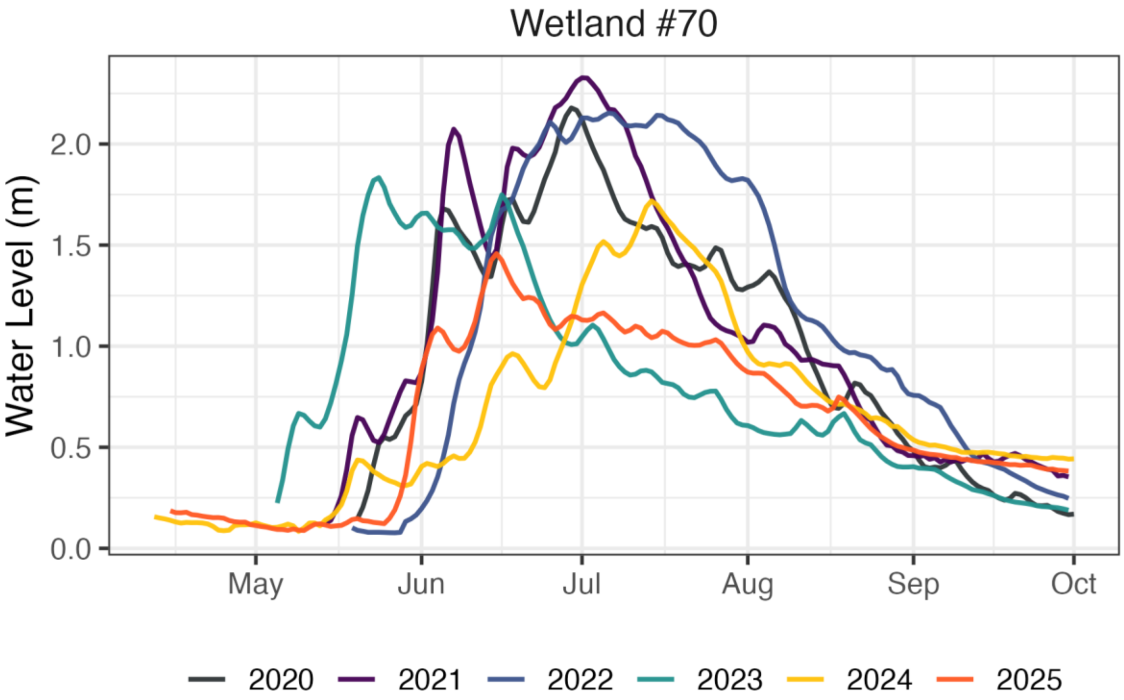

Figure A-30: Wetland #70

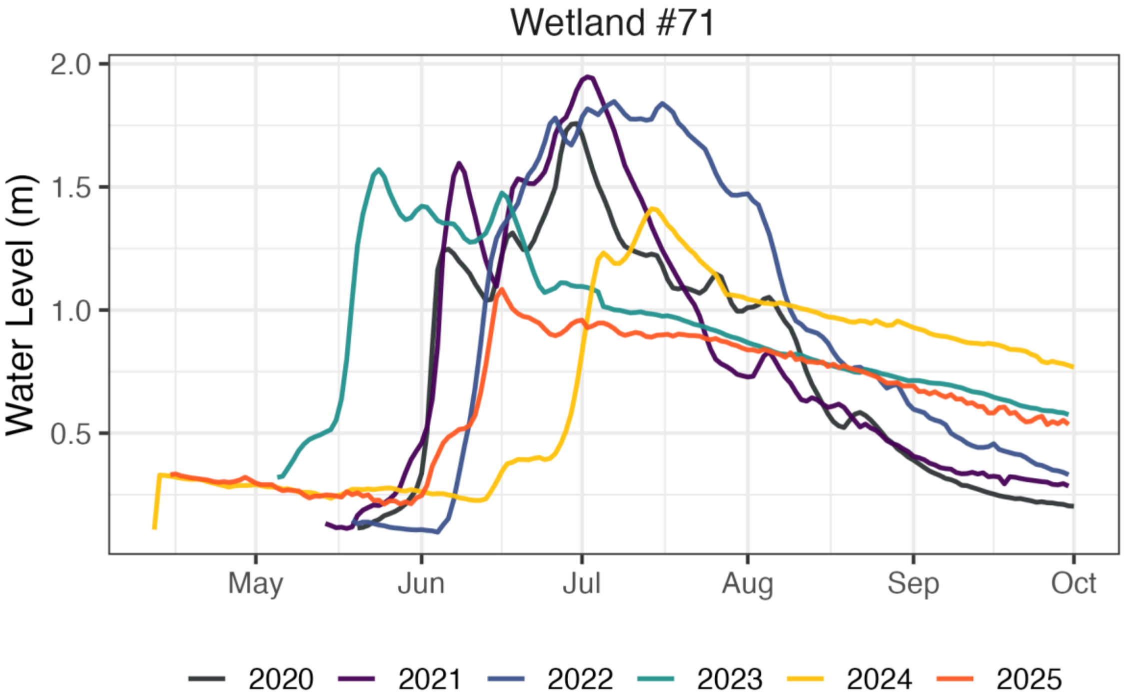

Figure A-31: Wetland #71

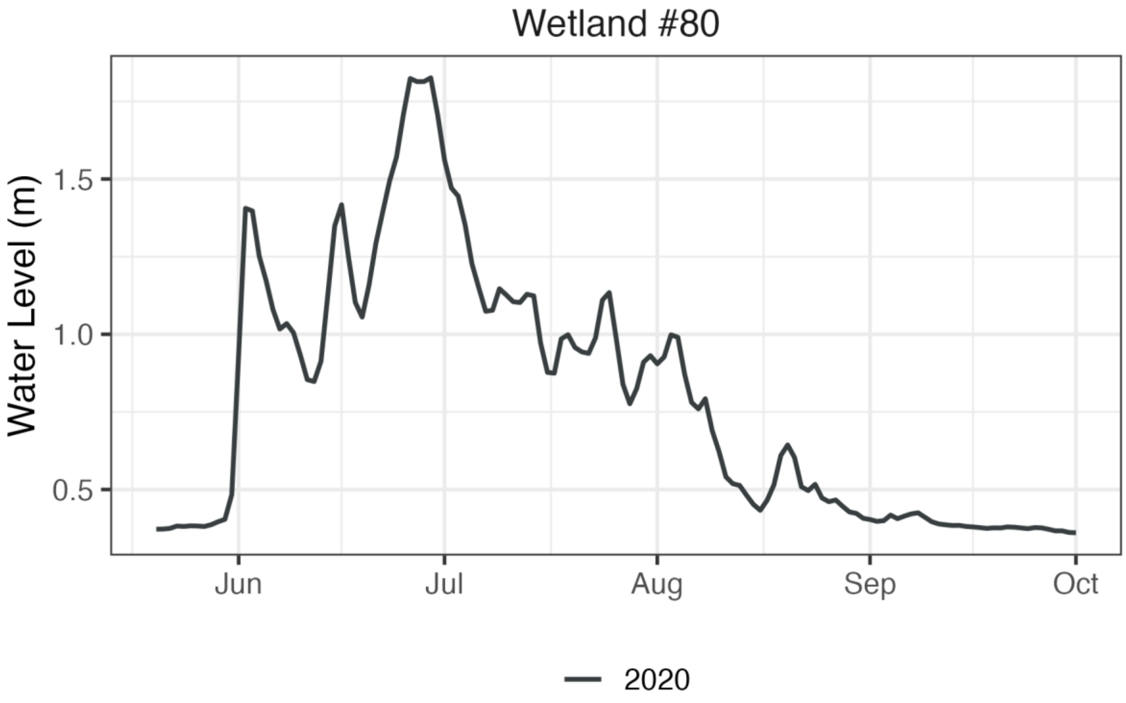

Figure A-32: Wetland #80

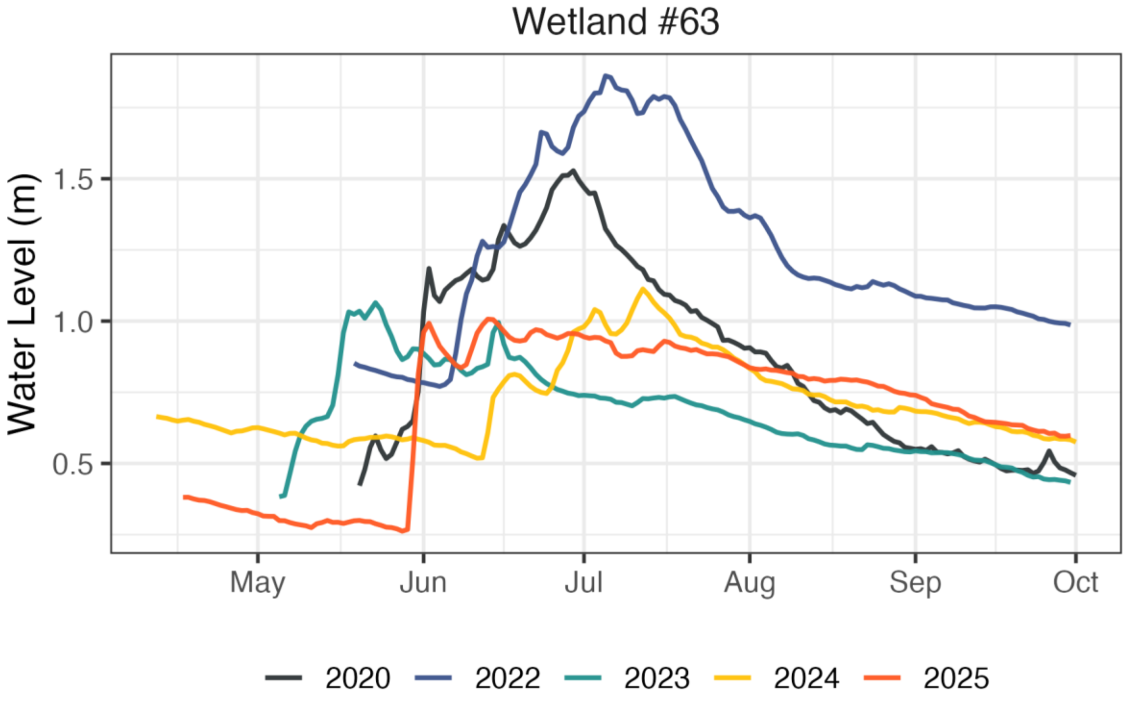

Figure A-33: Wetland #63

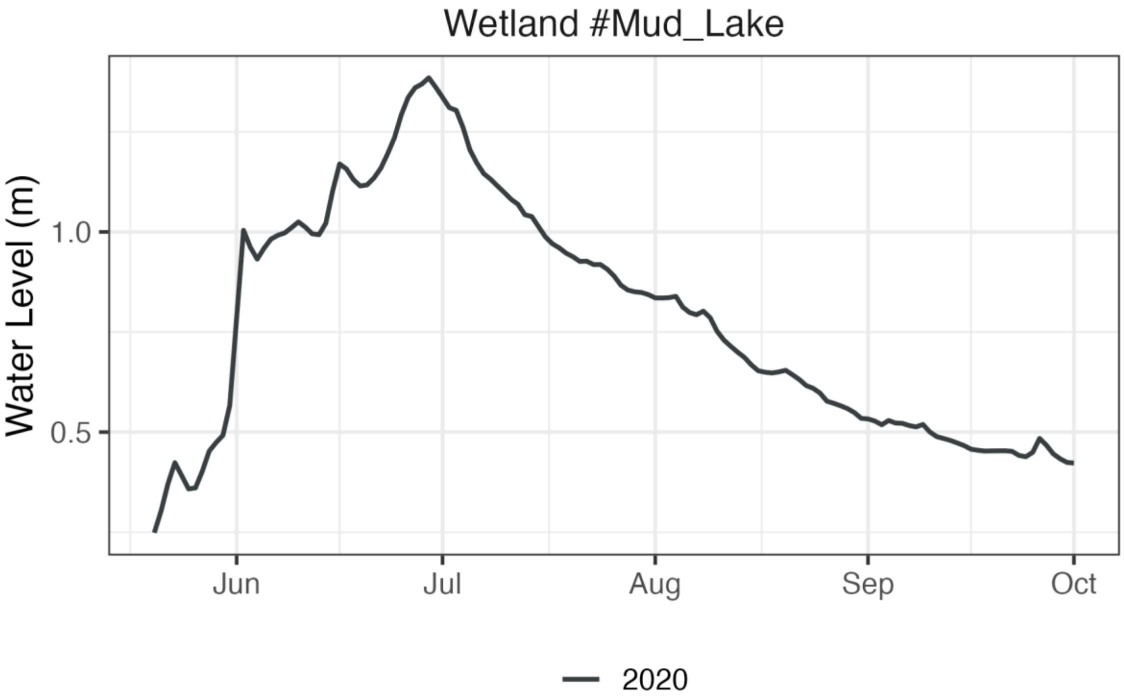

Figure A-34: Wetland #Mud #Lake

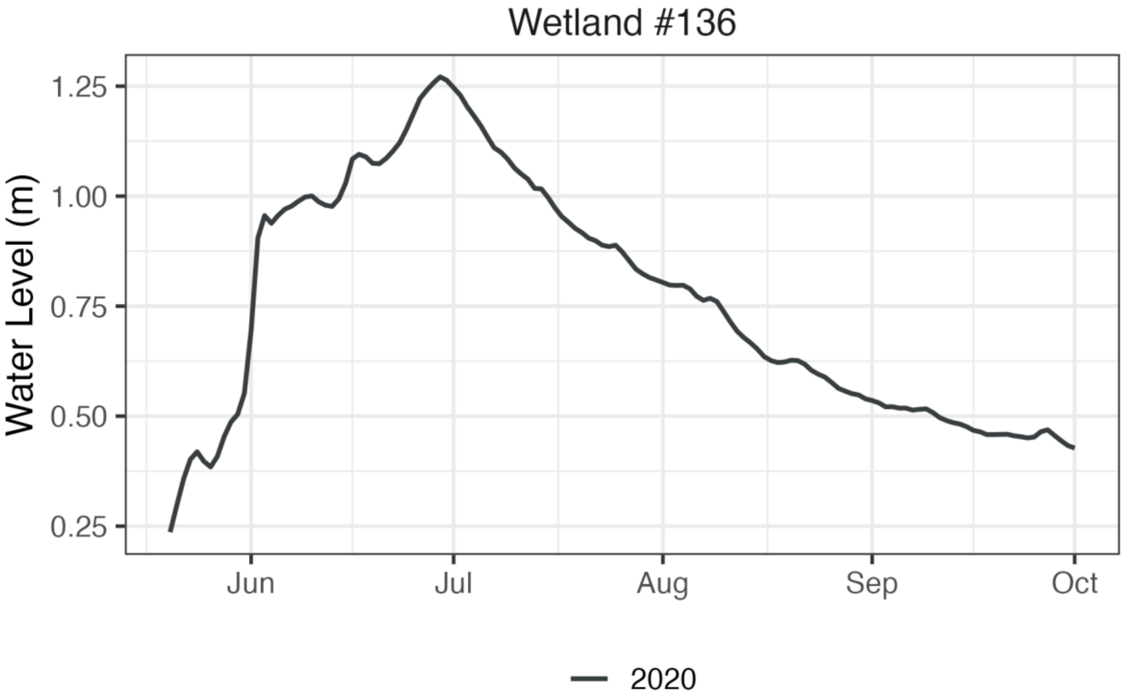

Figure A-35: Wetland #136

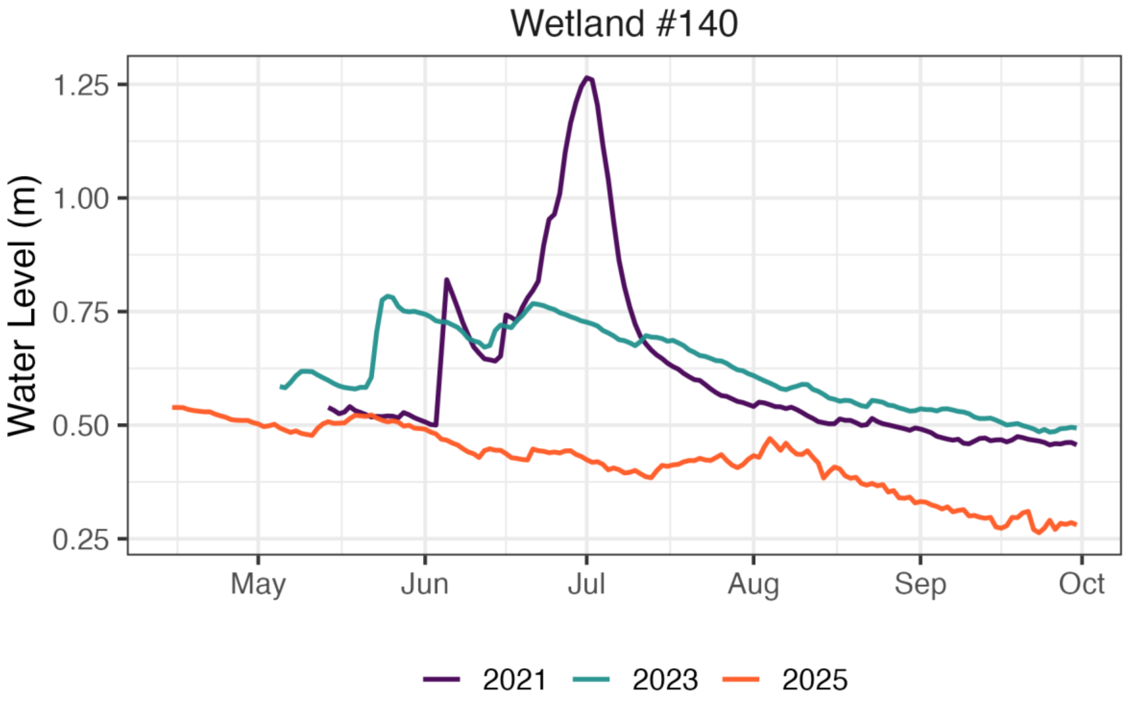

Figure A-36: Wetland #140

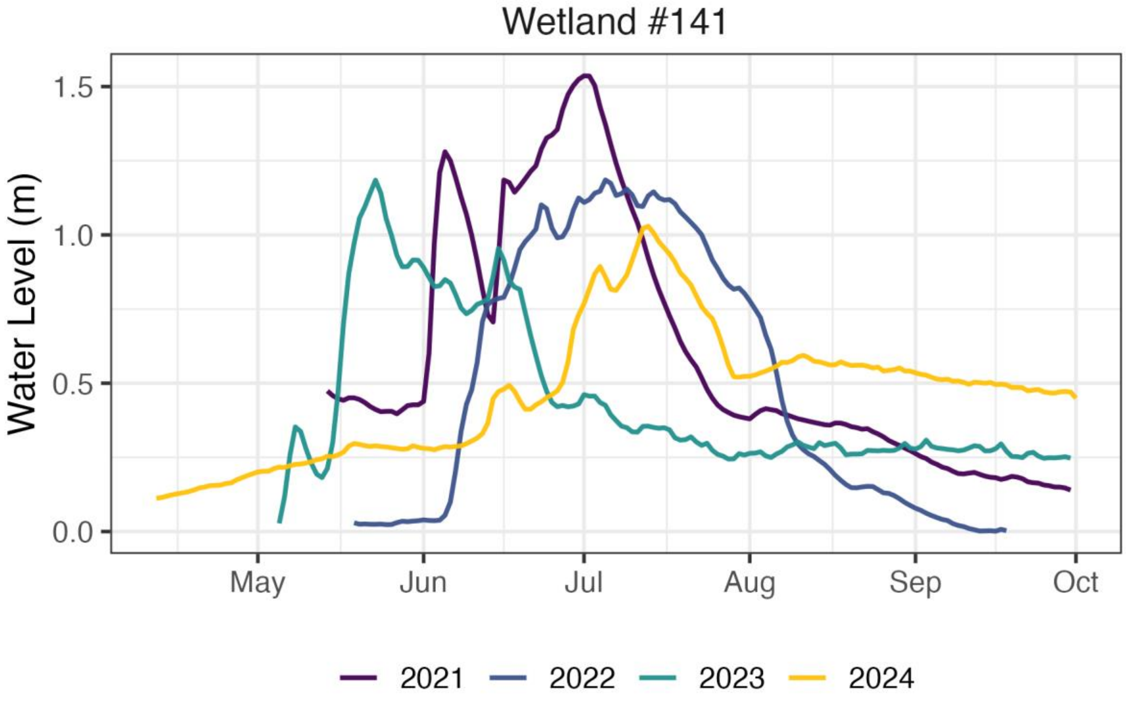

Figure A-37: Wetland #141

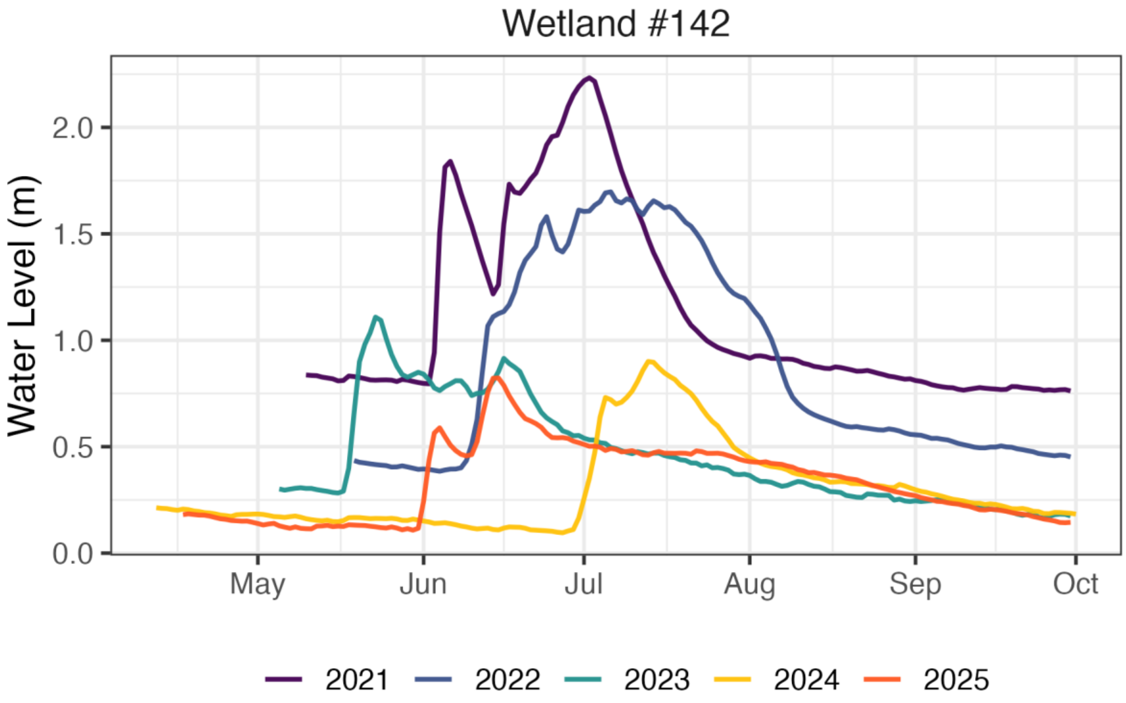

Figure A-38: Wetland #142

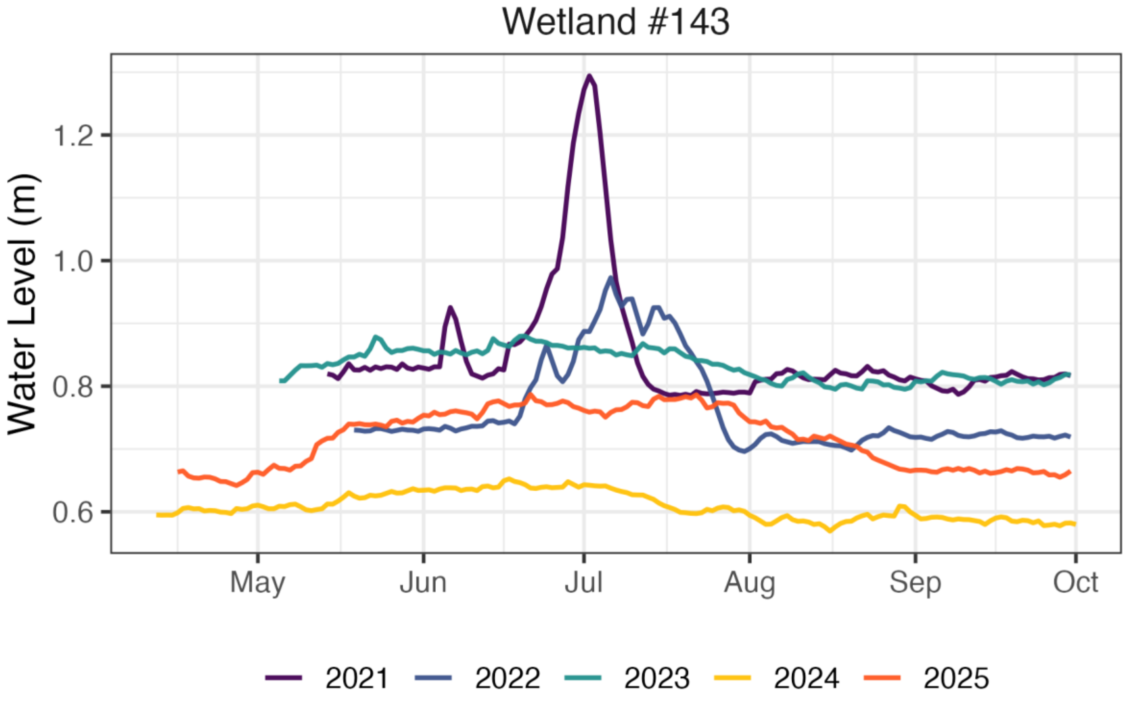

Figure A-39: Wetland #143

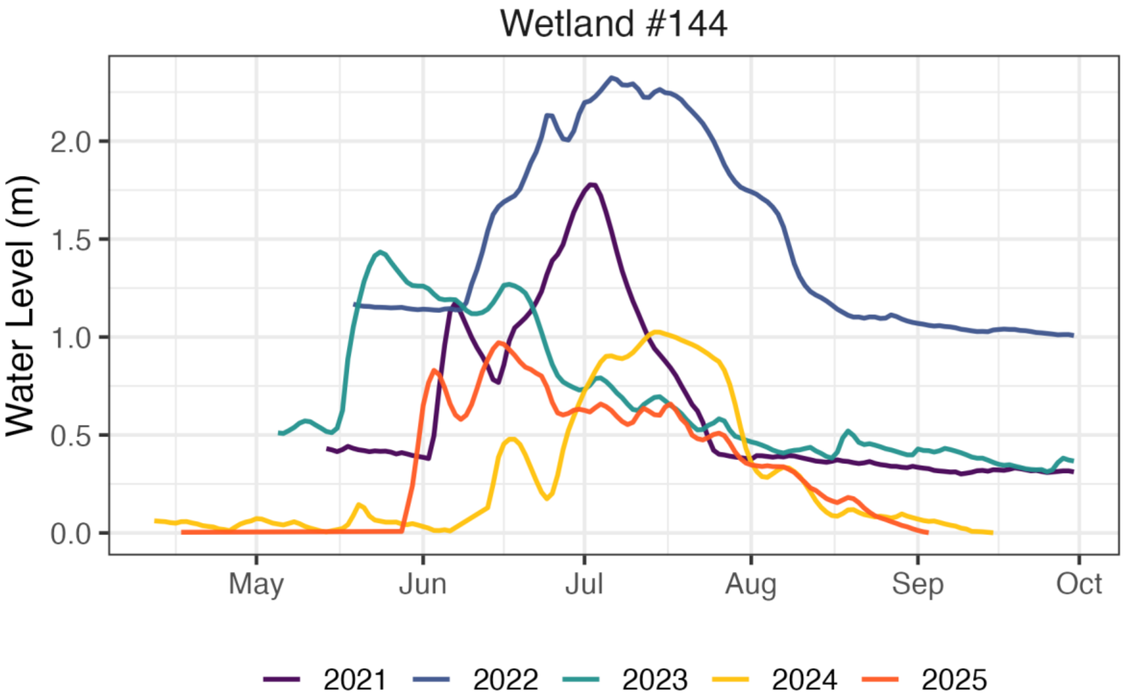

Figure A-40: Wetland #144

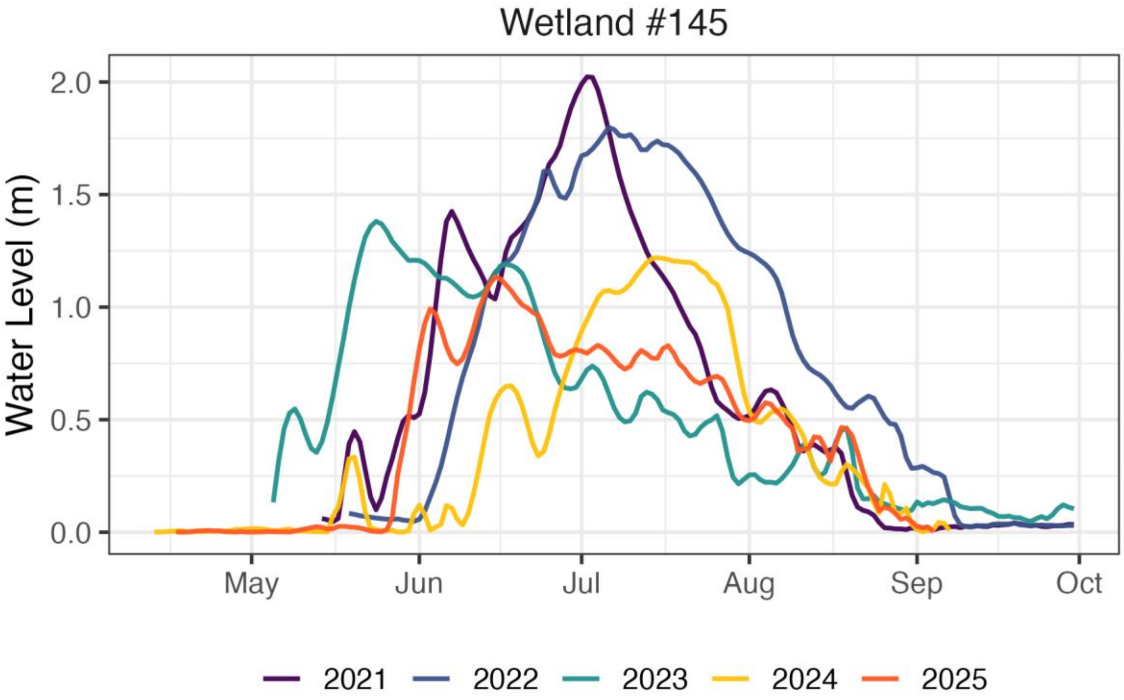

Figure A-41: Wetland #145

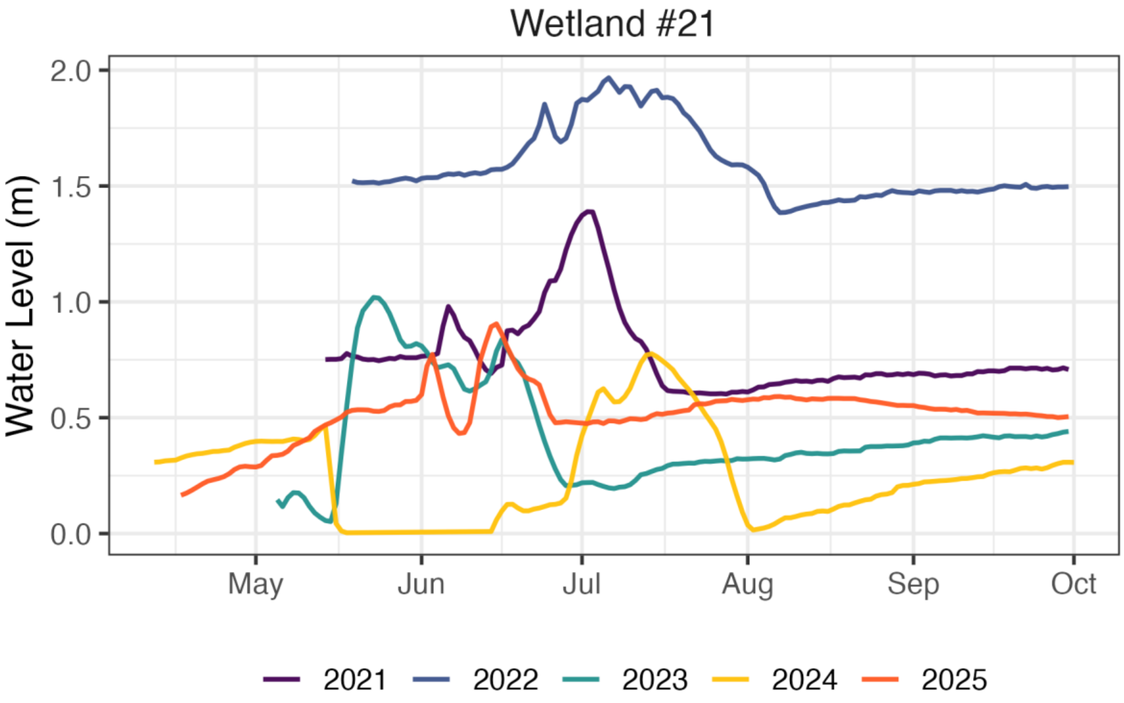

Figure A-42: Wetland #21

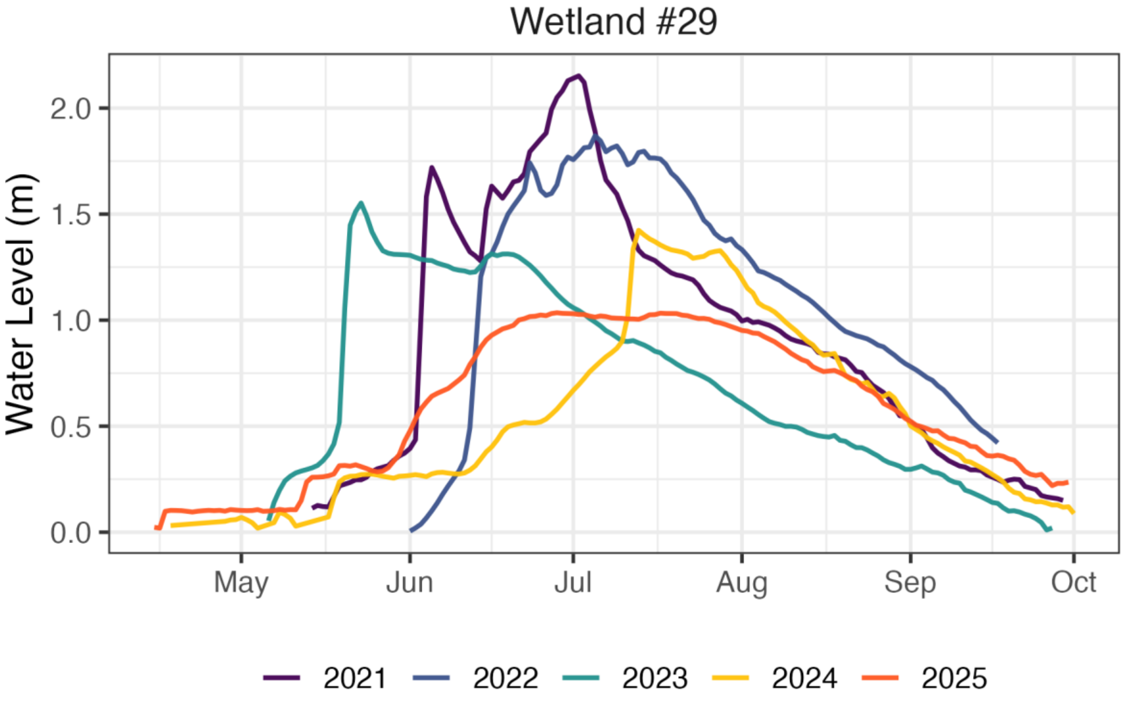

Figure A-43: Wetland #29

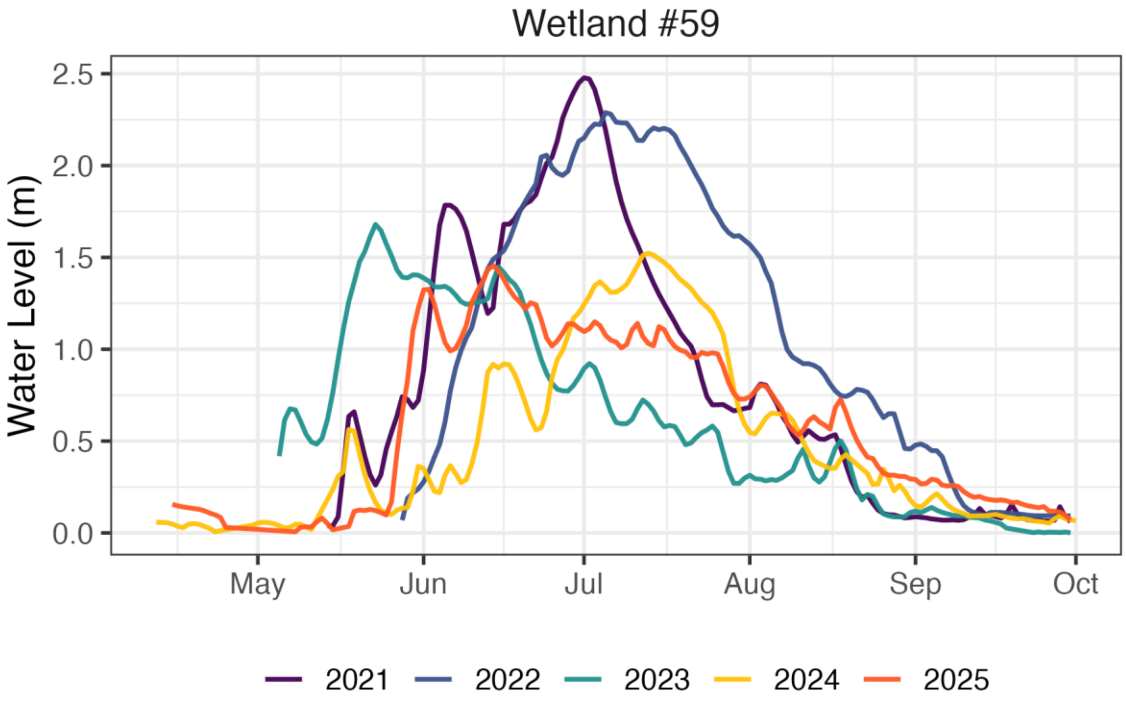

Figure A-44: Wetland #59