

H2Ohio Wetland Monitoring Program 2024 Annual Report

Volume 2, Project by Project Data Summaries and Narratives; Sampling Approaches; Nutrient Budget Calculation Methods



A wetland pool at the H2Ohio Burntwood-Langenkamp Wetland Conservation Area Project in July 2024. Photo credit: Lauren Kinsman-Costello

Please cite this document as: Lake Erie and Aquatic Research Network, Wetlands and Water Quality Group. 2025. H2Ohio Wetland Monitoring Program: 2024 Annual Progress Report, Vol. 2. Ohio Department of Natural Resources, Office of Coastal Management

The present volume (Volume 2) of the 2024 Annual Report describes the main H2Ohio Wetland Monitoring Program results from the Water Year 2024 (October 1, 2023–September 30, 2024).

There are five core chapters to this volume:

- Comparing Monitored Projects: Nutrient Function Indicators
- Project by Project data summaries and narratives
- Appendix with additional figures and narratives
- Appendix with sampling approaches
- Appendix with nutrient budget calculation methods

Note: The data and management summaries contained in this report are provisional. Every effort has been made to ensure their correctness. The H2Ohio Wetland Monitoring Program is supported by the Ohio Department of Natural Resources, the Ohio Water Development Authority, U.S. Environmental Protection Agency’s Great Lakes Restoration Initiative, and the Ohio Department of Higher Education’s Harmful Algal Bloom Research Initiative Program. The information, findings, and conclusions in this report are those of the authors and do not necessarily represent the views of the funding organizations. Any use of trade, product, or firm names is for descriptive purposes only and does not imply endorsement by the State of Ohio or U.S. Government. Contact the H2Ohio Wetland Monitoring Program prior to using these data and before citing research and management findings.

Authors

Coordination Team

Lauren Kinsman-Costello, Principal Research Lead, Kent State University
Olivia Schloegel, Research Coordinator, Kent State University
Raíssa Mendonça, Chief Data Manager, Kent State University
Kenneth J. Anderson, Postdoctoral Scholar, Kent State University
Siena Larrick, Outreach & Engagement Coordinator, Kent State University
Lauren Brown, Vegetation Research Coordinator, Bowling Green State University

Research Team Leads

Richard Becker, University of Toledo
Thomas Bridgeman, University of Toledo
Kennedy Doro, University of Toledo
Stephen J. Jacquemin, Wright State University
Nathan Manning, Heidelberg University
Ganming Liu, Bowling Green State University
Kevin McCluney, Bowling Green State University
Helen Michaels, Bowling Green State University
W. Robert Midden, Bowling Green State University
Silvia Newell, University of Michigan

Technical Co-Authors

Ahzegbobor P. Aizebeokhai, University of Toledo
Jakob Boehler, Heidelberg University
David Dean, University of Toledo
Ethan Glassman, Bowling Green State University
Connor Gluck, Kent State University
Haley Hoehn, Wright State University
Genna Hunt, Bowling Green State University
Ewan Isherwood, Bowling Green State University
Morgan Jutte, Wright State University
Corbin Kohart, Bowling Green State University
Hannah LaPoint, University of Toledo
Sang Suk Lee, Bowling Green State University
Austin Nainiger, Heidelberg University
Ishfaq Rahman, University of Toledo
Leticia Sandoval, University of Toledo
Zach Swan, University of Toledo

Contents

Authors.....	3
Contents	4
Comparing Monitored Projects: Nutrient Function Indicators	7
Nutrient Retention and Removal Indicators Measured in All Sampled Projects.....	7
Routine Water Level Monitoring.....	8
Routine Surface Water Nutrient Monitoring	9
Soil Characterization and Nutrient Status.....	13
Relationships Among Soil Parameters.....	24
Vegetation Stock at Focal Projects	27
Project by Project Summaries.....	30
Focal Projects.....	30
Brooks Park Wetland Creation & Water Quality Initiative (BROP).....	30
Burntwood-Langenkamp Wetland Conservation Area (BWLK)	43
Forder Bridge Floodplain Reconnection (FORB).....	61
Magee Marsh Turtle Creek Bay Wetland Reconnection (MAGM).....	83
Oakwoods Nature Preserve Wetland Restoration, East (OAKE) and West (OAKW)	96
Redhorse Bend Preserve Wetland Restoration (REDB).....	125
St. Joseph River Restoration (SJRE)	139
Non-Focal Projects.....	160
Coastal (University of Toledo)	160
Darby Refuge Wetland Reconnection (DARR).....	160
Duck and Otter Creek Wetland and Stream Restoration (DUCO)	174
North Ridge Hunt Club Wetland Restoration (NORR)	183
Ottawa National Wildlife Refuge Wetland Reconnection Project (OTTN)	195
Northeast (Kent State University).....	207
Trumbull Creek H2Ohio (TRUC).....	207
Northwest (Bowling Green State University).....	217
Maumee River Floodplain (MAUR).....	217
Montpelier Wetland (MONW)	227
Oak Openings Preserve Wetland Restoration (OOPR)	232
Otsego Schools' Fox-Shank Living Laboratory (OTSS).....	242
St. Joseph Confluence (SJCO).....	256

Van Order Wetland & Forest Restoration (VANO)	266
Weisgerber-Pohlman Nature Preserve (WEIP)	276
Southwest (Wright State University)	286
Williamsburg Wetland Treatment System (EFLA)	286
Indian Creek-Hoffman Wetland and Stream Restoration (INDC)	288
Mercer Wetland Complex Restoration (MERW)	301
Springcreek Confluence Off-Channel Wetlands (SPRC)	314
Tipp City Off-Channel Wetlands (TIPC)	327
Walnut Creek Treatment Wetland Restoration (WALC)	338
West Central (Heidelberg University)	349
Andreoff Wetland Restoration (ANDW)	349
Blanchard River Floodplain Restoration (BLAR)	358
Bright Conservation Area Wetland Restoration Initiative (BRIC)	369
Buehler Farms Treatment Wetland (BUEF)	379
Clary-Boulee-McDonald (CBMC)	383
Fruth Wetland Nature Preserve (FRUW)	392
Sandusky River Headwaters Preserve Wetland and Habitat Restoration (SRHE)	405
Sugarcamp 7 Blanchard Habitat (SUGB)	419
Upper Blanchard River Watershed Project (UPPB)	431
Appendix I: Additional Figures and Narratives	440
Focal Projects	440
Non-Focal Projects	463
Appendix II: Sampling Approaches	494
Focal Projects	494
Non-Focal Projects	502
Coastal (University of Toledo)	502
West Central (Heidelberg University)	503
Northwest (Bowling Green State University)	510
Southwest (Wright State University)	512
Northeast (Kent State University)	514
Focal and Non-Focal Projects: Hydrogeophysics	516
Focal Projects: 3-D Hydrodynamic Modeling	516
Focal Projects: Vegetation	517

Definitions of Vegetation Terms	518
Summary of Vegetation Nutrient Stock Calculations.....	521
Appendix III: Nutrient Budget Calculations.....	522
Runoff Prevention Method Used Across Projects	522
Focal Project Nutrient Budget Methods	523
Brooks Park Wetland Creation & Water Quality Initiative	523
Burntwood-Langenkamp Wetland Conservation Area.....	524
Forder Bridge Floodplain Restoration	526
Oakwoods Nature Preserve Wetland Restoration Project East and West.....	531
Magee Marsh Turtle Creek Bay Wetland Reconnection	535
Redhorse Bend Preserve Wetland Restoration	543
St. Joseph River Farm and Floodplain Restoration Project	546
Non-Focal Project Nutrient Budget Methods	550
Montpelier Wetland Restoration.....	550
Springcreek Confluence Off-Channel Wetlands	550
Tipp City Off-Channel Wetlands.....	554
Williamsburg Wetland.....	556
Walnut Creek Treatment Wetland Restoration.....	563

Comparing Monitored Projects: Nutrient Function Indicators

Nutrient Retention and Removal Indicators Measured in All Sampled Projects

To assess nutrient function across all monitored wetland Projects, researchers measure wetland water level, surface water nutrient concentration, and basic soil nutrient status. These measurements provide underlying information about the average and range of hydrologic conditions and nutrients within and among Projects. In Water Year 2024, Wetland Monitoring Program (WMP) researchers monitored 45 H2Ohio Projects (Figure 1). Affiliate researchers monitored the Montpelier Project's water and calculated the subsequent nutrient budget; the WMP collected soil data. Two additional Projects, the Williamsburg Project and the Duck and Otter Creek Project, were monitored entirely by partners external to the WMP. Of these 47 total monitored Projects, 35 had sufficient data for a Project summary below.



Figure 1. Map displaying all 45 wetland Projects monitored by the H2Ohio Wetland Monitoring Program in Water Year 2024 (Oct 1, 2023–Sep 30, 2024) and their respective HUC8 watersheds. Colors represent the geographic areas sampled by specific base crews, as shown in the legend (BG = Bowling Green State University, HU = Heidelberg University, KS = Kent State University, UT = University of Toledo, WS = Wright State University). Project names, map labels, and 4-letter codes are indicated in the associated table. Note: Map Labels marked with an asterisk (*) indicate Projects that are sampled by affiliate researchers and not included the Project Name list in the legend: 36 (Duck and Otter Creek Wetland and Stream Restoration), 63 (Williamsburg Wetland Treatment System).

Routine Water Level Monitoring

Surface water depths varied from 0 to 2.5 m within 43 H2Ohio wetland Projects from 2021 to 2024 (Figure 2). Most surface water samples were collected from locations with less than 1 m of standing water. Across monitored Projects, most wetland features experienced some degree of variable inundation, in which wetland pools, streams, and other features held standing water for part of the year, typically in winter and spring, and dried considerably by the end of the growing season and into the fall.

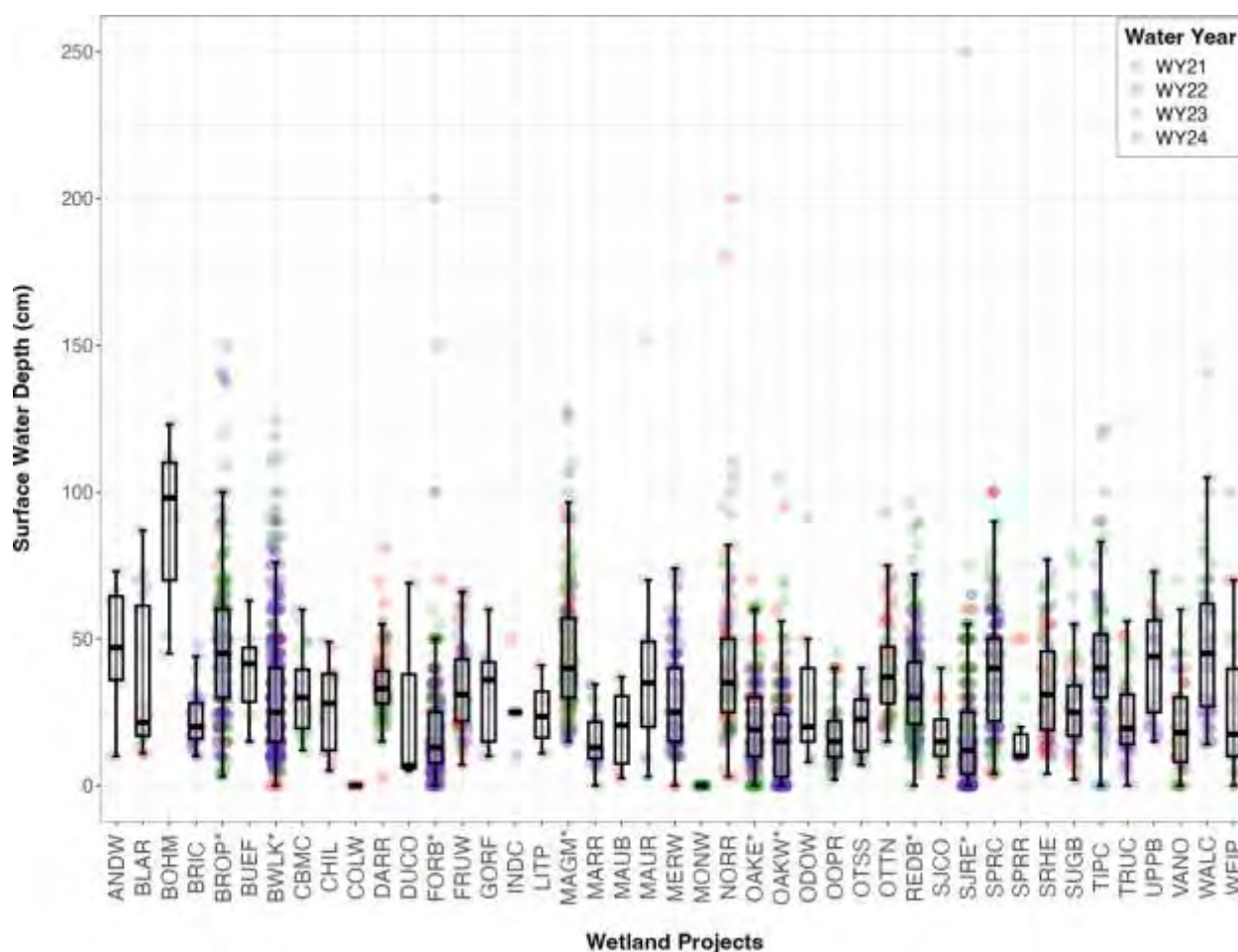


Figure 2. Boxplots displaying the variability in discrete, manually measured surface water depth (in cm) across wetland Projects. For each boxplot, the thick line represents the median (middle) surface water depth across all measurements. The boxes indicate the value range for 50% of the measured depths and the whiskers show the spread of depth values that are outside the 50% of the data points. Each overlying point represents individual surface water depth measurements. Different colors denote the water year (WY; Oct 1–Sep 30) in which the measurements were collected, as shown in the legend. The asterisk (*) denotes an intensively monitored Focal Project with greater sampling effort. For more information on the wetland Projects, please refer to Figure 1.

Routine Surface Water Nutrient Monitoring

Phosphorus Concentrations

Total phosphorus (TP) concentrations in surface water ranged from below detection (i.e., < 0.001–0.01 mg phosphorus (P)/L, depending on the analytical instrument) to nearly 5 mg P/L (Figure 4).

The concentration of dissolved reactive phosphorus (DRP) in surface water samples collected over four years of monitoring ranged from below the limit of detection (i.e., < 0.001–0.009 mg P/L, depending on the analytical instrument) to over 2 mg P/L (Figure 3). Higher DRP concentrations (> 0.25 mg/L) were measured most frequently in samples collected during hydrologic events (e.g., storm events).

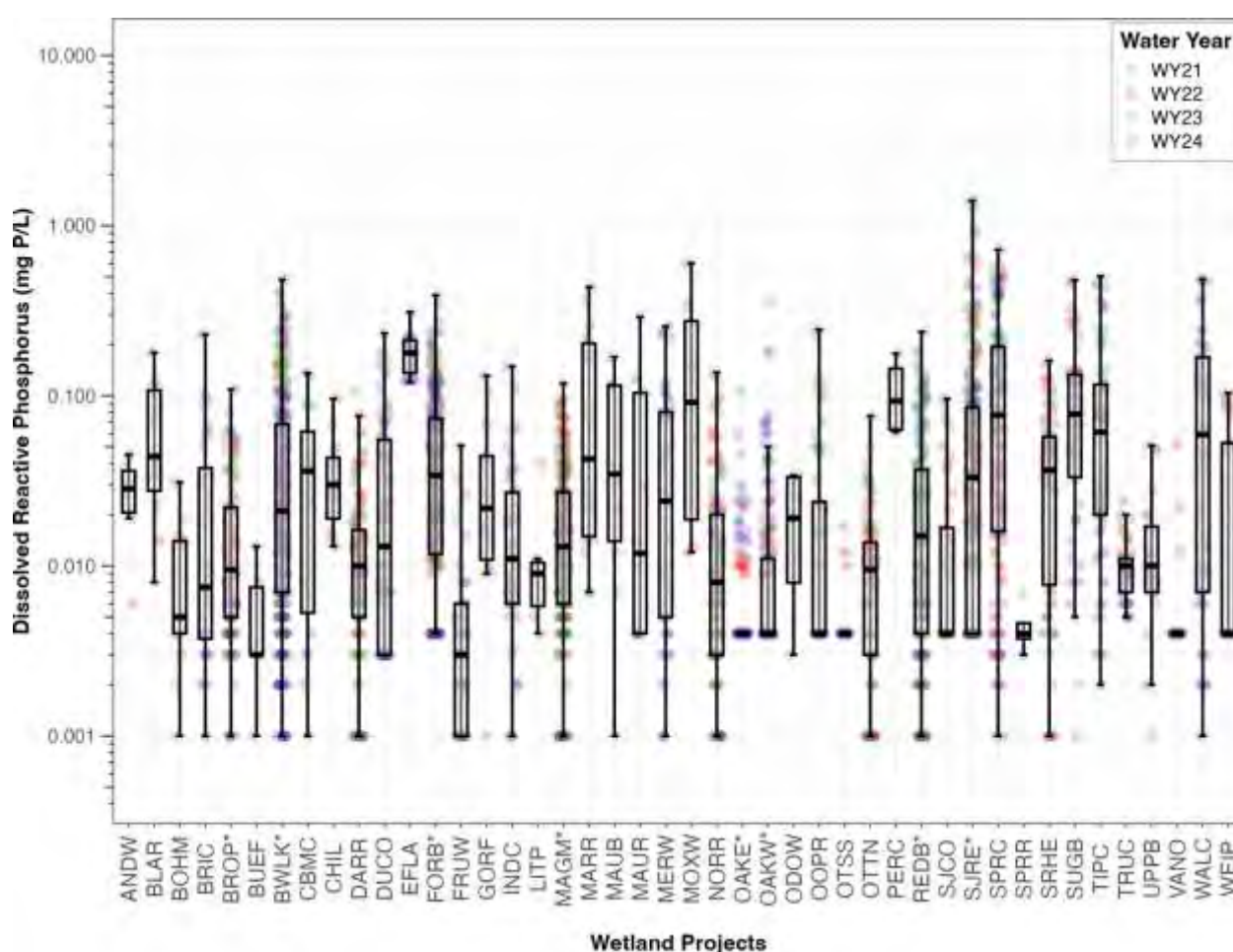


Figure 3. Boxplots displaying the variability in dissolved reactive phosphorus (DRP) concentration in surface water samples across wetland Projects. For each boxplot, the thick line represents the median (middle) DRP concentration across all measurements. The boxes indicate the value range for 50% of the measured DRP concentrations and the whiskers show the spread of DRP concentration values that are outside the 50% of the data points. Each overlying point represents individual DRP concentration measurements. Different colors denote the water year (WY; Oct 1–Sep 30) in which the measurements were collected, as shown in the legend. The asterisk (*) denotes an intensively monitored Focal Project with

greater sampling effort. For more information on the wetland Projects, please refer to Figure 1. Note the log transformation on the y-axis.

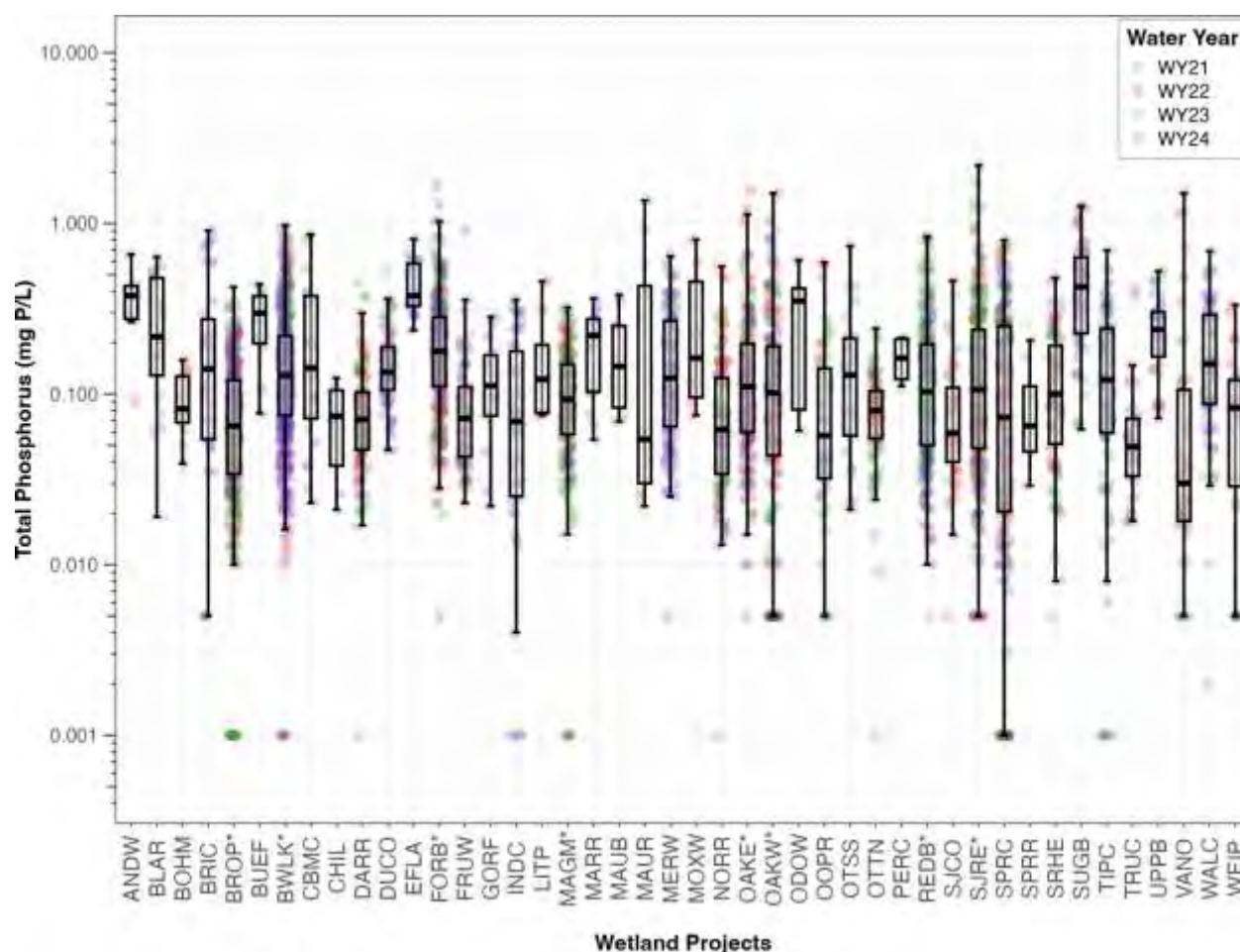


Figure 4. Boxplots displaying the variability in total phosphorus (TP) concentration in surface water samples across wetland Projects. For each boxplot, the thick line represents the median (middle) TP concentration across all measurements. The boxes indicate the value range for 50% of the measured TP concentrations and the whiskers show the spread of TP concentration values that are outside the 50% of the data points. Each overlying point represents individual TP concentration measurements. Different colors denote the water year (WY; Oct 1–Sep 30) in which the measurements were collected, as shown in the legend. The asterisk (*) denotes an intensively monitored Focal Project with greater sampling effort. For more information on the wetland Projects, please refer to Figure 1. Note the log transformation on the y-axis.

Nitrogen Concentrations

The combined nitrite+nitrate (NO_x) concentrations in surface water samples ranged from below detection limit (i.e., < 0.003–0.04 mg N/L, depending on the analytical instrument) to almost 50 mg N/L (Figure 5). In Water Year 2024, the highest NO_x concentrations were measured in water samples from Burntwood-Langenkamp Wetland Conservation Area (Burntwood-Langenkamp), Bright Conservation Area Wetland Restoration Initiative, and St. Joseph River Restoration (St. Joseph Restoration) Projects. Total ammonium nitrogen (NH_4 -

N) concentrations ranged from below detection (i.e., < 0.001–0.02 mg N/L, depending on the analytical instrument) to about 10 mg N/L (Figure 6), and the highest concentrations were detected in St. Joseph Restoration, Mercer Wetland Complex Restoration, and Duck and Otter Creek Wetland and Stream Restoration Projects. Total nitrogen (TN) concentration in surface water samples ranged from below detection (i.e., < 0.001–0.05 mg N/L, depending on the analytical instrument) to nearly 30 mg N/L (Figure 7) in the high-nitrate samples from Burntwood-Langenkamp (BWLK).

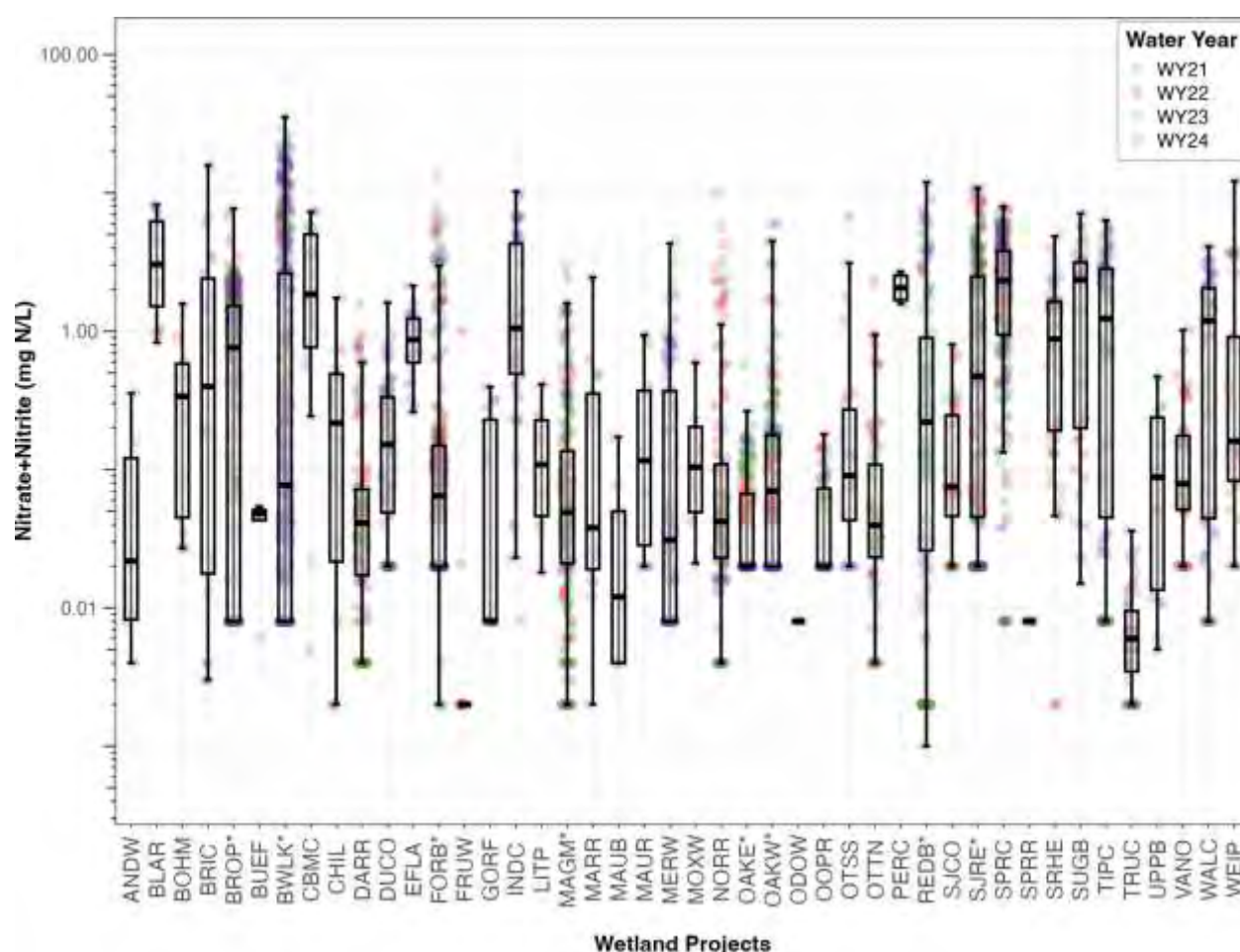


Figure 5. Boxplots displaying the variability in nitrite+nitrate (NO_x) concentrations in surface water samples across wetland Projects. For each boxplot, the thick line represents the median (middle) NO_x concentration across all measurements. The boxes indicate the value range for 50% of the measured NO_x concentrations and the whiskers show the spread of NO_x concentration values that are outside the 50% of the data points. Each overlying point represents individual NO_x concentration measurements. Different colors denote the water year (WY; Oct 1–Sep 30) in which the measurements were collected, as shown in the legend. The asterisk (*) denotes an intensively monitored Focal Project with greater sampling effort. For more information on the wetland Projects, please refer to Figure 1. Note the log transformation on the y-axis.

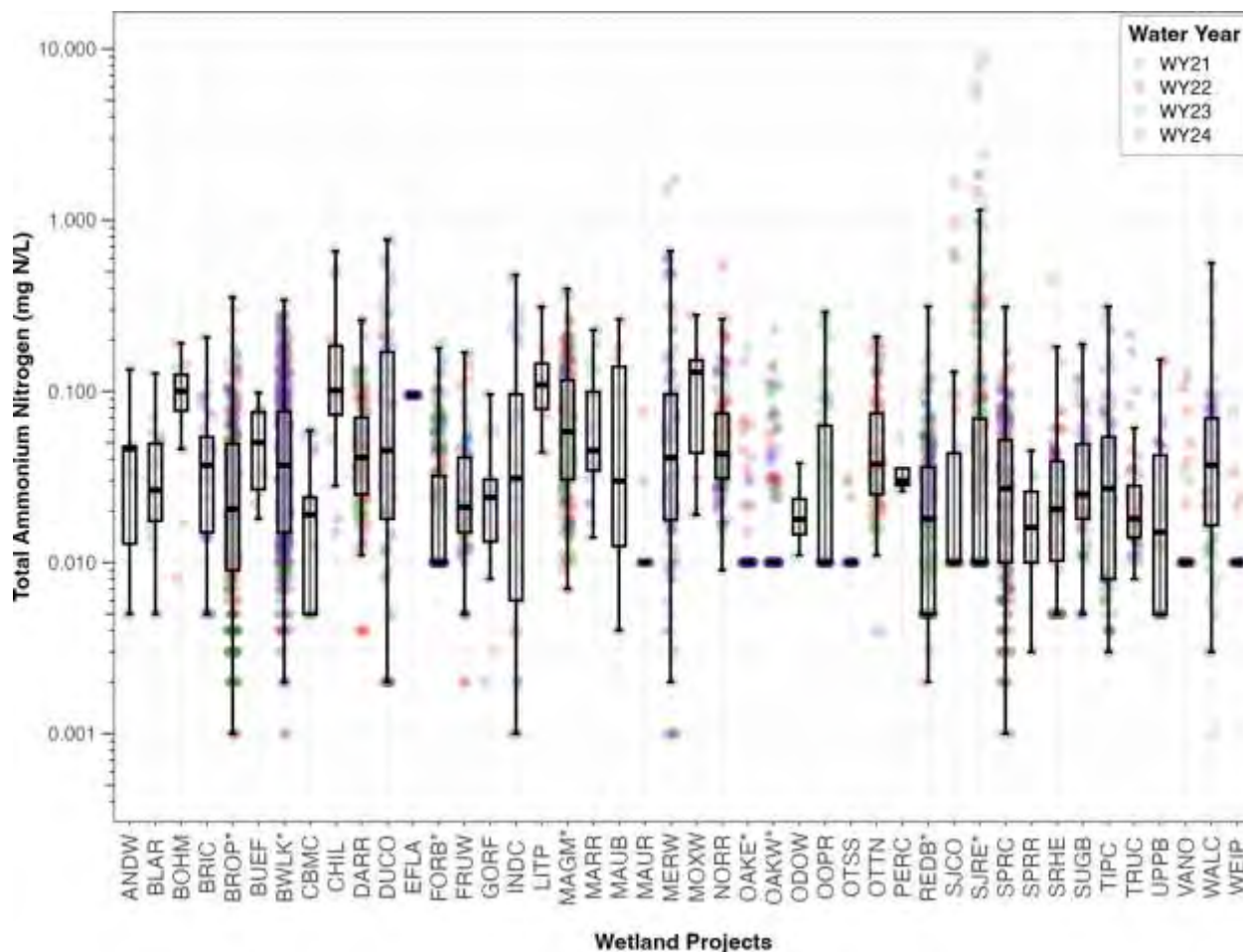


Figure 6. Boxplots displaying the variability in total ammonium nitrogen ($\text{NH}_4\text{-N}$) concentration in surface water samples across wetland Projects. For each boxplot, the thick line represents the median (middle) $\text{NH}_4\text{-N}$ concentration across all measurements. The boxes indicate the value range for 50% of the measured $\text{NH}_4\text{-N}$ concentrations and the whiskers show the spread of $\text{NH}_4\text{-N}$ concentration values that are outside the 50% of the data points. Each overlying point represents individual $\text{NH}_4\text{-N}$ concentration measurements. Different colors denote the water year (WY; Oct 1–Sep 30) in which the measurements were collected, as shown in the legend. The asterisk (*) denotes an intensively monitored Focal Project with greater sampling effort. For more information on the wetland Projects, please refer to Figure 1. Note the log transformation on the y-axis.

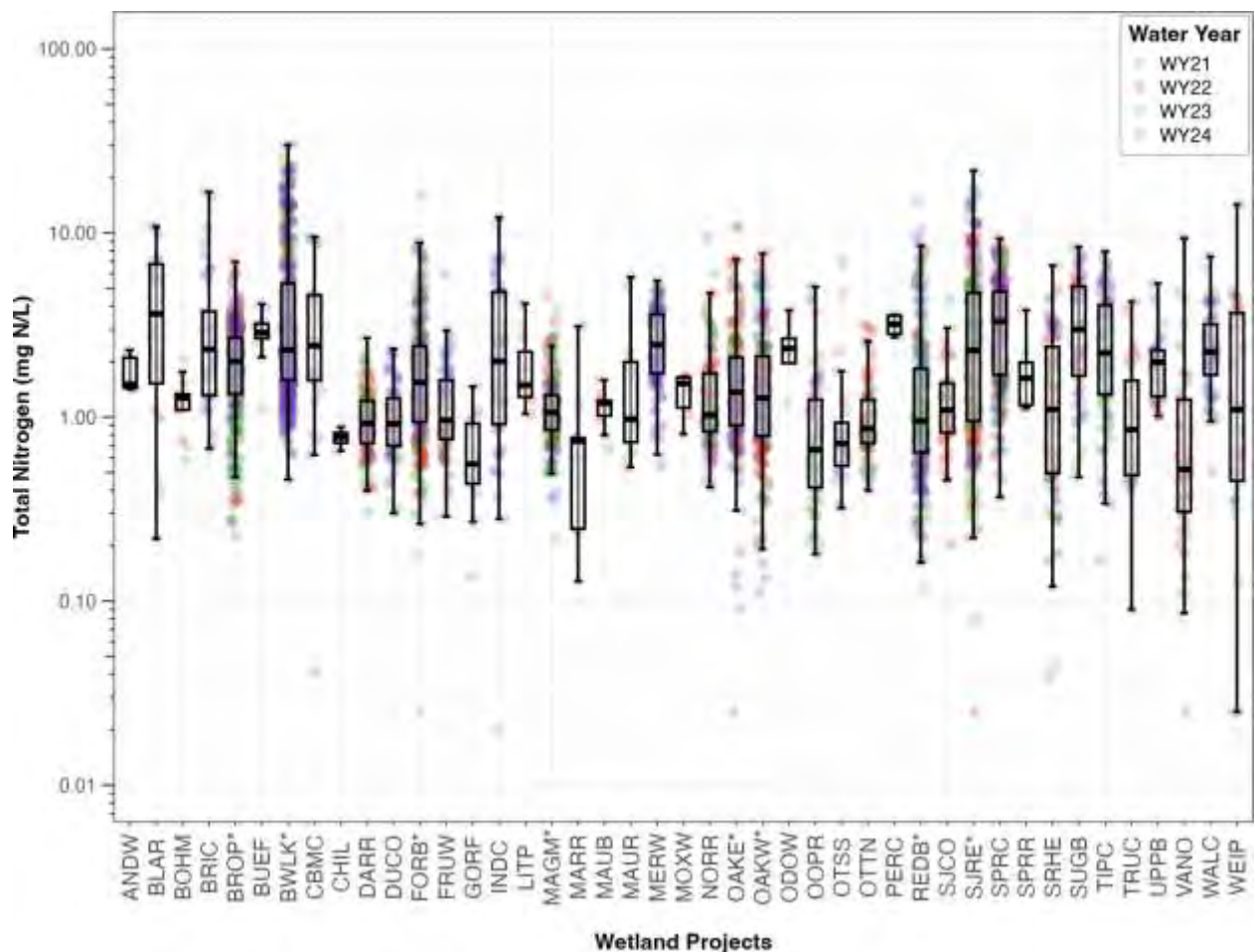


Figure 7. Boxplots displaying the variability in total nitrogen (TN) concentration in surface water samples across wetland Projects. For each boxplot, the thick line represents the median (middle) TN concentration across all measurements. The boxes indicate the value range for 50% of the measured TN concentrations and the whiskers show the spread of TN concentration values that are outside the 50% of the data points. Each overlying point represents individual TN concentration measurements. Different colors denote the water year (WY; Oct 1–Sep 30) in which the measurements were collected, as shown in the legend. The asterisk (*) denotes an intensively monitored Focal Project with greater sampling effort. For more information on the wetland Projects, please refer to Figure 1. Note the log transformation on the y-axis.

Soil Characterization and Nutrient Status

Soil Phosphate Sorption Capacity (SPSC)

Soil phosphate sorption capacity (SPSC) ranged from -117 to 403 mg phosphorus/kg soil across all H2Ohio wetland Projects. Eight different Projects had at least one sample with a negative SPSC value, however only two Projects had greater than 20% of all soil samples with negative SPSC values (Figure 8). Soils in most of the monitored wetlands have the potential to sorb additional phosphate (i.e., positive SPSC values), although a few indicate a risk of releasing phosphate (i.e., negative SPSC values). Out of 1876 soil samples, only 87 (5%) indicated a risk of phosphate release ($\text{SPSC} < 0 \text{ mg/kg}$), while 1186 samples (63%) indicated a low but positive sorption capacity ($0 \text{ mg/kg} < \text{SPSC} < 100 \text{ mg/kg}$). The variation

in concentration of soil parameters used in the calculation of SPSC (i.e., Mehlich-3-extracted concentrations of soil aluminum, iron, and phosphorus) are shown below (Figure 9, Figure 10, Figure 11), along with geochemical characteristics, like soil electrical conductivity (Figure 12) and soil pH (Figure 13). Soil pH and electrical conductivity can modify the biogeochemical environment and potentially affect the sorption capacity of soils. Soil pH and electrical conductivity influence soil sorption capacity and are used by the H2Ohio Wetland Monitoring Program as general indicators of soil geochemical conditions. Additionally, soil pH and electrical conductivity are metrics that can be compared to specialty crew data (i.e., hydrogeophysics results) to 1) scale up point measurements of nutrients across the whole ecosystem, and 2) assess the extent to which these simpler soil metrics can be a proxy for the more resource-intensive collection of detailed soil geophysical properties.

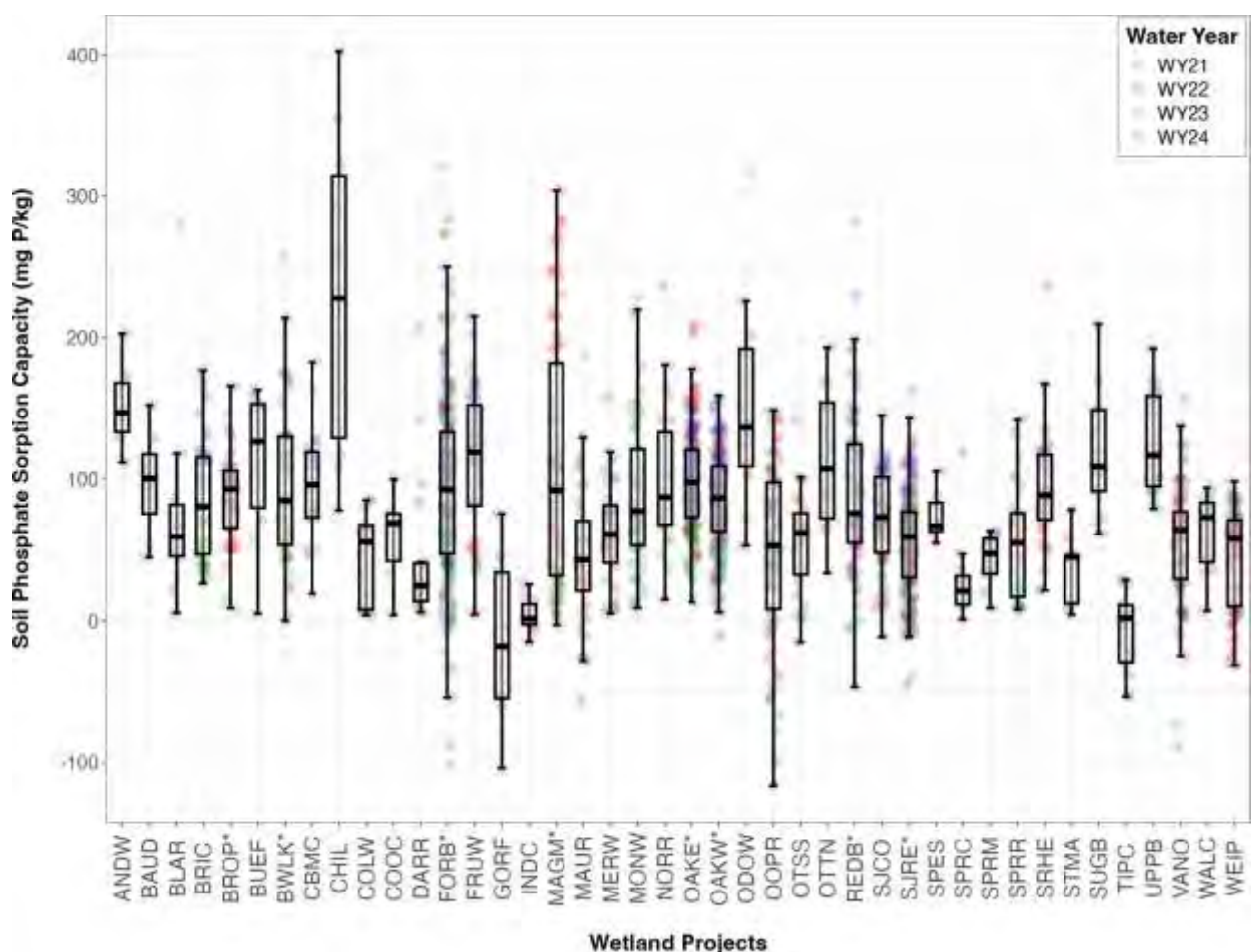


Figure 8. Boxplots displaying the variability in soil phosphate sorption capacity (SPSC) values in soil samples (0–5 cm) across wetland Projects. For each boxplot, the thick line represents the median (middle) SPSC value across all measurements. The boxes indicate the value range for 50% of the measured SPSC values and the whiskers show the spread of SPSC values that are outside the 50% of the data points. Each overlying point represents individual SPSC measurements. Different colors denote the water year (WY; Oct 1–Sep 30) in which the measurements were collected, as shown in the legend. The asterisk (*) denotes an intensively monitored Focal Project with greater sampling effort. For more information on the wetland Projects, please refer to Figure 1.

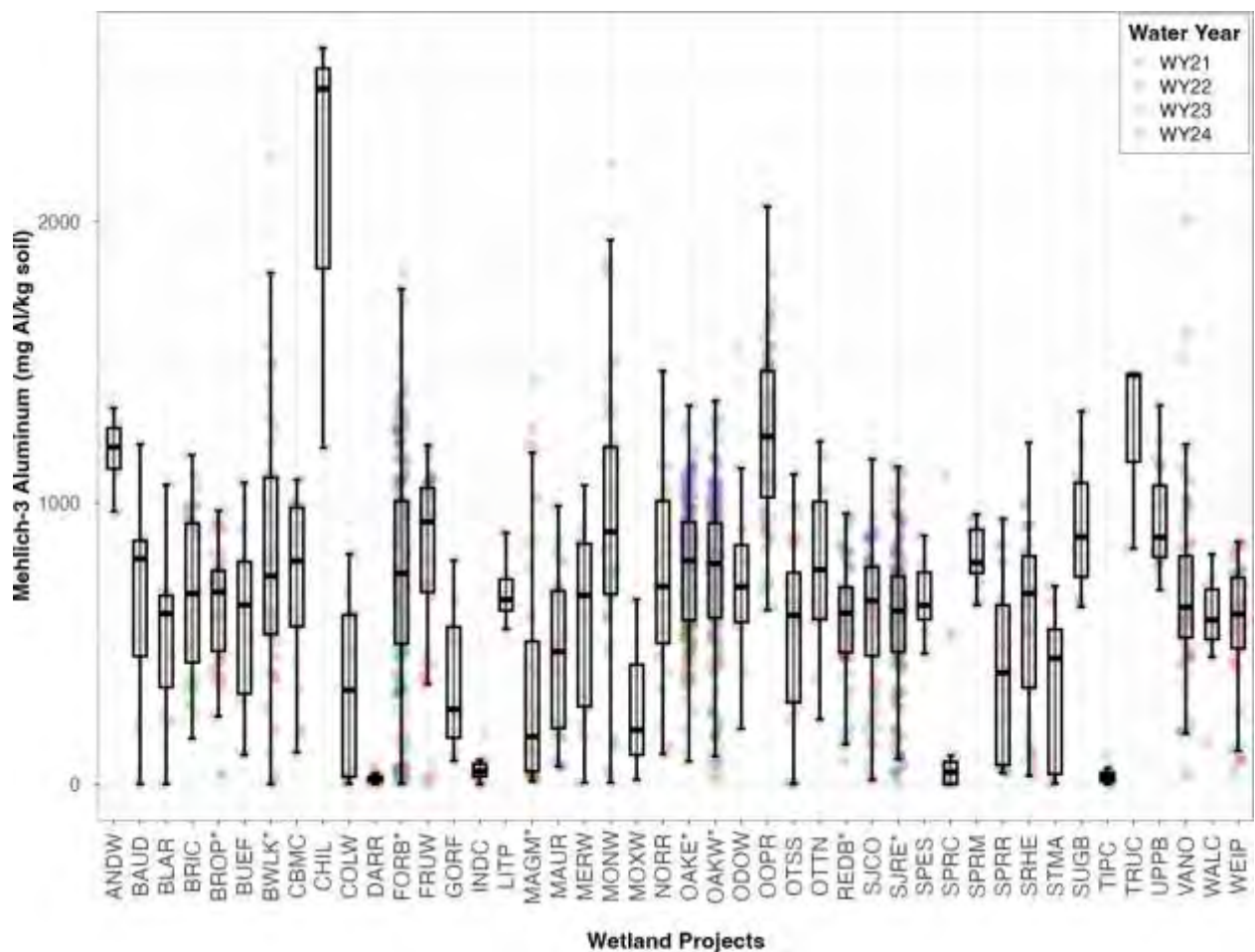


Figure 9. Boxplots displaying the variability in soil aluminum (Al) concentration from Mehlich-3 extractions (M3) of soil samples (0–5 cm) across wetland Projects. For each boxplot, the thick line represents the median (middle) M3-Al concentration across all measurements. The boxes indicate the value range for 50% of the measured M3-Al concentrations and the whiskers show the spread of M3-Al concentration values that are outside the 50% of the data points. Each overlying point represents individual M3-Al concentration measurements. Different colors denote the water year (WY; Oct 1–Sep 30) in which the measurements were collected, as shown in the legend. The asterisk (*) denotes an intensively monitored Focal Project with greater sampling effort. For more information on the wetland Projects, please refer to Figure 1.

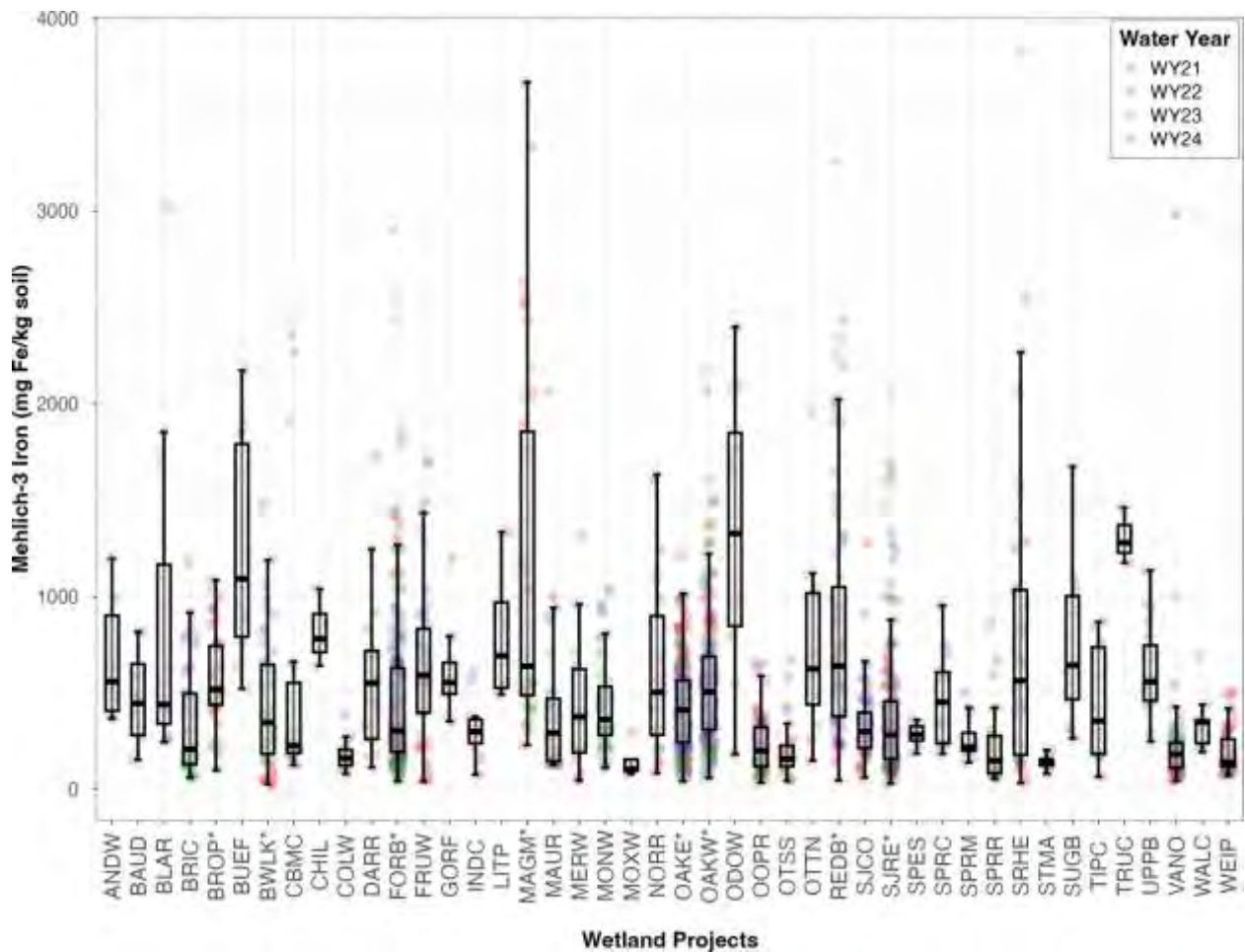


Figure 10. Boxplots displaying the variability in soil iron (Fe) concentration from Mehlich-3 extractions (M3) of soil samples (0–5 cm) across wetland Projects. For each boxplot, the thick line represents the median (middle) M3-Fe concentration across all measurements. The boxes indicate the value range for 50% of the measured M3-Fe concentrations and the whiskers show the spread of M3-Fe concentration values that are outside the 50% of the data points. Each overlying point represents individual M3-Fe concentration measurements. Different colors denote the water year (WY; Oct 1–Sep 30) in which the measurements were collected, as shown in the legend. The asterisk (*) denotes an intensively monitored Focal Project with greater sampling effort. For more information on the wetland Projects, please refer to Figure 1.

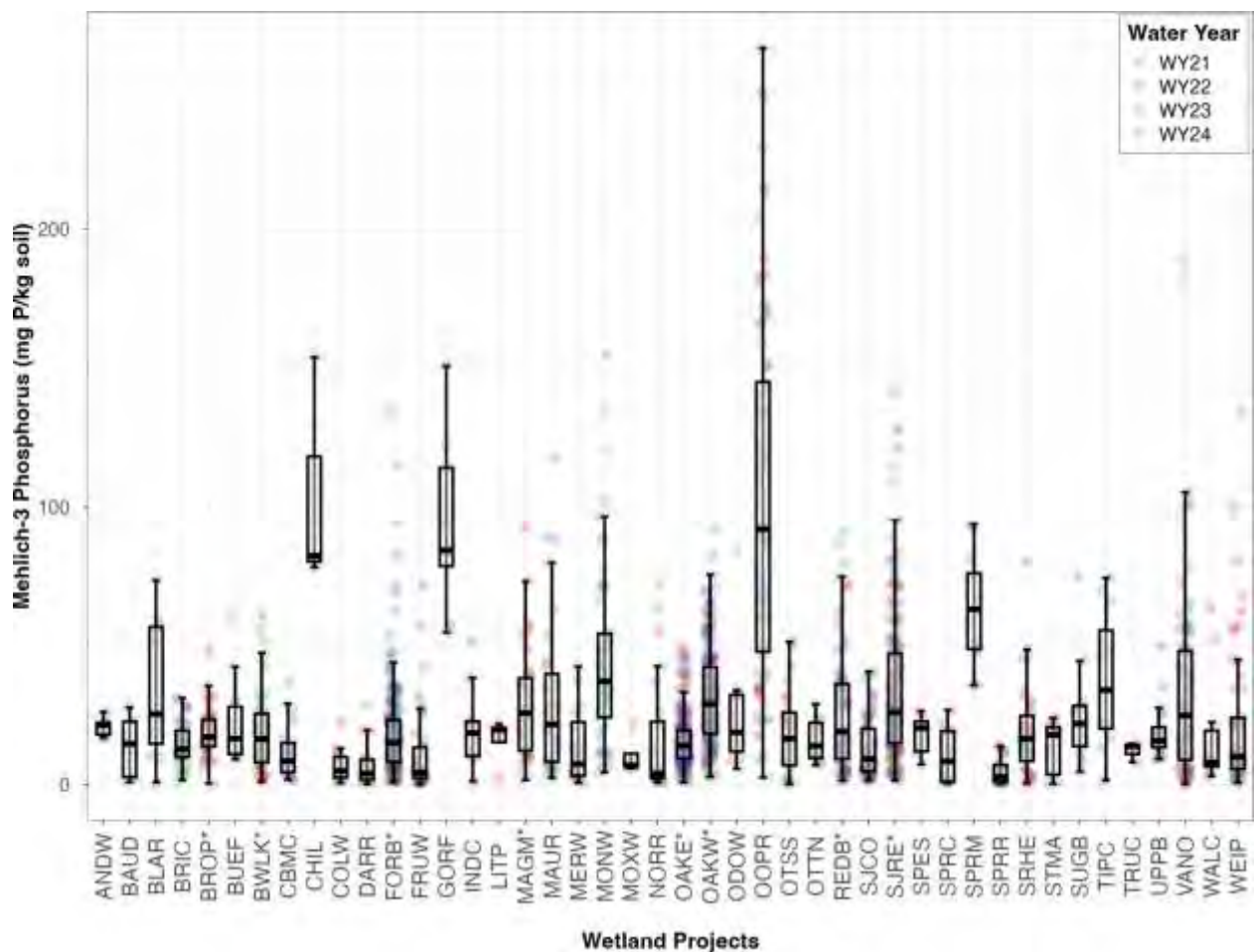


Figure 11. Boxplots displaying the variability in soil phosphorus (P) concentration from Mehlich-3 (M3) extractions of soil samples (0–5 cm) across wetland Projects. For each boxplot, the thick line represents the median (middle) M3-P concentration across all measurements. The boxes indicate the value range for 50% of the measured M3-P concentrations and the whiskers show the spread of M3-P concentration values that are outside the 50% of the data points. Each overlying point represents individual M3-P concentration measurements. Different colors denote the water year (WY; Oct 1–Sep 30) in which the measurements were collected, as shown in the legend. The asterisk (*) denotes an intensively monitored Focal Project with greater sampling effort. For more information on the wetland Projects, please refer to Figure 1.

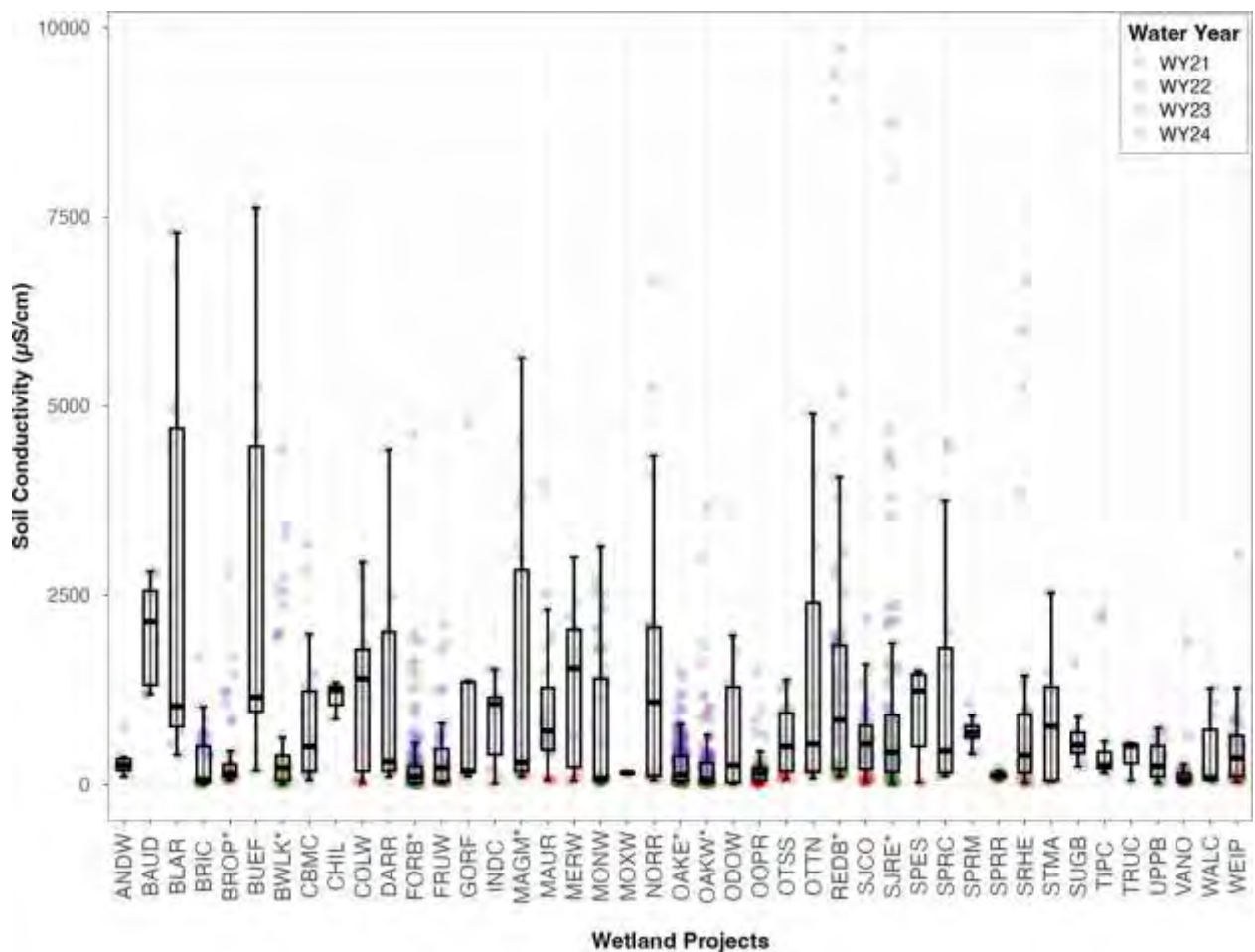


Figure 12. Boxplots displaying the variability in soil conductivity measured in soil samples (0–5 cm) across wetland Projects. For each boxplot, the thick line represents the median (middle) soil conductivity across all measurements. The boxes indicate the value range for 50% of the measured soil conductivity values and the whiskers show the spread of soil conductivity values that are outside the 50% of the data points. Each overlying point represents individual soil conductivity measurements. Different colors denote the water year (WY; Oct 1–Sep 30) in which the measurements were collected, as shown in the legend. The asterisk (*) denotes an intensively monitored Focal Project with greater sampling effort. For more information on the wetland Projects, please refer to Figure 1.

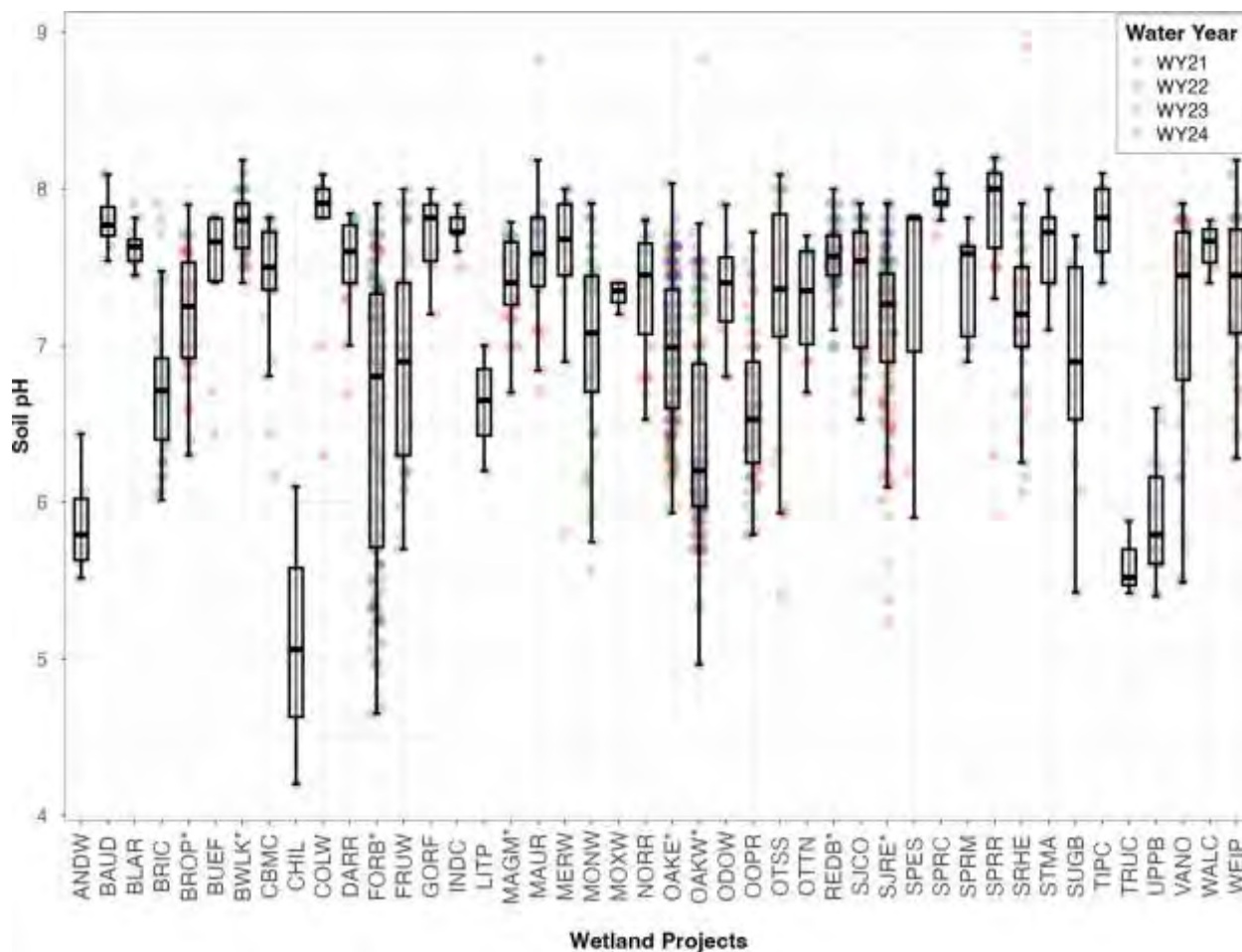


Figure 13. Boxplots displaying the variability in soil pH measured in soil samples (0–5 cm) across wetland Projects. For each boxplot, the thick line represents the median (middle) soil pH across all measurements. The boxes indicate the value range for 50% of the measured soil pH values and the whiskers show the spread of soil pH values that are outside the 50% of the data points. Each overlying point represents individual soil pH measurements. Different colors denote the water year (WY; Oct 1–Sep 30) in which the measurements were collected, as shown in the legend. The asterisk (*) denotes an intensively monitored Focal Project with greater sampling effort. For more information on the wetland Projects, please refer to Figure 1.

Soil Nutrient Content

Total soil nutrient content ranged from 14 to 10,800 mg nitrogen/kg soil for total nitrogen (TN; Figure 14) and from 3 to 2,800 mg phosphorus/kg soil for total phosphorus (TP; Figure 15) across all wetland Projects. Easily mobilizable (i.e., water-extractable) soil nutrients

varied considerably across Projects for total ammonium nitrogen (WEx-NH₄-N; Figure 16), nitrite+nitrate (WEx-NO_x; Figure 17), and phosphate (WEx-PO₄; Figure 18) concentrations.

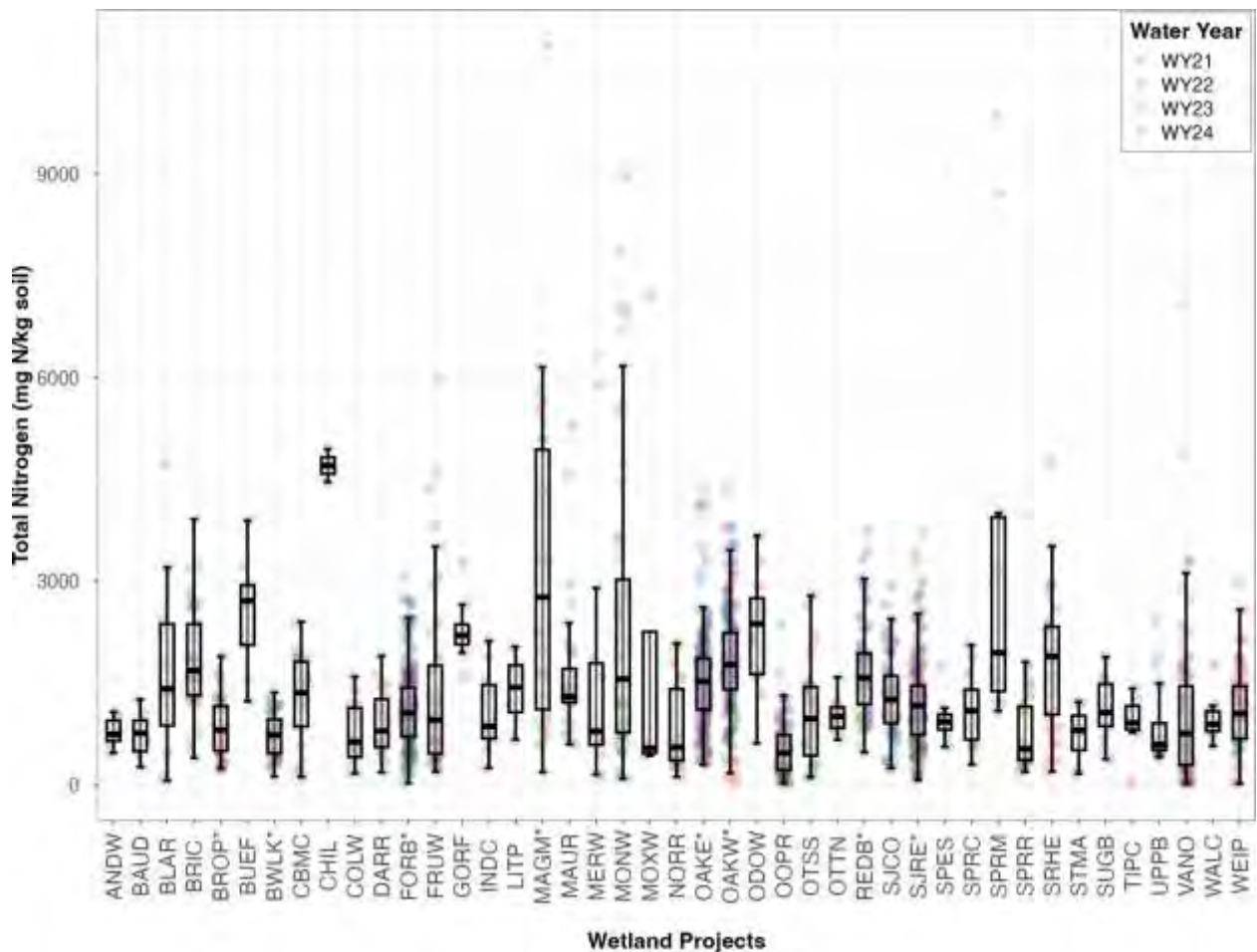


Figure 14. Boxplots displaying the variability in soil total nitrogen (TN) concentration measured in soil samples (0–5 cm) across wetland Projects. For each boxplot, the thick line represents the median (middle) TN concentration across all measurements. The boxes indicate the value range for 50% of the measured TN concentrations and the whiskers show the spread of TN concentration values that are outside the 50% of the data points. Each overlying point represents individual TN concentration measurements. Different colors denote the water year (WY; Oct 1–Sep 30) in which the measurements were collected, as shown in the legend. The asterisk (*) denotes an intensively monitored Focal Project with greater sampling effort. For more information on the wetland Projects, please refer to Figure 1.

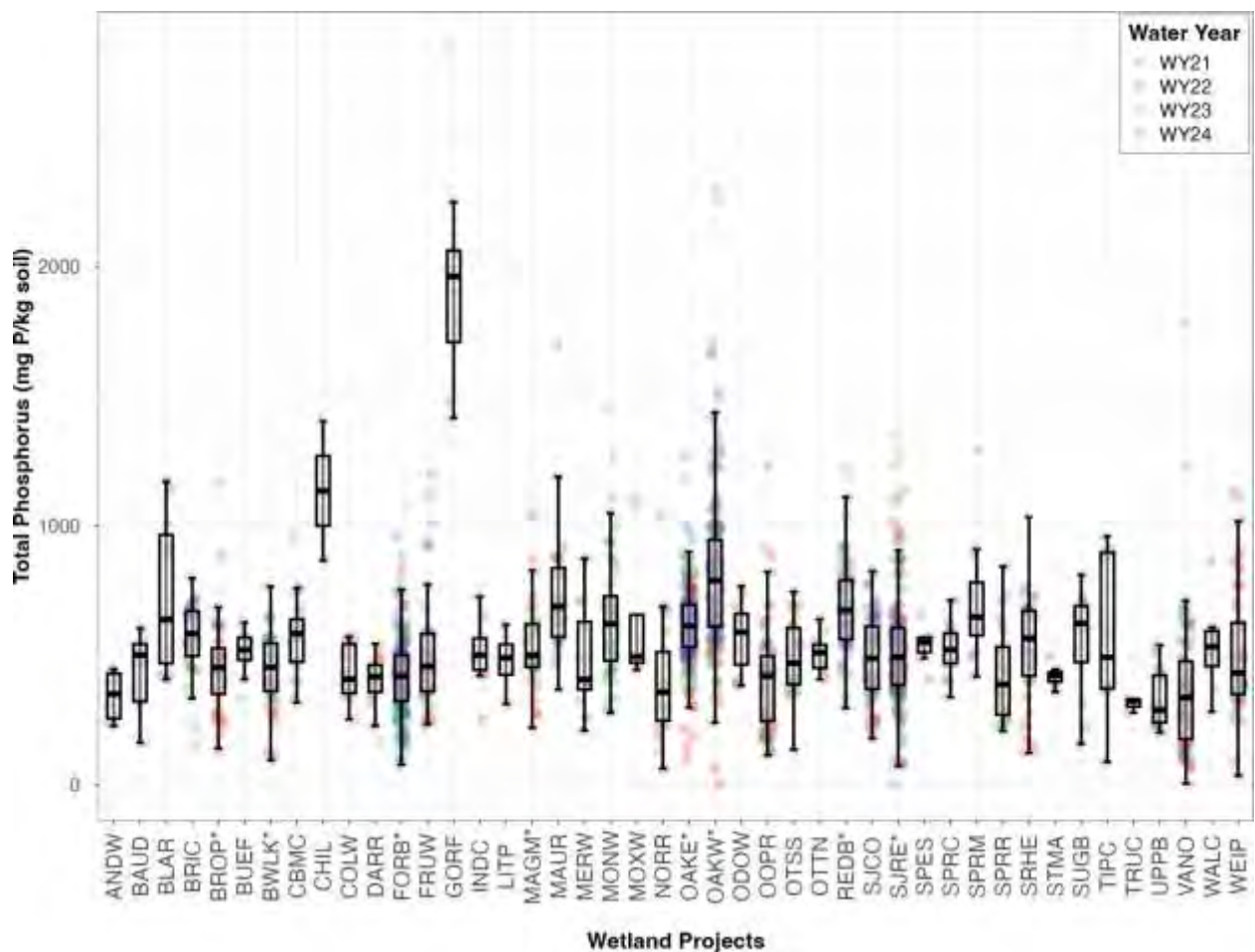


Figure 15. Boxplots displaying the variability in soil total phosphorus (TP) concentration measured in soil samples (0–5 cm) across wetland Projects. For each boxplot, the thick line represents the median (middle) TP concentration across all measurements. The boxes indicate the value range for 50% of the measured TP concentrations and the whiskers show the spread of TP concentration values that are outside the 50% of the data points. Each overlying point represents individual TP concentration measurements. Different colors denote the water year (WY; Oct 1–Sep 30) in which the measurements were collected, as shown in the legend. The asterisk (*) denotes an intensively monitored Focal Project with greater sampling effort. For more information on the wetland Projects, please refer to Figure 1.

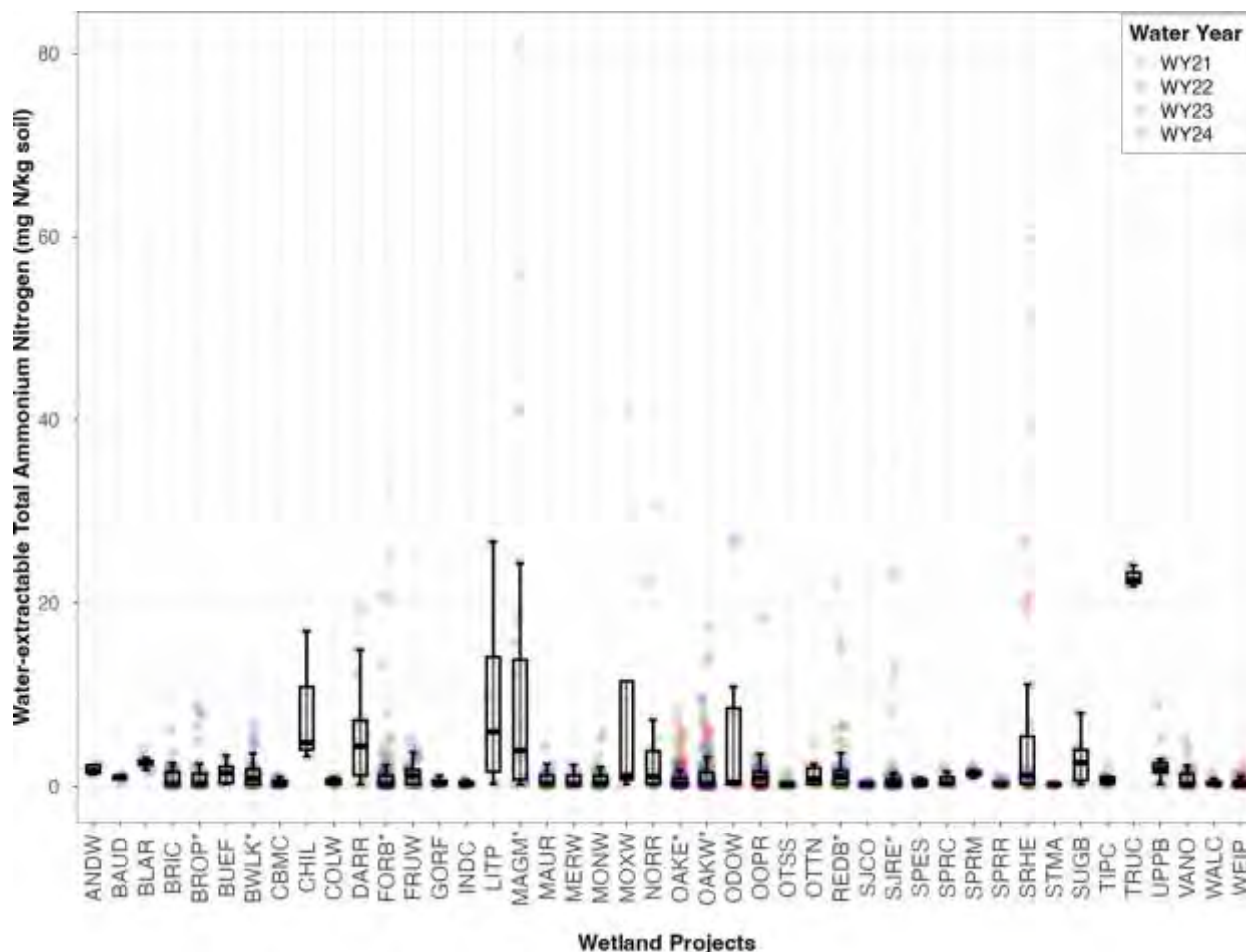


Figure 16. Boxplots displaying the variability in easily mobilizable (water-extractable) soil total ammonium nitrogen ($\text{NH}_4\text{-N}$) concentration measured in soil samples (0–5 cm) across wetland Projects. For each boxplot, the thick line represents the median (middle) $\text{NH}_4\text{-N}$ concentration across all measurements. The boxes indicate the value range for 50% of the measured $\text{NH}_4\text{-N}$ concentrations and the whiskers show the spread of $\text{NH}_4\text{-N}$ concentration values that are outside the 50% of the data points. Each overlying point represents individual $\text{NH}_4\text{-N}$ concentration measurements. Different colors denote the water year (WY; Oct 1–Sep 30) in which the measurements were collected, as shown in the legend. The asterisk (*) denotes an intensively monitored Focal Project with greater sampling effort. For more information on the wetland Projects, please refer to Figure 1.

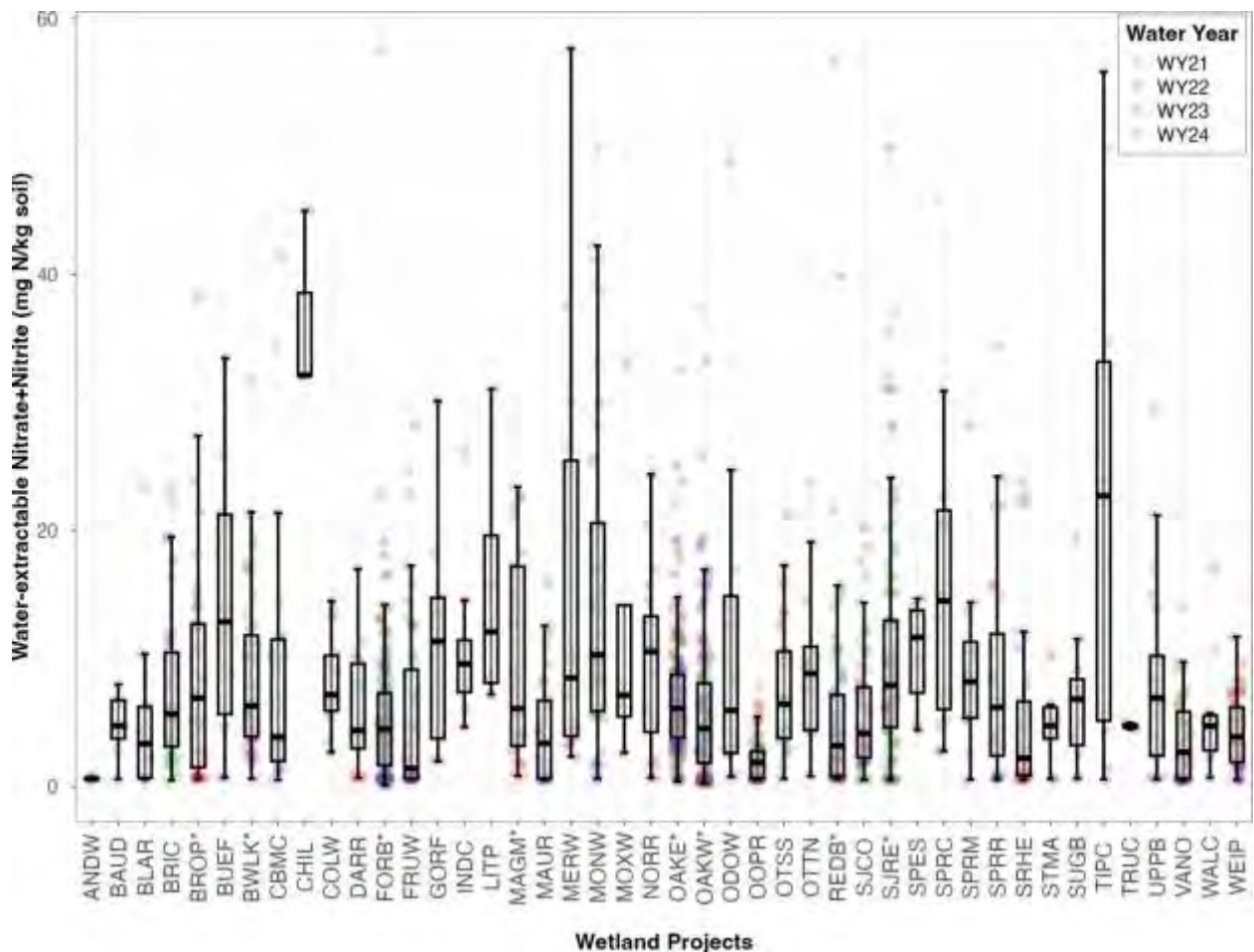


Figure 17. Boxplots displaying the variability in easily mobilizable (water-extractable) soil nitrate and nitrate (NO_x) concentrations measured in soil samples (0–5 cm) across wetland Projects. For each boxplot, the thick line represents the median (middle) NO_x concentration across all measurements. The boxes indicate the value range for 50% of the measured NO_x concentrations and the whiskers show the spread of NO_x concentration values that are outside the 50% of the data points. Each overlying point represents individual NO_x concentration measurements. Different colors denote the water year (WY; Oct 1–Sep 30) in which the measurements were collected, as shown in the legend. The asterisk (*) denotes an intensively monitored Focal Project with greater sampling effort. For more information on the wetland Projects, please refer to Figure 1.

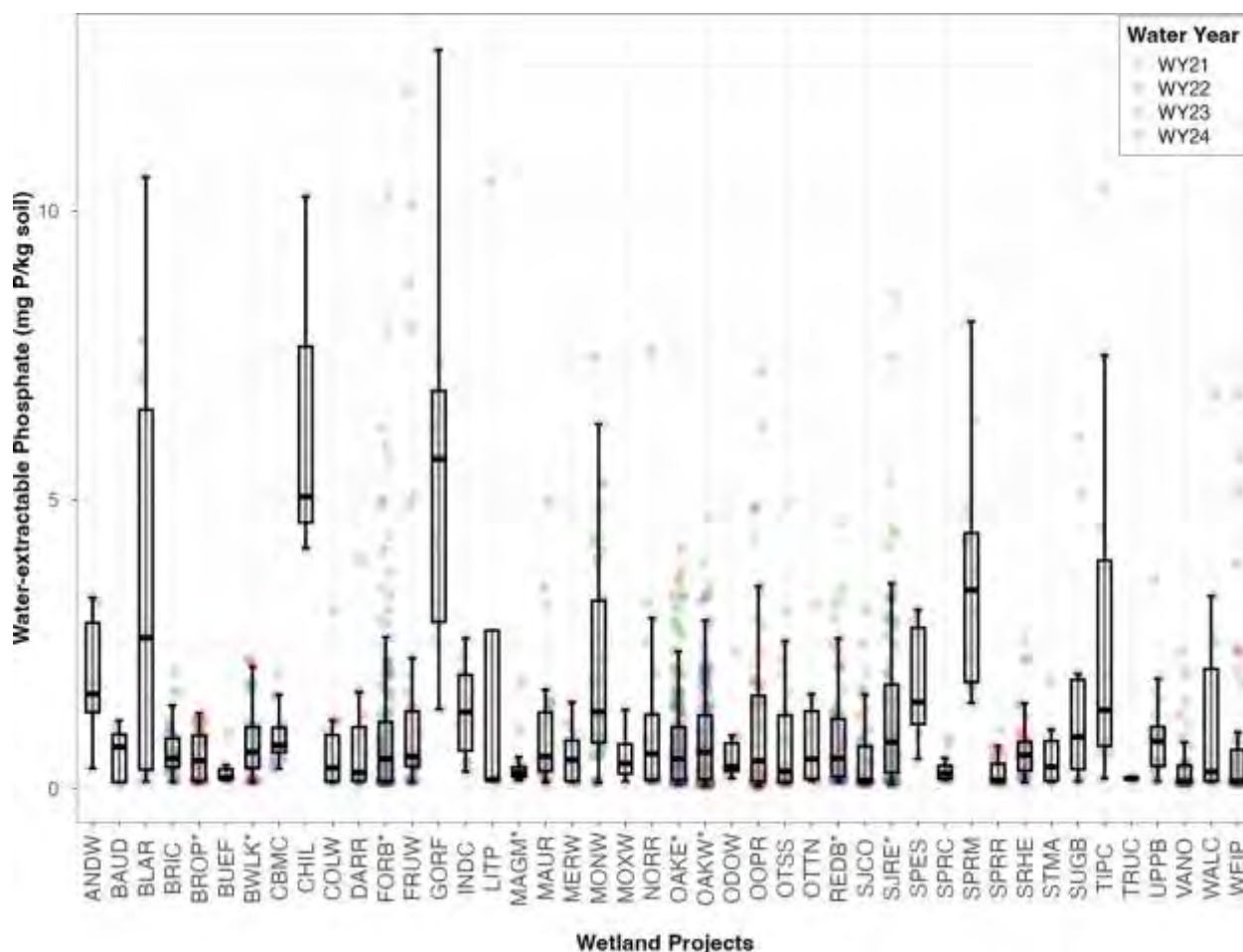


Figure 18. Boxplots displaying the variability in easily mobilizable (water-extractable) soil phosphate (PO_4^{3-}) concentration measured in soil samples (0–5 cm) across wetland Projects. For each boxplot, the thick line represents the median (middle) PO_4^{3-} concentration across all measurements. The boxes indicate the value range for 50% of the measured PO_4^{3-} concentrations and the whiskers show the spread of PO_4^{3-} concentration values that are outside the 50% of the data points. Each overlying point represents individual PO_4^{3-} concentration measurements. Different colors denote the water year (WY; Oct 1–Sep 30) in which the measurements were collected, as shown in the legend. The asterisk (*) denotes an intensively monitored Focal Project with greater sampling effort. For more information on the wetland Projects, please refer to Figure 1.

Relationships Among Soil Parameters

SPSC is positively correlated with Mehlich-3-extractable iron (M3-Fe, $r = 0.527$) and Mehlich-3-extractable aluminum (M3-Al, $r = 0.614$) but negatively correlated with Mehlich-3-extractable phosphorus (M3-P, $r = -0.337$), which is expected, as SPSC is calculated based on the ratio of the mass of M3-Fe and M3-Al to the mass of M3-P. SPSC is also positively correlated with soil electrical conductivity (soil EC, $r = 0.140$), $\text{WEx-NH}_4\text{-N}$ ($r = 0.256$), and TN ($r = 0.119$). In land not previously used for agriculture, soil ECa is strongly positively correlated with M3-Fe ($r = 0.745$) and TN ($r = 0.735$). Relationships seem strongest among parameters from Projects that are considered non-agricultural, potentially because far fewer

observations were made at these Projects (n = 251) than those defined by previous agricultural use (n = 1620).

The relationship between soil TP and WEx-PO₄ indicates the proportion of TP that is easily mobilizable in the soil and therefore represents the relative bioavailability of the phosphorus that is retained by wetland soils. Note that the difference in scales between the total and water-extractable nutrients is several orders of magnitude. For example, WEx-PO₄ ranges from 0 to 12 mg P/kg soil, and TP values are as high as 2,800 mg P/kg soil. So, while they may be correlated, the water-extractable fraction is a very small portion of the TP that is retained in the soil. There are positive correlations between soil TN and WEx-NO_x and WEx-NH₄-N, as well as between soil TP and WEx-PO₄ (Figure 19). Continued analysis, supported in part by leveraged funding from the U.S. Environmental Protection Agency Great Lakes Restoration Initiative, will help researchers clarify relationships among soil characteristics to provide a better understanding of the biogeochemical processes in the wetlands, and how they relate to nutrient retention.

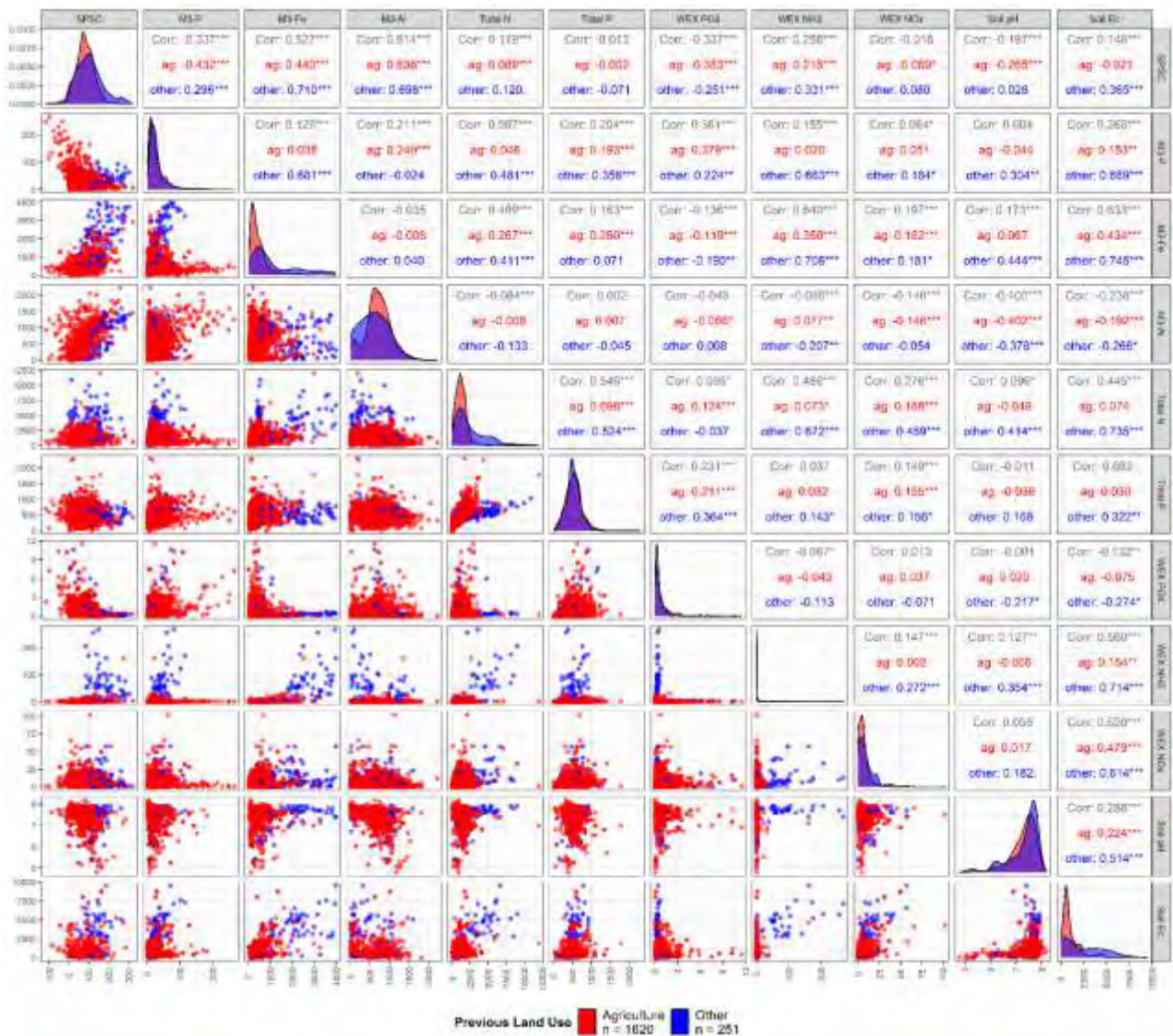


Figure 19. Pairs plot displaying correlations across a suite of soil characteristics (0–5 cm) measured in all H2Ohio Projects, grouped by previous land use (i.e., Projects that were previously agricultural land vs. other prior land uses). The number for each land use category shown in the legend reflect the maximum possible number of samples in that category. Samples that did not have available data for a given set of soil parameters were excluded from the respective pairwise comparison. Plots shown in the diagonal represent the relative density distribution of SPSC values for each previous land use category. Scatterplots to the left of the diagonal display the relationship of each soil parameter pair, with red points denoting Projects that were previously agricultural and blue points showing Projects that had other prior land use. Panels to the right of the diagonal show the correlation coefficient of each pairwise comparison, including all data points (“Corr”, gray), or only agricultural prior land use (“ag”, red) or other prior land use (“other,” blue). Asterisks (***) denote statistically significant ($p < 0.001$) relationships, though some relationships should be interpreted carefully as they may be biased by few outliers.

Vegetation Stock at Focal Projects

As Projects develop after construction, wetland plant species increase in prevalence¹ in comparison to non-wetland plants, generally with corresponding increases in above and belowground biomass and nutrient stock (Table 1). However, there is substantial year-to-year variability in nutrient stock, likely associated with changes in precipitation and thus active vegetated wetland area². Both 2023 and 2024 were drought years and thus some wetlands stored less nutrient mass in vegetation than they did in the wetter 2022 (Table 1). This can be seen in declines in active vegetated wetland area for both Forder Bridge Floodplain Restoration and St. Joseph River Restoration (St. Joseph Restoration) Projects³, along with declines in biomass density in certain wetland plant species that are important for nutrient stock in vegetation⁴. Although belowground root biomass is increasing over time, it currently makes up a relatively small proportion of total nutrient stock for studied wetlands during the peak of the growing season (Table 1). However, belowground biomass and nutrient stock are likely to increase with time and, more importantly, perennial species move aboveground nutrients belowground in the fall to store over winter. Ongoing research with leveraged additional funding is quantifying overwinter belowground stock and aboveground decomposition as part of an effort to quantify the amount of annual vegetation nutrient stock that is stored in vegetation across multiple years.

Cattails, which are often undesirable due to their propensity to exclude other wetland plant species, dominate vegetation nutrient stock and areal cover at most of the sampled Focal Projects. However, the Project with the highest vegetation nutrient stock, St. Joseph Restoration Project, is not dominated by Cattails and has other wetland plant species making more important contributions to stock. The substantial vegetation changes observed as these wetlands have developed in the 2–4 years following construction, as well as the year-to-year variability associated with precipitation, highlight the need for long-term vegetation monitoring.

¹ By-Project figures for Focal Projects showing the increase in the relative percent of wetland plant species compared to non-wetland plant species can be found in Supplemental Information (Volume 4 of the H2Ohio Wetland Monitoring Program 2024 Annual Report).

² Active vegetated wetland area is the area dominated by wetland obligate or facultative wetland species in a given water year. For more information on these or other vegetation terms see vegetation terms in Supplemental Information (Volume 4 of the H2Ohio Wetland Monitoring Program 2024 Annual Report). Year-to-year changes in total active vegetated wetland area for Focal Projects can be found in their respective Project-specific summary sections (Volume 2 of the H2Ohio Wetland Monitoring Program 2024 Annual Report).

³ See previous footnote.

⁴ Species-by-species aboveground nutrient density trends in Focal Projects can be found in their respective Project-specific summary sections (Volume 2 of the H2Ohio Wetland Monitoring Program 2024 Annual Report).

Table 1. Average above- and belowground nutrient stock per acre (lbs./acre) stored in vegetation for phosphorus (P) and nitrogen (N) across Focal Projects. Where Focal Projects were not monitored for vegetation in a given water year, table is marked with “–”. Calculation methods and total stock for Projects monitored in 2024 can be found in Supplemental Information (Volume 4 of the H2Ohio Wetland Monitoring Program 2024 Annual Report).

		Average P Stock (lbs./acre)				Average N Stock (lbs./acre)			
		2021	2022	2023	2024	2021	2022	2023	2024
Aboveground	BROP	34	–	27	–	135	–	140	–
	BWLK	–	–	13	62	–	–	47	253
	FORB	28	165	60	51	106	584	217	201
	MAGM	–	–	60	–	–	–	236	–
	OAKE	18	22	11	–	60	61	32	–
	OAKW	10	38	17	17	37	102	54	64
	REDB	–	78	49	–	–	298	185	–
	SJRE	34	42	119	84	110	147	406	446
Belowground	BROP	–	–	–	–	–	–	–	–
	BWLK	–	–	1	1	–	–	2	7
	FORB	–	1	–	2	–	8	–	8
	MAGM	–	–	–	–	–	–	–	–
	OAKE	–	0	4	–	–	4	4	–
	OAKW	–	1	2	1	–	4	7	7
	REDB	–	–	7	–	–	–	8	–
	SJRE	–	–	1	1	–	–	7	7

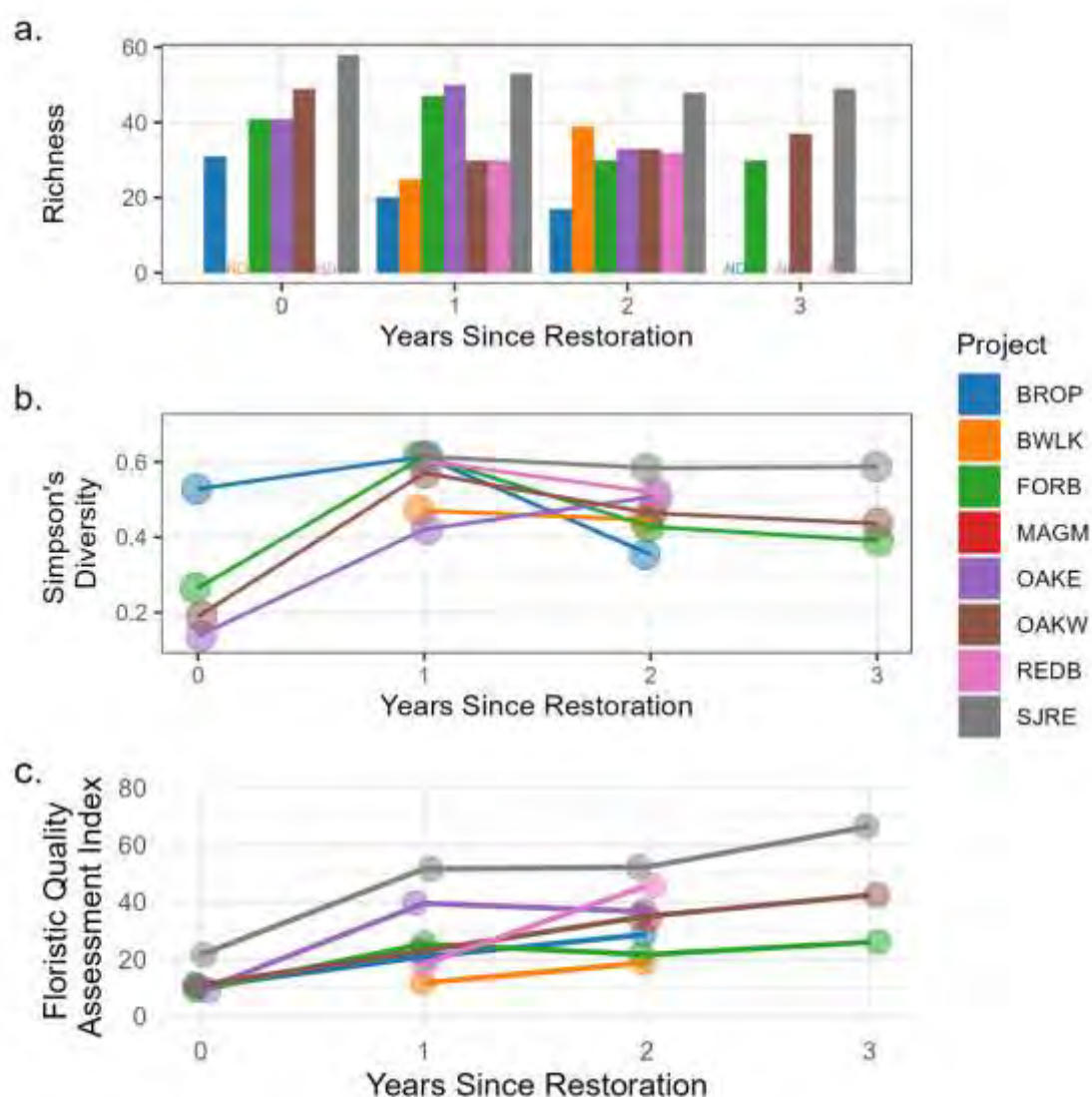


Figure 20. (a) Species richness, (b) Simpson's Diversity Index, and (c) Floristic Quality Assessment Index (FQAI) for all Focal Projects displayed by years since restoration. Starting in Year 3 (2024), current resources allow for vegetation monitoring every other year. For definitions of species richness, information on how diversity was calculated, and more information on FQAI as an indication of habitat quality, please see Supplemental Information (Volume 4 of the H2Ohio Wetland Monitoring Program 2024 Annual Report).

Project by Project Summaries

The following project-specific summaries contain detailed results from each Project monitored by the H2Ohio Wetland Monitoring Program. While the data presented in these summaries spans multiple years, the interpretations and narratives often focus on key results from Water Year 2024. Note: Starting in March 2023, sampling events started to be categorized according to the hydrologic condition in which it occurred so that data for baseflow and hydrologic event (e.g., storm) scenarios could be easily identified. Sampling dates prior to March 2023 were all categorized as baseflow.

Focal Projects

Focal Projects are sampled at lower frequency and with fewer to no specialty crew (e.g., vegetation, hydrogeophysics) collected metrics, though some Non-Focal Projects receive water level sensors⁵.

Brooks Park Wetland Creation & Water Quality Initiative (BROP)

Project Description

Fairfield County | Licking River Watershed | Inland Eastern Ohio

Project size: 5 Acres

Partner: ODNR Division of Parks & Watercraft

The hydrology at this Project is mixed in terms of management. The Project (5 acres of restored wetland) is a flow-through wetland, nuanced by periodic backflow from Buckeye Lake. Water enters from Murphy's Run via a solar-powered pump (maintained, though not actively managed, by a state park staff) or passively through a separate inlet location. The water resides in wetland pools that permanently/seasonally flood before reaching the outflow into Buckeye Lake. There is often backflow from Buckeye Lake into the wetland pools during the summer when the water level in the lake is raised. A hydrologic event at this Project is operationally defined as an event in which Murphy's Run stream discharge is greater than 1.55 cubic feet per second. At this threshold, Murphy's Run flows into the wetland. The water level threshold at which Buckeye Lakes backflows into the wetland pools is 271 m, a number inferred based on elevation information in the Project design plans.

⁵ H2Ohio Wetland Monitoring Program, 2024. H2Ohio Wetland Monitoring Program: Monitoring Framework. Kinsman-Costello, L.E., K. Fussell, C. Winslow, J. Kerns, O.F.Schloegel, R. Mendonça, R. Becker, T. Bridgeman, K. Doro, S. J. Jacquemin, L. Johnson, G. Liu, K. McCluney, H. Michaels, W.R. Midden, S. Newell, M. Back, L. Brown, I. Rahman, and Z. Swan. Lake Erie and Aquatic Research Network (LEARN) for the Ohio Department of Natural Resources (ODNR). Columbus, OH, USA.



Figure 21. Aerial image showing surface water flow and sampling locations for the Brooks Park Wetland Creation & Water Quality Initiative. Blue arrows indicate direction of surface water flow. Dots represent geographic base crew sampling locations, which are grouped by Project features (fill color) where relevant. Text annotations provide additional context about the Project's watershed connection or other important features.

Management Considerations

In Water Year 2024, the Project acted as a nutrient sink and interacted with 1.2 million m³ from Murphy's Run. However, nutrient load reductions associated with Murphy's Run could be increased with simple design modifications. Increasing the water residence time by maximizing the volume of water that enters the West Pool could increase nutrient load reduction (Figure 22). The average surface water phosphorus and nitrogen concentrations in the West Pool were generally lowest, compared to other features at the Project. Researchers have observed that the current solar-powered pump moves little to no water. A more efficient pump would be able to bring in a greater water volume. Installing a cement wall between the Main Pool and the Mid-wetland Stream also has the potential to reduce nutrient loads, if used with a more powerful pump. In this scenario, a pump would divert water from the Main Pool to the West Pool before flowing back into the Mid-Wetland Stream. This would slow down flows from Murphy's Run, increasing residence time of water in the wetland pools. This design modification would still allow for Buckeye Lake backflows to be treated during times of high water elevation.

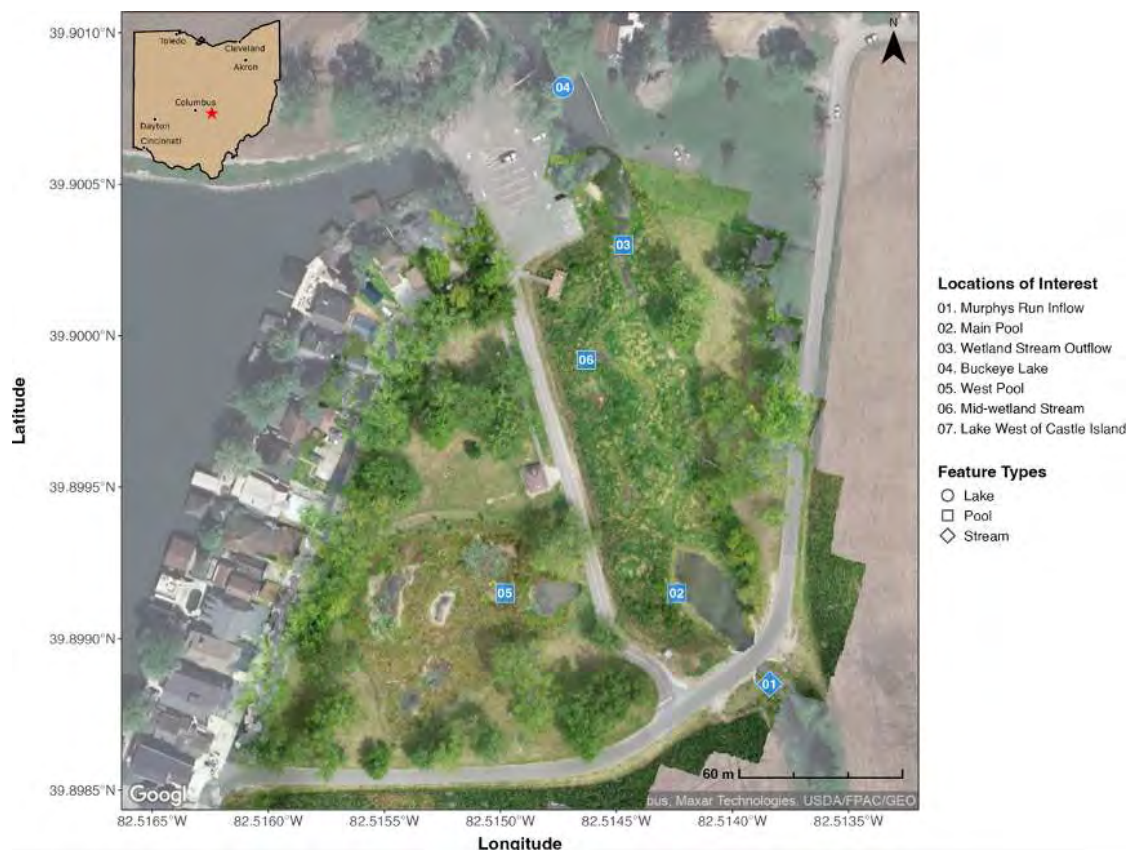


Figure 22. Aerial image of approximate locations of interest for water and soil sampling and discrete manual measurements of water depth and physicochemical parameters at Brooks Park Wetland Creation & Water Quality Initiative Project during water year 2024 (Oct 1, 2023–Sep 30, 2024). The legend provides the name of each sampling point. Different shapes denote the types of wetland features represented by the locations of interest. If present, different colors represent locations of interest that belong to a group or complex of features (e.g., a treatment train).

Nutrient Budget Takeaways

In Water Year (WY) 2024, the Brook Parks Project received approximately 1.2 million m³ of water. The Project filtered 57 lbs. of total phosphorus (TP), 22 lbs. of dissolved reactive phosphorus, 4,316 lbs. of total nitrogen (TN), 3,718 lbs. of nitrite+nitrate (NO_x), and 93 lbs. of total ammonium nitrogen (NH₄-N). The greatest overall nutrient filtration occurred in spring, which correlates to the two large rain events that occurred in April. TP load reductions were greatest in summer. Nitrogen load reductions for Buckeye Lake varied seasonally, with the greatest NO_x reduction occurring in winter and the greatest TN and NH₄-N reduction occurring in spring. Seasonal differences in nutrient filtration highlight the importance of sampling across seasons, with an aim to capture rain events.

The design of the Project allows the wetland to capture 100% of the discharge from Murphy's Run and some backflow from Buckeye Lake during summer pool when the water level in the lake is raised. The amount of backflow during winter pool (period of the year when Buckeye Lake water level is lowered to allow capacity for winter and spring rains) is minimal due to the lake surface water elevation being lower than the Wetland Stream

Outflow notch elevation. In WY 2024, the Project interacted with an additional 14.5 million L from Buckeye Lake.

No land within the Project was previously used for agriculture, thus the Project does not prevent any additional phosphorus runoff. Soils throughout the Project have moderate capacity to sorb phosphate, as suggested by soil phosphate sorption capacity values

Surface Water Hydrology and Nutrients

The Main Pool and Mid-wetland Stream of the Project are permanently flooded throughout the year. The West Pool and the floodplain surrounding the Mid-wetland Stream are seasonally flooded, typically drying out by late summer or early fall. If Murphy's Run stream discharge is greater than 1.55 cubic feet per second (cfs), the Murphy's Run sampling location is an inflow source to the wetland (otherwise, researchers infer that location contains backflow water from the wetland). There were 15 hydrologic events during Water Year 2024 in which stream discharge in Murphy's Run exceeded 1.55 cfs, and five of these periods were sampled by base crew (Figure 23, Figure 24, Figure 25). Murphy's Run dissolved reactive phosphorus (DRP) and total phosphorus (TP) concentrations were greatest in the fall, and nitrite+nitrate (NO_x) and total nitrogen (TN) concentrations were greatest in winter (Figure 27, Figure 26, Figure 29, Figure 28). Both seasons coincide with Murphy's Run high-flow events (≥ 1.55 cfs). Average concentrations for certain nutrients were reduced between inflow (Murphy's Run Inflow) and outflow (Wetland Stream Outflow) during sampled high-flow events: DRP was reduced by 10% and NO_x by 22%. However, there was an average increase in concentrations of total ammonium nitrogen (21%), TN (10%), and TP (113%) between inflow and outflow during high-flow events. These increases in concentration during high-flow events lead to a load export of these nutrients to Buckeye Lake.

Water levels recorded at Mid-Wetland Stream, Wetland Stream Outflow, and Murphy's Run and flow captured by the acoustic velocity (AV) sensor (SonTek SL1500). Sensors at Murphy's Run were used to detect periods of backflow from Buckeye Lake (Figure 24). Periods of Buckeye Lake backflow are characterized by water level increases at Wetland Stream Outflow and/or Mid-Wetland Stream, with negative flow values detected by the AV sensor at Murphy's Run. (Because the AV sensor detects bidirectional flow, positive is flow from Murphy's run to Wetland and negative flow is Buckeye Lake back flow).

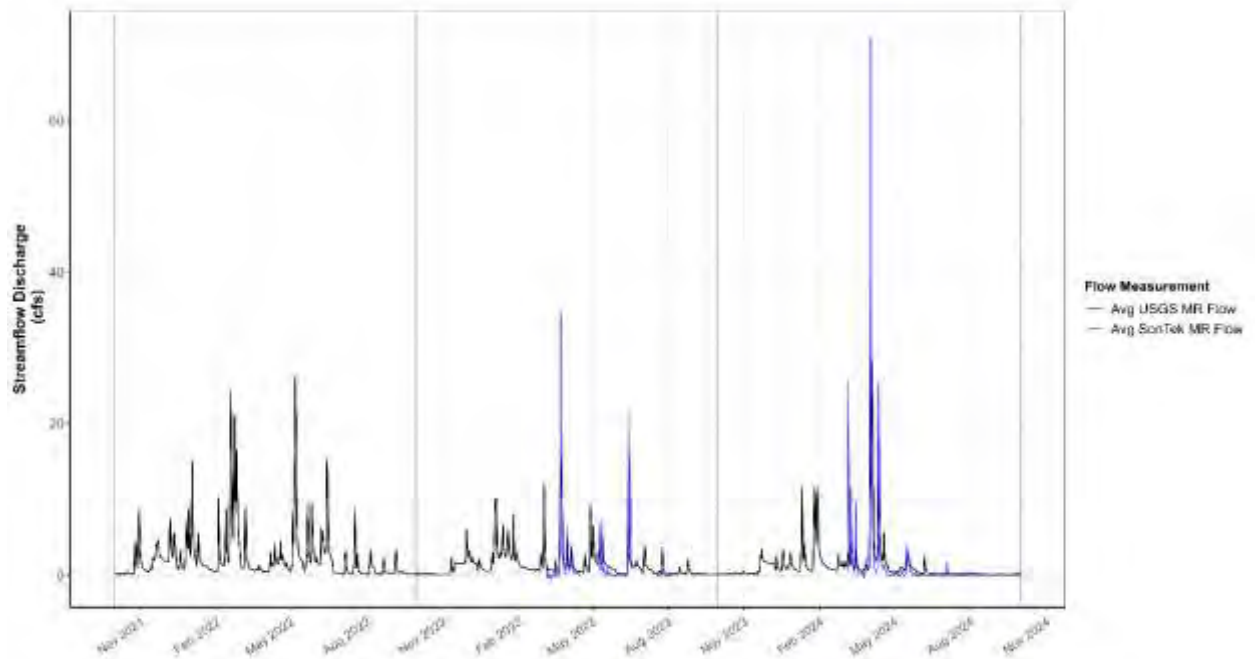


Figure 23. Murphy's Run streamflow from October 1, 2022 to September 30, 2024. Blue indicates USGS gage South Fork Licking River near Hebron OH - 03145000 watershed weighted to get discharge at the wetland and black indicates flow monitored using an acoustic velocity (AV) sensor (SonTek SL1500).

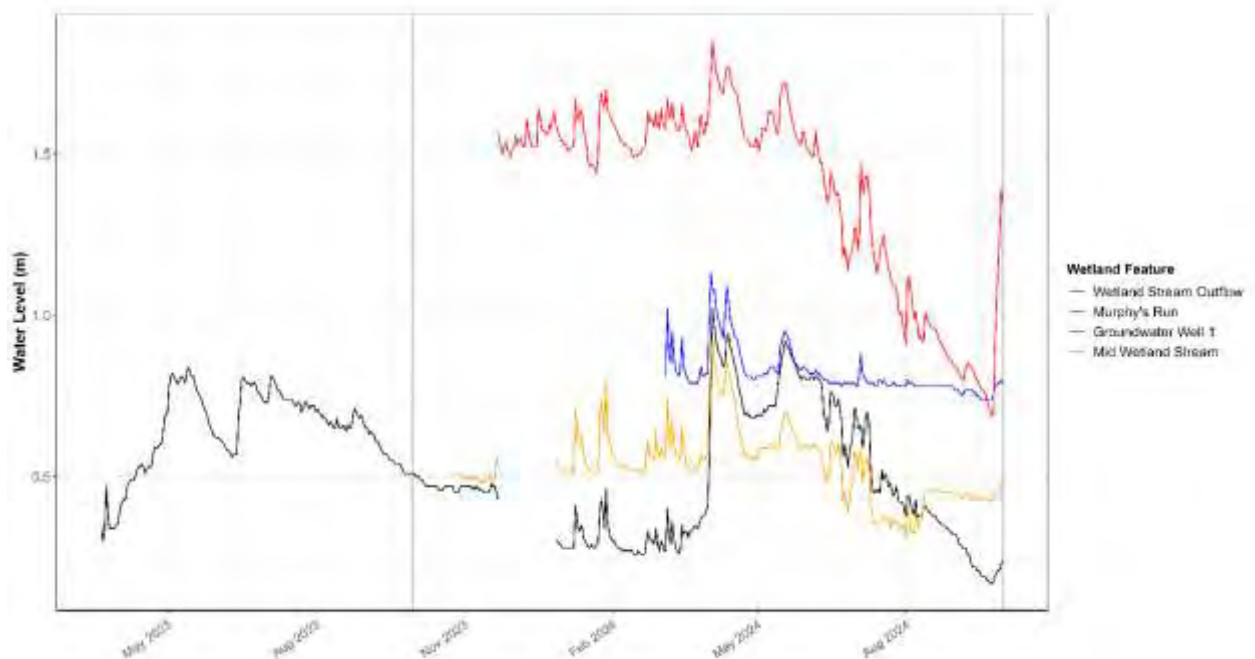


Figure 24. Water level data (surface water and groundwater) recorded by Solinst Levelloggers and acoustic velocity (AV) sensor (SonTek SL1500) sensor at multiple locations throughout the Brooks Park Wetland Creation & Water Quality Initiative Project.

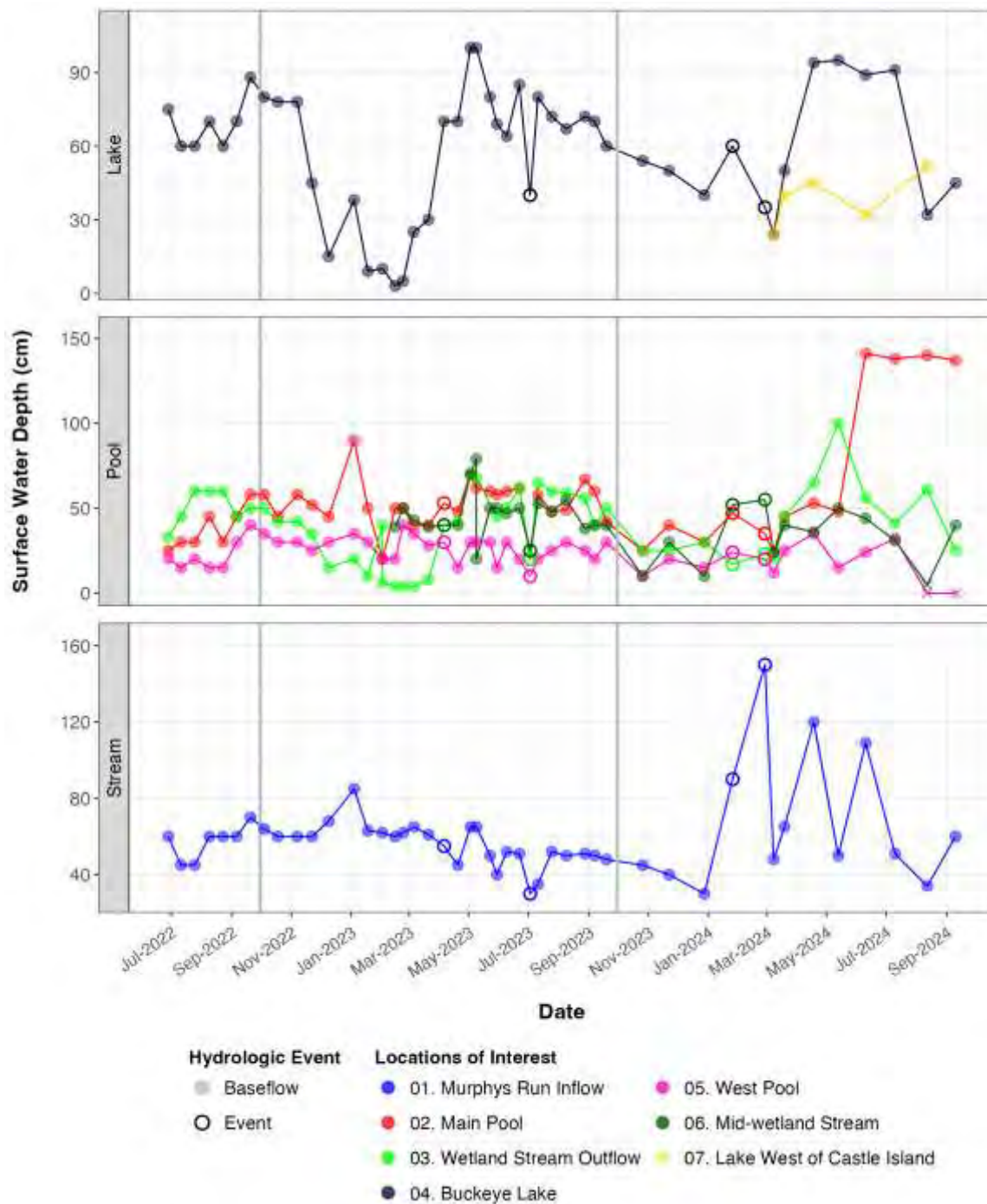


Figure 25. Time series of discrete, manually measured surface water depth at the Brooks Park Wetland Creation & Water Quality Initiative Project. Depths were measured approximately monthly. Each point represents one measurement and colors denote the locations of interest, as indicated in the legend. Open symbols indicate samples that were collected during a hydrologic event (e.g., storm event) and filled symbols denote samples collected during baseflow. Crosses (×) represent instances when no surface water was detected during the visit. If present, different shapes denote the types of wetland features represented by the locations of interest. Gray vertical lines indicate the start of a water year (Oct 1–Sep 30).

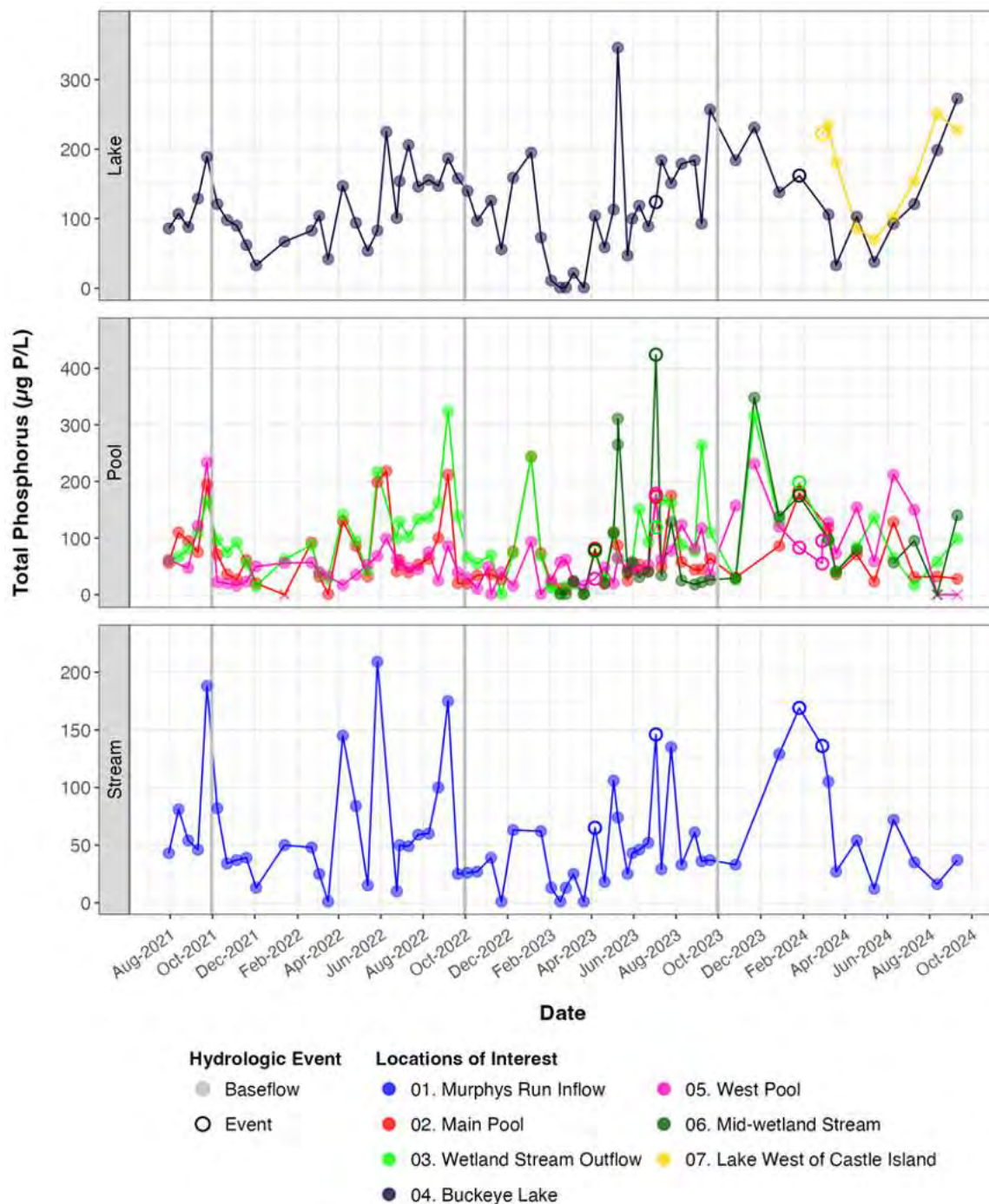


Figure 26. Time series of total phosphorus (TP) concentrations in surface water samples collected at the Brooks Park Wetland Creation & Water Quality Initiative Project. Values below the detection limit of the analytical equipment were replaced with half the value of the detection limit. Each point represents one measurement and colors denote the locations of interest, as indicated in the legend. Open symbols indicate that measurements were collected during a hydrologic event (e.g., storm event) and filled symbols denote measurements collected during baseflow. Crosses (×) represent instances when no surface water was detected during the visit. If present, different shapes denote the types of wetland features represented by the locations of interest. Gray vertical lines indicate the start of a water year (Oct 1–Sep 30).

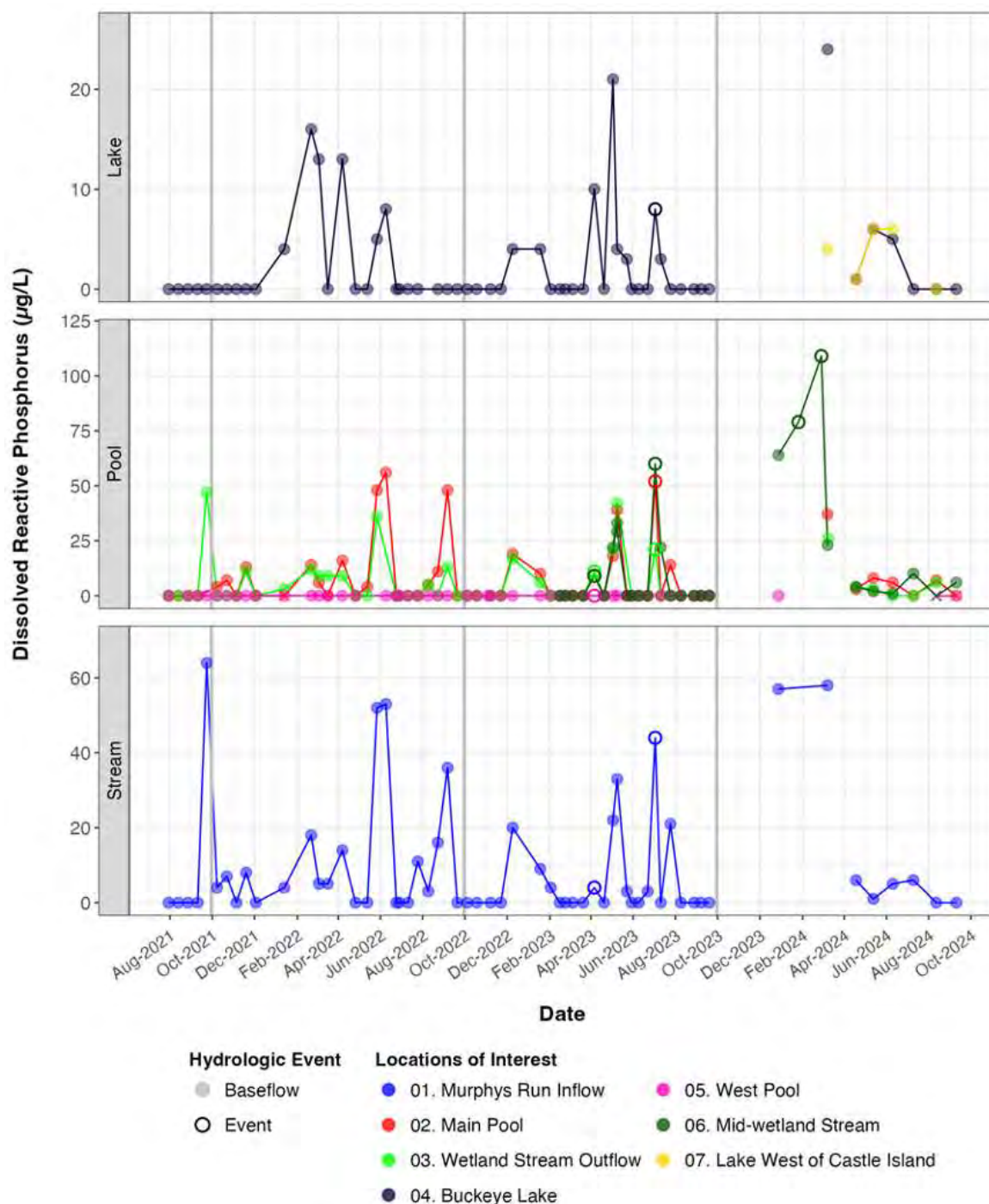


Figure 27. Time series of dissolved reactive phosphorus (DRP) concentrations in surface water samples collected at the Brooks Park Wetland Creation & Water Quality Initiative Project. Values below the detection limit of the analytical equipment were replaced with half the value of the detection limit. Each point represents one measurement and colors denote the locations of interest, as indicated in the legend. Open symbols indicate that measurements were collected during a hydrologic event (e.g., storm event) and filled symbols denote measurements collected during baseflow. Crosses (×) represent instances when no surface water was detected during the visit. If present, different shapes denote the types of wetland

features represented by the locations of interest. Gray vertical lines indicate the start of a water year (Oct 1–Sep 30).

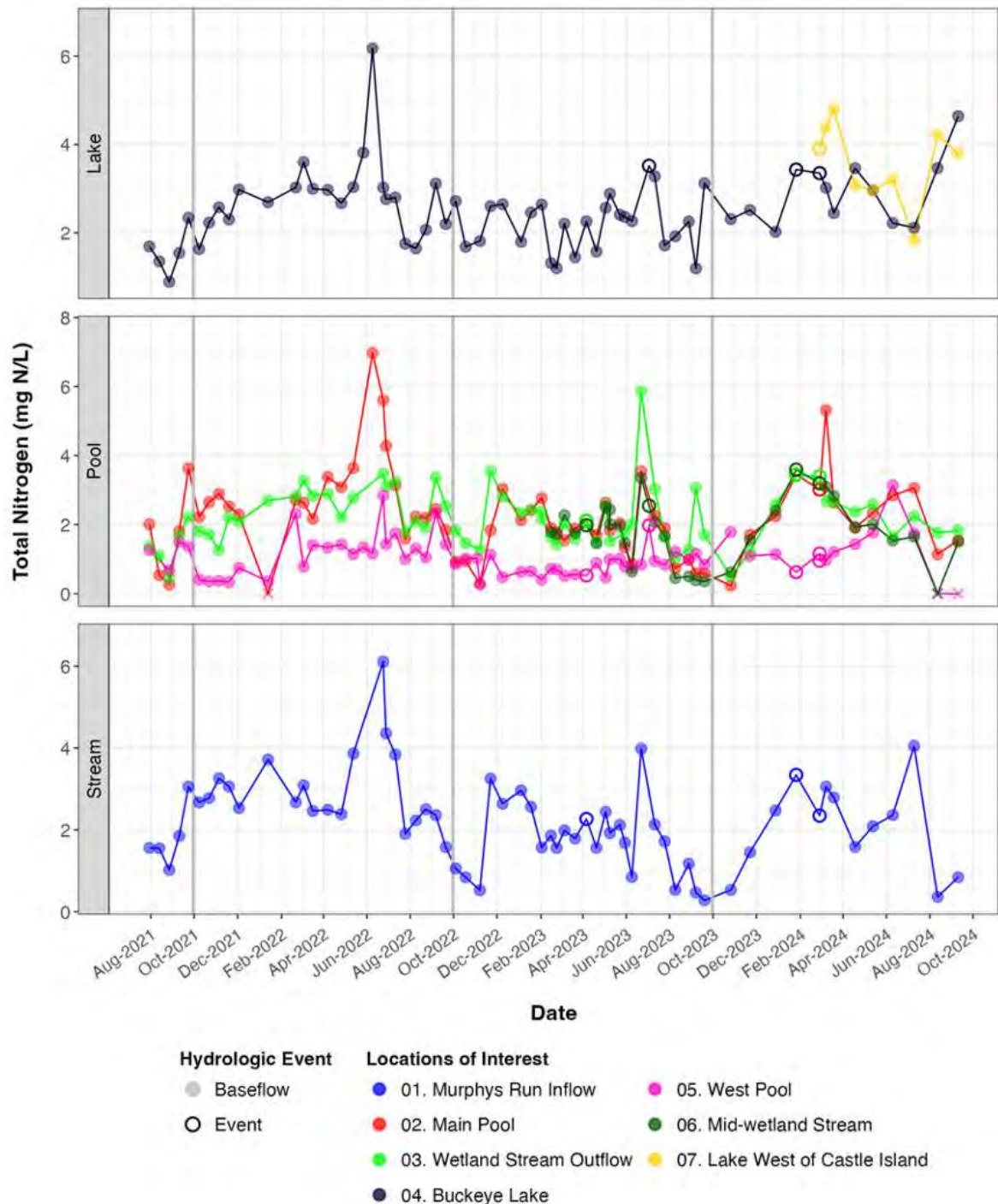


Figure 28. Time series of total nitrogen (TN) concentrations in surface water samples collected at the Brooks Park Wetland Creation & Water Quality Initiative Project. Values below the detection limit of the analytical equipment were replaced with half the value of the detection limit. Each point represents one measurement and colors denote the locations of

interest, as indicated in the legend. Open symbols indicate that measurements were collected during a hydrologic event (e.g., storm event) and filled symbols denote measurements collected during baseflow. Crosses (×) represent instances when no surface water was detected during the visit. If present, different shapes denote the types of wetland features represented by the locations of interest. Gray vertical lines indicate the start of a water year (Oct 1–Sep 30).

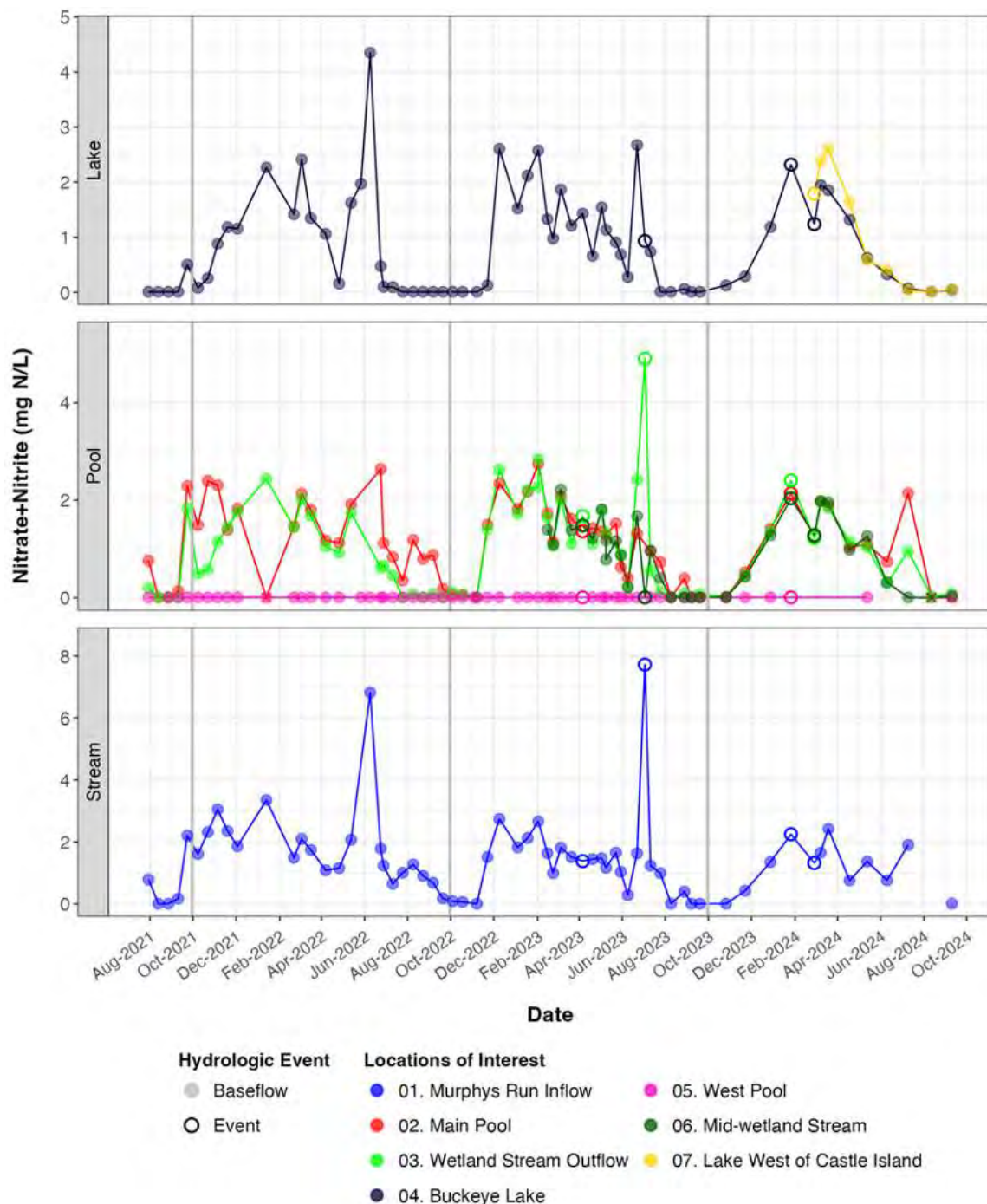


Figure 29. Time series of Nitrite+nitrate (NO_x) concentrations in surface water samples collected at the Brooks Park Wetland Creation & Water Quality Initiative Project. Values

below the detection limit of the analytical equipment were replaced with half the value of the detection limit. Each point represents one measurement and colors denote the locations of interest, as indicated in the legend. Open symbols indicate that measurements were collected during a hydrologic event (e.g., storm event) and filled symbols denote measurements collected during baseflow. Crosses (×) represent instances when no surface water was detected during the visit. If present, different shapes denote the types of wetland features represented by the locations of interest. Gray vertical lines indicate the start of a water year (Oct 1–Sep 30).

Soil Nutrient Status and Processes

Soil phosphate sorption capacity (SPSC) values were positive across the Project, indicating the capacity for sediment to sorb phosphate (Figure 31). At this Project, researchers sampled a subset of paired locations to compare inundated (i.e., flooded) and upland (i.e., dry) soils. The average SPSC value across inundated sampling locations was greater in Water Year (WY) 2024 (115 mg phosphorus (P)/kg) than in WY 2023 (74 mg/kg). In WY 2024, inundated soils had higher sediment total phosphorus concentrations (817 mg P/L) than did dry soils (510 mg/L).

The bulk apparent electrical conductivity (ECa) of the soil was measured using a Geonics EM38-Mk2 at 0.5 m and 1.0 m coil spacings, corresponding to 0.75 m and 1.5 m approximate depth of investigation, respectively. ECa values for both coil spacings ranged from 3 to 35 mS/m. Generally, ECa values were higher for inundated areas than upland areas at the time of the survey (Figure 30). While spatial patterns were similar between sampling depths, ECa increased with depth.



Figure 30. Apparent bulk soil electrical conductivity (ECa) at Brooks Park Wetland Creation & Water Quality Initiative Project in October 2024 for the (top) 0.75-m depth and (bottom) 1.5-m depth of investigation.

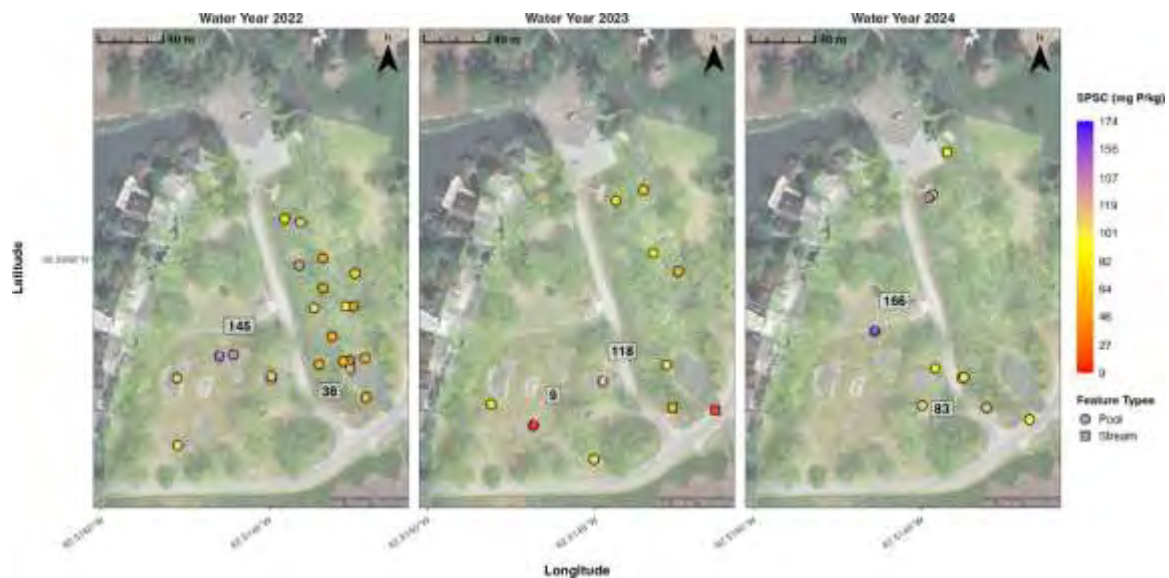


Figure 31. Soil Phosphate Sorption Capacity (SPSC) throughout the Brooks Park Wetland Creation & Water Quality Initiative Project. Each point denotes a soil sample (0–5 cm) and different shapes indicate the wetland feature type, as shown in the legend. Colors indicate the SPSC value of each sample relative to the overall range of values observed at the wetland project, as shown in the color bar. Each panel shows the soil samples collected during a respective water year (Oct 1–Sep 30), along with the minimum and maximum SPSC values observed during a given water year. Negative SPSC values indicate the potential for soils to release phosphate, while positive values indicate soils have capacity to sorb phosphate, based on Mehlich-3 extractions of phosphate, iron, and aluminum.

Next Steps to Strengthen Understanding

The H2Ohio Wetland Monitoring Program does not plan to collect data after April 2025 at the Brooks Park Project in Water Year (WY) 2025. The Project has now been monitored for three water years, with surface water and soil samples collected all three years, ground water samples collected one year, and hydrology data collected one and a half years. Although new sample collection will end in WY 2025, analysis of existing data will continue. Nutrient and water data that has been collected will be used to improve and calibrate a constructed 3D hydrology model of the Project, after which a thorough assessment of the Project’s nutrient reduction function will be carried out.

Burntwood-Langenkamp Wetland Conservation Area (BWLK)

Project Description

Mercer County | Grand Lake St. Marys Watershed

Project size: 90 Acres

Partner: Division of Parks & Watercraft and Lake Facilities Authority

The hydrology at this flow-through Project is actively managed. The Project has 27 acres of restored wetland. Water enters from Burntwood Creek via a pump (managed by ODNR staff) or via the inflow notch when water reaches a certain threshold. The water resides in a pool or flows through a sinuous path between various pools before reaching the outflow into Coldwater Creek, at which there is a water level control structure that can be manually adjusted. A hydrologic event at this Project is operationally defined as a storm event in which the Burntwood Creek flow reaches 27 cubic feet per second, as this is when researchers estimate the creek flows through the inflow notch.



Figure 32. Aerial image showing surface water flow and sampling locations for the Burntwood-Langenkamp Wetland Conservation Area Project. Blue arrows indicate direction of surface water flow. Dots represent geographic base crew sampling locations, which are grouped by Project features (fill color) where relevant. Text annotations provide additional context about the Project's watershed connection or other important features.

Management Considerations

Managers Altered Wetland in 2024 to Increase Inflow Volume

The Burntwood-Langenkamp Project received an inflow volume of nearly 454 million L during Water Year (WY) 2024, up from 193 million L of inflow during WY 2023. This was a direct result of management decisions made in response to low flows in Burntwood Creek beginning in July 2023. In winter of WY 2024, a sump pit (a hole in front of the pump to allow greater water volumes) was dug in order to pump water into the wetland for longer durations. The wetland was able to treat approximately 9% of the annual Burntwood Creek discharge in WY 2024, nearly double the total inflow volume treated in WY 2023, resulting in greater phosphorus load reductions in WY 2024.

Increasing Vegetation Establishment Could Increase Nutrient Retention

Researchers note that only a small portion (9.5 of 90 acres) of the total Burntwood-Langenkamp Project area is suitable habitat for wetland vegetation. Steep slopes and channelization deplete the area of shallow, slow-flowing water necessary for wetland vegetation establishment. Creating a more shallow, slow-flow habitat with longer residence time would increase the capacity of the wetland to retain nutrients through vegetation by expanding the available area for wetland plants to establish.

Actively Managed System Moderated Impacts of Drought

Overall, WY 2024 drought conditions had a minimal impact on the Project due to its active water management, pump-driven system, and sump pit. Burntwood Creek had a greater discharge volume into the Project in WY 2024 (5.2 billion L) than in WY 2023 (3.8 billion L). In WY 2024 most of the flow into the Project occurred in spring from two large rain events. The first large rain event (approximately 6.35 cm over 48 hours), which occurred in early April, caused the wetland to become completely inundated. Setting the stoplogs in the water level control structure to 53.3 cm allowed the wetland to interact with approximately 37.9 million L at the outflow with a residence time of approximately 12 hours. If fewer stop logs were engaged at the time of the storm event, the residence time would have been essentially zero, resulting in lower load reductions.



Figure 33. Aerial image of approximate locations of interest for water and soil sampling and discrete manual measurements of water depth and physicochemical parameters at Burntwood-Langenkamp Wetland Conservation Area Project during water year 2024 (Oct 1, 2023–Sep 30, 2024). The legend provides the name of each sampling point. Different shapes denote the types of wetland features represented by the locations of interest. If present, different colors represent locations of interest that belong to a group or complex of features (e.g., a treatment train).

Nutrient Budget Takeaways

In Water Year (WY) 2024, the Burntwood-Langenkamp Project received approximately 454,000 m³ of water. Overall, load filtration of total phosphorus (TP) and dissolved reactive phosphorus (DRP) increased from Water Year (WY) 2023 to WY 2024. Load filtration of total nitrogen (TN), nitrite+nitrate (NO_x), and total ammonium nitrogen (NH₄-N) decreased (Table 2). In WY 2024, Burntwood-Langenkamp filtered 240 lbs. TP, 121 lbs. DRP, 5,961 lbs. TN, 5,407 lbs. NO_x, and 5 lbs. NH₄-N. The largest portion of the TP and DRP load filtration occurred in summer while the largest portion of the TN and NO_x load filtration occurred in winter. Seasonal and yearly differences in load reduction highlight the importance of sampling across seasons and years.

Table 2. Total mass and percent nutrient load filtered at the Burntwood-Langenkamp Wetland Conservation Area. Numbers in table are total pounds followed by percent filtered in parentheses.

Water Year	TP Load Filtered lbs. (%)	DRP Load Filtered lbs. (%)	TN Load Filtered lbs. (%)	NO _x Load Filtered lbs. (%)	NH ₄ -N Load Filtered lbs. (%)
2023	45 (26)	24 (52)	7,307 (85)	6,747 (92)	204 (94)
2024	240 (52)	121 (67)	5,961 (62)	5,407 (74)	5 (3)

Two large rain events resulted in a 2024 spring TP inflow load (459 lbs.) that was 170% greater than the 2023 spring TP inflow load (171 lbs.). Greater inflow loads generally increase the potential for load filtration, contingent on the functionality of the wetland. Lower nitrogen filtration could be a result of the 2024 rain events occurring within one month of each other and of a large volume (151 L) of flow through the wetland. Combined, these factors reduced the residence time to less than one day, which is not generally considered sufficient time for nitrogen to be treated. The TN spring inflow load was 12% greater in WY 2023 than in WY 2024.

There was significantly less NH₄-N filtration in WY 2024 (3%) than in WY 2023 (94%). The only net release of NH₄-N occurred in spring of WY 2024, in which the outflow load was 38% greater than the inflow load. Inflow NH₄-N loads differed drastically between summer 2023 (144 lbs.) and summer 2024 (47 lbs.). Nearly 100% of the summer 2023 load was filtered while only 54% of the summer 2024 load was filtered. This could be caused by several factors: lower inflow NH₄-N concentrations in 2024 (0.144 mg nitrogen (N)/L) compared to concentrations in 2023 (0.272 mg N/L); the higher residence times in 2023 as the pump moved less water; or due to another variable not yet measured or understood.

Soils throughout the Project have a moderate to high capacity to sorb phosphate, as suggested by soil phosphate sorption capacity values.

Surface Water Hydrology and Nutrients

Active management of the wetland pump and outflow water level control structure (WLCS) allows the wetland to treat water approximately six months (April–September) out of the water year. Water pumped from Burntwood Creek reaches all wetland pools along the sinuous flow path, but not the vernal pools (Overland Drainage and Overland Pool A, Figure 34). When the pump is off during the fall and winter months, the wetland pools are permanently inundated with water (≥ 0.3 m). Vernal pools are seasonally flooded from overland drainage and only receive water during storm or melting events (usually in spring and fall). The vernal pools likely filter 100% of all nutrients that enter the pools with the exception of very large storm events. During very large storm events, water can flow through Agri Drains from Overland Pool A to Overland Drainage pool. For example, on April 2, 2024, the wetland received an inflow of 42 million L. If the water level in the Overland Drainage pool gets high enough (above the stop logs in the WLCS, which are set to 130 cm), water can flow from Overland Drainage pool to Settling Pool through a vegetated flow path.

During Water Year (WY) 2024, there were a total of six inflow events in which the USGS gage (Chickasaw Creek at St. Marys OH - 402913084285400⁶) surpassed 50 cubic feet per second (cfs), which is what researchers use as a storm event threshold; it translates to a watershed weighted 27 cfs at the wetland inflow. There was an increase in wetland outflow discharge during each inflow event (Figure 35). Across each of the three winter events and two spring events, the inflow water (Burntwood Creek) nutrient concentrations spiked. They did not spike during the one summer event. Generally, when nutrient concentrations spiked in Burntwood Creek, nutrient concentrations also increased in the Settling Pool and then decreased as water flowed through the wetland to the Outflow pool (Figure 37).

Concentration reductions between inflow and outflow occurred when water from Burntwood Creek was actively flowing into the wetland (via pump or inflow notch) to Outflow (Figure 37, Figure 38, Figure 39, Figure 40). Annual average total phosphorus (TP) inputs were reduced by 60%, total nitrogen (TN) by 71%, dissolved reactive phosphorus (DRP) by 77%, nitrite+nitrate (NO_x) by 81%, and total ammonium nitrogen (NH₄-N) by 54%. Concentration reductions between inflow and outflow also varied seasonally; winter experienced the greatest percent reduction for TN (91%), NO_x (97%), and NH₄-N (81%), and summer experienced the greatest percent reduction for TP (81%) and DRP (94%). This data highlights how seasons with the greatest nutrient load reduced do not always have the greatest percent concentration reduction, meaning the nutrient load reduced is driven by high flow volumes. For example, percent concentration reductions were greatest in summer for SRP and TP and winter for NO_x and TN, but the greatest total nutrient load reductions were in spring for all nutrients due to much larger flow volumes.

3-D hydrodynamic model development for the Burntwood-Langenkamp Project began in 2024. Preliminary simulation results based on a synthesized hydrologic scenario suggest that the water flows along the surface-water wetland pools quickly, taking between two and three days to move from the settling pool to the outlet (Figure 36, Figure 41). It is worth noting that the estimated travel time within the Project's stream channel only represents the result from one hypothetical scenario with a certain synthesized boundary condition. Like all other flow-through wetland systems, this Project's residence time could vary dramatically as responses to such boundary conditions (i.e., how much and how fast water comes from the culvert or inlet pool to the stream). It is for this reason that researchers believe measuring inflow volume is one of the key next steps to strengthen understanding of the project.

⁶ "Chickasaw Creek at St. Marys OH – 402913084285400." [waterdata.usgs.gov](https://waterdata.usgs.gov/monitoring-location/402913084285400/). U.S. Department of Interior. <https://waterdata.usgs.gov/monitoring-location/402913084285400/>

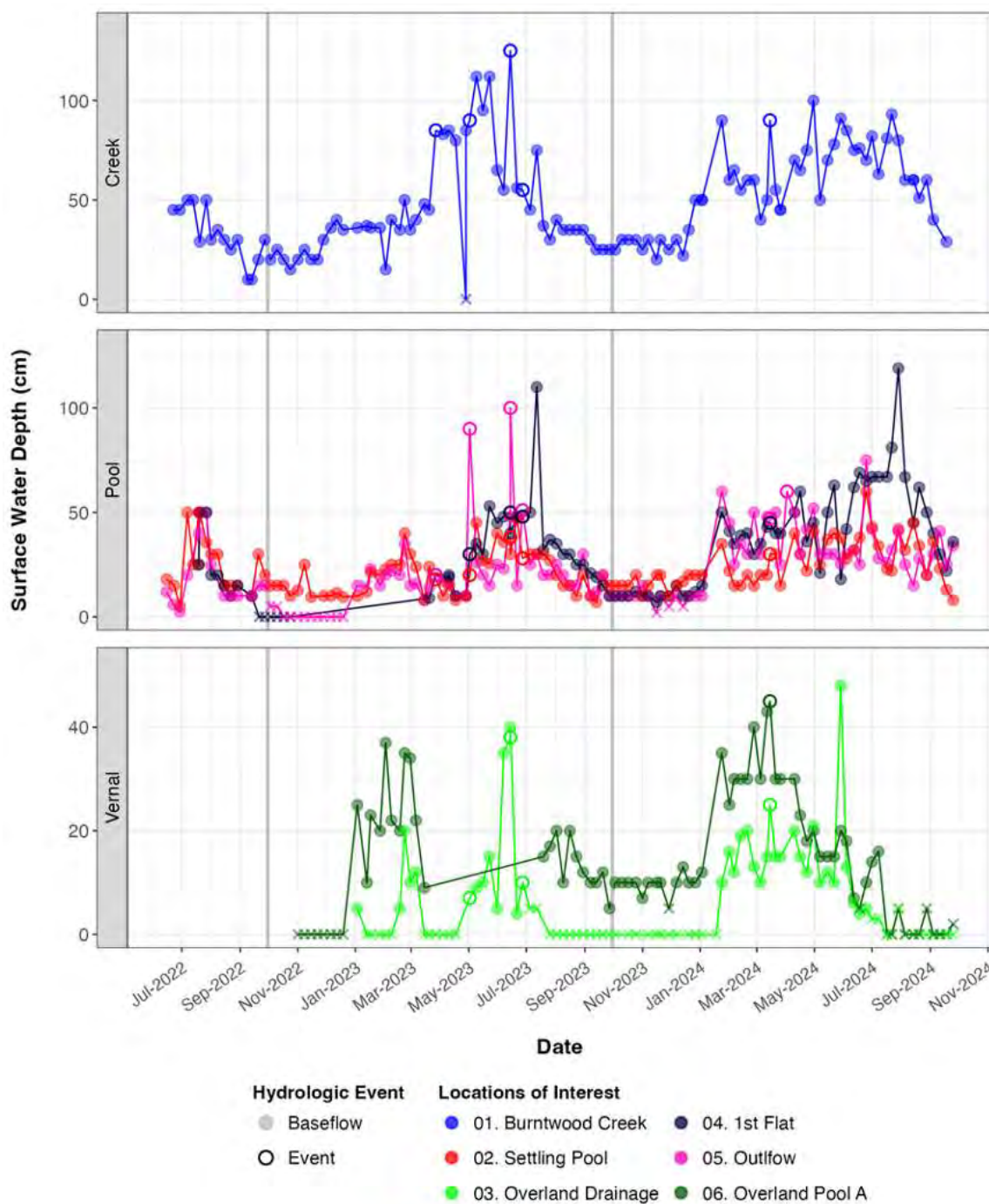


Figure 34. Time series of discrete, manually measured surface water depth at the Burntwood-Langenkamp Wetland Conservation Area Project. Depths were measured approximately monthly. Each point represents one measurement and colors denote the locations of interest, as indicated in the legend. Open symbols indicate samples that were collected during a hydrologic event (e.g., storm event) and filled symbols denote samples collected during baseflow. Crosses (×) represent instances when no surface water was detected during the visit. If present, different shapes denote the types of wetland features represented by the locations of interest. Gray vertical lines indicate the start of a water year (Oct 1–Sep 30).

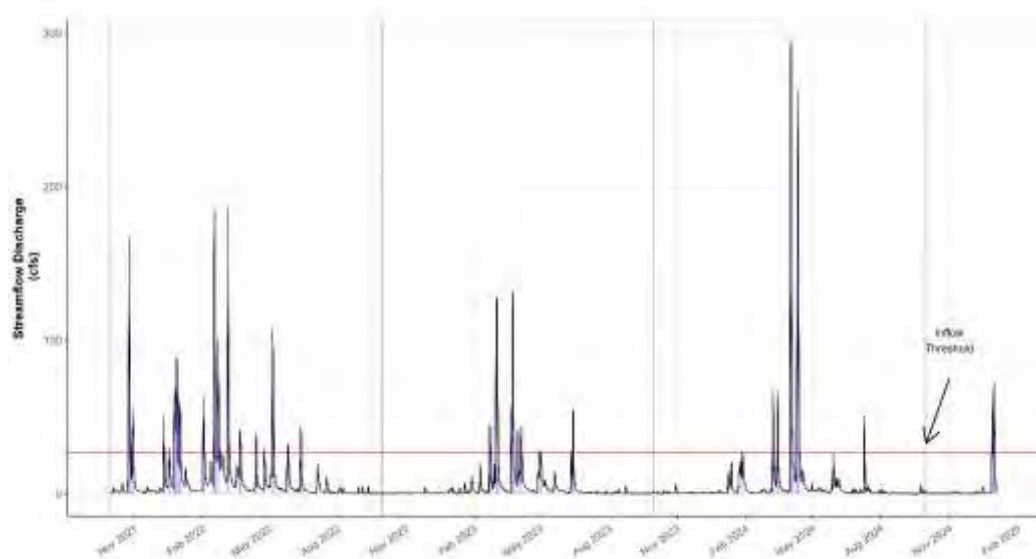


Figure 35. Burntwood Creek streamflow from USGS gage Chickasaw Creek at St. Marys - 402913084285400 transformed (watershed weighted) to indicate discharge at the wetland. The black line indicates flow, and the red line indicates the 27 cubic feet per second threshold, above which storm flow water will enter Burntwood-Langenkamp Wetland Conservation Area through the inflow notch. The blue shading indicates hydrologic events at which point the streamflow reaches above the threshold.

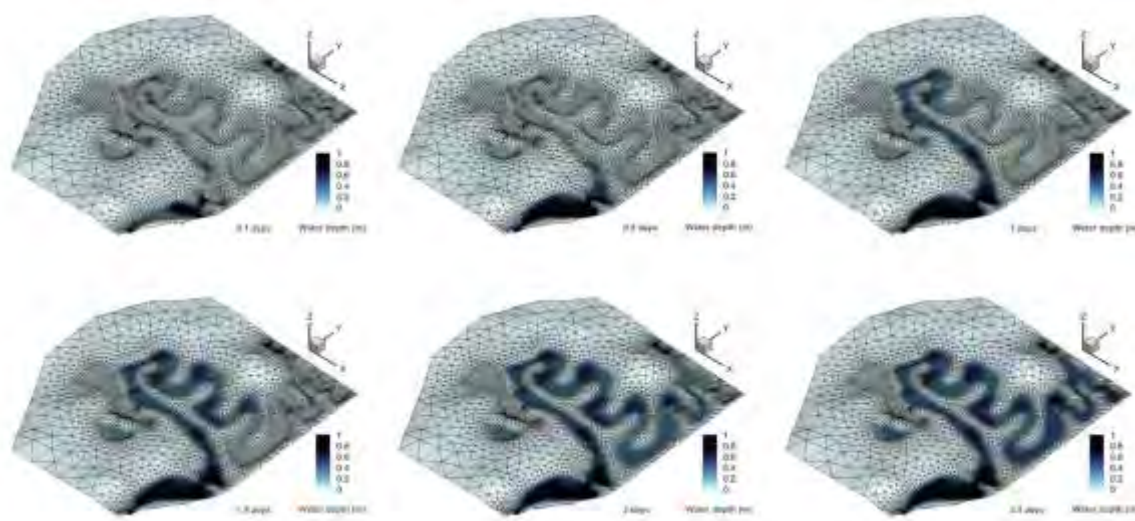


Figure 36. Demonstration of simulated water depths at the Burntwood-Langenkamp Wetland Conservation Area Project. Panels show how water moves along the stream channel and pools through time, assuming a specified head (266.5 meters above sea level) boundary condition at the inlet/settling pool.

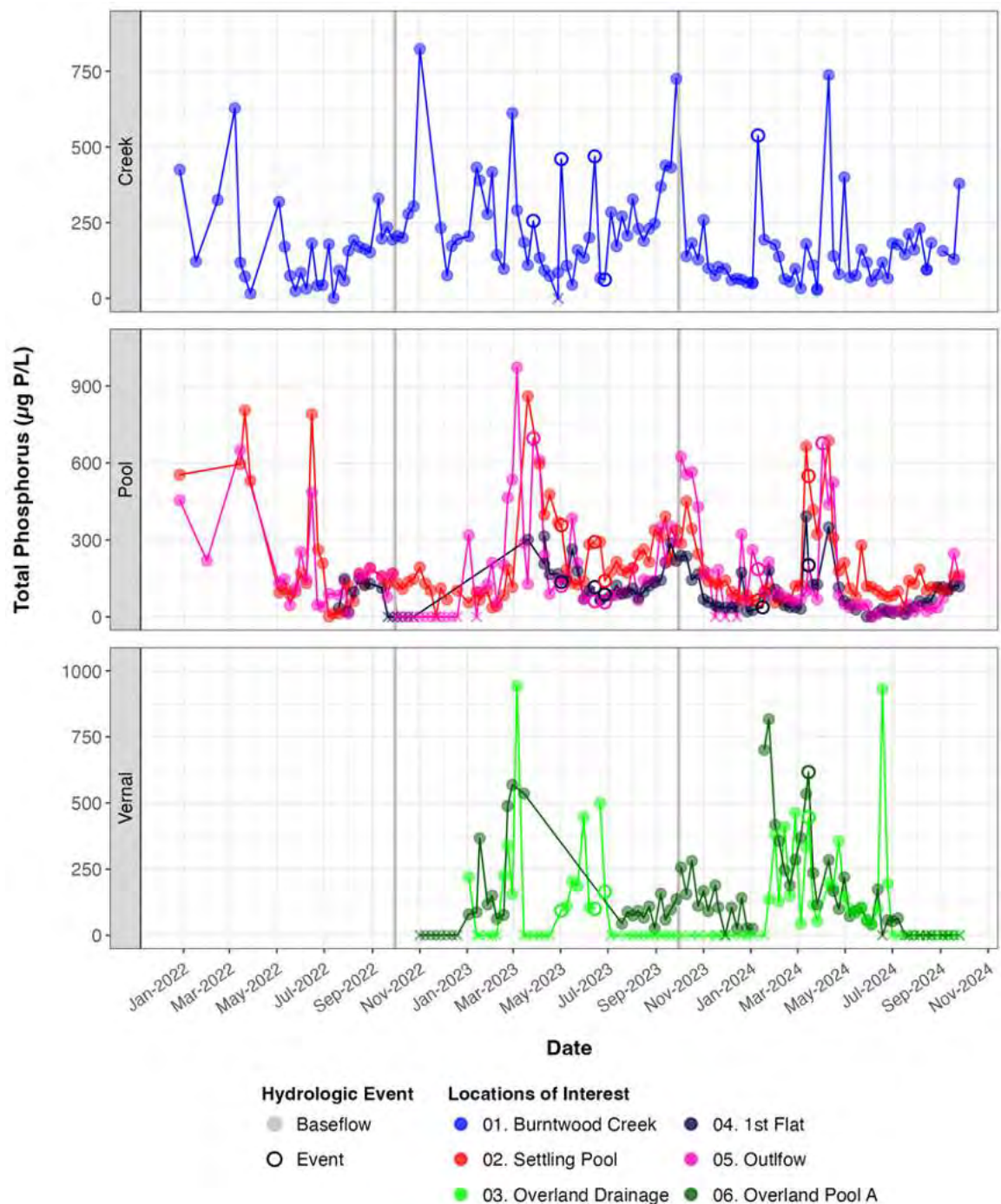


Figure 37. Time series of total phosphorus (TP) concentrations in surface water samples collected at the Burntwood-Langenkamp Wetland Conservation Area Project. Values below the detection limit of the analytical equipment were replaced with half the value of the detection limit. Each point represents one measurement and colors denote the locations of interest, as indicated in the legend. Open symbols indicate that measurements were collected during a hydrologic event (e.g., storm event) and filled symbols denote measurements collected during baseflow. Crosses (×) represent instances when no surface water was detected during the visit. If present, different shapes denote the types of wetland features represented by the locations of interest. Gray vertical lines indicate the start of a water year (Oct 1–Sep 30).

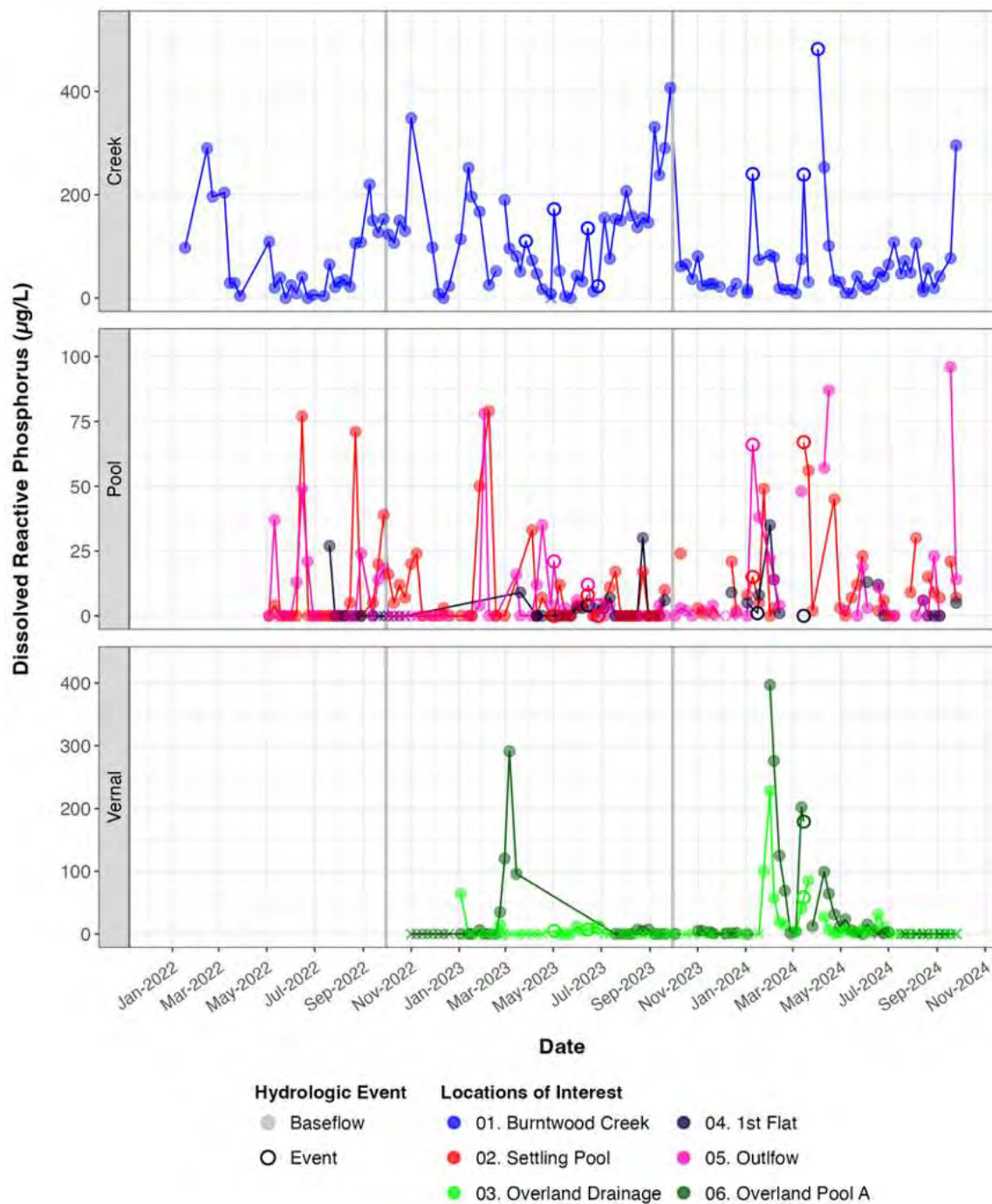


Figure 38. Time series of dissolved reactive phosphorus (DRP) concentrations in surface water samples collected at the Burntwood-Langenkamp Wetland Conservation Area Project. Values below the detection limit of the analytical equipment were replaced with half the value of the detection limit. Each point represents one measurement and colors denote the locations of interest, as indicated in the legend. Open symbols indicate that measurements were collected during a hydrologic event (e.g., storm event) and filled symbols denote measurements collected during baseflow. Crosses (×) represent instances when no surface water was detected during the visit. If present, different shapes denote the types of wetland features represented by the locations of interest. Gray vertical lines indicate the start of a water year (Oct 1–Sep 30).

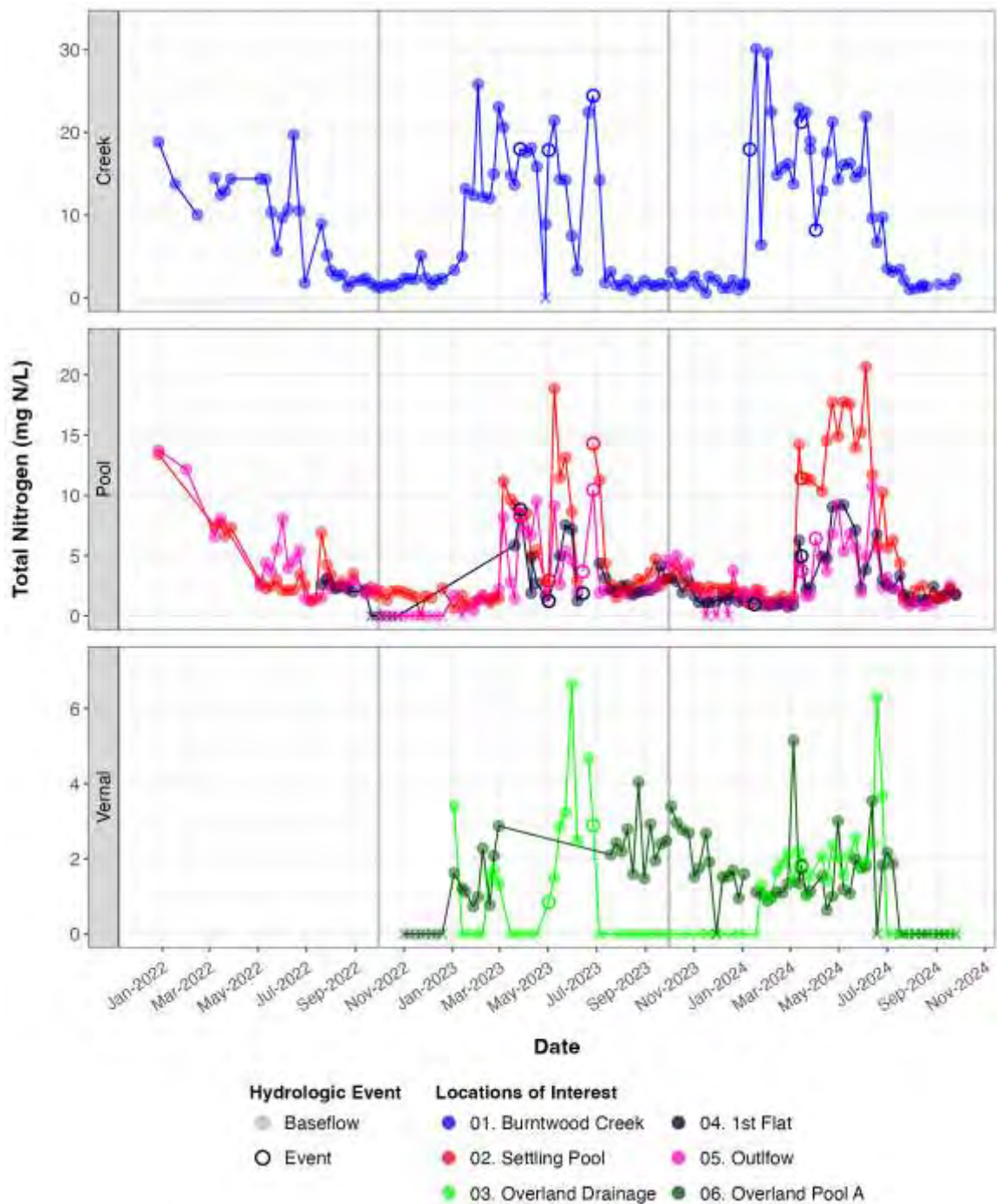


Figure 39. Time series of total nitrogen (TN) concentrations in surface water samples collected at the Burntwood-Langenkamp Wetland Conservation Area Project. Values below the detection limit of the analytical equipment were replaced with half the value of the detection limit. Each point represents one measurement and colors denote the locations of interest, as indicated in the legend. Open symbols indicate that measurements were collected during a hydrologic event (e.g., storm event) and filled symbols denote measurements collected during baseflow. Crosses (×) represent instances when no surface water was detected during the visit. If present, different shapes denote the types of wetland features represented by the locations of interest. Gray vertical lines indicate the start of a water year (Oct 1–Sep 30).

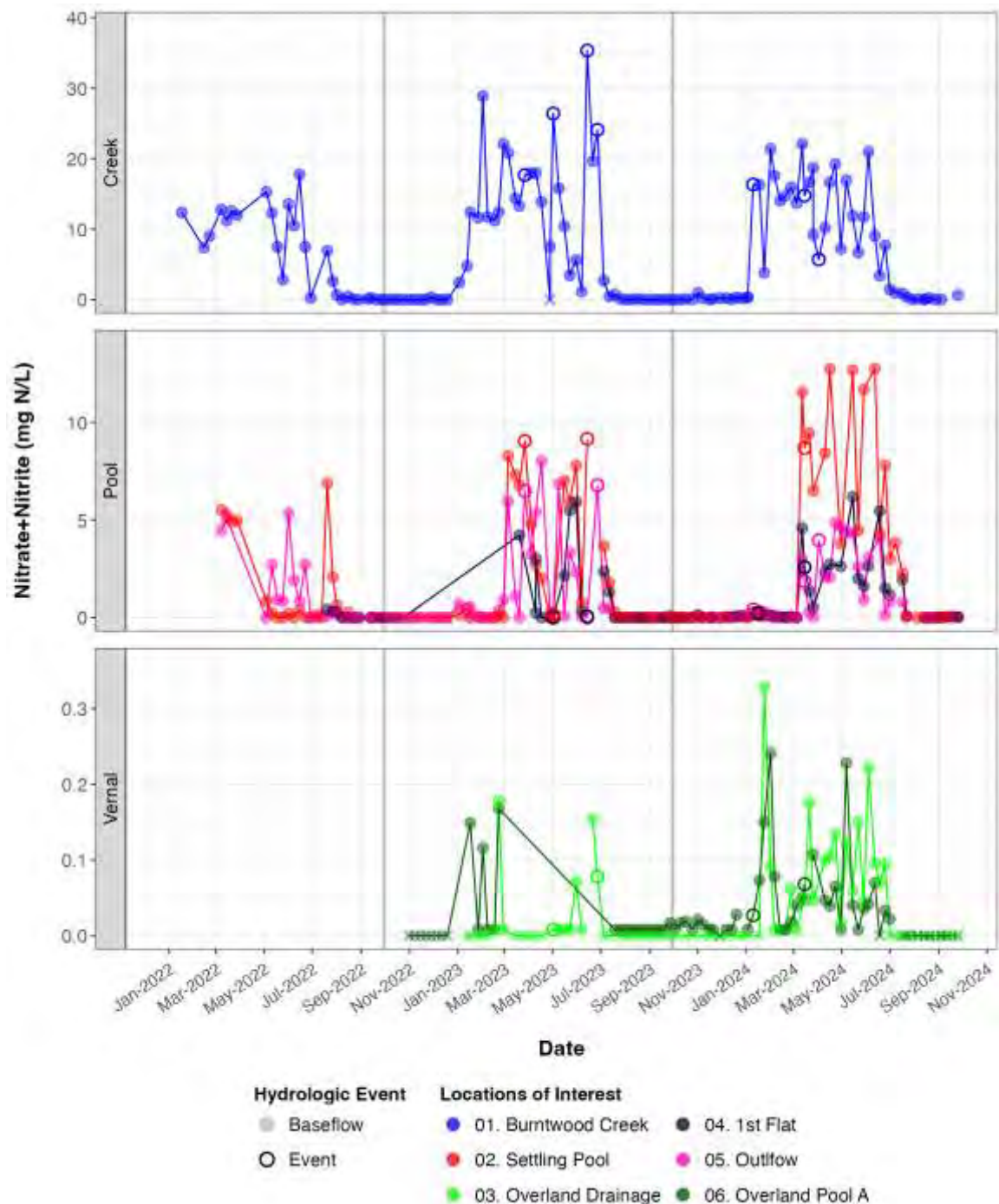


Figure 40. Time series of Nitrite+nitrate (NO_x) concentrations in surface water samples collected at the Burntwood-Langenkamp Wetland Conservation Area Project. Values below the detection limit of the analytical equipment were replaced with half the value of the detection limit. Each point represents one measurement and colors denote the locations of interest, as indicated in the legend. Open symbols indicate that measurements were collected during a hydrologic event (e.g., storm event) and filled symbols denote measurements collected during baseflow. Crosses (×) represent instances when no surface water was detected during the visit. If present, different shapes denote the types of wetland features represented by the locations of interest. Gray vertical lines indicate the start of a water year (Oct 1–Sep 30).

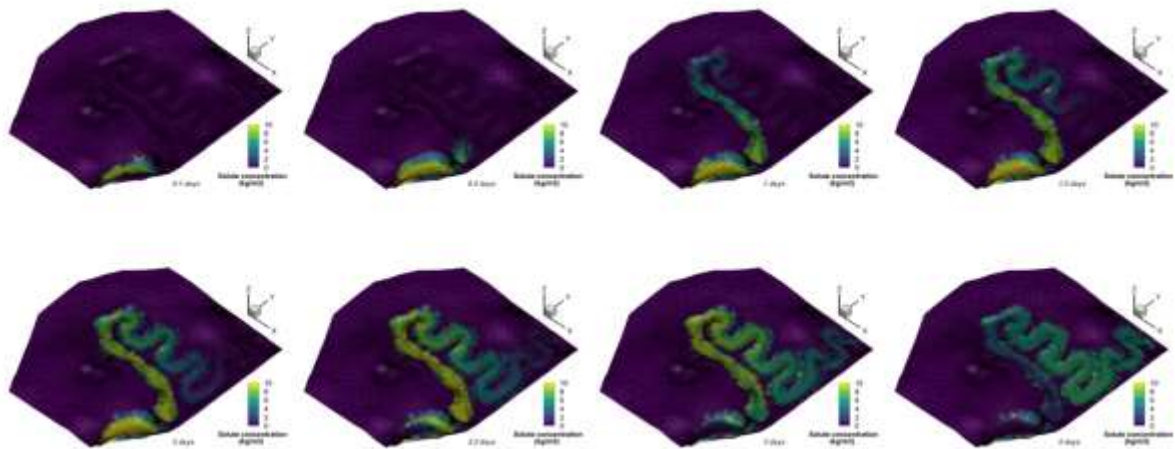


Figure 41. Simulated solute transport at the Burntwood-Langenkamp Wetland Conservation Area Project. Panels show the migration process of a conservative solute from its sources, (i.e., the inlet pool), assuming a hypothetical specified-concentration boundary at 10 kg/m³, towards the outlet.

Soil Nutrient Status and Processes

Overall, soil phosphate sorption capacity (SPSC) values were positive across the Project, indicating the capacity for sediment to sorb phosphate (Figure 42).



Figure 42. Soil Phosphate Sorption Capacity (SPSC) throughout the Burntwood-Langenkamp Wetland Conservation Area Project. Each point denotes a soil sample (0–5 cm) and different shapes indicate the wetland feature type, as shown in the legend. Colors indicate the SPSC value of each sample relative to the overall range of values observed at the wetland project, as shown in the color bar. Each panel shows the soil samples collected during a respective water year (Oct 1–Sep 30), along with the minimum and maximum SPSC values observed during a given water year. Negative SPSC values indicate the potential for soils to release

phosphate, while positive values indicate soils have capacity to sorb phosphate, based on Mehlich-3 extractions of phosphate, iron, and aluminum.

Vegetation Results

The Burntwood-Langenkamp Project increased total above- and belowground nutrient stock (net increases of 530 lbs. phosphorus and 2199 lbs. nitrogen) in vegetation from 2023 to 2024, despite the dry conditions of Water Year 2024 (Figure 44, Figure 45, Figure 46). The observed increases can largely be attributed to increases in the relative abundance of wetland indicator species (e.g., obligate wetland (OBL), facultative wetland (FACW)) relative to non-wetland species (e.g., facultative upland plants (FACU), obligate upland (UPL)) as well as an increase in the active vegetated wetland area (areas dominated by wetland plants). Such large increases from the first to second year of restoration have been observed in other Focal Projects (e.g., Forder Bridge Floodplain Reconnection, Oakwoods Nature Preserve Wetland Restoration Project, East and West) and likely demonstrate new growth moving labile nutrients into more recalcitrant forms.

Overall, Burntwood-Langenkamp shows the same increases in vegetative nutrient stock, species richness, and floristic quality assessment index as other H2Ohio Focal Projects have shown in the second year of restoration (Figure 47). There was an observed decrease in diversity from 2023 to 2024. Such a decrease in the second or third year of a restoration is a common pattern for early restoration Projects because, early in development, both upland and wetland plants are still in competition; as wetland species out-compete upland species diversity declines. Cattail (*Typha sp.*), Rice cut grass (*Leersia oryzoides*), and Barnyard grasses (*Echinochloa sp.*) are species which contributed heavily to nutrient stock at the Project. While these species are known to help remove nutrients, they can also be aggressive competitors and reduce the overall diversity of a wetland.

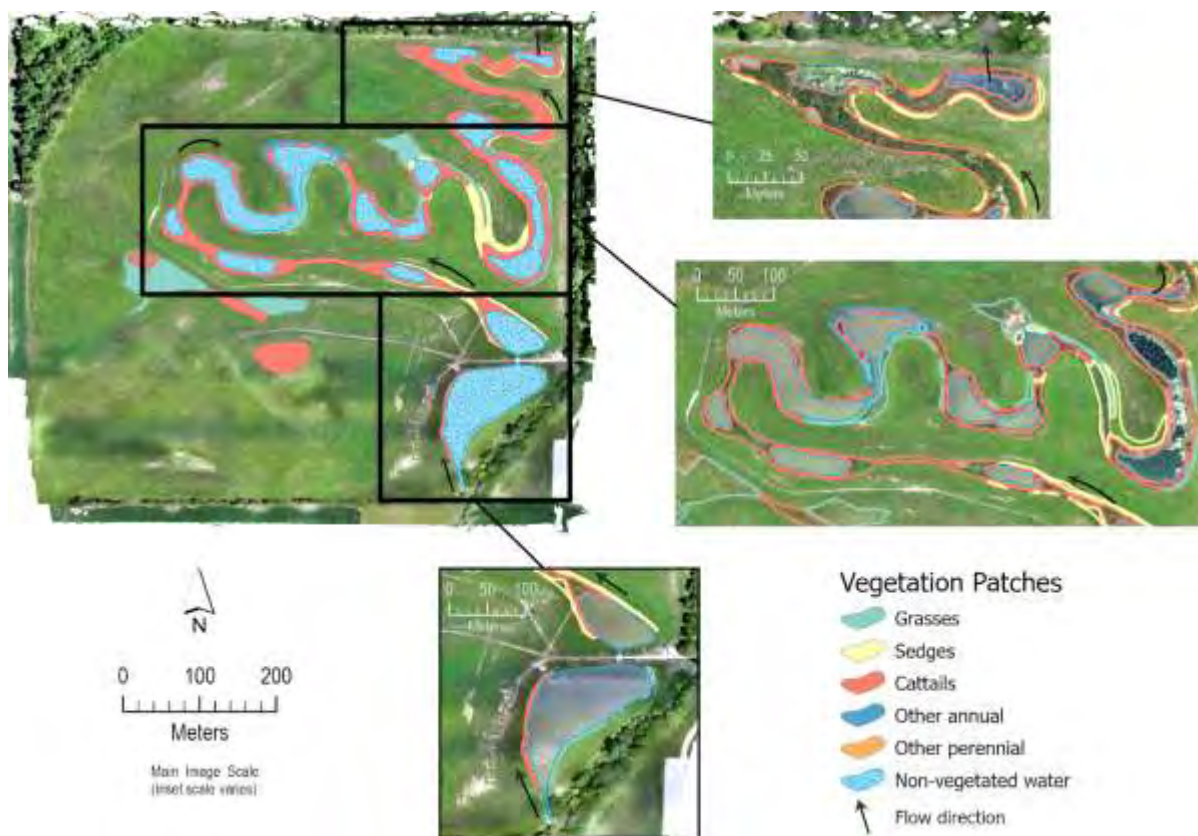


Figure 43. Aerial imagery (collected July 2024) with simplified vegetation patches based on expert-drawn vegetation maps (based on data collected July 2024) at Burntwood-Langenkamp Wetland Conservation Area. The magnified sections show the outlines of the vegetation patches. Vegetation patch types used in analyses have been combined in this image to visually simplify patch categories. Flow Direction (black arrows) indicates the general flow direction of surface water.

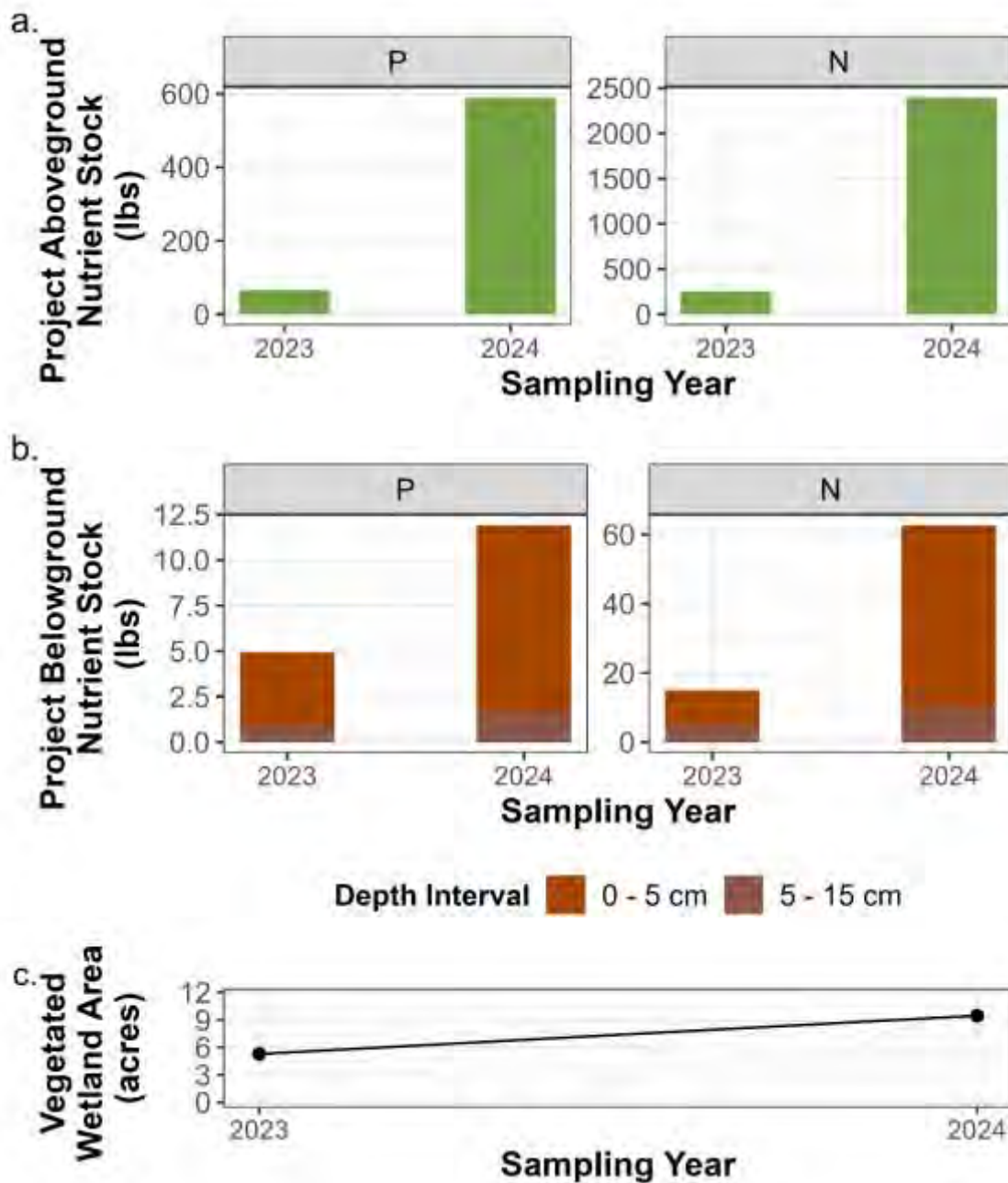


Figure 44. Nutrient stock in (a) above- and (b) belowground vegetation at Burntwood-Langenkamp Wetland Conservation Area. Estimates of the total mass of Phosphorus (P) and Nitrogen (N) stock in vegetation in the areas surveyed by the Monitoring Program for each year Burntwood Langenkamp was monitored for vegetation. (c) Vegetated Wetland Area refers to areas observed to have wetland-dominant species composition and all other Project areas were excluded from vegetation stock calculations. For more detailed information on how estimates were calculated, see Appendix II.

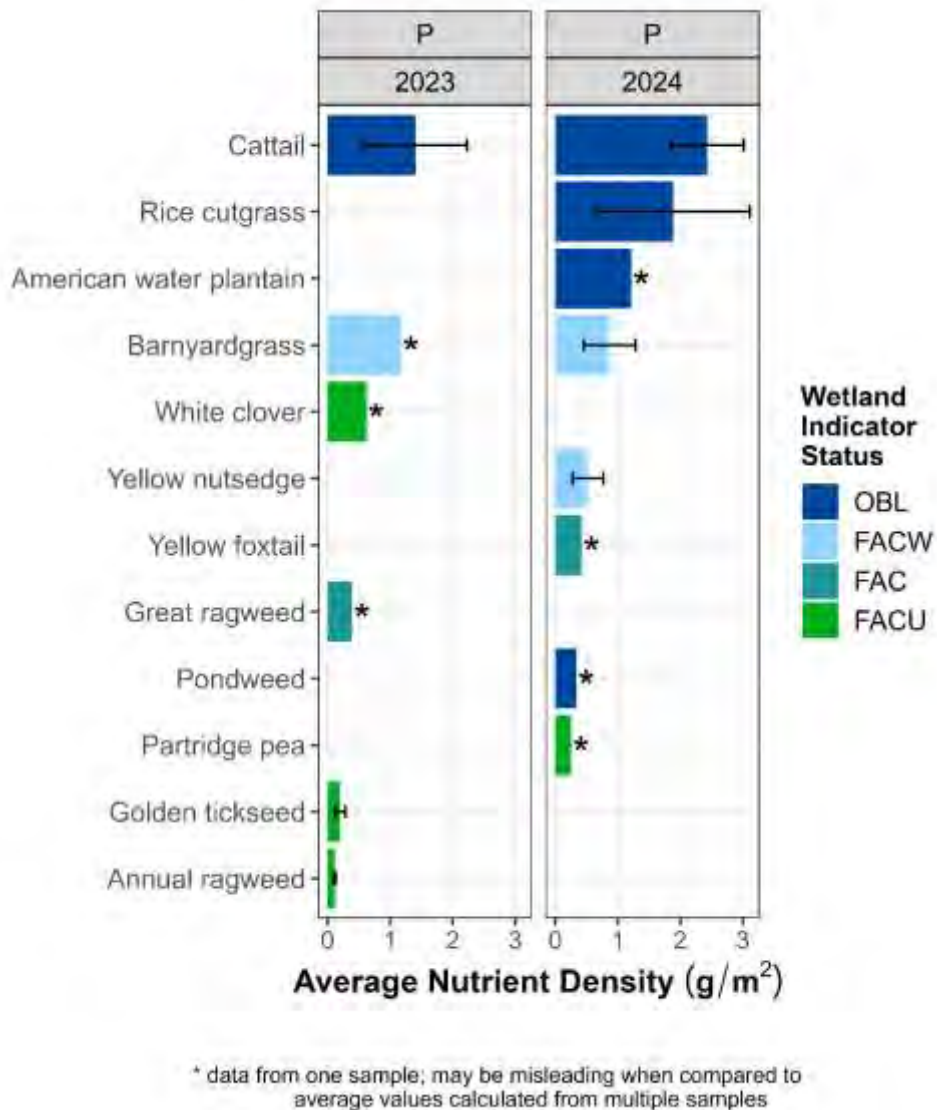


Figure 45. Average nutrient density of Phosphorus (P) in vegetation species at Burntwood-Langenkamp Wetland Conservation Area. The average mass of P stock in aboveground plant material per square meter for species sampled that covered more than 20% of a sampling quadrat at Burntwood Langenkamp. Nutrient density is calculated by multiplying measured nutrient concentrations and aboveground dry biomass data, resulting in an estimate of the average aboveground nutrient mass observed in a species within a given area. Appendix II displays both common and scientific species names and Wetland Indicator Status (WIS) designations can be found in Appendix II.

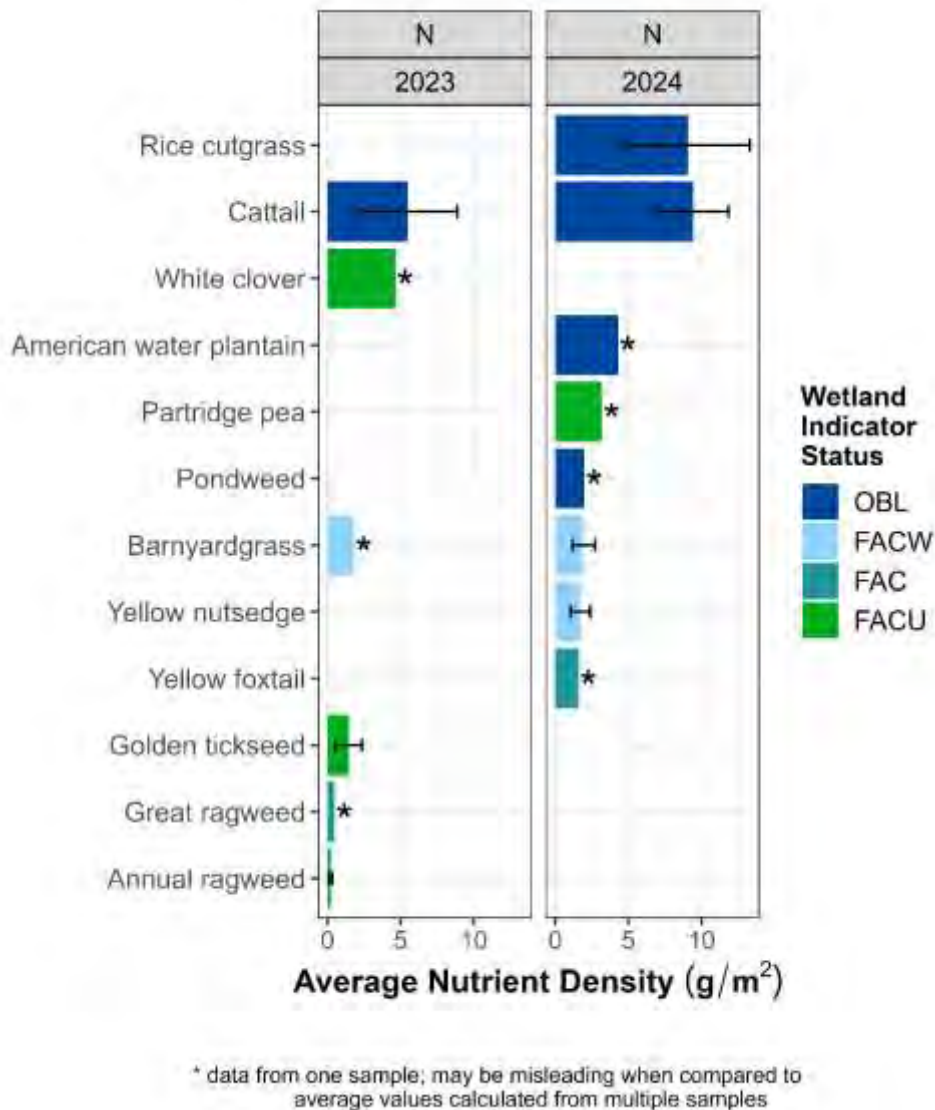


Figure 46. Average nutrient density of Nitrogen (N) in vegetation species at Burntwood-Langenkamp Wetland Conservation Area. The average mass of N stock in aboveground plant material per square meter for species sampled that covered more than 20% of sampling quadrat. at Burntwood Langenkamp. Nutrient density is calculated by multiplying measured nutrient concentrations and aboveground dry biomass data, resulting in an estimate of the average aboveground nutrient mass observed in a species within a given area. Appendix II displays both common and scientific species names and Wetland Indicator Status (WIS) designations can be found in Appendix II.

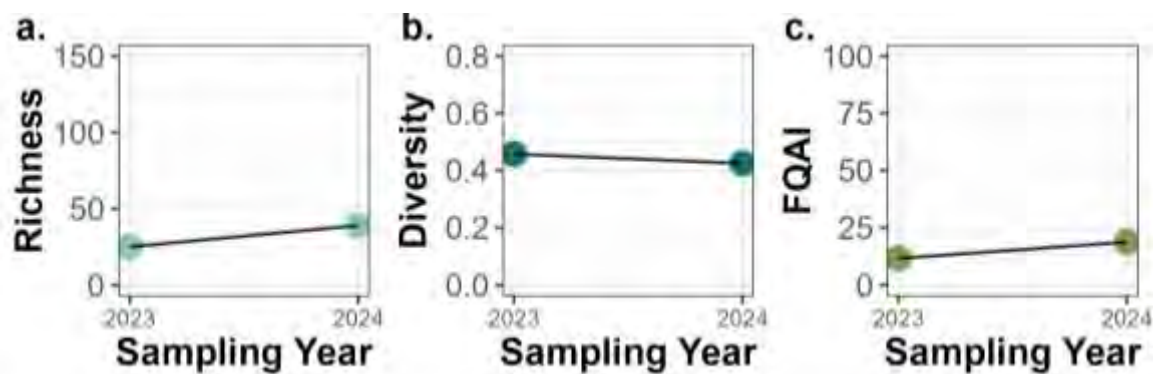


Figure 47. Species richness, diversity, & the Floristic Quality Assessment Index (FQAI) at Burntwood-Langenkamp Wetland Conservation Area. These graphs display (a) species richness, or a count of the total number of species, (b) species diversity calculated with Simpson’s Diversity Index (See Appendix II), and (c) the FQAI, a measure of habitat quality based on vegetation present (See Appendix II), for Burntwood Langenkamp.

Next Steps to Strengthen Understanding

The Penman Monteith equation was used to calculate average daily potential evapotranspiration rates using historical weather data for years during which monitoring has taken place⁷. These evapotranspiration rates were converted to water volumes using wetland acreage and added to the outflow volumes in order to obtain an estimate of inflow volume. To calculate exact inflow volume measurements from Burntwood Creek, an acoustic velocity (AV) sensor is needed in the elliptical culvert after the settling pool. At this location, the AV sensor will capture flows incoming from both the pump and inflow notch upstream. Exact inflow volume measurements will be used to further refine the nutrient budget for the Burntwood-Langenkamp Wetland Conservation Area and drive the 3-D hydrodynamic model being developed as a specified-flux boundary condition.

⁷ Allen, R. G., Pereira, L. S., Raes, D., Smith, M. (1998). Crop evapotranspiration - Guidelines for computing crop water requirements. Food and Agriculture Organization of the United Nations. <https://www.fao.org/4/x0490e/x0490e00.htm#Contents>

Forder Bridge Floodplain Reconnection (FORB)

Project Description

Paulding County | Upper Maumee Watershed

Project size: 54 Acres

Partner: Black Swamp Conservancy

The hydrology of this Project is passively managed. The Project has 5 acres of restored wetland, including multiple wetland features: a culvert-fed treatment train (Complex 4), elevated pools adjacent to the Maumee River (Complex 2), and sets of depressional pools fed only by surface water (Complexes 1 and 3). Water from land southeast of the Project enters the treatment train from a culvert during storm events. Each treatment train pool passively flows into the next and eventually into a small stream that delivers water to the Maumee River. The elevated riverbank pools and the depressional pools primarily receive water from only surface runoff. A hydrologic event at this Project is operationally defined as a storm event in which flow is expected through the culvert that feeds the treatment train.

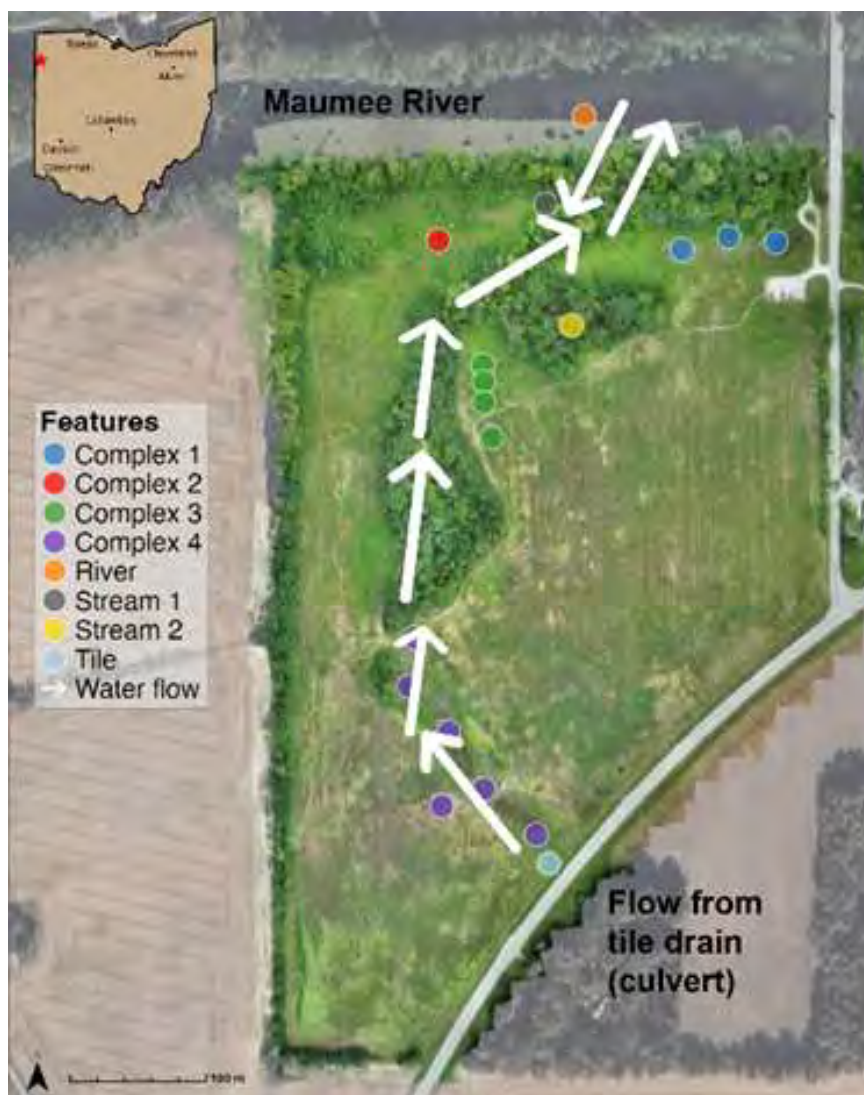


Figure 48. Aerial image showing surface water flow and sampling locations for the Forder Bridge Floodplain Reconnection Project. Blue arrows indicate direction of surface water flow. Dots represent geographic base crew sampling locations, which are grouped by Project features (fill color) where relevant. Text annotations provide additional context about the Project's watershed connection or other important features.

Management Considerations

Accurate Estimation of Wetland Drainage Area Helps Better Determine Nutrient Delivery

The Forder Bridge Project is a case study in why accurately identifying the area draining into a wetland is challenging, but also necessary to accurately estimate wetland nutrient function. The Forder Bridge Project primarily removes nutrients from the outlet of a tile drain (via a culvert) that drains a small agricultural field (7.3 acres); a small, forested plot (6.2 acres); and a smaller residential area (1 acre). The treatment train feature (Complex 4) receives the most of this drainage from a culvert running under County Road 424 and is the main contributor to new nutrient filtration (i.e., filtration of nutrients from outside the Project boundary).

Researchers confirmed that the actual drainage area (~16 acres) was much smaller than the initial estimated drainage area (~160 acres, based on topography) because of previously unclear tile drain networks. Specifically, researchers learned from discussions with on-the-ground experts from the local partner (a soil and water conservation district) that a culvert outside of the Project boundaries drained a majority of the initially estimated drainage area for the site. Continued monitoring and new real-time sensor capabilities in 2024 confirmed that the smaller drainage area is accurate. Nutrient filtration estimates in the H2Ohio Wetland Monitoring Program 2024 Annual Report are lower and more constrained than in the 2023 report, and researchers have re-estimated the nutrient filtration for Water Year (WY) 2023. Researchers estimated 3 lbs. of phosphorus (P) were filtered by this Project in WY 2024, similar to the newly estimated 2.6 lbs. P filtered in WY 2023. The previous estimate for annual nutrient filtration was 4–45 lbs. P; the spread of values was due to previous uncertainty in the drainage area. This Project was featured as a case study in the 2024 H2Ohio Wetland Monitoring Program webinar, in which the Monitoring Program shared the strength of such dialogue between analog methods (i.e., talking with on-the-ground experts) and technological expertise (i.e., data interpretation from sensors) toward accurate understanding of a wetland's impact in agricultural-heavy watersheds.

Hydrologically Disconnected “Idle” Areas Have Untapped Nutrient Removal Potential

Although intended as a floodplain reconnection, the Maumee River rarely floods the Forder Bridge Project because of the elevation at which the majority of the wetland pools are located. The pools closest to the riverbank berm (Complex 2) rarely hold water, likely due to their higher elevation relative to the nominal river level and to other Project features. The two sets of depressional pools (Complexes 1 and 3) receive minimal nutrient inputs because they were designed to receive only surface runoff from within the Project boundaries. Since 2021, these depressional pools have functioned as isolated depressional pools; researchers have not yet observed any output from these pools. The Monitoring Program has confirmed that the isolated and the “floodplain” pools are hydrologically “idle” in practice, meaning that, in the majority of conditions, they receive little to no hydrologic, and therefore nutrient, inputs from outside the Project's parcel boundary.

Installing pumps and underground pipes would enhance the hydrologic connectivity between the inlet stream and wetland complexes, which could transfer nutrient-rich water to those idle pools and even to the large “dryland” located in the eastern portion of the wetland site, enhancing overall nutrient retention. Increasing hydrologic connectivity to the “idle” areas would require detailed hydrologic modeling and engineering to ensure adequate functionality, and installation and maintenance of drainage control infrastructure. This infrastructure may also depend on ongoing, frequent, and active management of the Project to optimize nutrient reduction capacity and associated labor costs. Increased hydrologic connectivity could increase the capacity of vegetation within the depressional pools to take up nutrient-rich water and may improve the diversity of vegetation. However, altering hydrologic function in this way may also have unintended ecological consequences and could change the biodiversity and habitat quality of this Project. Finally, the elevation of these “idle” features in comparison to the Maumee River may make changes to increase their hydrologic connection prohibitively costly.



Figure 49. Aerial image of approximate locations of interest for water and soil sampling and discrete manual measurements of water depth and physicochemical parameters at Forder Bridge Floodplain Reconnection Project during water year 2024 (Oct 1, 2023–Sep 30, 2024). The legend provides the name of each sampling point. Different shapes denote the types of wetland features represented by the locations of interest. If present, different colors represent locations of interest that belong to a group or complex of features (e.g., a treatment train).

Nutrient Budget Takeaways

The Forder Bridge Project received approximately 18,000 m³ of water in Water Year (WY) 2024. Monitoring in WY 2024 indicates the Project filtered an estimated 7.4 lbs. phosphorus (P) as total phosphorus and 34 lbs. nitrogen as total nitrogen. The Project also filtered 0.8 lbs. of dissolved reactive phosphorus and 3.6 lbs. of total ammonium nitrogen. Forder Bridge potentially released 24 lbs. of nitrite+nitrate in WY 2024. Conversion of former agricultural areas in the parcel to wetland prevents the loss of 36 ± 24 lbs. of P each year. Soils throughout the Project have capacity to sorb phosphate, except for samples from a single location on the banks of the Maumee River.

Surface Water Hydrology and Nutrients

It is along the treatment train flow path that H2Ohio Wetland Monitoring Program results show the greatest variation (i.e., range of values across space and time) in water level and nutrient content in surface water (Figure 49, Figure 52, Figure 54, Figure 56). On the other hand, the pools closest to the Maumee River riverbank berm (Complex 2) rarely hold water, likely due to their higher elevation relative to the river and to other Project features (Figure 51). The two sets of depressional pools (Complexes 1 and 3) receive minimal nutrient inputs because they receive only surface runoff from within the Project boundaries; observations by the base monitoring crew and 3-D hydrodynamic modeling team align with each other, and the modeling researchers term these pools “idle” in regard to current nutrient reduction function.

After multiple years (2022–2024) of observation, researchers can now characterize the Forder Bridge Wetland features by flooding regime. Complexes 1, 3, and 4 all exhibit a seasonal flooding regime with one or two pools (Complex 3 Pool D, Complex 4 Pool A, Figure 52) that are near-permanent even during drought years. These classifications may adjust over time as the Monitoring Program continues to visit the Project during both wet and dry years. Complex 2, despite its proximity to the Maumee River, has almost never been observed with standing water, and is thus considered an ephemeral flooding regime. The differences in flooding regime result in different vegetation zones; the seasonally flooded pools are dominated by Cattails (*Typha spp.*) and Sedges (*Cyperaceae*), whereas the ephemerally flooded pools had little to no wetland vegetation present.

Water level data captured by high resolution sensors (Vegapuls, VEGA, Shiltach, Germany) in 2024 was paired with precipitation data to monitor the relationship between rainfall events and increasing water level at Forder Bridge (Figure 51). The isolated depressional wetlands (Complex 1 and 3) and the treatment train (Complex 4) had water levels that responded in a relatively clear pattern to rainfall; water depth rose with the event and steadily declined after. The pools closest to the Maumee River (Complex 2) have elevated topography compared to the river and exhibited a water depth pattern independent of precipitation accumulation, rising and falling (within 20-cm range) more frequently in a shorter time period, though vegetation accumulation under these sensors may be confounding the water level observations, so further analysis is needed. The sensor data underscores the importance of detecting storm events that manual monitoring trips miss (e.g., in August 2024 there appears to be precipitation accumulation but no accompanying base crew sampling trip).

The treatment train (Complex 4) receives direct input from the SW Tile, which delivers relatively large volumes of water during late winter and early spring storm events. This connectivity is reflected in water depth as well as nutrient concentrations. Pools in the treatment train tend to have the deepest sampling location water depths of the entire Forder Bridge Project (up to 40 cm in Pool D, Figure 52). Dissolved reactive phosphorus (DRP) and Nitrite+nitrate (NO_x) concentrations were higher on average and more variable (i.e., range of values across space and time) in the treatment train pools than in the other Project features (Figure 54, Figure 56; note the differences in scale across NO_x results). During storm events, Pool D exhibited a nutrient pulse in July 2024 (approximately 0.3 mg P/L for DRP, Figure 54). The dominant vegetation in the treatment train shifts from Cattails (*Typha spp.*) to Sedges (*Cyperaceae*) with distance from the tile drain, suggesting that the plant community composition may be shaped by differences in the hydroperiods and flooding regime differences in pools along the flow path. There are also differences in pH and surface water conductivity among the treatment train pools, which may be indicative of road salt influence in Pool A (the pool closer to the road), which could have implications for vegetation.

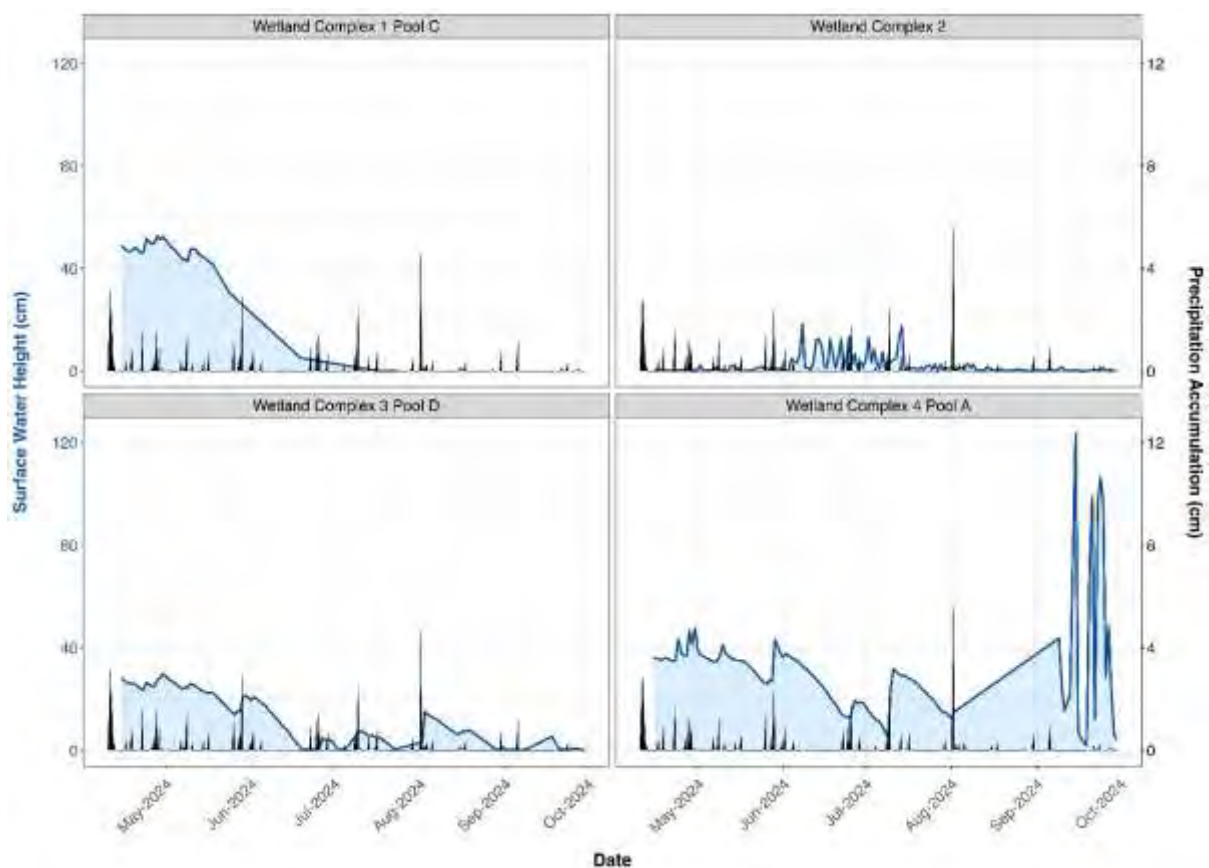


Figure 50. Daily average surface water height (bold blue line) and daily precipitation accumulation (black peaks, secondary y-axis) over time across the Forder Bridge Floodplain Reconnection from mid-April to October 2024. Each panel indicates a location of interest at the Forder Bridge Project. For the approximate location of the Wetland Complex and Pools, see Figure 49. Note: The Vegapuls sensor recording surface water height in Wetland Complex 1 Pool C had a malfunction in mid-May 2024 and there is no data the rest of the water year for that Complex.

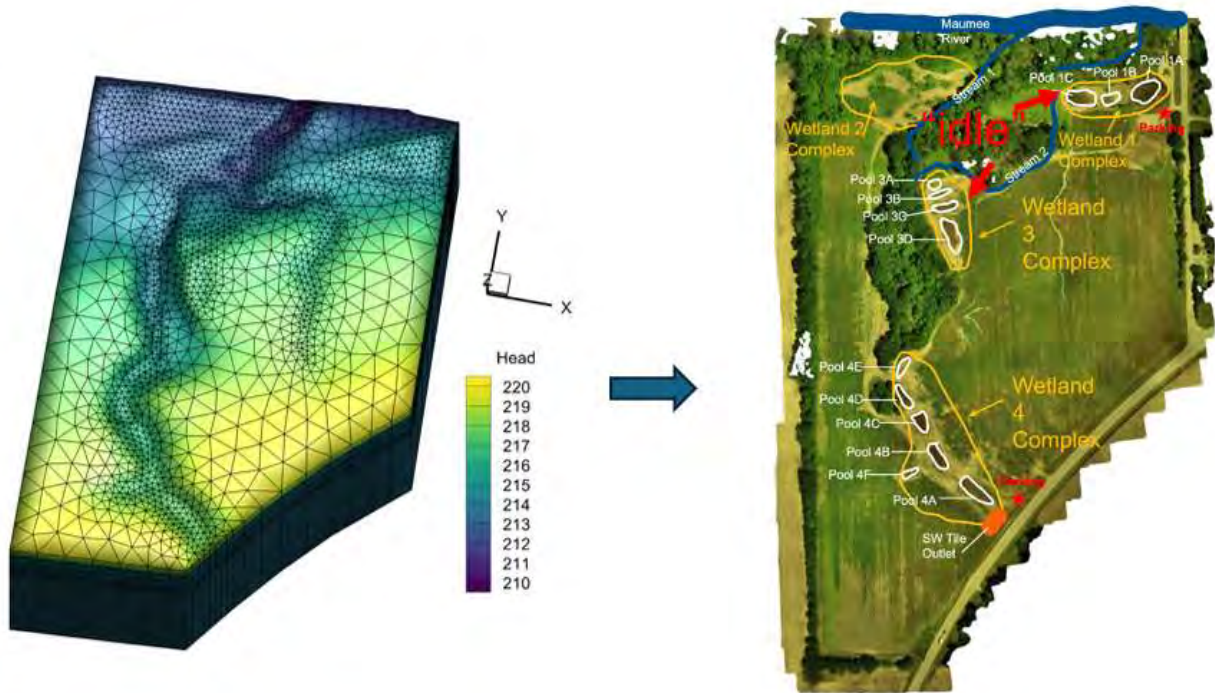


Figure 51. Development and application of 3-dimensional (3-D) hydrodynamic models to identify “idle” wetland complexes at the Forder Bridge Floodplain Reconnection Project. The left panel displays the simulation domain and 3-D mesh of the model as well as an example of simulated head value distribution (in meters), based on which flow pattern and “idle” pools of the Project were delineated and identified.. Wetland Complexes 1 and 3 indicated by red arrows in the right panel were identified as “idle” based on scenario simulations of different hydrologic conditions.

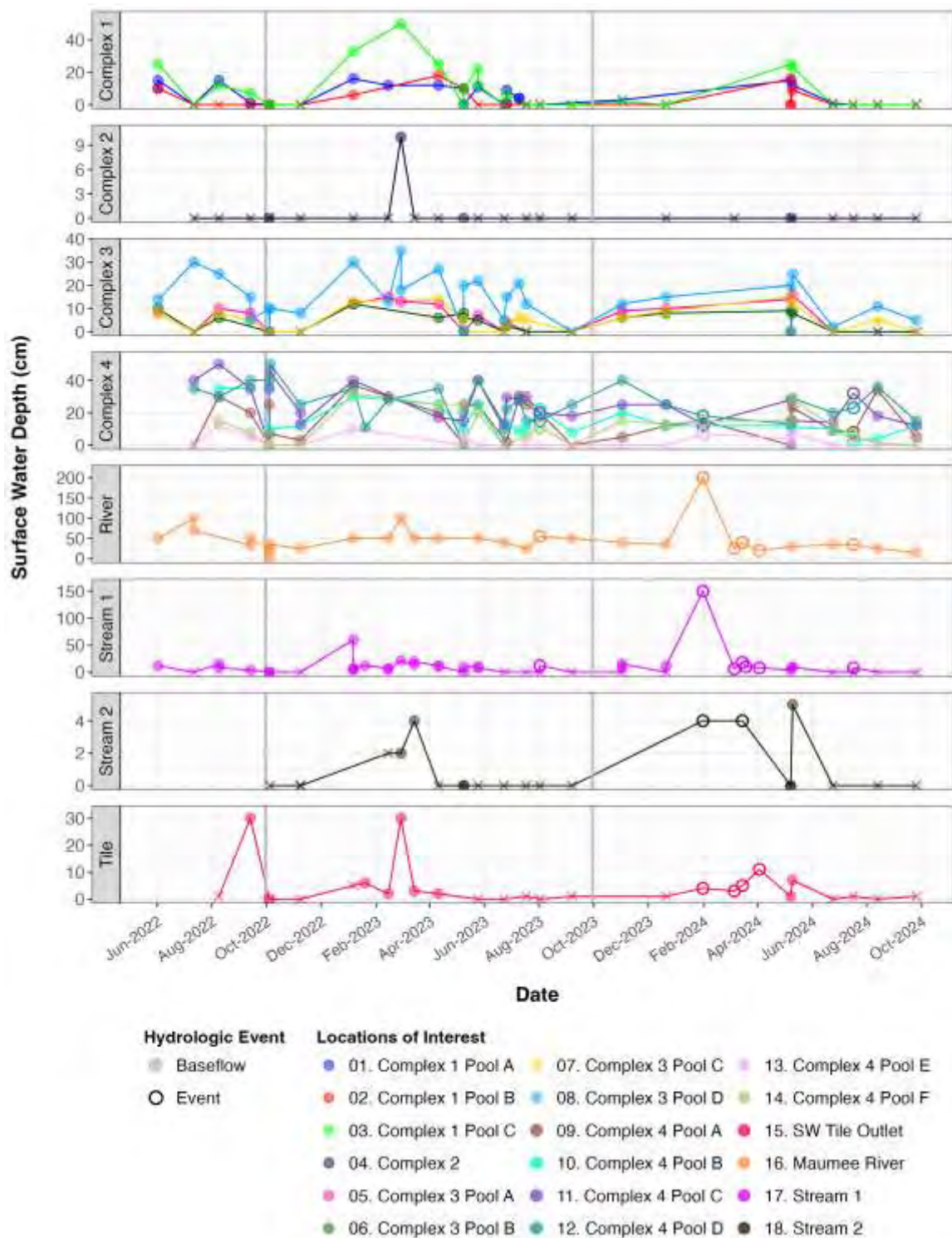


Figure 52. Time series of discrete, manually measured surface water depth at the Forder Bridge Floodplain Reconnection Project. Depths were measured approximately monthly. Each point represents one measurement and colors denote the locations of interest, as indicated in the legend. Open symbols indicate samples that were collected during a hydrologic event (e.g., storm event) and filled symbols denote samples collected during baseflow. Crosses (×) represent instances when no surface water was detected during the visit. If present, different shapes denote the types of wetland features represented by the locations of interest. Gray vertical lines indicate the start of a water year (Oct 1–Sep 30).

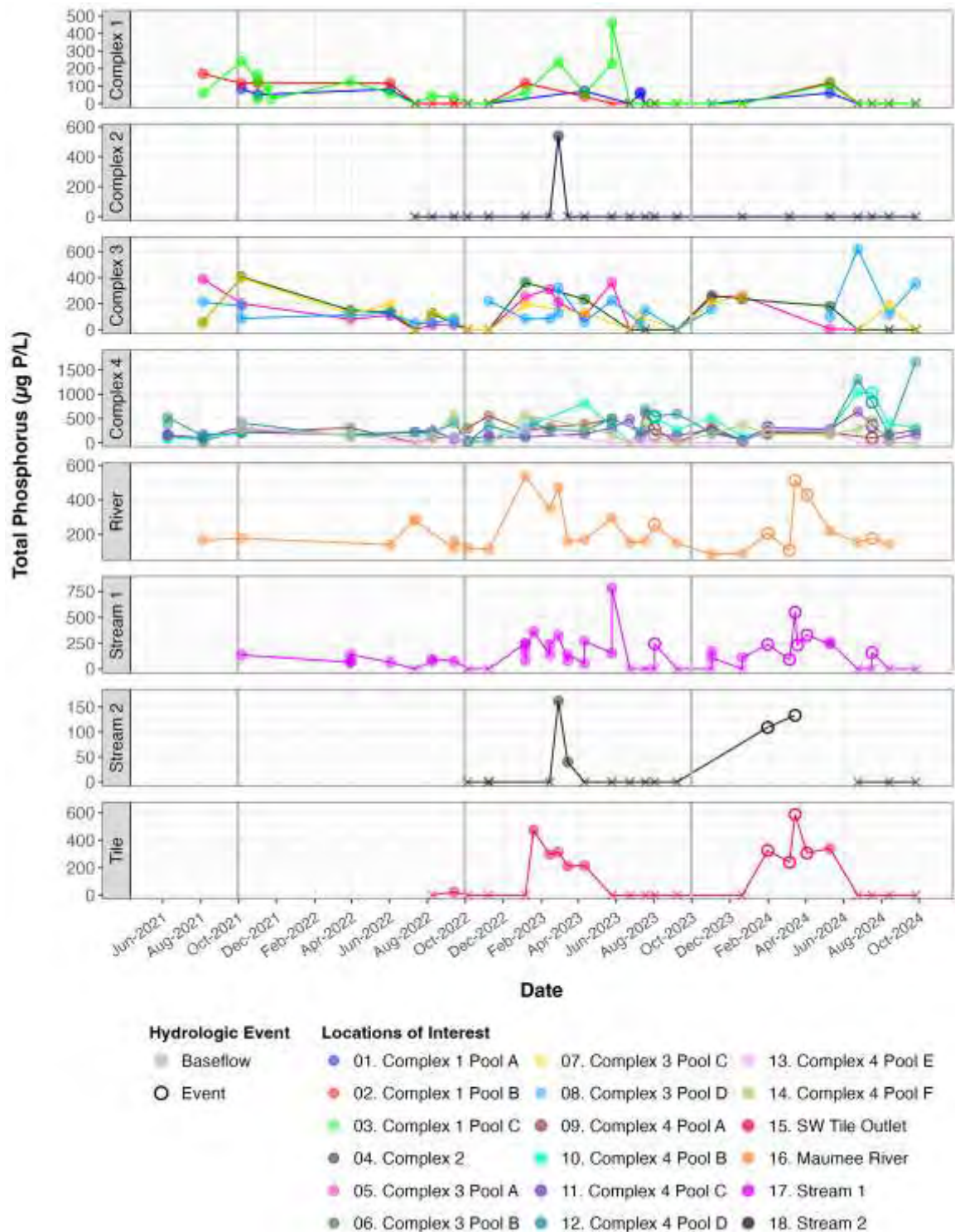


Figure 53. Time series of total phosphorus (TP) concentrations in surface water samples collected at the Forder Bridge Floodplain Reconnection Project. Values below the detection limit of the analytical equipment were replaced with half the value of the detection limit. Each point represents one measurement and colors denote the locations of interest, as indicated in the legend. Open symbols indicate that measurements were collected during a hydrologic event (e.g., storm event) and filled symbols denote measurements collected during

baseflow. Crosses (×) represent instances when no surface water was detected during the visit. If present, different shapes denote the types of wetland features represented by the locations of interest. Gray vertical lines indicate the start of a water year (Oct 1–Sep 30).

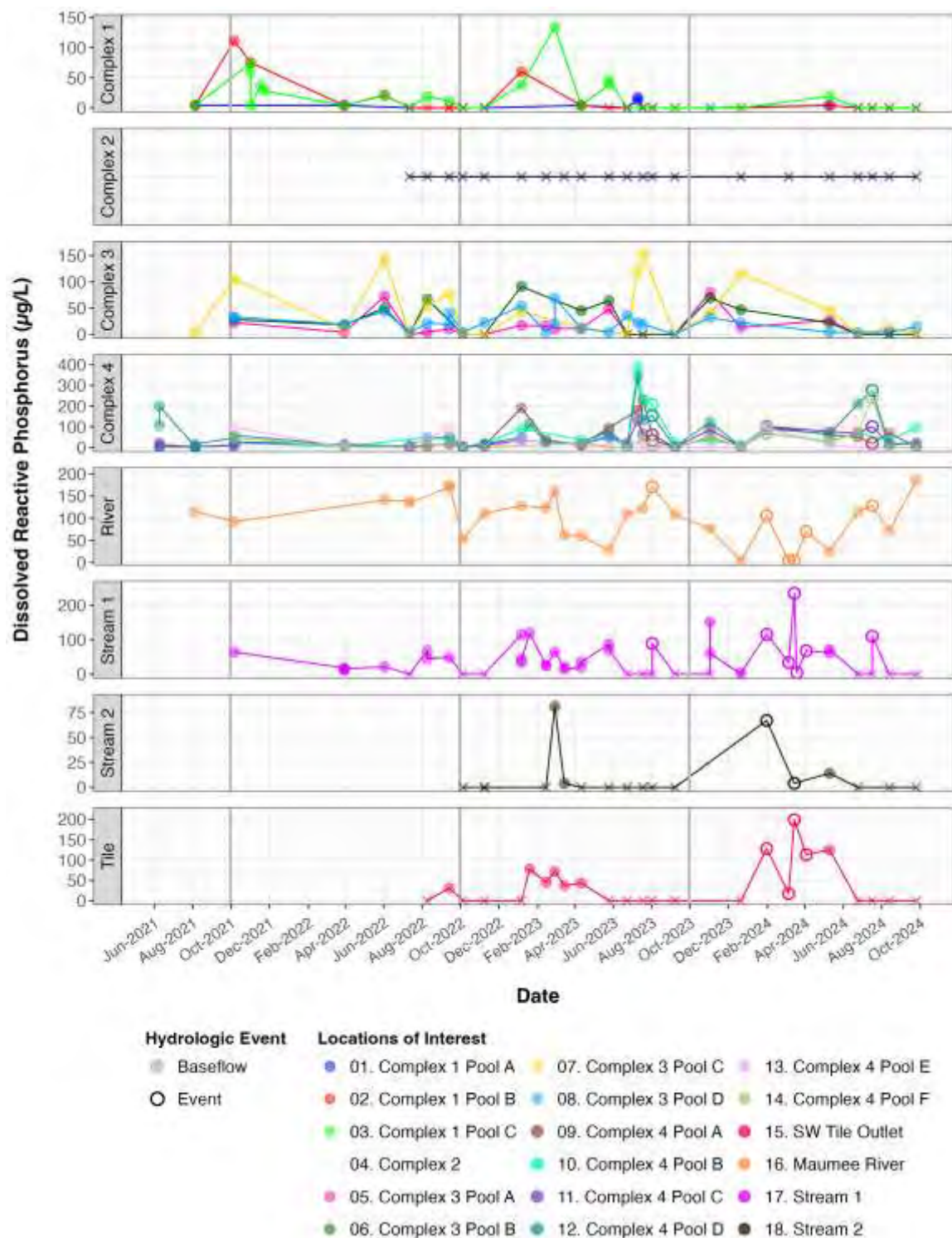


Figure 54. Time series of dissolved reactive phosphorus (DRP) concentrations in surface water samples collected at the Forder Bridge Floodplain Reconnection Project 2021–2024. Each symbol represents one sample point and colors denote the sampling locations, as indicated in the legend. Open symbols indicate samples that were collected during a

hydrologic event (e.g., storm event) and filled symbols denote samples collected during baseflow. Crosses represent instances when no water sample was collected because surface water was either not detected or too low during the visit. Values below detection limit were replaced with half the detection limit. Gray vertical lines indicate the start of a water year (Oct 1–Sep 30).

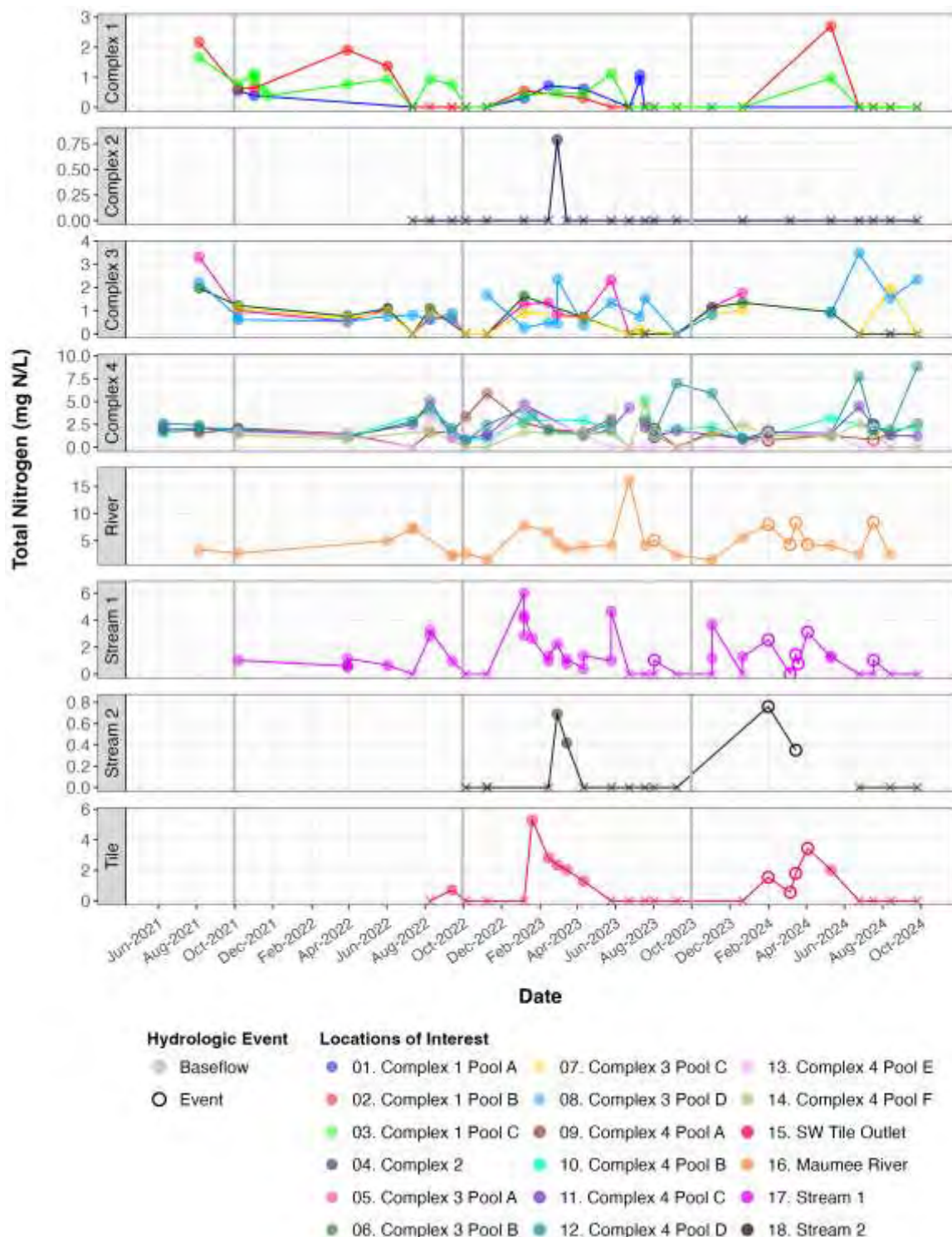


Figure 55. Time series of total nitrogen (TN) concentrations in surface water samples collected at the Forder Bridge Floodplain Reconnection Project. Values below the detection

limit of the analytical equipment were replaced with half the value of the detection limit. Each point represents one measurement and colors denote the locations of interest, as indicated in the legend. Open symbols indicate that measurements were collected during a hydrologic event (e.g., storm event) and filled symbols denote measurements collected during baseflow. Crosses (×) represent instances when no surface water was detected during the visit. If present, different shapes denote the types of wetland features represented by the locations of interest. Gray vertical lines indicate the start of a water year (Oct 1–Sep 30).

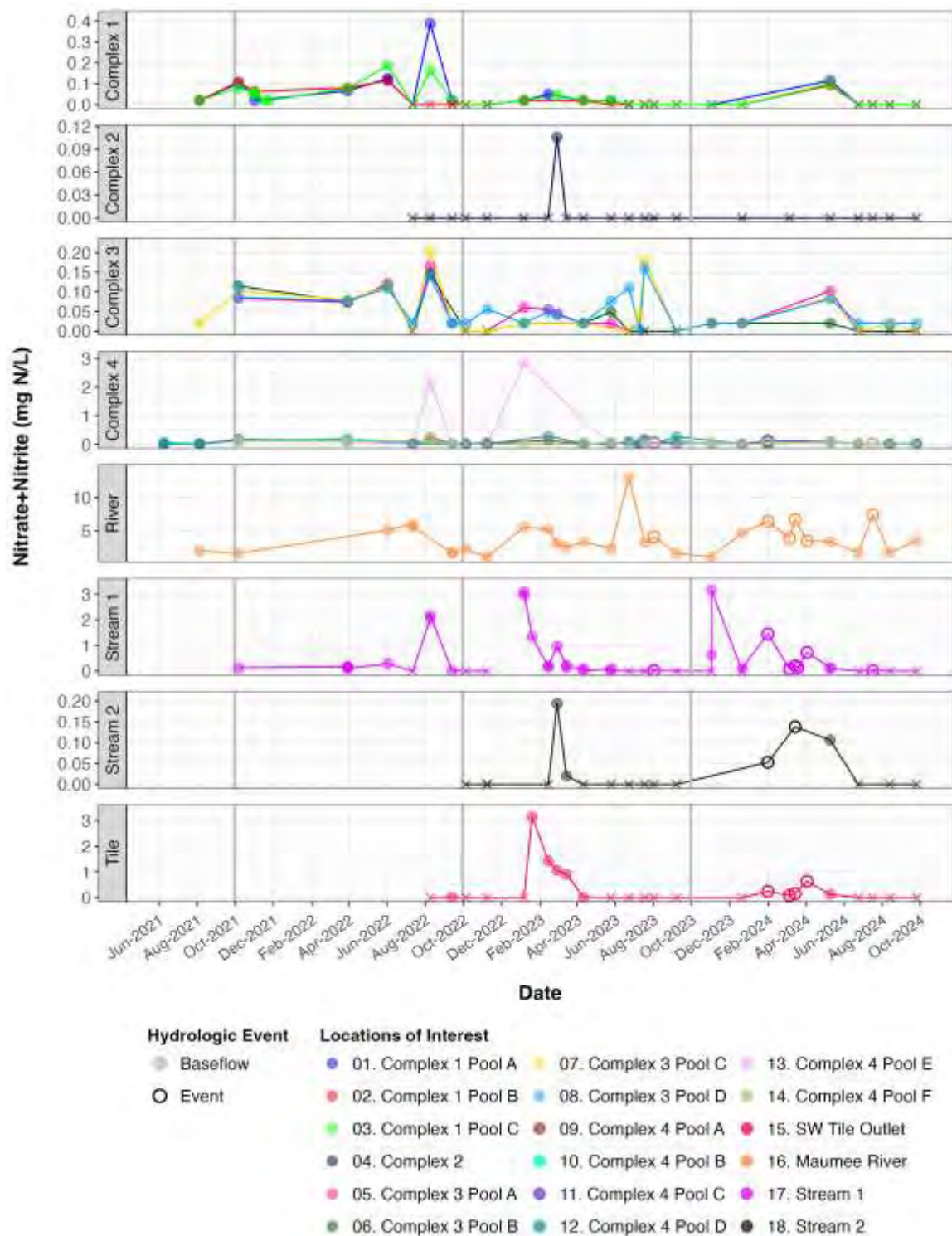


Figure 56. Time series of Nitrite+nitrate (NO_x) concentrations in surface water samples collected at the Forder Bridge Floodplain Reconnection Project. Values below the detection limit of the analytical equipment were replaced with half the value of the detection limit. Each point represents one measurement and colors denote the locations of interest, as indicated in the legend. Open symbols indicate that measurements were collected during a hydrologic event (e.g., storm event) and filled symbols denote measurements collected during baseflow. Crosses (x) represent instances when no surface water was detected during the

visit. If present, different shapes denote the types of wetland features represented by the locations of interest. Gray vertical lines indicate the start of a water year (Oct 1–Sep 30).

Soil Nutrient Status and Processes

Soil sample analysis and geophysical surveys reveal spatial gradients in soil characteristics and nutrient retention capacity. Generally, soil conditions along the southern end of the parcel and around the treatment train pools (Complex 4) differ from soil conditions in the middle portion of the parcel near the isolated wetlands (Complexes 1 and 3). The southern end of the Project has higher apparent soil conductivity (ECa) and lower soil phosphate sorption capacity (SPSC) than the middle portion.

Soil at Forder Bridge showed a wide range in capacity to sorb phosphate, as indicated by SPSC values (-106–337 mg phosphorus/kg), and the overall spatial trends from previous sampling years were observed again in 2024 (Figure 58). Soil in the isolated wetlands and treatment train pools generally had positive SPSC values (Complexes 1 and 3, Complex 4; > 90 mg/kg; Supplemental Information). Soil nearest the Maumee River showed low or negative SPSC values, which indicates a potential to release phosphate. Patterns in phosphate sorption capacity reflect patterns of connectivity and nutrient delivery at Forder Bridge. Positive SPSC values in the isolated wetland pools (especially Complex 3) align with researcher's expectations, as the isolated wetland pools receive primarily surface water runoff with low nutrient concentrations from the meadow to the east, so the capacity to sorb phosphate may remain high. SPSC values in the treatment train (Complex 4 Pools A–D) are likely influenced by nutrient-rich tile drainage water and accumulating phosphate, likely using up the binding sites in soil.

The H2Ohio Wetland Monitoring Program has now collected and analyzed soil samples throughout the Forder Bridge Project over three consecutive years and can begin to assess how soil nutrient retention capacity has changed over time since wetland feature construction. Within each feature at Forder Bridge, the individual pools' SPSC changed differently over time, and the change is not always linear (i.e., not always decreasing or increasing at a similar rate across the years). SPSC values in all three pools of Complex 1 remained about the same as in previous years (~80–120 mg/kg; Figure 58). The treatment train (Complex 4) exhibited more mixed changes across years; the first pools in the train (A and B) had slightly higher SPSC values in 2024 (113–136 mg/kg) than in preceding years. This might be due to Pools A and B receiving some new sediment with higher SPSC in the flow from the culvert. That sediment settles out in the first couple of pools, so it doesn't reach Pools C or D. Dissolved P in the water does reach those later pools (C and D) and fills some of the P-binding sites, potentially lowering their SPSC. These results underscore the importance of relatively high spatial resolution of soil sampling; if monitoring had only included one location from each feature (i.e., each Complex), it may have misrepresented the capacity of the soil to sorb phosphate. Further, the implications of these results are similar to the complexity noted in the water results above. Variation within a wetland parcel decreases confidence in ecosystem-level estimates of nutrient storage capacity, but such variation can be better accounted for and better incorporated into assessments each year the monitoring continues.

Additionally, detailed soil characteristics of the Forder Bridge Project may help lay the groundwork for scaling up the point measurements collected by the Monitoring Program. The

hydrogeophysical results give clues about the past that help predict the future. SPSC and soil organic matter (SOM) were negatively correlated with ECa (Figure 59). Factors limiting microbial decomposition, such as soil salinity, can decrease the amount of SOM while increasing ECa^{8,9}. Soil at Forder Bridge adjacent to County Road 424 (near the southern half of the site) could have experienced years of road salt application prior to construction, leaving the soil with a higher ECa (Figure 57). Then, construction of Wetland Complex 4 likely revealed lower conductivity soils beneath the surface, now present in the channel. North of the treatment train pools (Complex 4), ECa alternates in bands of lower and higher values ranging from about 24 to 37 mS/m, which extend across the Project in the southwest/northeast orientation. These features could be coarse and fine-grained sediment deposition, respectively, resulting from previous river flooding events, potentially indicating past flooding extent of the Maumee River.

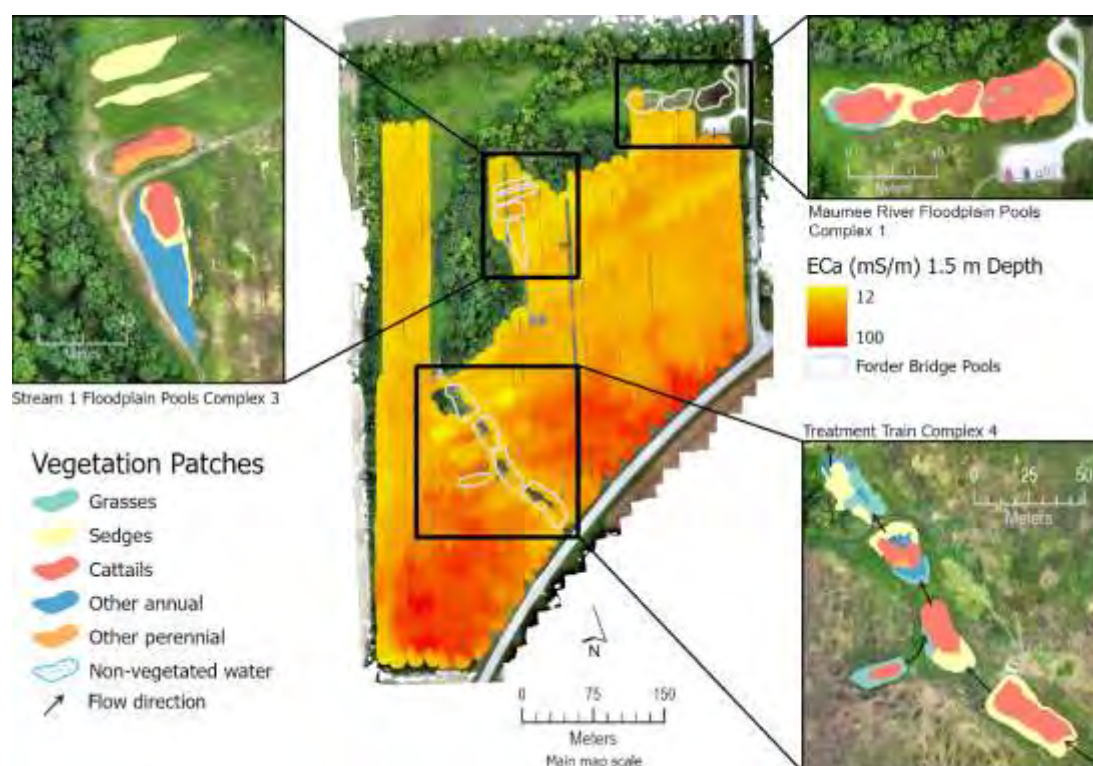


Figure 57. Aerial imagery (collected July 2024) at the Forder Bridge Floodplain Reconnection with (center panel) apparent bulk soil conductivity (ECa) at 1.0 m depth (collected September 2020) and (zoomed-in adjacent sections) simplified vegetation patches based on expert-drawn vegetation maps (based on data collected July 2024). Vegetation patch

⁸ Peralta, N. R., and Costa, J. L. (2013). Delineation of management zones with soil apparent electrical conductivity to improve nutrient management. *Computers and Electronics in Agriculture*, 99, 218–226. <https://doi.org/10.1016/j.compag.2013.09.014>

⁹ Tripathi, S., Kumari, S., Chakraborty, A., Gupta, A., Chakrabarti, K., and Bandyopadhyay, B. K. (2005). Microbial biomass and its activities in salt-affected coastal soils. *Biology and Fertility of Soils*, 42(3), 273–277. <https://doi.org/10.1007/s00374-005-0037-6>

types used in analyses have been combined in this image to visually simplify patch categories.

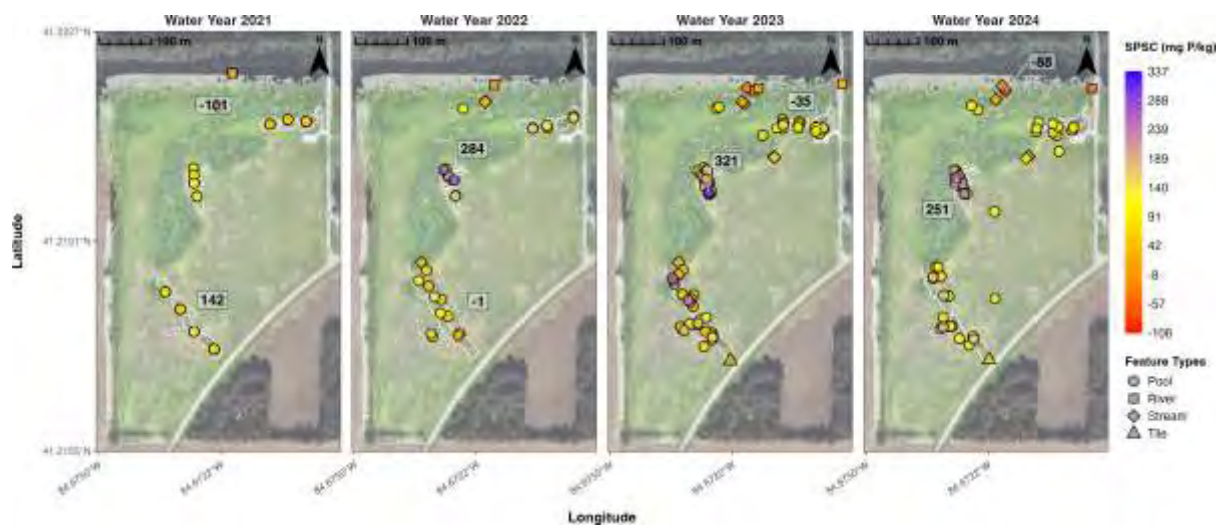


Figure 58. Soil Phosphate Sorption Capacity (SPSC) throughout the Forder Bridge Floodplain Reconnection Project. Each point denotes a soil sample (0–5 cm) and different shapes indicate the wetland feature type, as shown in the legend. Colors indicate the SPSC value of each sample relative to the overall range of values observed at the wetland project, as shown in the color bar. Each panel shows the soil samples collected during a respective water year (Oct 1–Sep 30), along with the minimum and maximum SPSC values observed during a given water year. Negative SPSC values indicate the potential for soils to release phosphate, while positive values indicate soils have capacity to sorb phosphate, based on Mehlich-3 extractions of phosphate, iron, and aluminum.

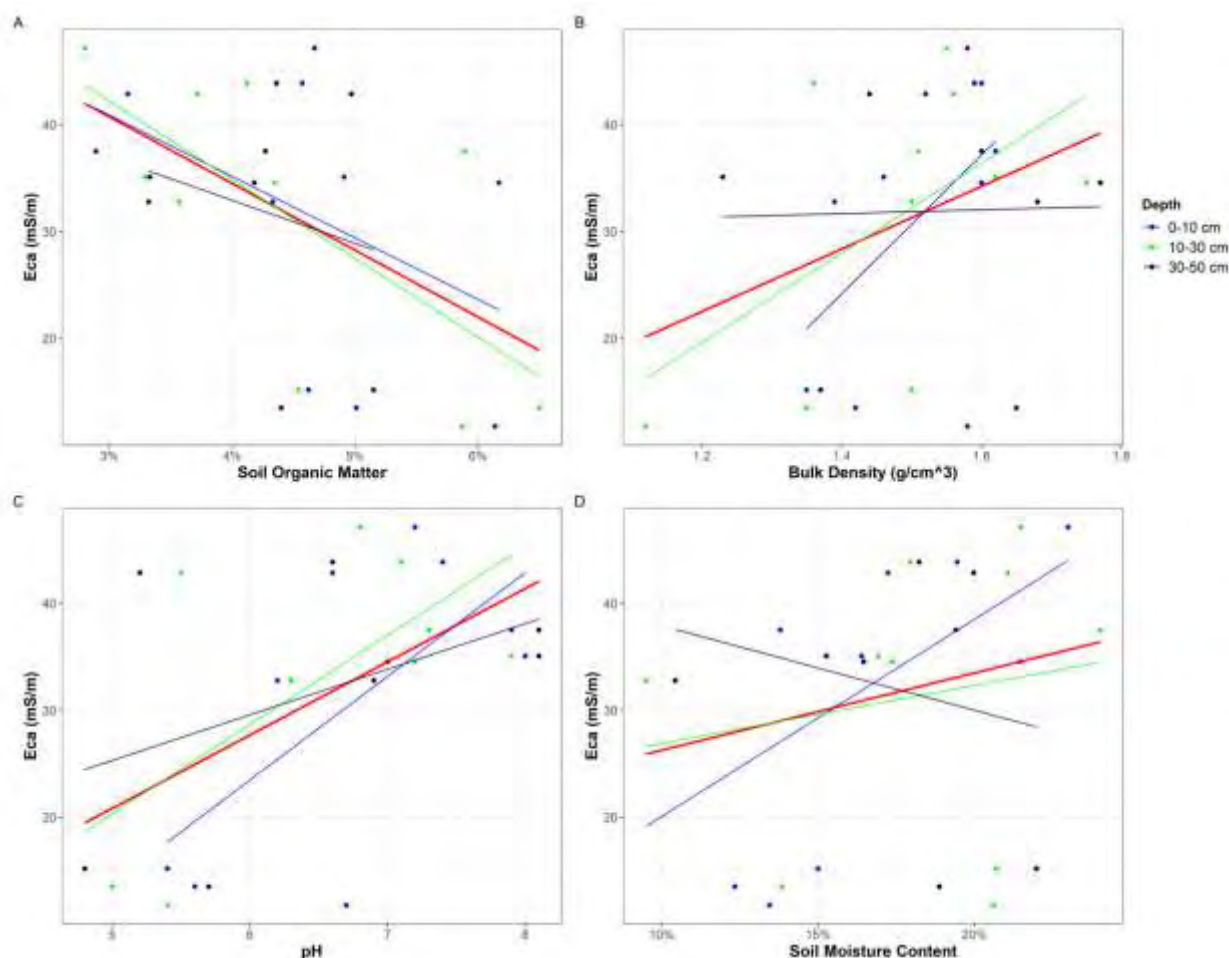


Figure 59. Relationship between lab-measured soil parameters (soil organic matter, total phosphorus (P) content, pH, and soil moisture) and field-measured apparent electrical conductivity (ECa, mS/m) in soil samples collected for hydrogeophysical analysis at the Forder Bridge Floodplain Reconnection Project. Each point represents a soil sample, and the lines represents the best-fit lines for the simple linear regression model at three different depths of soil samples. ECa values presented are for the conductivity meter with transmitter-receiver sensor spacing of 0.5 m (average depth sensitivity of 0.75 m), and parameter values are for 30–50 cm soil sample depth, except for 2 samples. Across all samples (all depths), linear regression analysis between ECa and selected soil properties showed that Soil Organic Matter (SOM, $R^2 = 0.63$), mg of pH ($R^2 = 0.46$), and soil moisture content (SMC, $R^2 = 0.35$) were the best correlated with ECa.

Vegetation Results

Vegetation stocks for 2024 showed a total of 116 lbs. of phosphorus (P, 111 lbs. aboveground and 4.5 lbs. belowground) and 463 lbs. nitrogen (N, 441 lbs. aboveground and 22 lbs. belowground) reside in the vegetation during peak biomass. This is a net decrease of 449 lbs. of P and over 1549 lbs. of N from 2022 peak biomass stock. Some of this net decrease is likely due to a decrease in estimated areal extent of the active vegetated wetland, which is used in calculations of Project-level nutrient stock (Figure 60). Supplementary research aims

to quantify nutrient retention in vegetation from one year to the next and to better understand internal nutrient cycling.

Total belowground nutrient stock and stock on a per-acre basis is relatively low at this Project (4.5 lbs. P and 21.5 lbs. N) compared to other Projects (12–35 lbs. P and 63–184 lbs. N). The total area of active wetland vegetation decreased at Forder Bridge since 2022 (Figure 60). Low belowground stock and recent decreases in aboveground vegetation stock may be partially attributed to this decrease in active vegetated wetland areas, but may also be due to impacts of drought on wetland vegetation density or the lower species diversity in comparison to other H2Ohio Focal Projects. Vegetation nutrient stock at Forder Bridge was greatly dominated by Cattails (*Typha spp.*). Average nutrient density of Cattail aboveground biomass was 13 g P/m² and 58 g N/m² in 2024, an increase from 4 g P/m² and 19 g N/m² in 2022.

Researchers note that there is a substantial decrease in the diversity of species sampled for biomass and nutrient concentration from 2022 to 2024 (Figure 61 and Figure 62). Sampling strategies targeting different goals is one contributing factor to the differences seen in the diversity of biomass samples (Figure 61 and Figure 62), as Forder Bridge was used as a “Super-Focal” sampling Project in 2022. The H2Ohio Wetland Monitoring Program deliberately over-sampled to determine the optimal sampling density for monitoring. The additional sampling quadrats in 2022 likely increased the total number of species sampled for biomass that year. However, even when correcting for sampling intensity, researchers still see decreases in species richness and diversity, and this likely contributed to sampling biomass from relatively few species at this location in 2024 (Figure 63). Some of this decreased diversity is expected when moving from a new restoration that has a mix of upland and wetland plants into a more developed wetland that is dominated by wetland species such as Woolgrass (*Scirpus cyperinus*) and Purpleleaf willowherb (*Epilobium coloratum*). But unlike other Projects, vegetation at Forder Bridge has not demonstrated continued increases in diversity and the floristic quality assessment index (FQAI) in the past year (2024, Figure 63). This may be partially due to dry conditions in 2023 and 2024 as well as the lack of hydrologic connectivity of some of the wetland pools (e.g., Complexes 1 and 3). While species diversity and FQAI were not as high at Forder Bridge as they were at Projects of similar restoration age, in 2024 the proportion of observed wetland species increased relative to the proportion of upland species, suggesting wetland development is still ongoing.

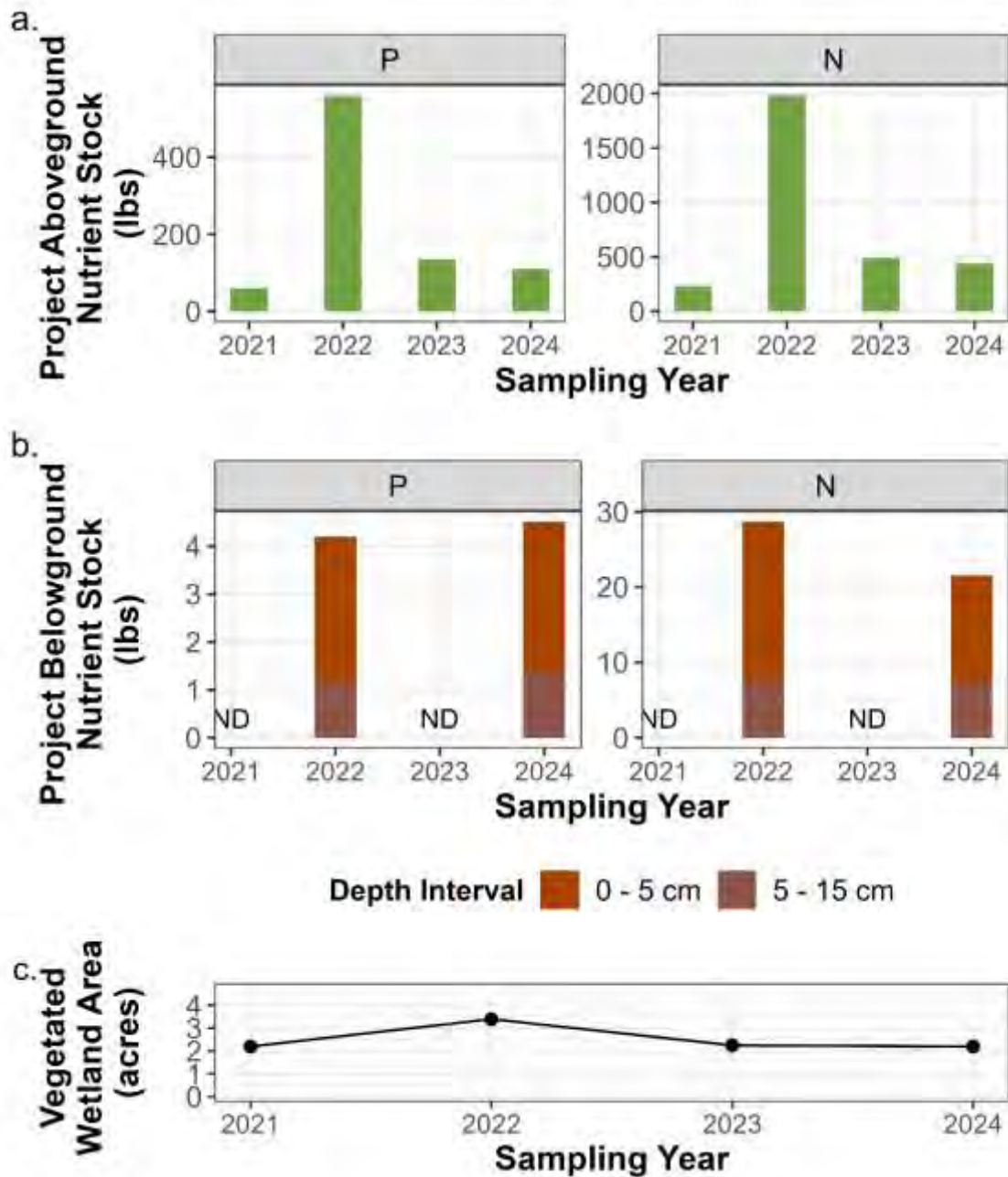


Figure 60. Nutrient Stock in (a) Above- and (b) Belowground Vegetation at Forder Bridge Floodplain Reconnection Project. Estimates of the total mass of phosphorus (P) and nitrogen (N) observed in vegetation in the areas surveyed by the Monitoring Program for each year Forder Bridge was monitored for vegetation. (c) Vegetated Wetland Area refers to areas observed to have wetland-dominant species composition and all other Project areas were excluded from vegetation stock calculations. For more detailed information on how estimates were calculated, see Appendix II.

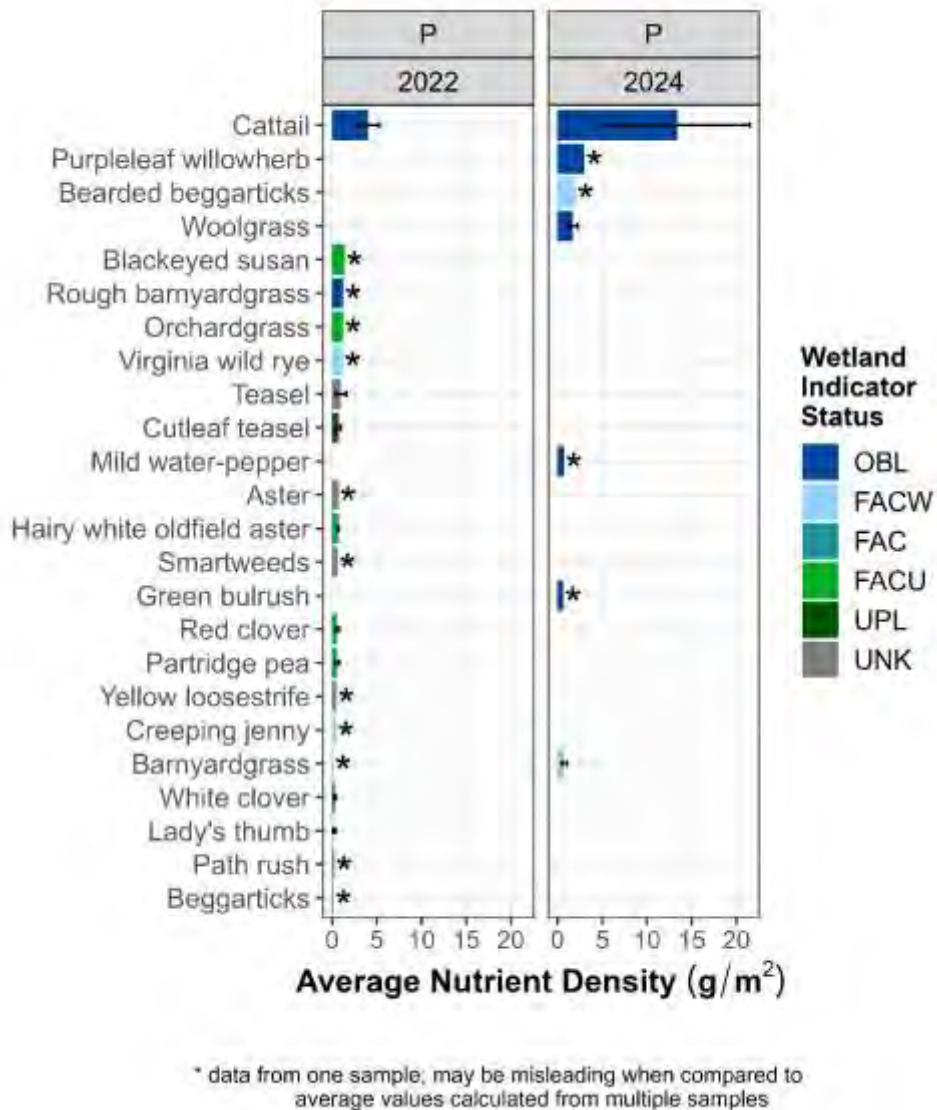


Figure 61. Average nutrient density of phosphorus (P) in vegetation species at Forder Bridge Floodplain Reconnection Project. The average mass of P stock in aboveground plant material per square meter for species sampled that covered more than 20% of sampling quadrat at Forder Bridge. Nutrient density is calculated by multiplying measured nutrient concentrations and aboveground dry biomass data, resulting in an estimate of the average aboveground nutrient mass observed in a species within a given area. Appendix II displays both common and scientific species names and Wetland Indicator Status (WIS) designations can be found in Appendix II.

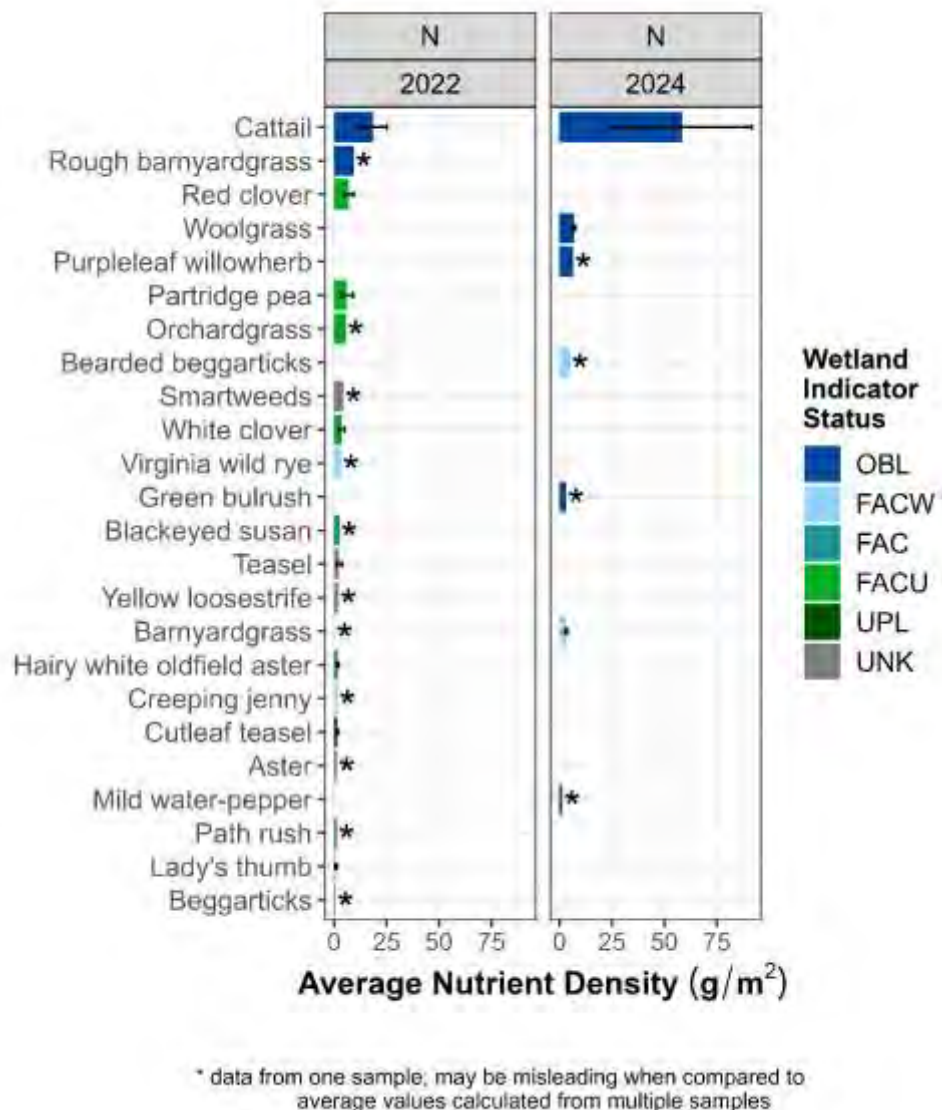


Figure 62. Average nutrient density of Nitrogen (N) in vegetation species at Forder Bridge Floodplain Reconnection Project. The average mass of N stock in aboveground plant material per square meter for species sampled that covered more than 20% of sampling quadrat at Forder Bridge. Nutrient density is calculated by multiplying measured nutrient concentrations and aboveground dry biomass data, resulting in an estimate of the average aboveground nutrient mass observed in a species within a given area. Appendix II displays both common and scientific species names and Wetland Indicator Status (WIS) designations can be found in Appendix II.

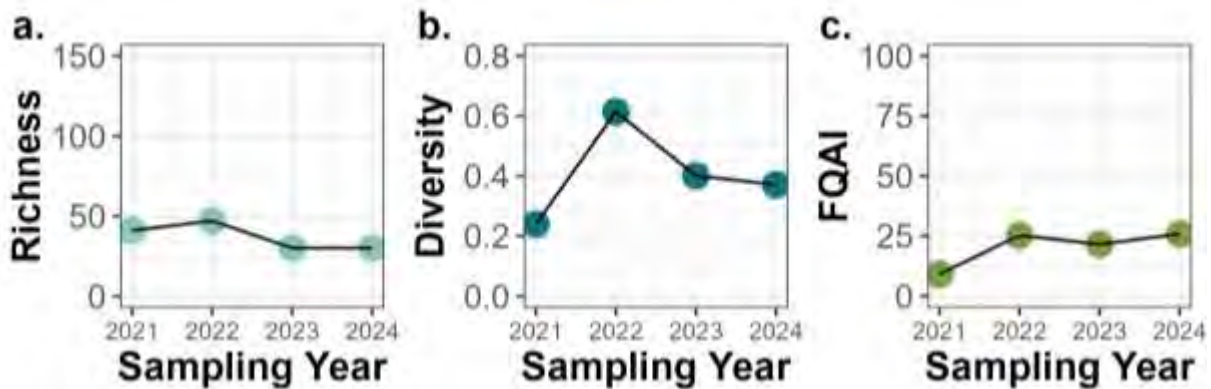


Figure 63. Species richness, diversity, & the Floristic Quality Assessment Index at Forder Bridge Floodplain Reconnection Project. These graphs display (a) species richness, or a count of the total number of species, (b) species diversity calculated with Simpson’s Diversity Index (See Appendix II), and (c) the floristic quality assessment index (FQAI), a measure of habitat quality based on vegetation present (See Appendix II), for Forder Bridge.

Next Steps to Strengthen Understanding

In 2025, researchers plan to use one or two autosamplers (ISCO, Teledyne, Lincoln, NE, USA) at the Forder Bridge Project to capture hydrologic event sampling of surface water nutrients, and acoustic doppler velocity sensors to measure water velocity so that water flow can be more accurately and continuously measured at the key inflow and outflow, especially during high flow events. Data collected during storm flow events at Forder Bridge will help to inform and predict how stormflow affects water (and nutrient) delivery for Non-Focal sites with similarly sized drainage areas. Researchers know that storm events often are the source of the majority of phosphorus and nitrogen influx, and logistical and resource constraints led to the H2Ohio Wetland Monitoring Program missing key storm event sampling at Forder Bridge in 2024. The sensors and automated water samplers will help address this challenge.

Researchers will continue to manually sample surface water monthly and sample soil once or twice per year. Continued monitoring efforts are critical for advancing understanding of wetland nutrient reduction function as this system matures post-construction. The changes over time in the vegetation and soil data, as well as the drought conditions researchers observed, underscore the importance of multiple years of monitoring. Soil conductivity can be used as a proxy for measuring soil characteristics. The geophysical results from 2024 will allow base crews to create targeted soil sampling campaigns in 2025, ensuring soil heterogeneity is captured with less effort and samples.

To better understand nutrient storage in vegetation, in the coming years researchers plan to more effectively integrate across different kinds of data. To facilitate this, starting in 2025 vegetation will be sampled from locations of interest where soil and water samples are also being collected. Additionally, the Monitoring Program will compare measurements of soil moisture by the Vegetation Crew, soil and water sampling by Base Crews, and soil geophysics by the Hydrogeophysics Crew. Such coordination of sampling locations and post-collection comparisons may result in a greater understanding of nutrient cycling within the wetland that can provide context for the contribution of vegetation to nutrient filtration year-

to-year at Forder Bridge. Additionally, nutrient and biomass vegetation sampling results in 2024 are from a relatively limited number of species because the Monitoring Program prioritized sampling species with high percent cover. With three years of data, it may be possible to conduct sensitivity analyses to understand the impact of the current sampling approach on nutrient stock calculations and enable better investment of effort and resources into areas that will have the most impact on final results.

Continued data collection will inform and improve the 3-D hydrodynamic model, which will eventually enable more accurate estimates of surface runoff volumes entering depressional pools in Complexes 1 and 3 and improve estimates of nutrient load reduction contributed by these features. Additionally, the modeling efforts may be able to simulate nutrient reduction capacity of the wetland under different hydrological conditions, such as droughts, deluges, and situations when the Maumee River inundates the floodplain during major flood events. Collectively, these efforts improve the confidence of science-based assessments of nutrient function and can be used as a tool to assess, infer the potential function of future wetlands with similar features as The Forder Bridge Project.

Magee Marsh Turtle Creek Bay Wetland Reconnection (MAGM)

Project Description

Ottawa County | Turtle Creek Watershed | Coastal

Project Size: 173 Acres

Partner: Erie Soil & Water Conservation District

The hydrology at this Project is actively managed and has one distinct feature: a large (~ 170 acre) wetland pool that is connected to the adjacent Turtle Creek in two locations. Water enters from Turtle Creek at the western portion of the pool via one water level control structure (WLCS) and exits at the eastern portion of the pool via another WLCS. In the northwestern portion of the pool, a third WLCS allows water to flow into a canal to the north where it can flow into a non-H2Ohio pool or Turtle Creek. A hydrologic event at this Project is operationally defined as an adjustment of a WLCS that alters water flow speed and/or direction into or out of the wetland pool.



Figure 64. Aerial image showing surface water flow and sampling locations for the Magee Marsh Turtle Creek Bay Wetland Reconnection Project. Blue arrows indicate direction of surface water flow. Dots represent geographic base crew sampling locations, which are grouped by Project features (fill color) where relevant. Text annotations provide additional context about the Project's watershed connection or other important features.

Management Considerations

Competing Management Goals Limit Nutrient Retention Opportunity

The source water inputs and resulting nutrient reduction impact of the Magee Marsh Turtle Creek Bay Wetland Reconnection Project (hereafter the Magee Marsh Project) were limited in Water Year (WY) 2024 by management decisions that prioritized infrastructure maintenance and enhancing wildlife habitat. Magee Marsh is an actively managed coastal Project, located within the Magee Marsh Wildlife Area near the point where Turtle Creek

meets Lake Erie. The Magee Marsh Project is surrounded by dikes and is hydrologically disconnected from the surrounding landscape except through three water level control structures (WLCSs): two WLCSs connect the wetland pool to Turtle Creek while another WLCS connects it to an adjacent wetland to the north (Figure 65). The Magee Marsh Project does not receive any inputs from the surrounding landscape unless the WLCSs along Turtle Creek are opened when the water level in the creek is higher than the water level in the wetland. Therefore, punctual or advance notification of management actions (i.e., lowering or raising the WLCSs) is critical for analysis of the nutrient content of water entering or leaving the wetland. These management actions trigger a hydrologic event, which is defined at this Project as an adjustment of a WLCS that alters water flow speed and/or direction. The property manager (Ohio Department of Natural Resources) primarily manages water levels in the Magee Marsh Project with the goal of providing wildlife habitat. The managing agency accomplishes this by allowing the water level to decrease to a minimum of 0.3 m in July and increasing it to 1 m by November. Thus, active management typically maintains the highest water levels in early spring and late fall, and the lowest water levels in mid-summer regardless of external weather conditions.

As in WY 2023, the Magee Marsh Project was isolated from Turtle Creek throughout WY 2024 to facilitate construction projects on the wetland complex. The exception was a 10-day period (March 27–April 6, 2024) when a water level control structure was opened for the purpose of exercising the structure mechanisms. During this period 149,224,718 L of creek water containing up to 42 lbs. of total phosphorus (TP) flowed into Magee Marsh, based on data from water level sensors, water samples, and the soil surface elevation (bathymetry) throughout the wetland. After April 6, all WLCSs were closed for the remainder of the year and managers removed as much water from the marsh as possible by pumping into an adjacent canal. From the canal, water either entered another wetland unit or was returned to Turtle Creek. A more accurate estimate of nutrient retention for WY 2024 would have required prompt notification of WLCS actions to enable timely sampling as well as information on the fate of pumped water.

Because Magee Marsh was isolated except for one 10-day event in WY 2024, nutrient load reduction was limited to 0–12 lbs. of dissolved reactive phosphorus and 0–42 lbs. of TP (see Nutrient Budget Takeaways section for details). It is worth noting that nutrient sequestration could be significantly enhanced in the future by management actions that allow for more frequent filling events in spring, when nutrient sequestration is most impactful for preventing harmful algal blooms in nearby Lake Erie. However, there may be trade-offs among nutrient sequestration actions, wildlife habitat considerations, and maintenance and construction needs at the Magee Marsh Project.



Figure 65. Aerial image of approximate locations of interest for water and soil sampling and discrete manual measurements of water depth and physicochemical parameters at Magee Marsh Turtle Creek Bay Wetland Reconnection Project during water year 2024 (Oct 1, 2023–Sep 30, 2024). The legend provides the name of each sampling point. Different shapes denote the types of wetland features represented by the locations of interest. If present, different colors represent locations of interest that belong to a group or complex of features (e.g., a treatment train).

Nutrient Budget Takeaways

The Magee Marsh Project received approximately 150 m³ of water that entered from Turtle Creek between March 27 and April 6 of 2024, but it was drained and isolated from the surrounding watershed for the rest of the year. Researchers estimate that the Project filtered 43 lbs. of total phosphorus, 3 lbs. of dissolved reactive phosphorus, 689 lbs. of total nitrogen, 363 lbs. of nitrite+nitrate, and 57 lbs. of total ammonium nitrogen. No land within the Project was previously used for agriculture, thus the Project does not prevent any additional phosphorus runoff. Soils throughout the Project have moderate to high capacity to sorb phosphate, as suggested by soil phosphate sorption capacity values.

Surface Water Hydrology and Nutrients

The Magee Marsh Project is a permanently inundated wetland, managed by a state agency for seasonal changes in water level via water level control structures (WLCSs) toward habitat-driven goals. Water Year (WY) 2024 was an atypical year, as the wetland was almost always drained of water due to infrastructure improvements. Because WLCSs were closed, water level decreased only through evaporation from October 2023 to March 2024. Then, water

was actively pumped out from April through July 2024, and evapotranspiration further decreased water levels from July to September 2024 (Figure 67). Sensor-collected water level data confirms a general downward trend in water levels within the wetland as the year progressed, and water levels approached zero throughout the wetland by September 2024 (Wetland WCS1, Figure 66, Figure 67).

During WY 2024, water level only increased substantially when the southwestern WLCS (WCS1) was opened for a 10-day period from March 27 to April 6, which researchers estimate added 149,224,718 L of water to the Magee Marsh Project (Figure 67). Total nitrogen (TN), total phosphorus (TP), and dissolved reactive phosphorus (DRP) concentrations briefly increased in late October and November of 2023 but remained relatively stable or slightly increased as water levels decreased over the course of WY 2024 at all sampling locations, except at the wetland pump and WCS1 (Figure 68, Figure 69, Figure 70). High concentrations of DRP were observed in September of 2024 at these two sampling locations (wetland pump, WCS1), which were exceptionally dry and turbid at the time of sampling, became isolated from the rest of the wetland, and supported very little vegetation in their pools to take up nutrients (Figure 69). The change in mass of DRP, TP, and TN present in the wetland over time is not clear, but it appears that phosphorus and organic forms of nitrogen were less likely than inorganic nitrogen to be taken up by organisms or sorbed to the sediment, and were possibly resuspended into the water column due to biological activity or the condition of wetland soils (i.e., pH or oxygen content).

The concentrations of total ammonium nitrogen ($\text{NH}_4\text{-N}$) and nitrite+nitrate (NO_x) peaked in the creek in November 2023, while they peaked in the wetland near WCS1 after the hydrologic event in spring 2024 and generally decreased thereafter as water levels decreased (Figure 71, Supplemental Info). This decrease in concentrations of inorganic forms of nitrogen (i.e., NO_x and $\text{NH}_4\text{-N}$ as wetland water levels decreased means that the total mass of these nutrients in the surface water decreased over time, suggesting that they may have sorbed to the sediment or been taken up by vegetation or microorganisms.

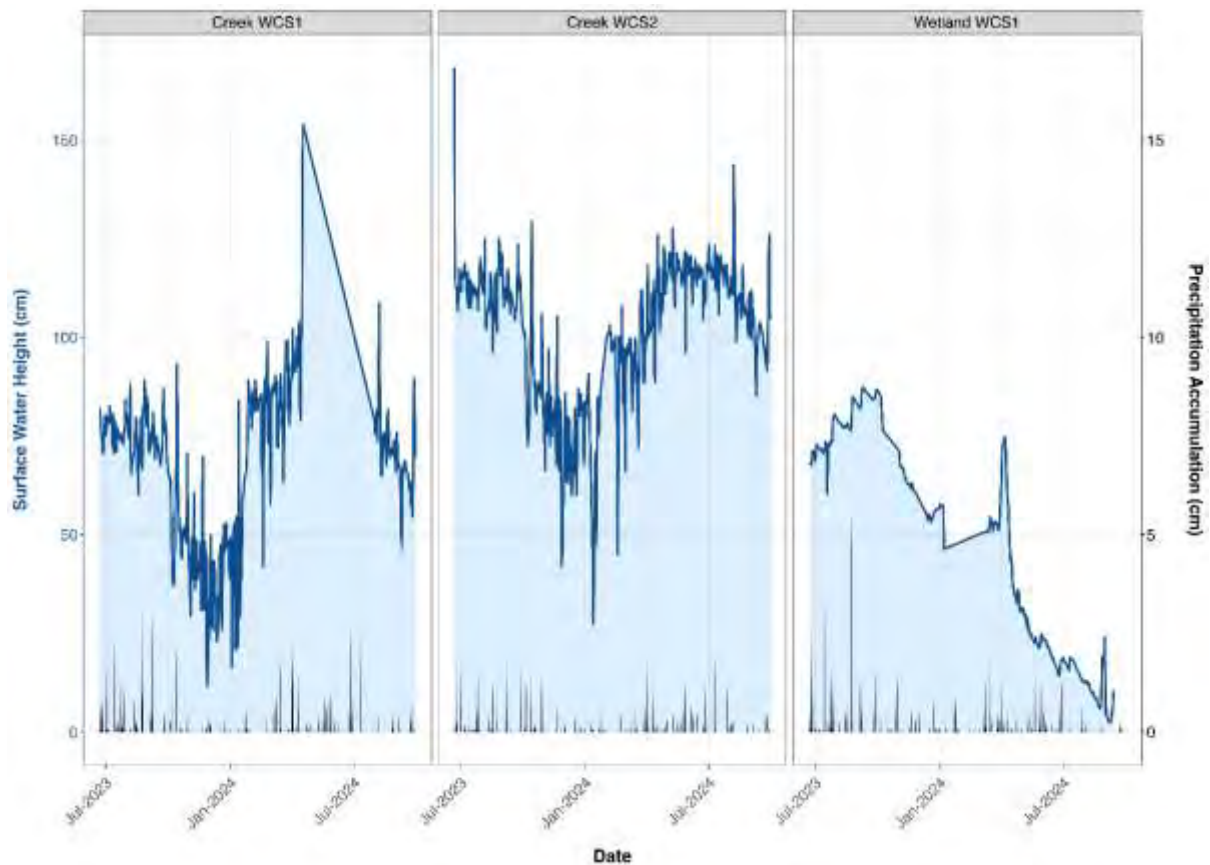


Figure 66. Time series of continuously measured surface water depth for the Magee Marsh Turtle Creek Bay Wetland Reconnection Project. Depths were measured by sensors deployed at select locations of interest that report live observations. Values are reported as daily averages. Where available, daily precipitation accumulation is reported on the secondary y-axis. For information on the locations of interest, please refer to the aerial map above. Note that measurements in some locations are missing or were interrupted due to sensor malfunction.

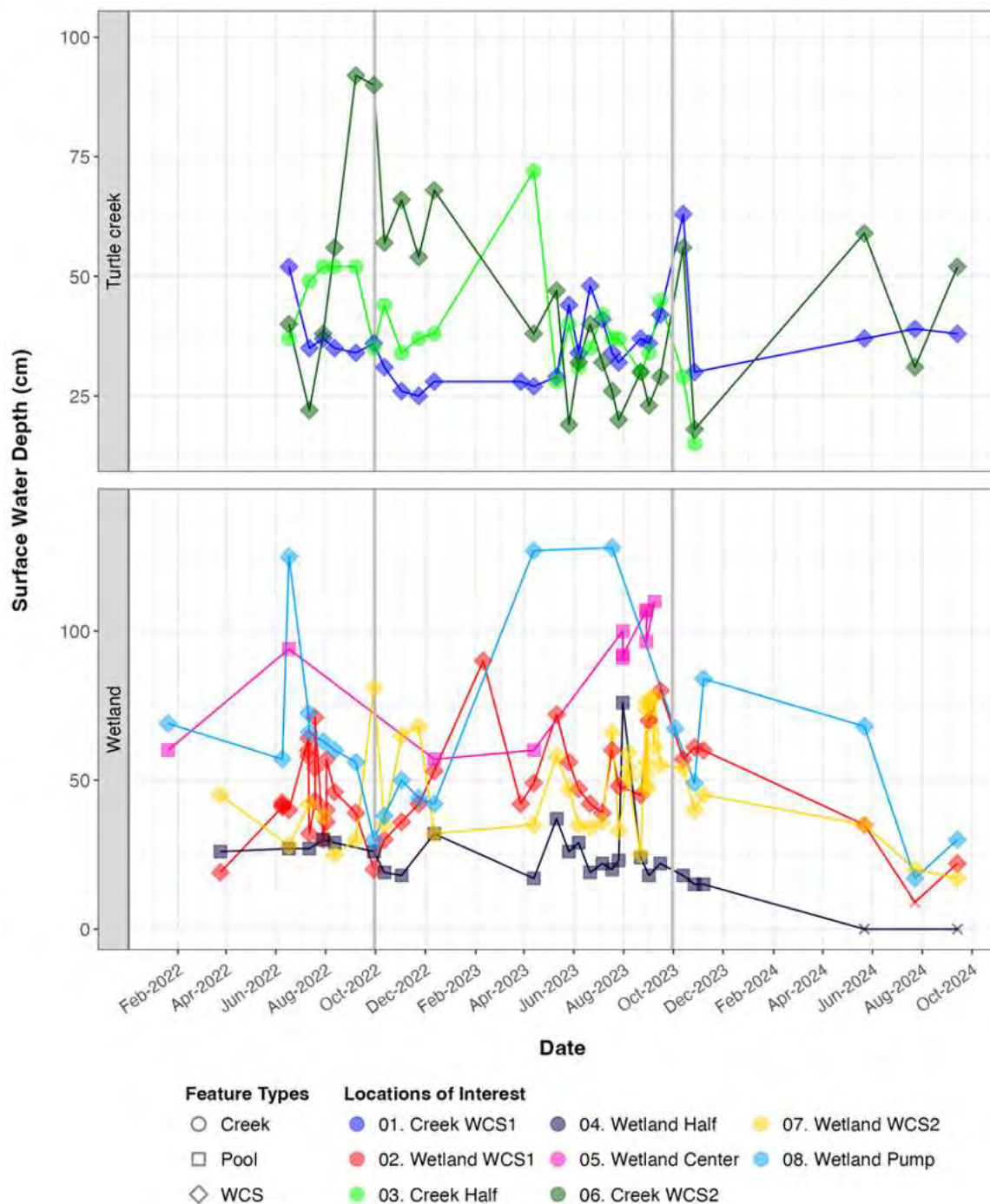


Figure 67. Time series of discrete, manually measured surface water depth at the Magee Marsh Turtle Creek Bay Wetland Reconnection Project. Depths were measured approximately monthly. Each point represents one measurement and colors denote the locations of interest, as indicated in the legend. Open symbols indicate samples that were collected during a hydrologic event (e.g., storm event) and filled symbols denote samples collected during baseflow. Crosses (×) represent instances when no surface water was detected during the visit. If present, different shapes denote the types of wetland features represented by the locations of interest. Gray vertical lines indicate the start of a water year (Oct 1–Sep 30).

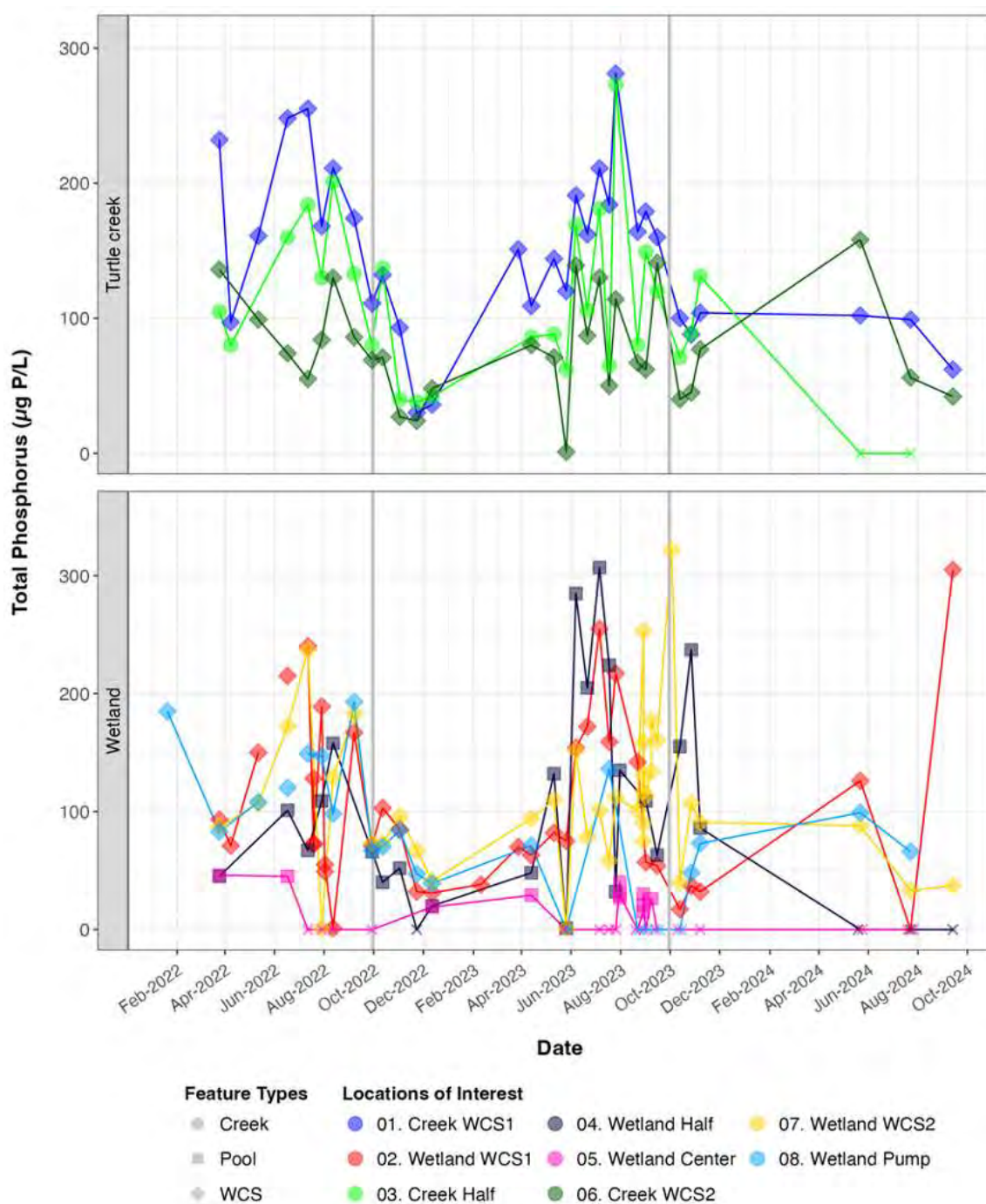


Figure 68. Time series of total phosphorus (TP) concentrations in surface water samples collected at the Magee Marsh Turtle Creek Bay Wetland Reconnection Project. Values below the detection limit of the analytical equipment were replaced with half the value of the detection limit. Each point represents one measurement and colors denote the locations of interest, as indicated in the legend. Open symbols indicate that measurements were collected during a hydrologic event (e.g., storm event) and filled symbols denote measurements collected during baseflow. Crosses (x) represent instances when no surface water was detected during the visit. If present, different shapes denote the types of wetland features represented by the locations of interest. Gray vertical lines indicate the start of a water year (Oct 1–Sep 30).

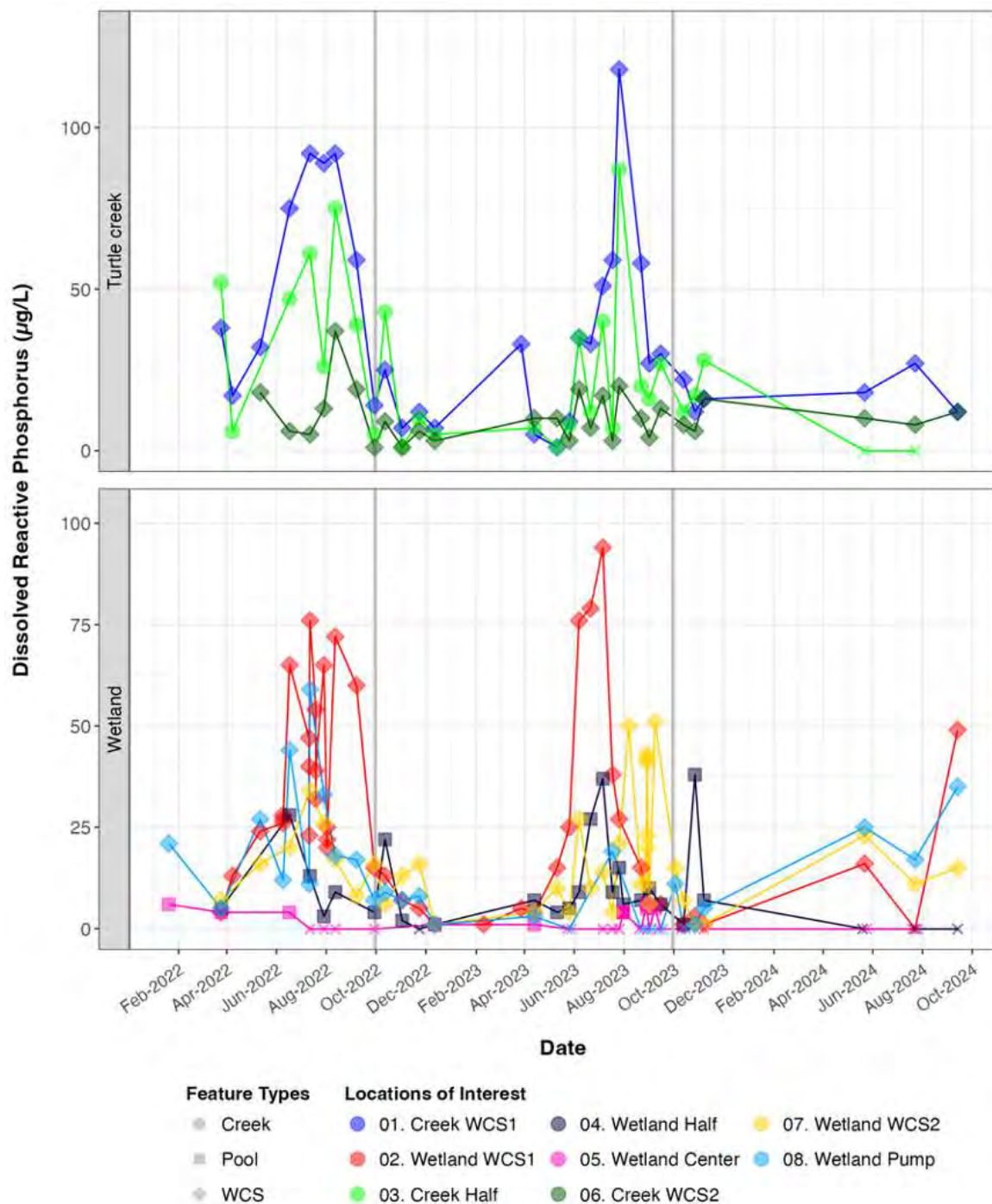


Figure 69. Time series of dissolved reactive phosphorus (DRP) concentrations in surface water samples collected at the Magee Marsh Turtle Creek Bay Wetland Reconnection Project. Values below the detection limit of the analytical equipment were replaced with half the value of the detection limit. Each point represents one measurement and colors denote the locations of interest, as indicated in the legend. Open symbols indicate that measurements were collected during a hydrologic event (e.g., storm event) and filled symbols denote measurements collected during baseflow. Crosses (×) represent instances when no surface water was detected during the visit. If present, different shapes denote the types of wetland features represented by the locations of interest. Gray vertical lines indicate the start of a water year (Oct 1–Sep 30).

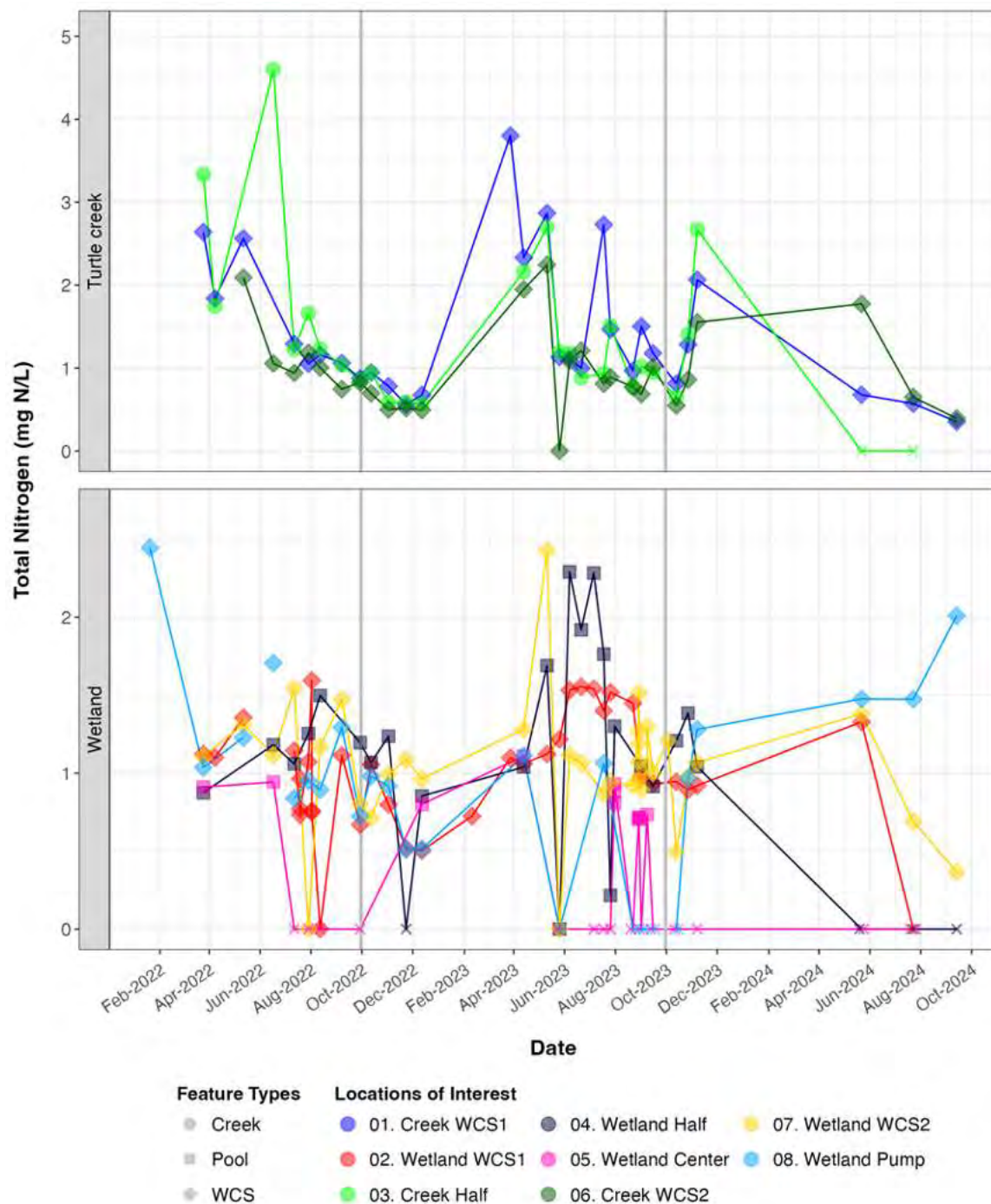


Figure 70. Time series of total nitrogen (TN) concentrations in surface water samples collected at the Magee Marsh Turtle Creek Bay Wetland Reconnection Project. Values below the detection limit of the analytical equipment were replaced with half the value of the detection limit. Each point represents one measurement and colors denote the locations of interest, as indicated in the legend. Open symbols indicate that measurements were collected during a hydrologic event (e.g., storm event) and filled symbols denote measurements collected during baseflow. Crosses (×) represent instances when no surface water was detected during the visit. If present, different shapes denote the types of wetland features represented by the locations of interest. Gray vertical lines indicate the start of a water year (Oct 1–Sep 30).

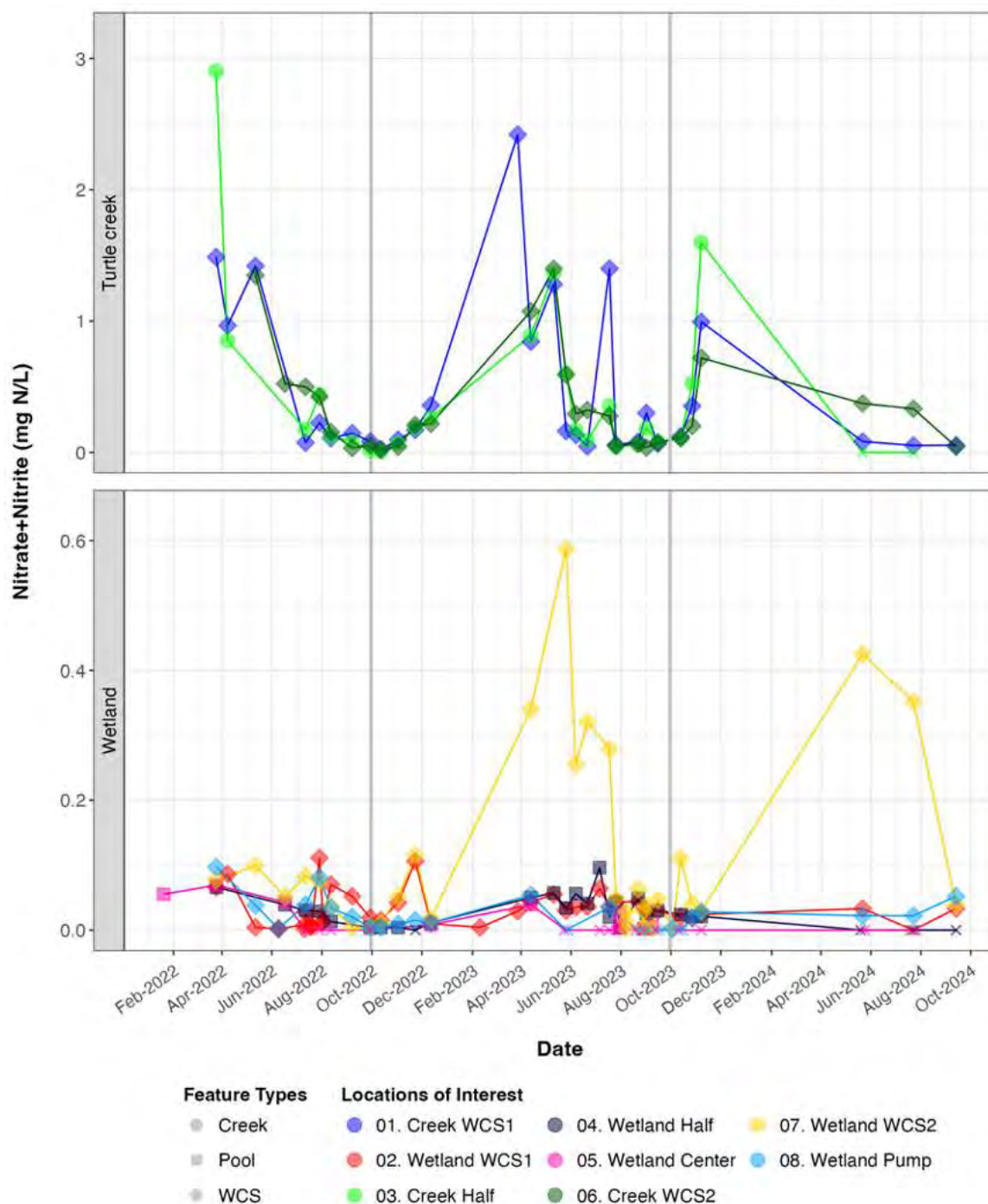


Figure 71. Time series of Nitrite+nitrate (NO_x) concentrations in surface water samples collected at the Magee Marsh Turtle Creek Bay Wetland Reconnection Project. Values below the detection limit of the analytical equipment were replaced with half the value of the detection limit. Each point represents one measurement and colors denote the locations of interest, as indicated in the legend. Open symbols indicate that measurements were collected during a hydrologic event (e.g., storm event) and filled symbols denote measurements collected during baseflow. Crosses (x) represent instances when no surface water was detected during the visit. If present, different shapes denote the types of wetland features represented by the locations of interest. Gray vertical lines indicate the start of a water year (Oct 1–Sep 30).

Soil Nutrient Status and Processes

Soil phosphate sorption capacity (SPSC) values at the Magee Marsh Project were positive in Water Year 2024, indicating a capacity to sorb phosphate (Figure 72). A spatial gradient in SPSC that exists within the wetland has remained evident during all sampling years, with higher values on the west side coinciding with the shallower areas of the wetland and lower values on the east side in deeper areas (Figure 73). The ammonium, total nitrogen, and total phosphorus content of the soil within the Magee Marsh Project decreased over the past year (from 2023 to 2024, Supplemental Information). While the nutrient content of soils within the wetland has generally decreased over time throughout the wetland, most areas have a higher capacity to sorb phosphorus in the future, especially in the shallower areas in the west and center of the wetland (Figure 72).

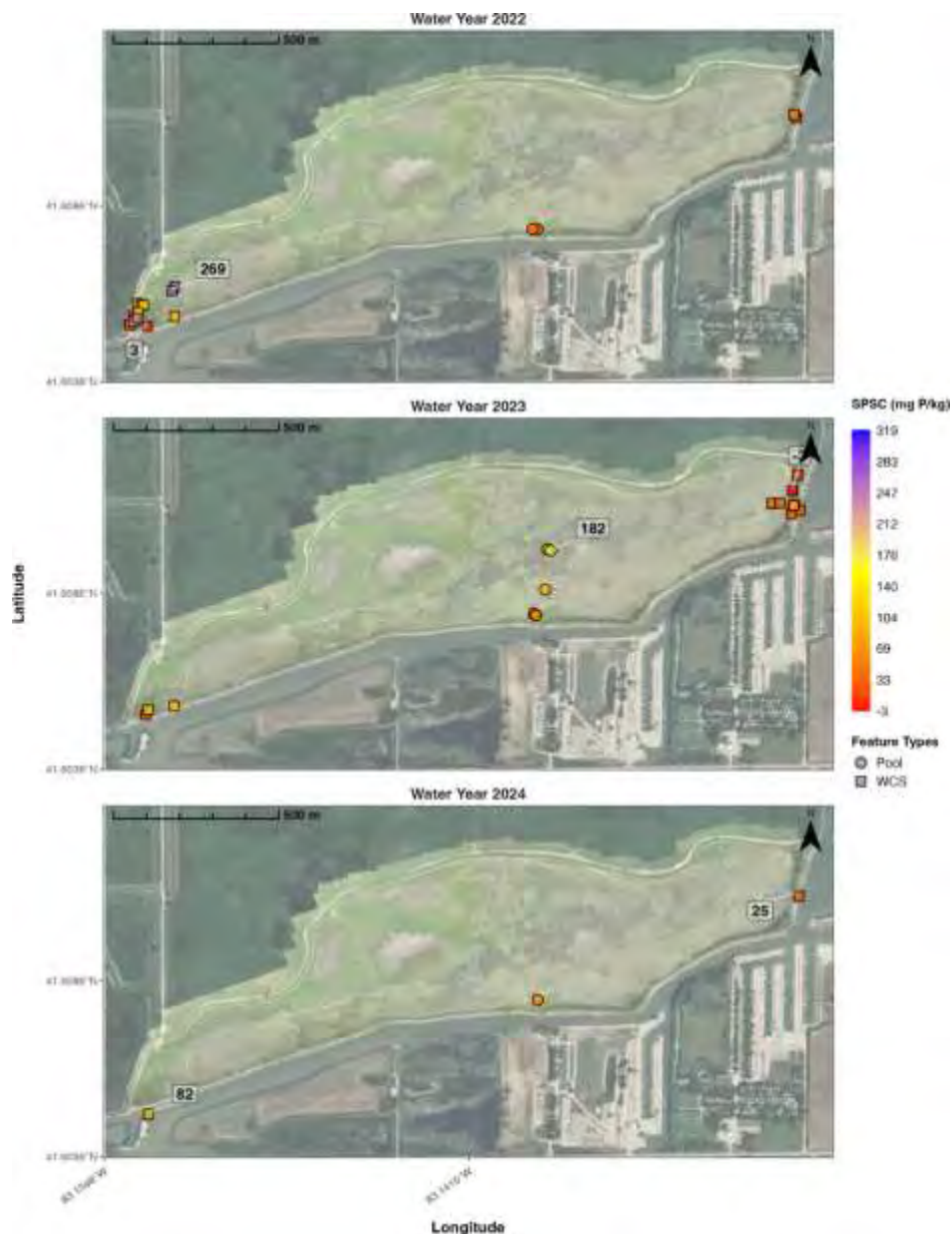


Figure 72. Soil Phosphate Sorption Capacity (SPSC) throughout the Magee Marsh Turtle Creek Bay Wetland Reconnection Project. Each point denotes a soil sample (0–5 cm) and different shapes indicate the wetland feature type, as shown in the legend. Colors indicate the SPSC value of each sample relative to the overall range of values observed at the wetland project, as shown in the color bar. Each panel shows the soil samples collected during a respective water year (Oct 1–Sep 30), along with the minimum and maximum SPSC values observed during a given water year. Negative SPSC values indicate the potential for soils to release phosphate, while positive values indicate soils have capacity to sorb phosphate, based on Mehlich-3 extractions of phosphate, iron, and aluminum.

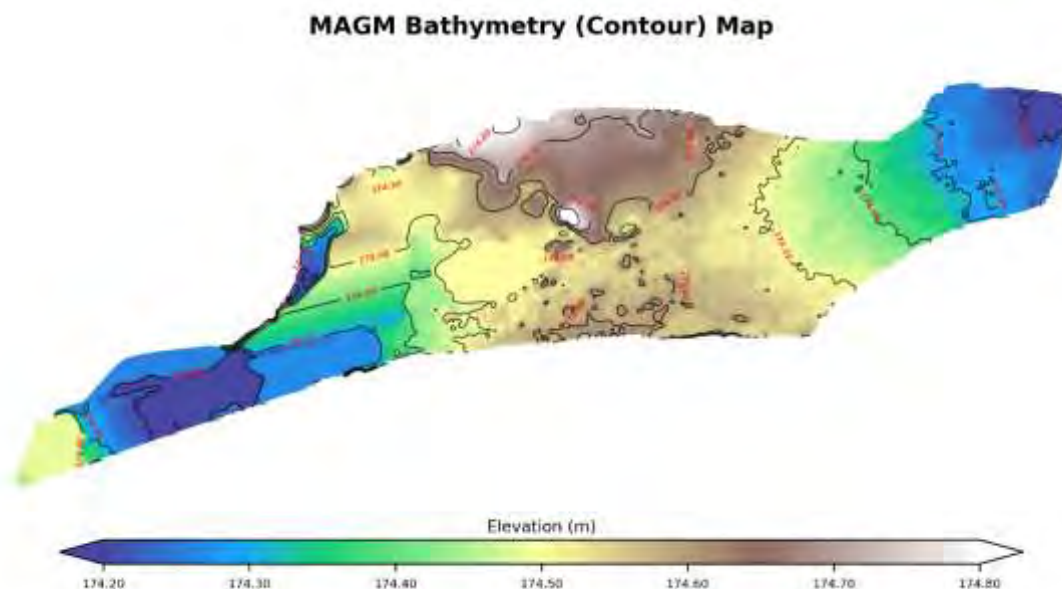


Figure 73. Contour map of Magee Marsh Turtle Creek Bay Wetland Reconnection Project. Colors correspond to the elevation of the soil surface. A high-resolution Digital Elevation Model (DEM) was generated from drone imagery and validated against a ground survey.

Next Steps to Strengthen Understanding

Researchers need more data across time to better measure seasonal differences in nutrient function drivers over the next year, as construction within the Project concludes and typical management activities resume. This will allow seasonal environmental drivers to become apparent during baseflow conditions. More frequent sampling will allow researchers to understand patterns in nutrient content and physical characteristics of water in the wetland and the creek. In addition, researchers need to collect water when hydrologic events occur, defined at the Magee Marsh Project as a modification of a water level control structure that alters water flow speed and/or direction, to calculate the wetland's nutrient inputs and

outputs. Efforts are being made to facilitate more timely communication between the Project managers and researchers to target hydrologic events for sampling.

This Project has unique uncertainties and researchers need more specialized data; inputs and outputs may shift unexpectedly due to the bi-directional nature of water level control structures. Water level sensors will help researchers better understand water flow dynamics and identify when water is flowing into or out of the wetland. Combined with bathymetry data, water level sensors will allow researchers to calculate water volume in the wetland every ten minutes and calculate the volume of water added or lost over time. Conductivity and turbidity sensors will monitor water quality for a greater portion of Water Year (WY) 2025 compared to WY 2024, because the wetland is expected to remain permanently inundated after construction concludes.

Starting in 2024, vegetation monitoring at Magee Marsh will occur every other year. In 2025, monitoring of vegetation in locations of interest will be prioritized at the Project to better facilitate comparison of nutrient levels in vegetation, water, and soil, with the aim of understanding how movement of nutrients within the wetland impacts the annual Project nutrient retention outcomes.

Oakwoods Nature Preserve Wetland Restoration, East (OAKE) and West (OAKW)

Project Description

Hancock County | Blanchard River Watershed

OAKE Project size: 65 Acres

OAKW Project size: 77 Acres

Partners: Hancock Park District

The hydrology of Oakwoods East and West is passively managed. Oakwoods East has 20 acres of restored wetland including four depressional pools connected to subsurface tile drains and 20 isolated depressional pools that are primarily precipitation-fed. A hydrologic event at Oakwoods East is operationally defined as a storm in which some pools overflow and intermix. Oakwoods West has 30 acres of restored wetland, including a water level control structure–equipped pool adjacent to Aurand Run that occasionally floods and 18 other depressional pools that are primarily precipitation-surface runoff-fed. A hydrologic event at this Project is operationally defined as a storm in which flow is expected to flood the pool adjacent to Aurand Run.

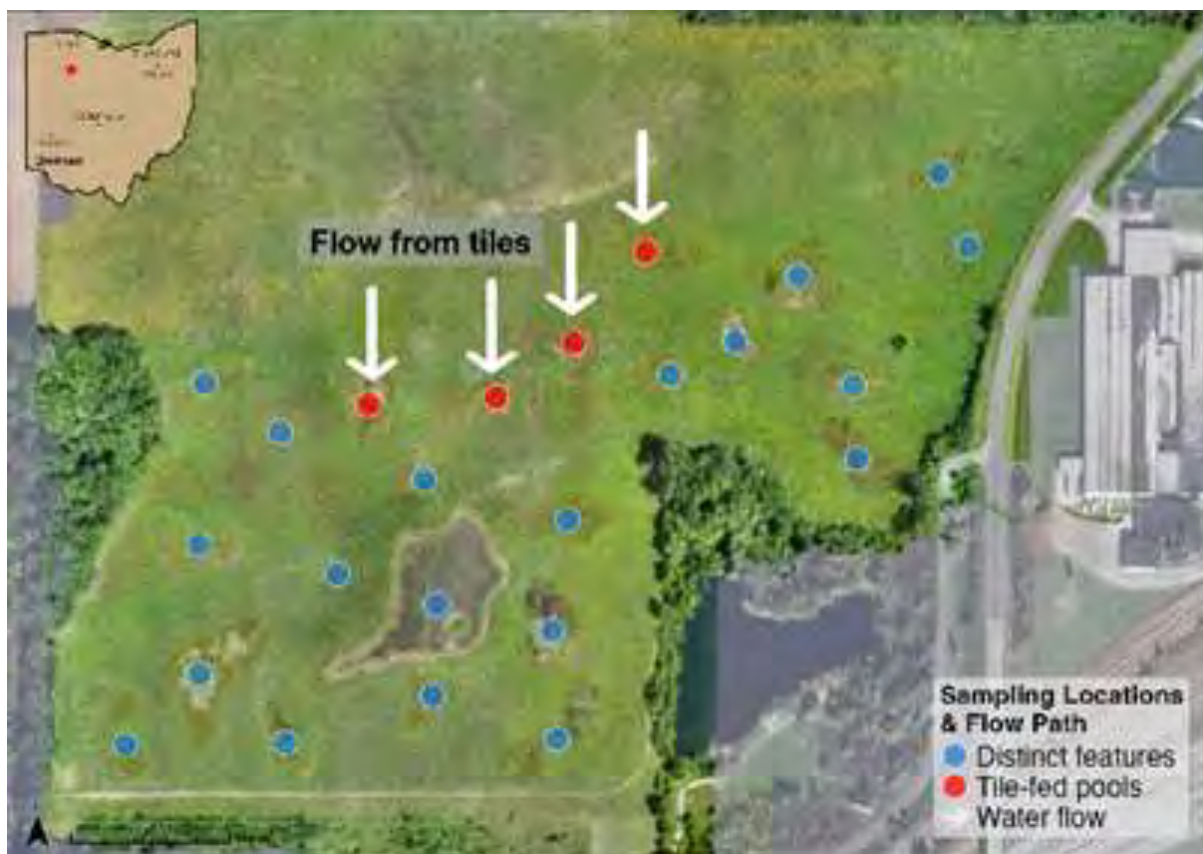


Figure 74. Aerial image showing surface water flow and sampling locations for the Oakwoods Nature Preserve Wetland Restoration, East Project. Blue arrows indicate direction of water flow into tile-fed pools. Dots represent geographic base crew sampling locations, which are grouped by Project features (fill color) where relevant. Text annotations provide additional context about the Project's watershed connection or other important features.

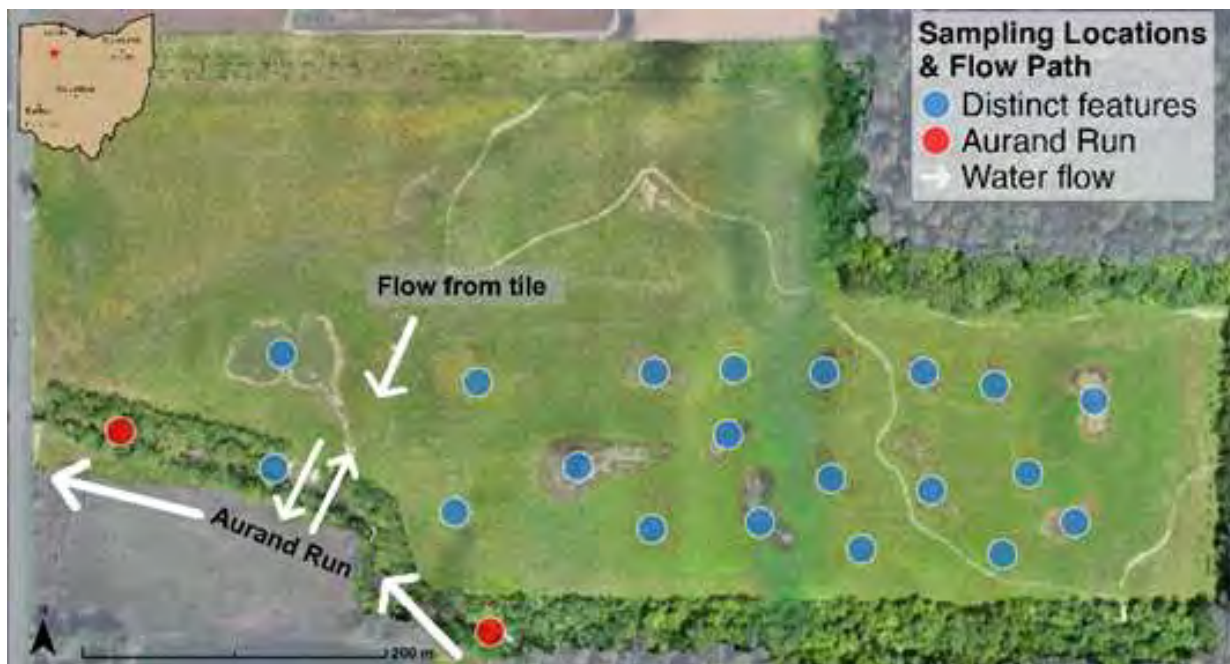


Figure 75. Aerial image showing surface water flow and sampling locations for the Oakwoods Nature Preserve Wetland Restoration, West Project. Blue arrows indicate direction of surface water flow. Dots represent geographic base crew sampling locations, which are grouped by Project features (fill color) where relevant. Text annotations provide additional context about the Project's watershed connection or other important features.

Management Considerations

Land Conversion Impact is One of the Primary Nutrient-Related Benefits of this Project

A majority of the wetland pools at these Projects do not receive water inflows from outside the parcel boundaries and thus filter relatively small amounts of new nutrient loads. This is due to a combination of the geomorphology of the as-built Projects and drier-than-average weather conditions in Water Year 2024. Since the conversion from farmland to present wetlands, no new nutrients have been added to this parcel of land as fertilizer. The excavation of a large number of isolated pools has eliminated nearly all surface runoff from this Project parcel, and the disruption of subsurface tiles has eliminated virtually all subsurface drainage leaving this parcel that occurred when it was agricultural land.

Limited Watershed Connection Limits Wetland Nutrient Inputs

In the Oakwoods West Project, Pool 1 was designed to function as a floodplain wetland but, as built, has a small water holding capacity relative to the flow volume of Aurand Run. Water depths during the last three years have been low, leading to very little connection between Pool 1 and Aurand Run. Researchers estimate that, given the elevation of the connection between Aurand Run and the wetland pool, the pool is only connected to Aurand Run when the stream has water levels of approximately 1.2 m. Modifications to enhance the connection between Aurand Run and this wetland pool could potentially increase treatment of nutrient loads from Aurand Run, but a small increase might not justify the cost. Nutrient concentrations in Aurand Run are relatively low, so there is relatively little phosphorus (P) and nitrogen (N) to be removed. Thus, even if the connection between Aurand Run and the wetland pool were enhanced to increase frequency of connection, the increased P and N

filtration is expected to be low due to both the low nutrient concentrations of the water in Aurand Run and the relatively small holding capacity of the wetland pool.

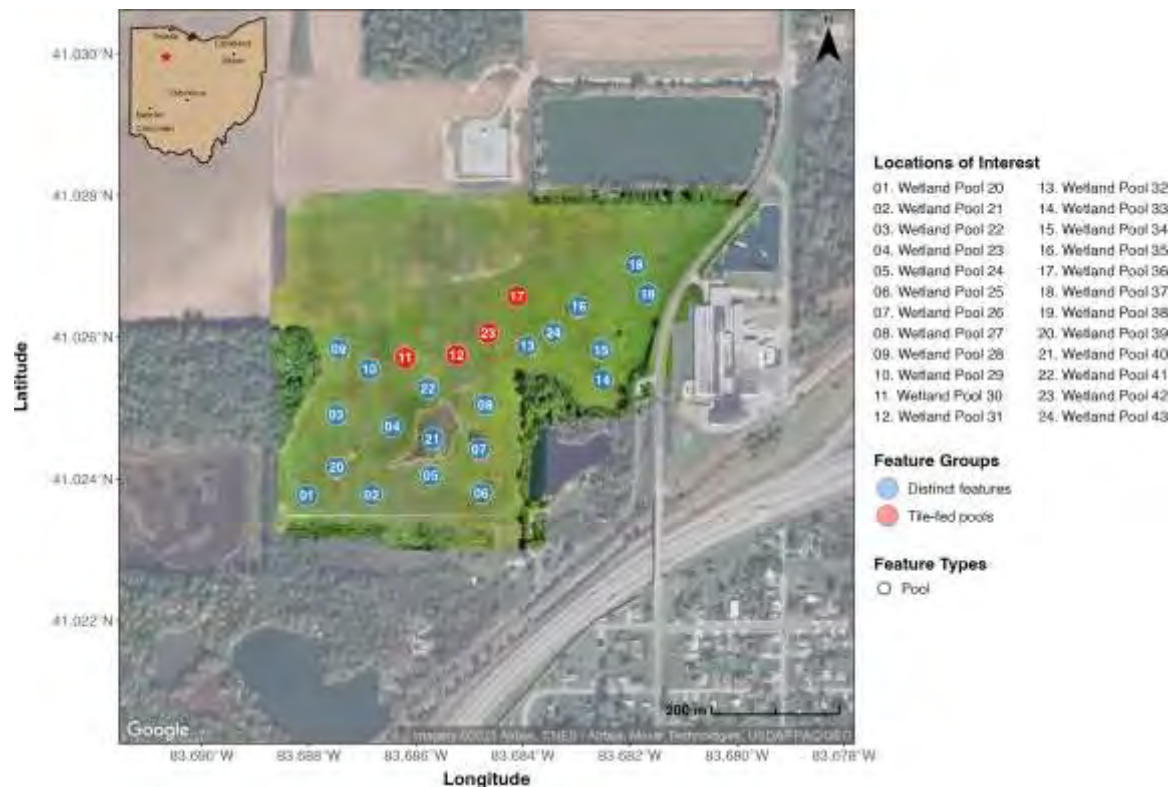


Figure 76. Aerial image of approximate locations of interest for water and soil sampling and discrete manual measurements of water depth and physicochemical parameters at Oakwoods Nature Preserve Wetland Restoration, East Project during water year 2024 (Oct 1, 2023–Sep 30, 2024). The legend provides the name of each sampling point. Different shapes denote the types of wetland features represented by the locations of interest. If present, different colors represent locations of interest that belong to a group or complex of features (e.g., a treatment train).



Figure 77. Aerial image of approximate locations of interest for water and soil sampling and discrete manual measurements of water depth and physicochemical parameters at Oakwoods Nature Preserve Wetland Restoration, West Project during water year 2024 (Oct 1, 2023–Sep 30, 2024). The legend provides the name of each sampling point. Different shapes denote the types of wetland features represented by the locations of interest. If present, different colors represent locations of interest that belong to a group or complex of features (e.g., a treatment train).

Nutrient Budget Takeaways

Oakwoods Nature Preserve East and West primarily prevent nutrient export by retaining water; its filtration effect is negligible. By evaluating the effect of converting formerly agricultural land to wetlands (assuming similar pre-wetland nutrient losses to published edge-of-field studies), researchers estimated that the Oakwoods East and West Projects annually prevent 117 lbs. phosphorus as total phosphorus from being exported to the Aurand Run watershed. Soils throughout the Project have moderate to high capacity to sorb phosphate, as suggested by soil phosphate sorption capacity values.

Surface Water Hydrology and Nutrients

The Oakwoods East and West Projects have minimal connectivity with the surrounding watershed. Storm events were rare in Water Year (WY) 2024 due to drier-than-normal conditions. During storm events in Oakwoods East, tile drainage water from six agricultural tile drains may be deposited into four pools on the north end of the Project. Many pools in the Oakwoods East Project have periods of intermixing when water levels are high, such as during spring (i.e., May 2023 and May 2024; Figure 79). This intermixing may cause any nutrients delivered by the tiles to affect other pools and not just the pools that have direct tile connection, which is important information to include when interpreting nutrient concentration trends observed by H2Ohio Wetland Monitoring Program researchers. Pools 25

and 20, which are the furthest from the tile-fed pools, are the only pools on the East Project that have not been observed to experience some degree of merging with the rest of the pools. During storm events in Oakwoods West, Aurand Run connects to Pool 1 and sometimes Pools 2 and 3 as well.

Throughout the Oakwoods East and West Projects, surface water concentrations were generally < 0.03 mg P/L for dissolved reactive phosphorus (DRP, Figure 81, Figure 87), < 0.15 mg N/L for nitrite+nitrate (NO_x, Figure 83, Figure 89), and < 0.04 mg N/L for total ammonium nitrogen (NH₄-N, Supplemental Information). Total phosphorus (TP) and total nitrogen (TN) were typically an order of magnitude higher than DRP and NO_x, which indicates particulate and organic fractions were dominant forms of P and N in these pools. The ranges of average wetland nutrient concentrations were 0.03–0.57 mg P/L for TP, 0.04–0.2 mg P/L for DRP, 0.12–3.64 mg N/L for TN, and 0.02–0.61 mg N/L for NO_x (Supplemental Information).

Oakwoods East Project

The Oakwoods East Project has potential for connectivity to the surrounding watershed only via Pools 30, 31, 36, and 42, which all have drainage tile outlets that might deliver water from nearby agricultural fields, but these inflows have not been conclusively observed due to their subsurface nature and low-flow conditions in WYs 2023 and 2024. Tile-fed pools 30, 31, and 36 all had very low DRP levels, below the minimum detection limit (MDL, < 0.004 mg P/L, Figure 81). Tile-fed pool 42 had DRP levels slightly above the MDL (0.006 mg P/L). Tile-fed pools had some of the lowest average TP concentrations (0.03–0.087 mg P/L across Pools 30, 31, 36, 42) whereas non tile-fed pool average TP concentrations ranged from 0.095 to 0.292 mg P/L (Figure 80, Supplemental Information). Tile-fed Pools 30 and 36 had relatively high NO_x concentrations (~0.1 mg N/L) compared to the other wetland pools (Figure 83, Supplemental Information).

Oakwoods pools are inundated seasonally. Similarly to most precipitation and surface-water fed ponds, pools at Oakwoods are maximally inundated in winter and spring. Water levels decline as they dry through the growing season to a minimum depth in fall, at the end of the water year. Six pools in the East Project have water level sensors (Vegapuls, VEGA, Shiltach, Germany), including the four tile-fed pools (30, 31, 36, 42) and two isolated wetland pools (39, 40). Pool 39 is noteworthy because it is located farthest from the tile-fed pools. Pool 40 is noteworthy because it is the largest pool of the Project by surface area. Pools 30 and 40 demonstrate similar temporal variation in Oakwoods East as in Oakwoods West. Pool 30, like Pool 9 in Oakwoods West, declines rapidly in water level during the fall as rain events become infrequent, and it eventually becomes dry. Pool 40 in Oakwoods East behaves similarly to Pool 18 in Oakwoods West; its water level declines more gradually and rarely, if ever, becomes totally dry.

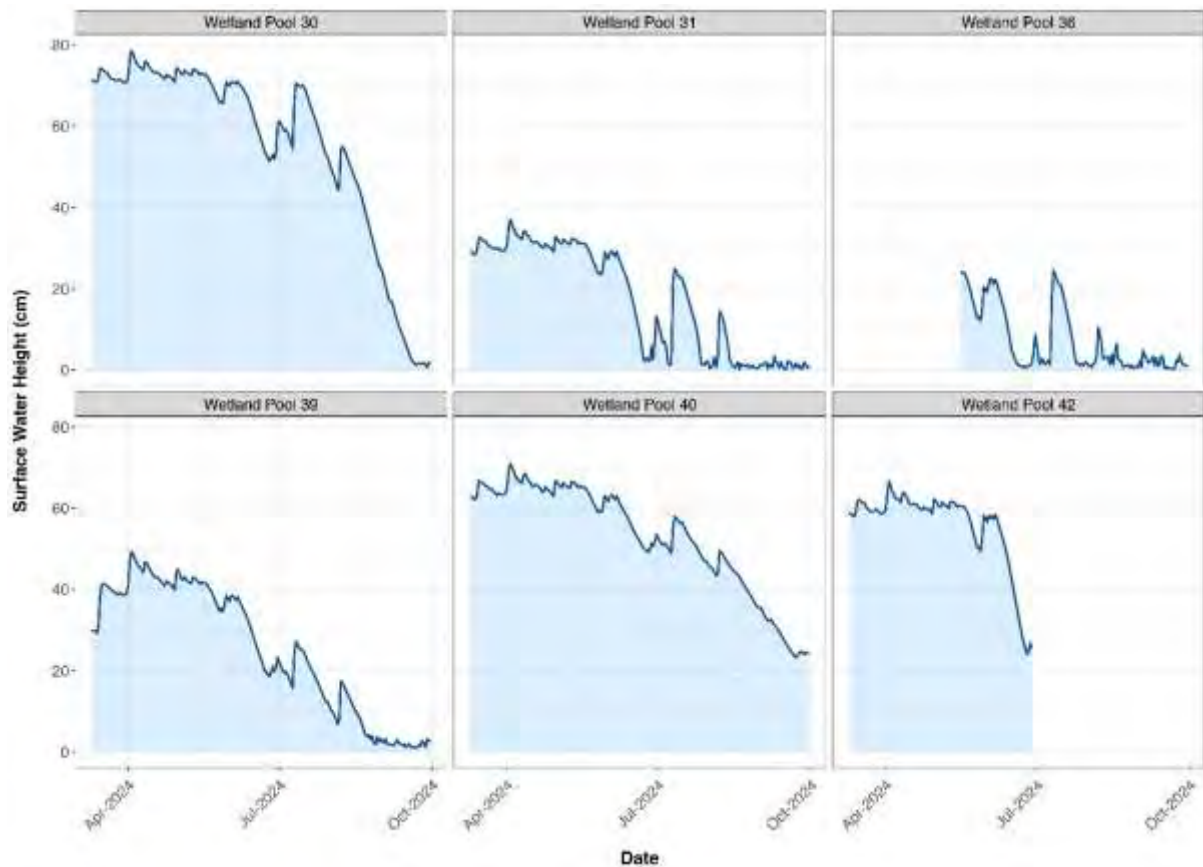


Figure 78. Time series of continuously measured surface water depth for the Oakwoods Nature Preserve Wetland Restoration, East Project. Depths were measured by sensors deployed at select locations of interest that report live observations. Values are reported as daily averages. Where available, daily precipitation accumulation is reported on the secondary y-axis. For information on the locations of interest, please refer to the aerial map above. Note that measurements in some locations are missing or were interrupted due to sensor malfunction

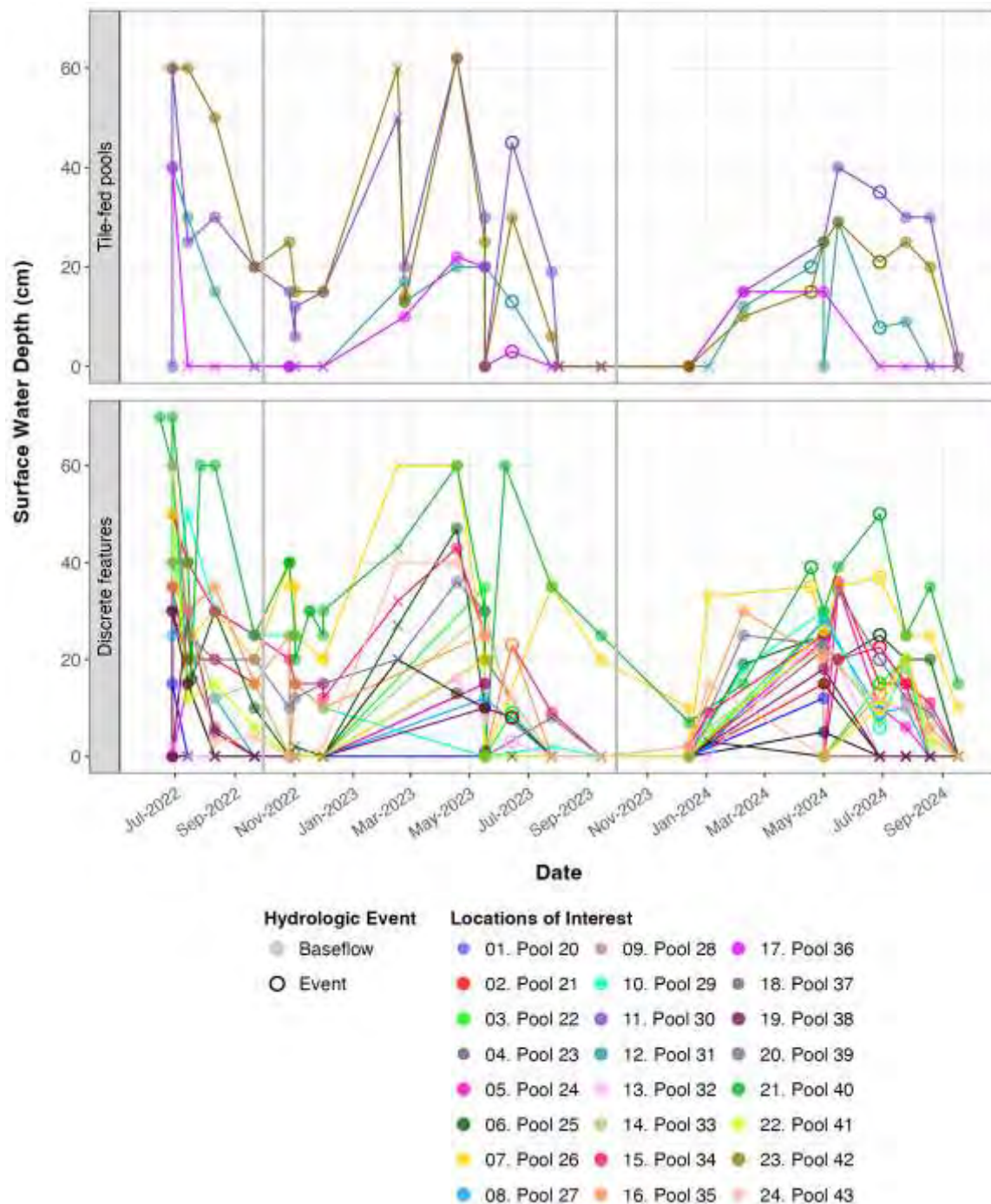


Figure 79. Time series of discrete, manually measured surface water depth at the Oakwoods Nature Preserve Wetland Restoration, East Project. Depths were measured approximately monthly. Each point represents one measurement and colors denote the locations of interest, as indicated in the legend. Open symbols indicate samples that were collected during a hydrologic event (e.g., storm event) and filled symbols denote samples collected during baseflow. Crosses (x) represent instances when no surface water was detected during the visit. If present, different shapes denote the types of wetland features represented by the locations of interest. Gray vertical lines indicate the start of a water year (Oct 1–Sep 30).

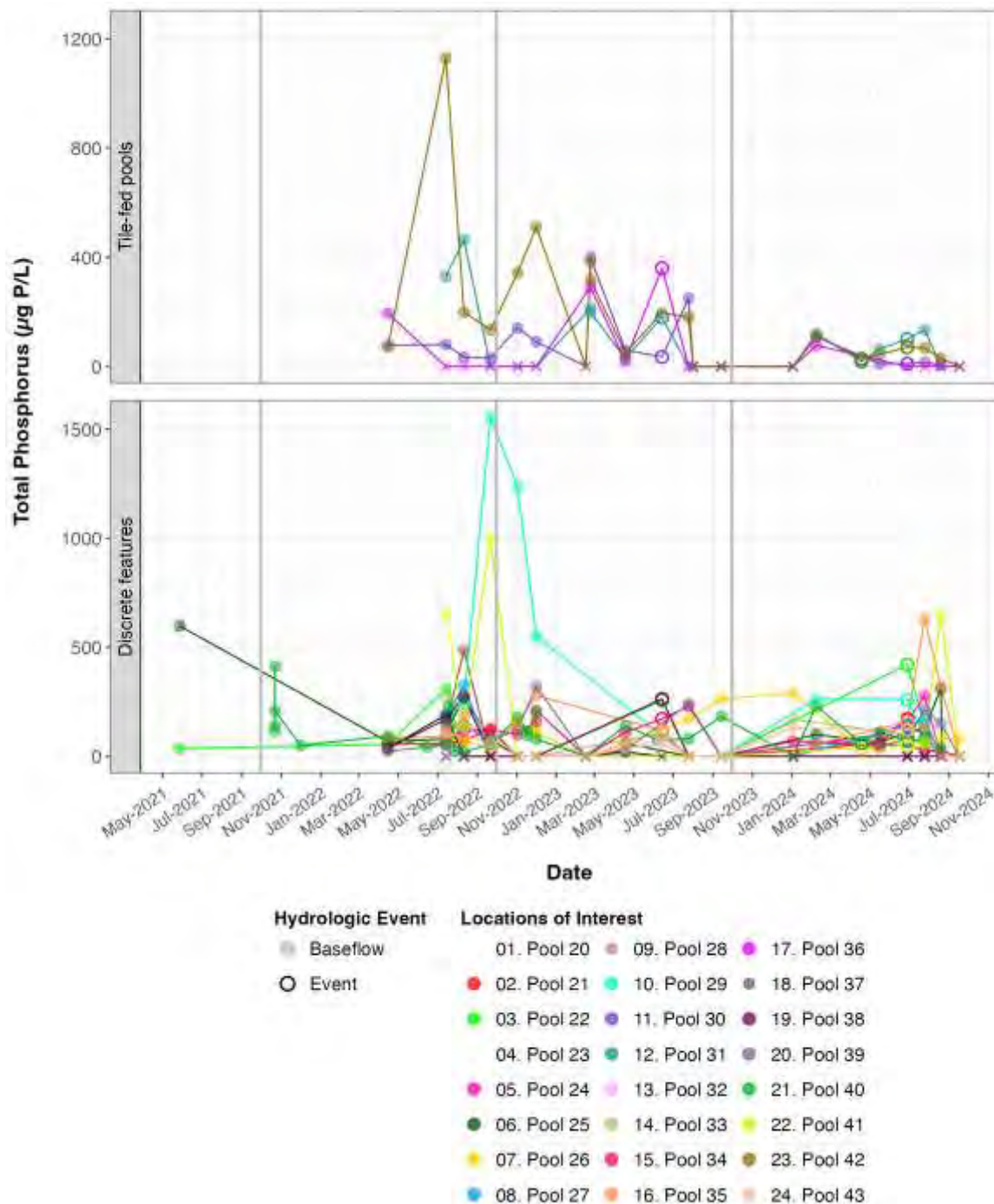


Figure 80. Time series of total phosphorus (TP) concentrations in surface water samples collected at the Oakwoods Nature Preserve Wetland Restoration, East Project. Values below the detection limit of the analytical equipment were replaced with half the value of the detection limit. Each point represents one measurement and colors denote the locations of interest, as indicated in the legend. Open symbols indicate that measurements were collected during a hydrologic event (e.g., storm event) and filled symbols denote measurements collected during baseflow. Crosses (×) represent instances when no surface water was detected during the visit. If present, different shapes denote the types of wetland features represented by the locations of interest. Gray vertical lines indicate the start of a water year (Oct 1–Sep 30).

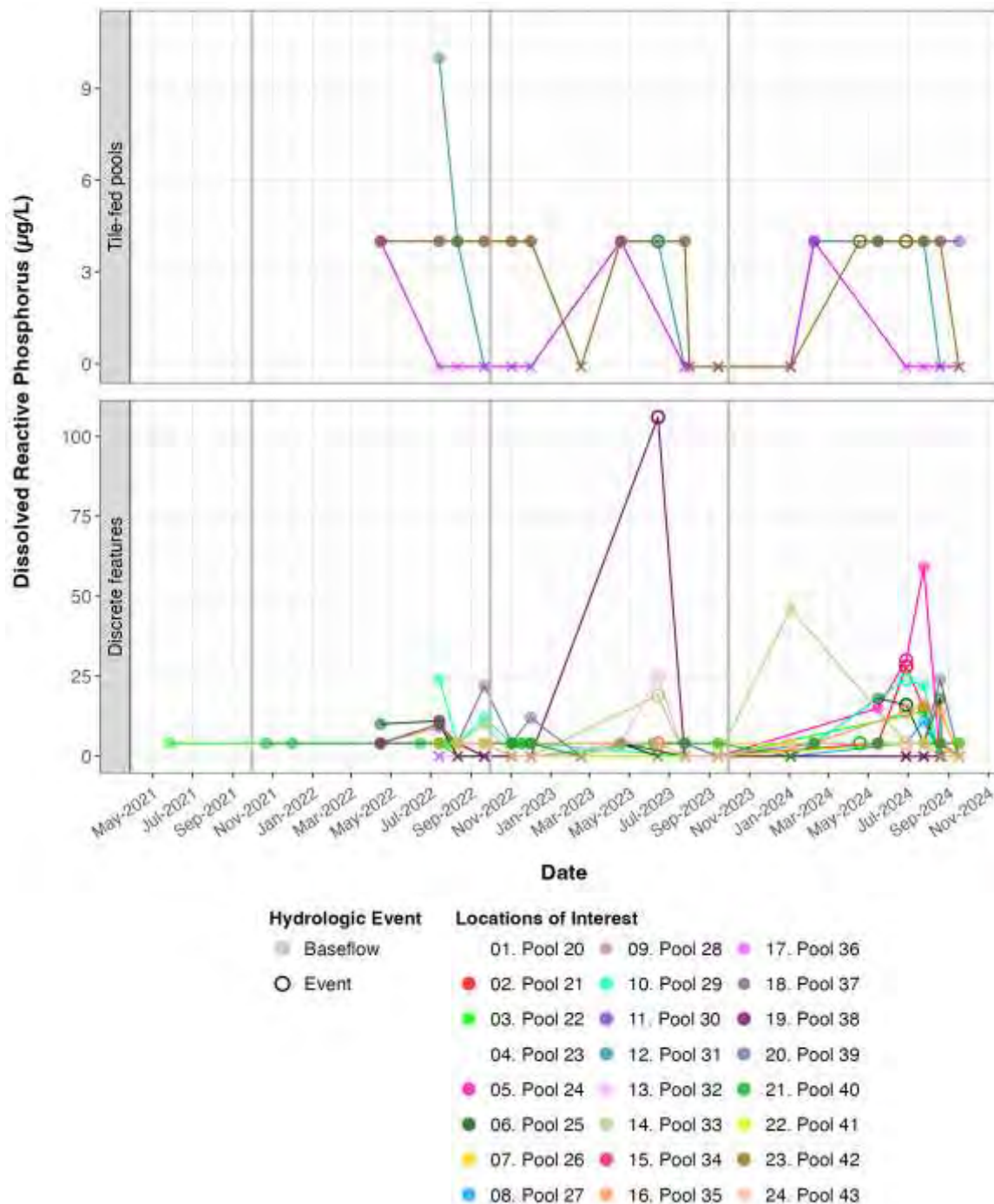


Figure 81. Time series of dissolved reactive phosphorus (DRP) concentrations in surface water samples collected at the Oakwoods Nature Preserve Wetland Restoration, East Project. Values below the detection limit of the analytical equipment were replaced with half the value of the detection limit. Each point represents one measurement and colors denote the locations of interest, as indicated in the legend. Open symbols indicate that measurements were collected during a hydrologic event (e.g., storm event) and filled symbols denote measurements collected during baseflow. Crosses (×) represent instances when no surface water was detected during the visit. If present, different shapes denote the types of wetland features represented by the locations of interest. Gray vertical lines indicate the start of a water year (Oct 1–Sep 30).

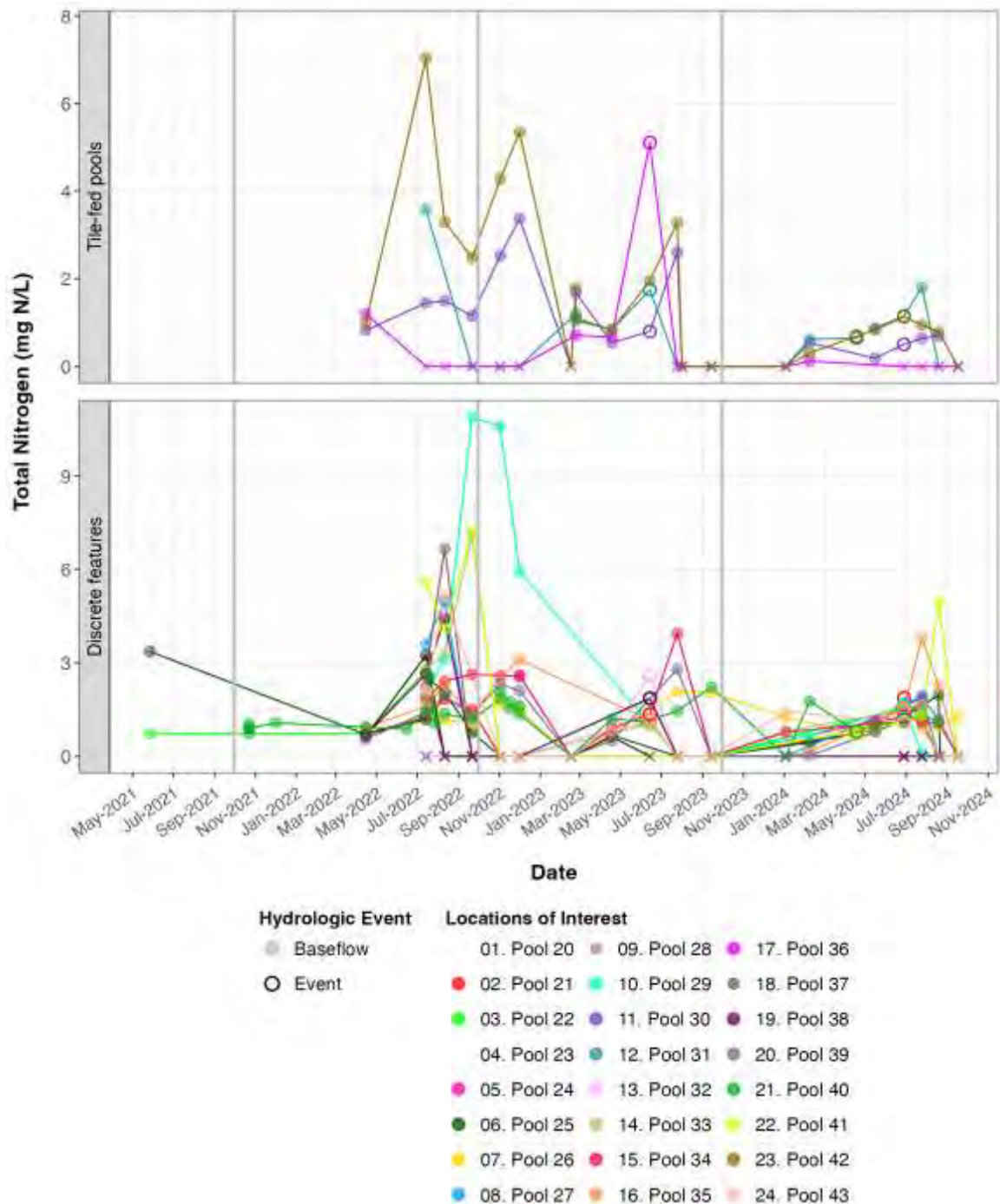


Figure 82. Time series of total nitrogen (TN) concentrations in surface water samples collected at the Oakwoods Nature Preserve Wetland Restoration, East Project. Values below the detection limit of the analytical equipment were replaced with half the value of the detection limit. Each point represents one measurement and colors denote the locations of interest, as indicated in the legend. Open symbols indicate that measurements were collected during a hydrologic event (e.g., storm event) and filled symbols denote measurements collected during baseflow. Crosses (×) represent instances when no surface water was detected during the visit. If present, different shapes denote the types of wetland features represented by the locations of interest. Gray vertical lines indicate the start of a water year (Oct 1–Sep 30).

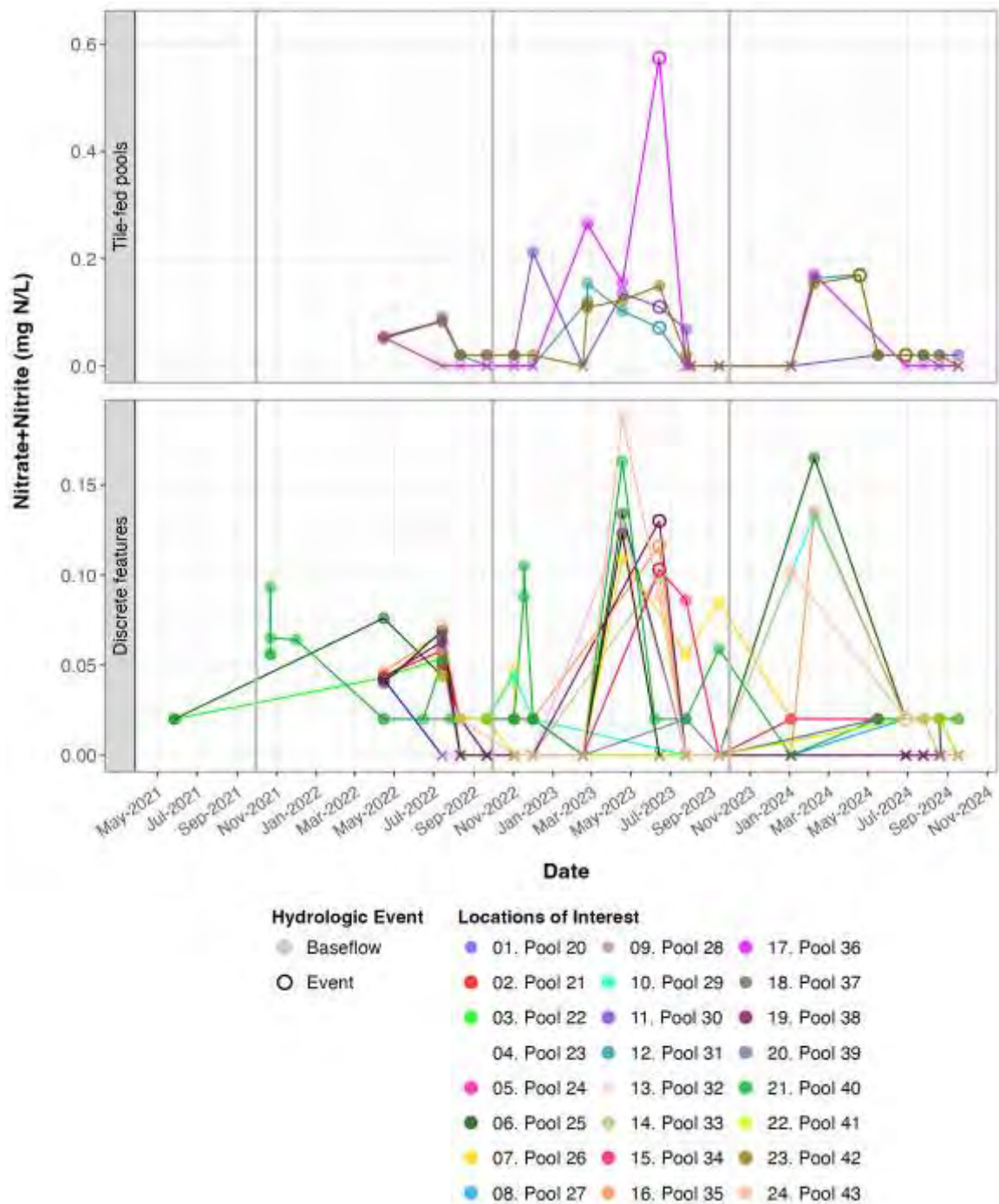


Figure 83. Time series of Nitrite+nitrate (NO_x) concentrations in surface water samples collected at the Oakwoods Nature Preserve Wetland Restoration, East Project. Values below the detection limit of the analytical equipment were replaced with half the value of the detection limit. Each point represents one measurement and colors denote the locations of interest, as indicated in the legend. Open symbols indicate that measurements were collected during a hydrologic event (e.g., storm event) and filled symbols denote measurements collected during baseflow. Crosses (x) represent instances when no surface water was detected during the visit. If present, different shapes denote the types of wetland features represented by the locations of interest. Gray vertical lines indicate the start of a water year (Oct 1–Sep 30).

Oakwoods West Project

Pool 1 on the Oakwoods West Project is the only pool directly connected to Aurand Run, although, since the Project's construction in 2021, researchers have rarely observed an active hydrologic connection between Pool 1 and Aurand Run. A partner (Hancock Park District Manager) shared that Pool 1 spills into Pool 2 at times of highest water level, which would increase the amount of water (and nutrients) that can be received and filtered by the Project from Aurand Run, though the spillover has not yet been observed by Monitoring Program field staff.

Inundation in Oakwoods West pools follows a seasonal pattern. Four pools in the Oakwoods West Project have water level sensors (Vegapuls, VEGA, Shiltach, Germany): Pools 1, 4, 9, and 18. Pool 9 has water for much of the year, but levels begin to drop rapidly when rain events decrease in the fall. Pool 18 water level appears to decline much more gradually and has never been completely dried up during the period of water level monitoring.

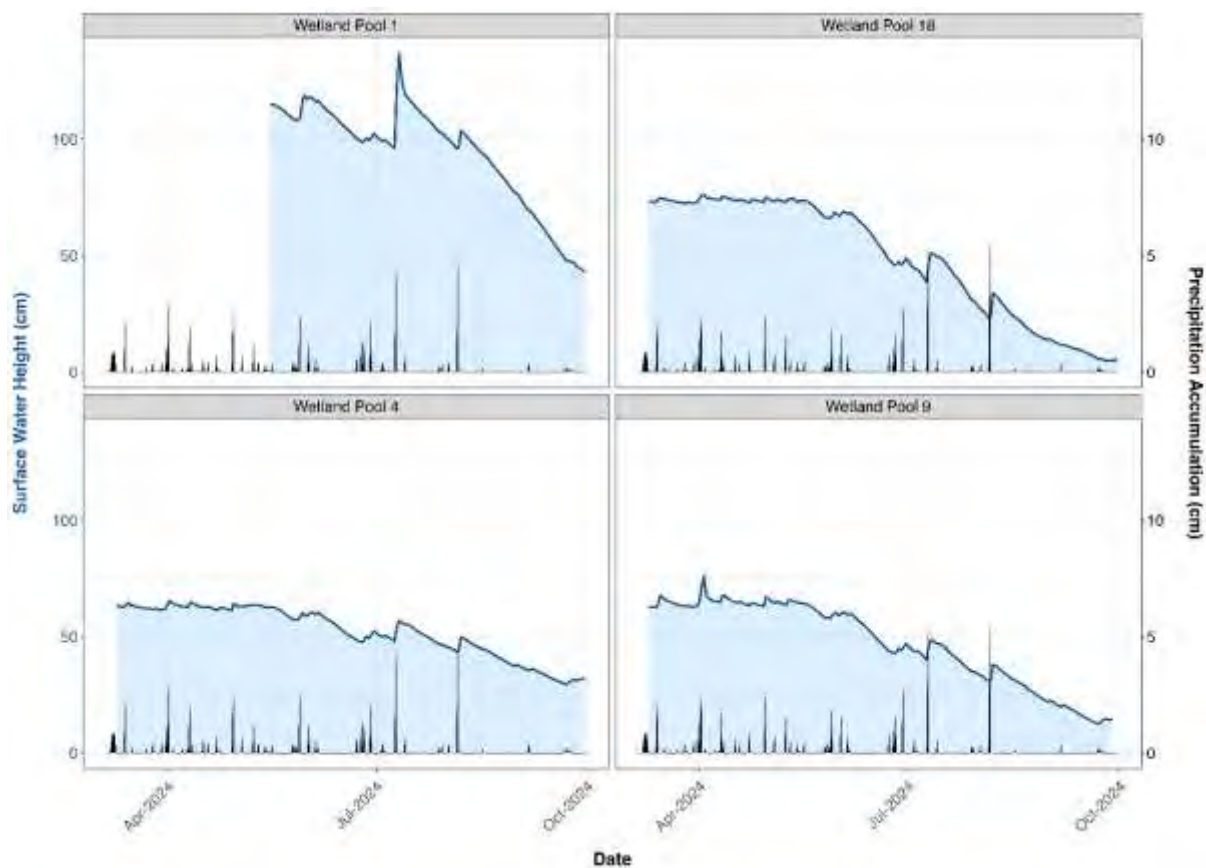


Figure 84. Time series of continuously measured surface water depth for the Oakwoods Nature Preserve Wetland Restoration, West Project. Depths were measured by sensors deployed at select locations of interest that report live observations. Values are reported as daily averages. Where available, daily precipitation accumulation is reported on the secondary y-axis. For information on the locations of interest, please refer to the aerial map above. Note that measurements in some locations are missing or were interrupted due to sensor malfunction

Pool 1 had relatively low average DRP (0.016 mg P/L) and TP (0.171 mg P/L) concentrations compared to other pools despite its potential to receive water from Aurand Run (Figure 86, Figure 87, Supplemental Information). Aurand Run also tends to be similarly low in DRP (0.015 mg P/L) and TP (0.044 mg P/L) at the connection between Pool 1 and Aurand Run (Supplemental Information). Though they were on average the highest across the Project, nitrite+nitrate at Aurand Run (1.932 mg N/L upstream, 2.07 mg N/L downstream) and Pool 1 (0.883 mg N/L) were still relatively low compared to regional watershed averages (Figure 89, Supplemental Information). The similar values between upstream and downstream of Pool 1 suggest little to no influence of Pool 1 on Aurand Run nutrient levels. The relatively low concentrations of P and N in Aurand Run and the relatively low water flow means that little reduction of P and N transport in the watershed can be achieved by filtering that water in the Oakwoods Wetland. Therefore, modifications that have additional costs may not be likely to provide greater P and N retention benefits. Pool 8 had the highest average DRP (0.202 mg P/L) and TP (0.492 mg P/L) concentrations (Supplemental Information). Pool 8 is one of the smallest and shallowest pools; high concentrations may be a result of evaporative concentration of solutes. Pool 8 is not connected to any water sources other than parcel-level surface runoff during rain events, like most other pools in Oakwoods West.

Researchers observed similar average TN concentrations in Aurand Run Upstream (2.86 mg N/L) and Aurand Run Downstream (2.35 mg N/L, Supplemental Information). Most of the isolated pools had average TN concentrations between 0.8 and 1.8 mg N/L (Figure 88). A few isolated pools (e.g., Pool 11, Pool 14) deviated had slightly elevated TN concentrations (average of approximately 3.7 mg N/L, Supplemental Information) but had small sample sizes because of their short-term flooding regime, which was even shorter in WY 2024 due to dry weather conditions. Since the pools are isolated from any off-parcel Project water sources, the elevated TN concentrations may reflect resuspension of N from sediment within the pools after rain events or could be due to decomposing vegetation or other organic material.

Four pools in the Oakwoods West Project have Vegapuls (VEGA, Shiltach, Germany) water level sensors: Pools 1, 4, 9, and 18. These high-resolution sensors record water height every 15 minutes year-round. Pool 9 has water for much of the year, but levels begin to drop rapidly when rain events decrease in the fall. Pool 18 water level appears to decline much more gradually and has never been completely dried up during the period of water level monitoring (Figure 85**Error! Reference source not found.**).

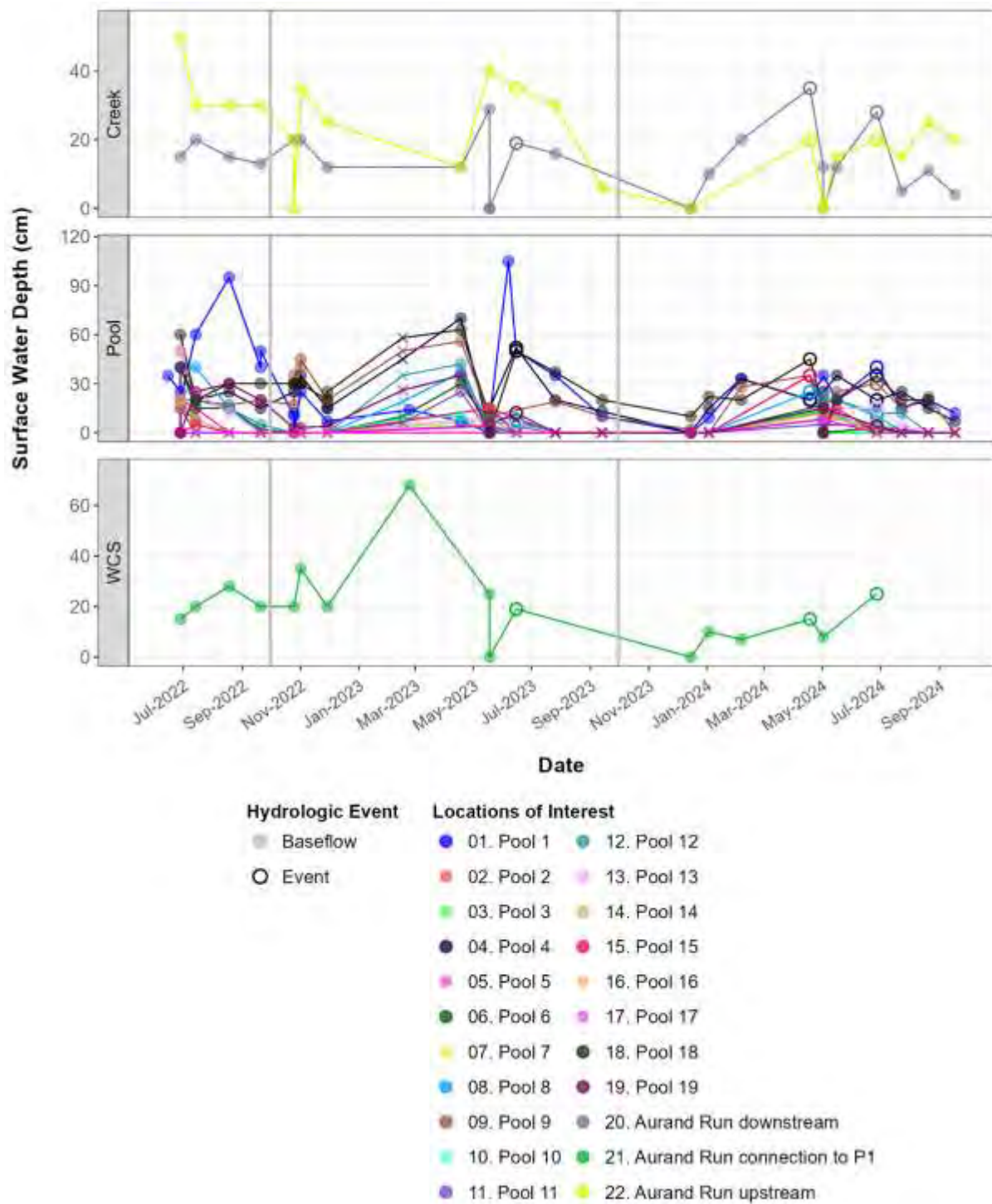


Figure 85. Time series of discrete, manually measured surface water depth at the Oakwoods Nature Preserve Wetland Restoration, West Project. Depths were measured approximately monthly. Each point represents one measurement and colors denote the locations of interest, as indicated in the legend. Open symbols indicate samples that were collected during a hydrologic event (e.g., storm event) and filled symbols denote samples collected during baseflow. Crosses (x) represent instances when no surface water was detected during the visit. If present, different shapes denote the types of wetland features represented by the locations of interest. Gray vertical lines indicate the start of a water year (Oct 1–Sep 30).

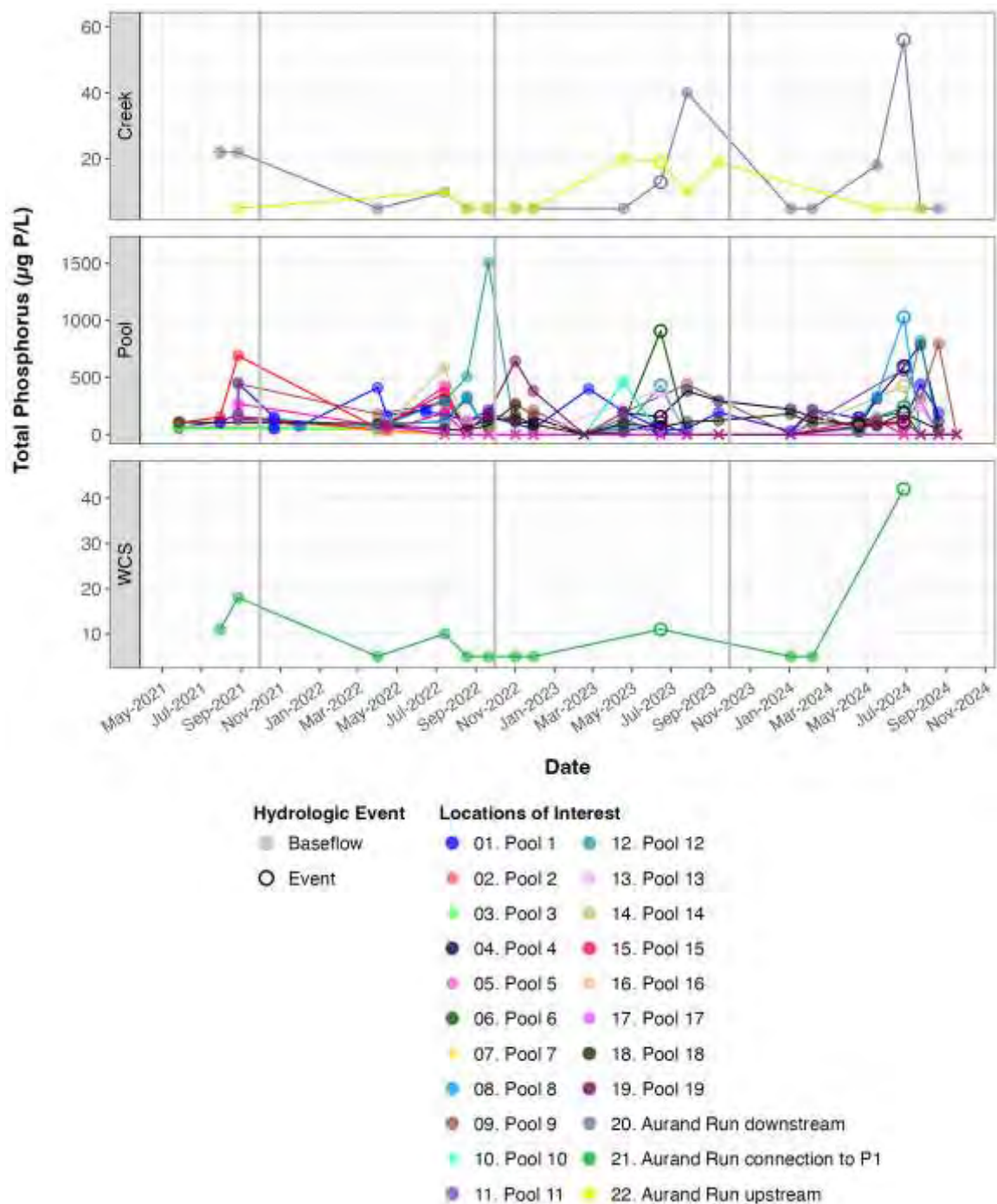


Figure 86. Time series of total phosphorus (TP) concentrations in surface water samples collected at the Oakwoods Nature Preserve Wetland Restoration, West Project. Values below the detection limit of the analytical equipment were replaced with half the value of the detection limit. Each point represents one measurement and colors denote the locations of interest, as indicated in the legend. Open symbols indicate that measurements were collected during a hydrologic event (e.g., storm event) and filled symbols denote measurements collected during baseflow. Crosses (×) represent instances when no surface water was detected during the visit. If present, different shapes denote the types of wetland features

represented by the locations of interest. Gray vertical lines indicate the start of a water year (Oct 1–Sep 30)

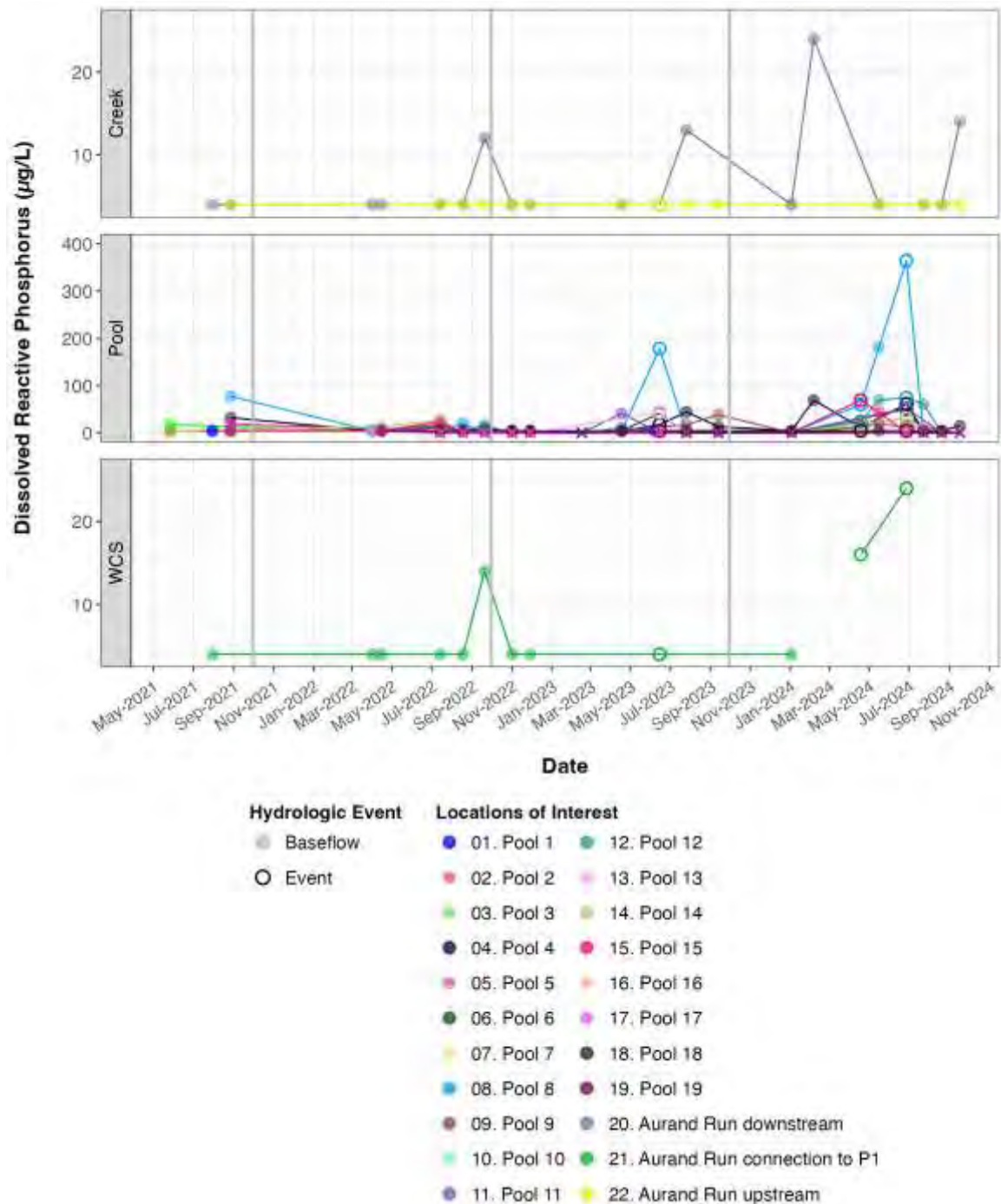


Figure 87. Time series of dissolved reactive phosphorus (DRP) concentrations in surface water samples collected at the Oakwoods Nature Preserve Wetland Restoration, West Project. Values below the detection limit of the analytical equipment were replaced with half the value of the detection limit. Each point represents one measurement and colors denote the locations of interest, as indicated in the legend. Open symbols indicate that measurements were collected during a hydrologic event (e.g., storm event) and filled symbols denote measurements collected during baseflow. Crosses (×) represent instances when no surface

water was detected during the visit. If present, different shapes denote the types of wetland features represented by the locations of interest. Gray vertical lines indicate the start of a water year (Oct 1–Sep 30).

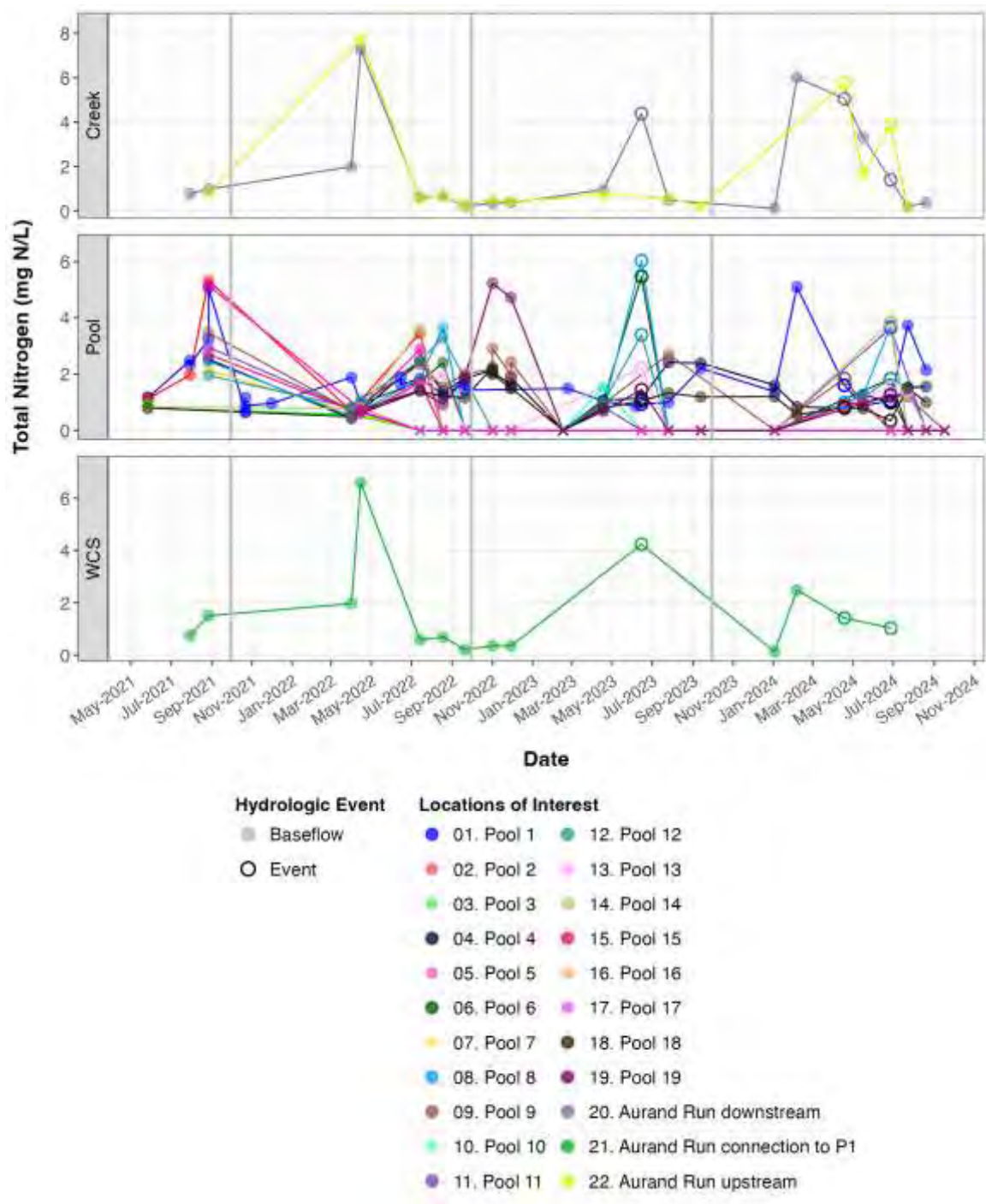


Figure 88. Time series of total nitrogen (TN) concentrations in surface water samples collected at the Oakwoods Nature Preserve Wetland Restoration, West Project. Values below the detection limit of the analytical equipment were replaced with half the value of the detection limit. Each point represents one measurement and colors denote the locations of interest, as indicated in the legend. Open symbols indicate that measurements were collected during a hydrologic event (e.g., storm event) and filled symbols denote measurements

collected during baseflow. Crosses (×) represent instances when no surface water was detected during the visit. If present, different shapes denote the types of wetland features represented by the locations of interest. Gray vertical lines indicate the start of a water year (Oct 1–Sep 30).

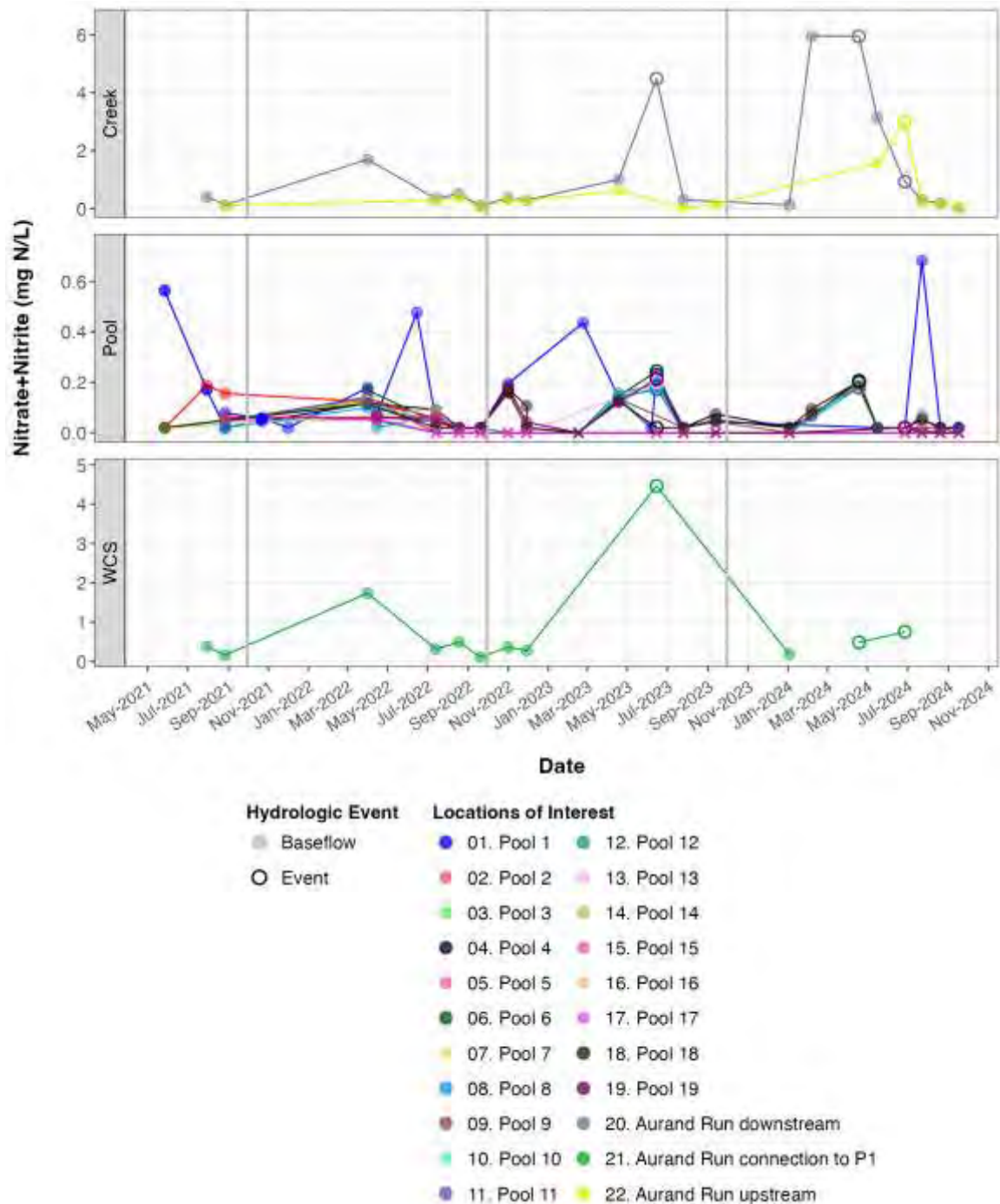


Figure 89. Time series of Nitrite+nitrate (NO_x) concentrations in surface water samples collected at the Oakwoods Nature Preserve Wetland Restoration, West Project. Values below detection limit were replaced with half the detection limit. Each point represents one measurement and colors denote the locations of interest, as indicated in the legend. Open symbols indicate that measurements were collected during a hydrologic event (e.g., storm

event) and filled symbols denote measurements collected during baseflow. Crosses represent instances when no surface water was detected during the visit. If present, different shapes denote the types of wetland features represented by the locations of interest. Gray vertical lines indicate the start of a water year (Oct 1–Sep 30).

Soil Nutrient Status and Processes

At the Oakwoods Projects, soil pH ranged from 5.7 to 7.6. The pH was higher in Aurand Run (7.4–7.6) and Pool 1 (7.4) than in the other wetland pools (Supplemental Information). Soil phosphate sorption capacity (SPSC) for both the East and West Projects was consistently positive, with a maximum of 164 mg phosphorus (P)/kg (Figure 90, Figure 91). High SPSC values at nearly all sampling locations across Oakwoods East and West indicate a high capacity for phosphate sorption. The lower SPSC values in Pool 1 may be due to its increased connectivity to Aurand Run or to the nearby tile outlet at the northeast edge of the pool, but, given that these values are still positive, Pool 1 soils still have the capacity to retain additional phosphate. Future soil sampling and analysis will monitor the SPSC for indications of potential nutrient release (negative SPSC values).

Oakwoods East Project

Pools 30 (tile-fed) and Pools 32, 34, and 38 (non-tile-fed) shared the highest soil pH in Oakwoods East (7.54). SPSC was consistently positive and generally high throughout the Oakwoods East Project (Figure 90). The highest average SPSC (140 mg P/kg) was measured in Pool 40, the largest pool of the East Project, and Pool 38, the eastern most pool in the Project, had the lowest average SPSC (91 mg/kg, Supplemental Information).

Oakwoods West Project

Pool 1, which has an occasional floodplain connection to Aurand Run, had the highest soil pH (7.4) in Oakwoods West. Pool 1 also had the lowest average SPSC values of any of the wetland pools at both Oakwoods Projects (75 mg P/kg average, Figure 91, Supplemental Information), which is likely because it is the only pool that receives water from Aurand Run, and the nutrients in the water from Aurand Run may take up binding sites in the soil in Pool 1. Aurand Run Upstream (14 mg/kg) and Downstream (36 mg/kg) had the lowest SPSC values of all sampling locations at both Oakwoods Projects (Supplemental Information). The majority of SPSC values in the Oakwoods West pools were > 100 mg/kg.

Hydrogeophysics Results at Oakwoods West

Oakwoods West contains similar spatial trends in bulk apparent soil electrical conductivity (ECa) at both sampling depths of 0.75 m and 1.5 m (Figure 92). There is a linear high conductivity anomaly in the northwest corner of the Project parcel indicating a buried utility line. Low conductivity anomalies exist around the Aurand Run floodplain (Pool 1) and high conductivity anomalies exist around most of the isolated depressional pools. Very high conductivity anomalies at the edges of the northeastern corner of the Project parcel may indicate a different soil type. There are additional hydrogeophysics results (e.g., groundwater well soil profiles) in Appendix I.

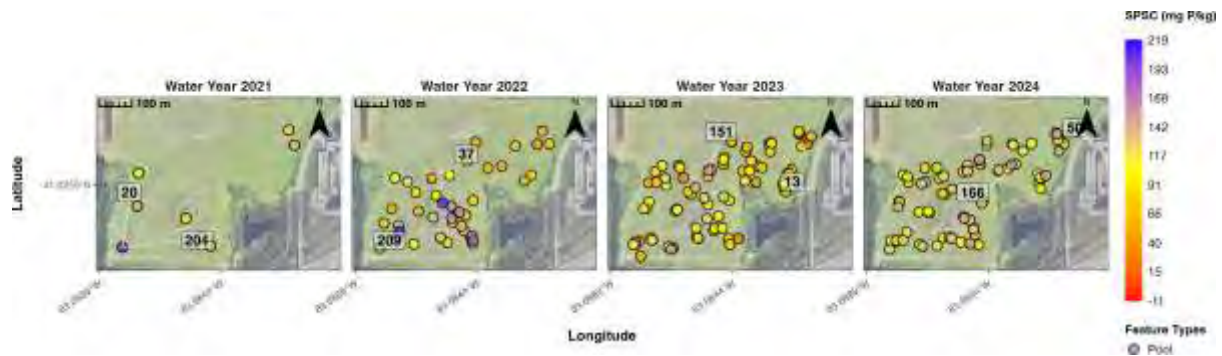


Figure 90. Soil Phosphate Sorption Capacity (SPSC) throughout the Oakwoods Nature Preserve Wetland Restoration, East Project. Each point denotes a soil sample (0–5 cm) and different shapes indicate the wetland feature type, as shown in the legend. Colors indicate the SPSC value of each sample relative to the overall range of values observed at the wetland project, as shown in the color bar. Each panel shows the soil samples collected during a respective water year (Oct 1–Sep 30), along with the minimum and maximum SPSC values observed during a given water year. Negative SPSC values indicate the potential for soils to release phosphate, while positive values indicate soils have capacity to sorb phosphate, based on Mehlich-3 extractions of phosphate, iron, and aluminum.

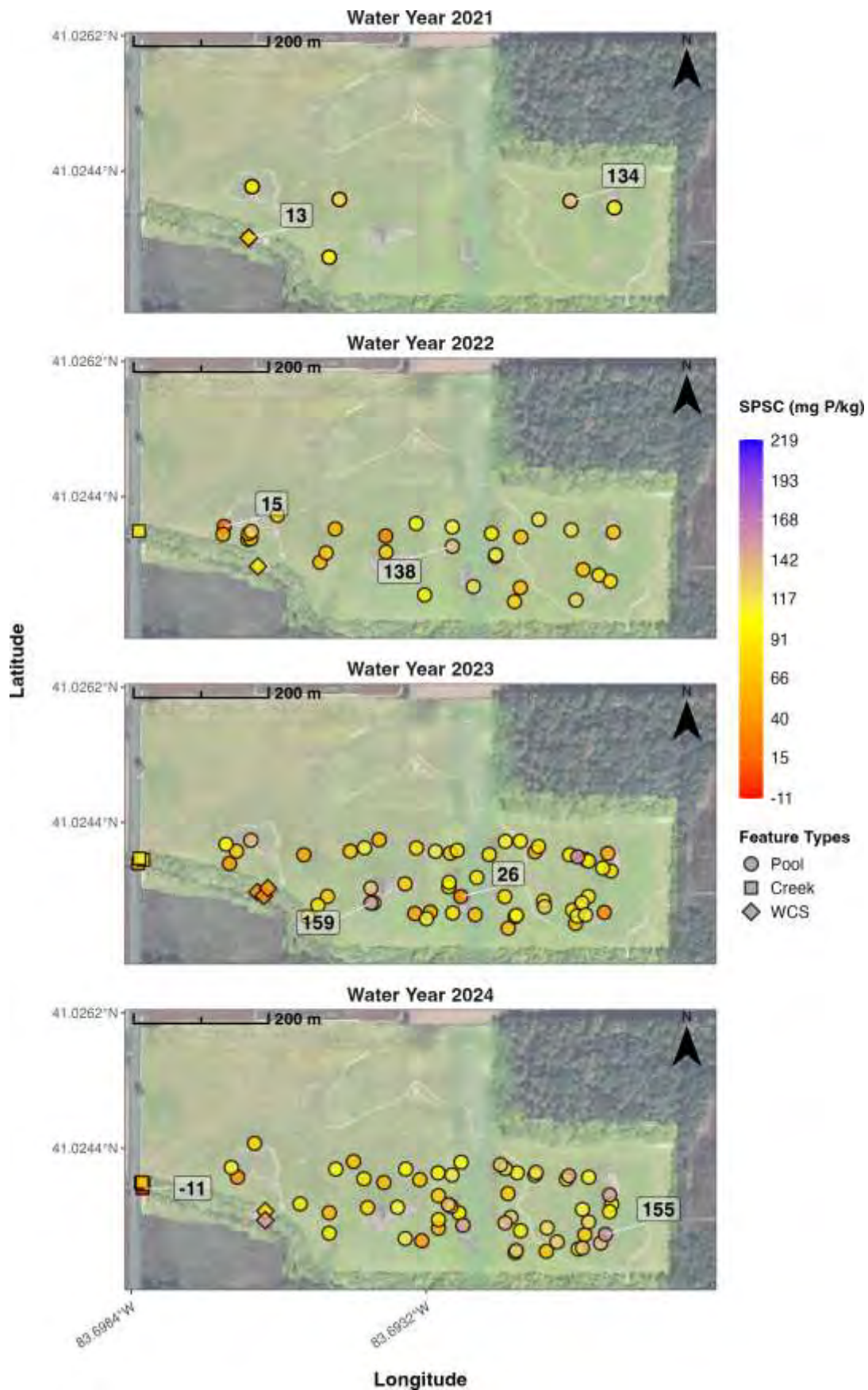


Figure 91. Soil Phosphate Sorption Capacity (SPSC) throughout the Oakwoods Nature Preserve Wetland Restoration, West Project. Each point denotes a soil sample (0–5 cm) and

different shapes indicate the wetland feature type, as shown in the legend. Colors indicate the SPSC value of each sample relative to the overall range of values observed at the wetland project, as shown in the color bar. Each panel shows the soil samples collected during a respective water year (Oct 1–Sep 30), along with the minimum and maximum SPSC values observed during a given water year. Negative SPSC values indicate the potential for soils to release phosphate, while positive values indicate soils have capacity to sorb phosphate, based on Mehlich-3 extractions of phosphate, iron, and aluminum.

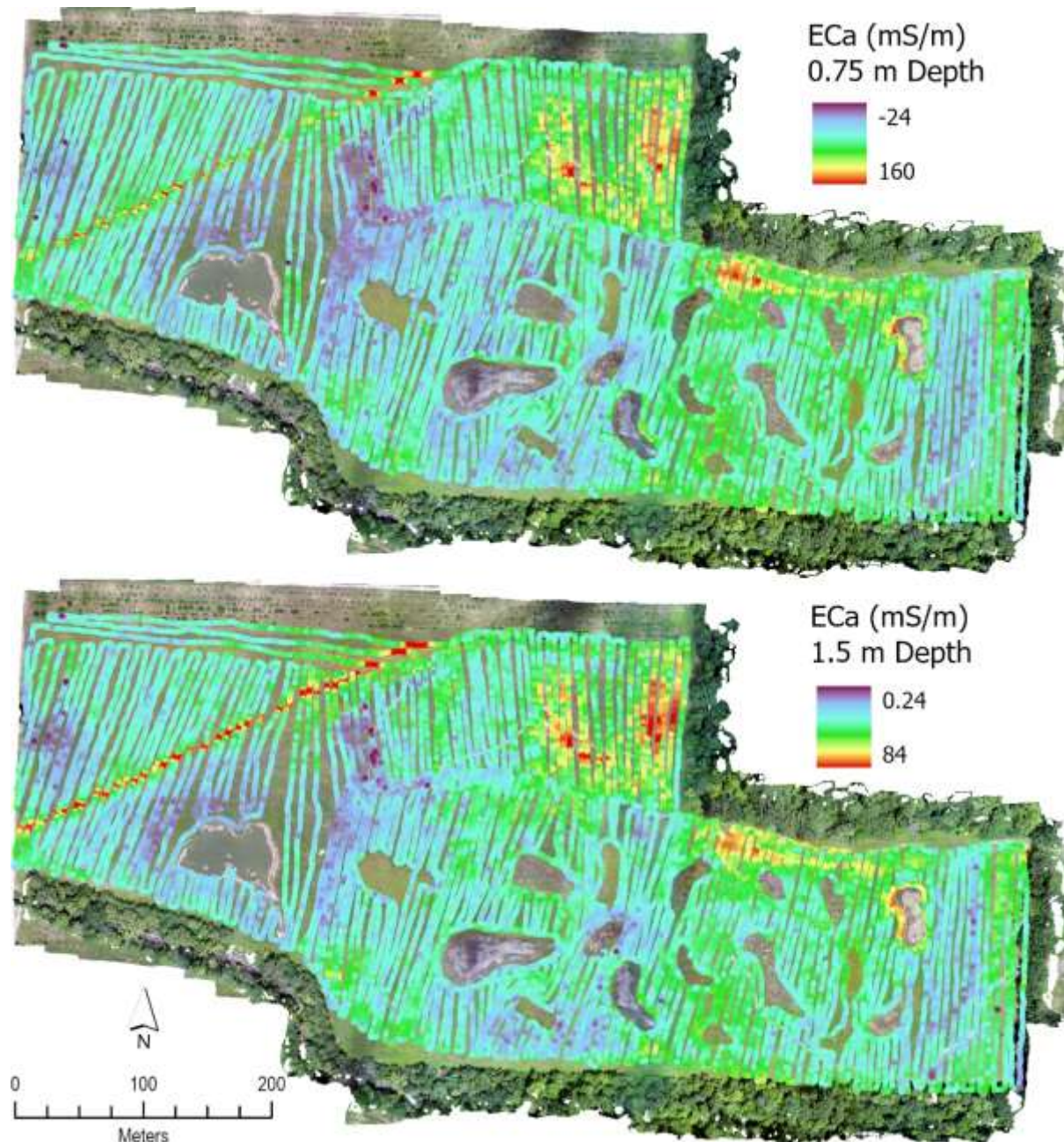


Figure 92. Apparent bulk soil electrical conductivity (ECa) at Oakwoods Nature Preserve Wetland Restoration West for (top) 0.5 m coil spacing (0.75 m depth) and (bottom) 1.0 m

coil spacing (1.5 m depth). Note: The relatively high values in a linear pattern indicate a utility line in the northwest corner of the Project parcel.

Vegetation Results

Oakwoods West

In 2024 researchers calculated vegetation nutrient stocks as 449 lbs. of phosphorus (P, 413 lbs. aboveground and 36 lbs. belowground) and 1753 lbs. of nitrogen (N, 1569 lbs. aboveground and 184 lbs. belowground) during peak biomass at Oakwoods West (Figure 94). This stock is a net decrease of 11 lbs. P but a net increase of 51 lbs. N from 2023. Vegetation nutrient stock at Oakwoods West peaked in 2022 at 956 lbs. P and 2584 lbs. N, but drought conditions likely have limited plant growth and contributed to the decreases in stock over the past two years. Despite drought conditions, the active vegetated wetland area has remained stable since restoration at Oakwoods West, suggesting declines in nutrient stock are related to decreased vegetation density or altered species composition.

On a per-acre basis, belowground nutrient stock was highest at Oakwoods West in 2023 and declined in 2024. Total belowground stock was highest at Oakwoods West for P in 2023, but for N in 2024. While the increases in total stock and per-acre stock from 2022 to 2023 may be attributed to increased average belowground biomass, relatively little change was seen in average belowground biomass from 2023 to 2024, so these trends in nutrient stock values may be related to biogeochemical changes associated with hydrologic conditions.

Cattails (*Typha spp.*) had the highest nutrient density of all species at Oakwoods West for sampling years 2022–2024, however species such as Common arrowhead (*Sagittaria latifolia*), Pickerelweed (*Pontederia cordata*), and Soft rush (*Juncus effusus*) have comparably high nutrient densities and may be more beneficial for species diversity (Figure 95, Figure 96). Oakwoods West has trended towards increases in species diversity and the floristic quality assessment index since restoration, although from 2023 to 2024 there was a

decrease in the relative proportion of wetland species compared to non-wetland species, possibly due to drought conditions (Figure 97).

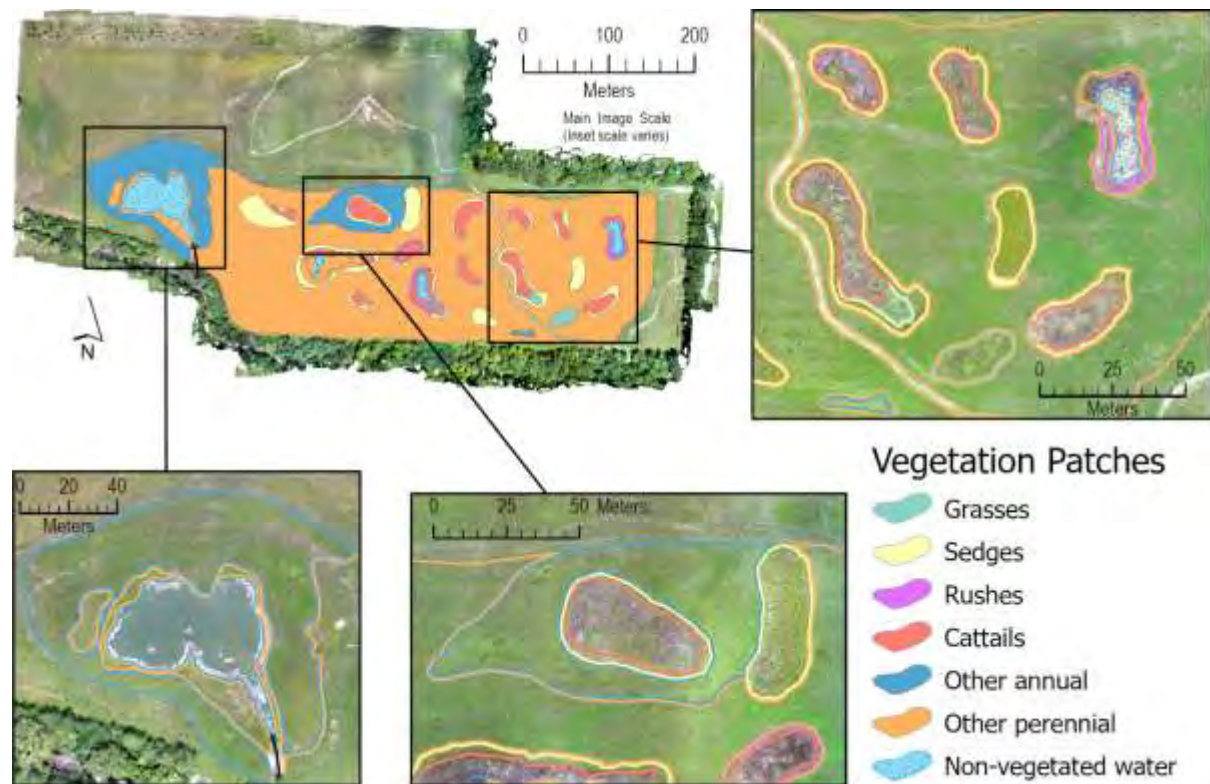


Figure 93. Aerial imagery (August 2024) with simplified vegetation patches based on expert-drawn vegetation maps (based on data collected July 2024) at Oakwoods Nature Preserve Wetland Restoration West. The magnified sections show the outlines of the vegetation patches. Vegetation patch types used in analyses have been combined in this image to visually simplify patch categories.

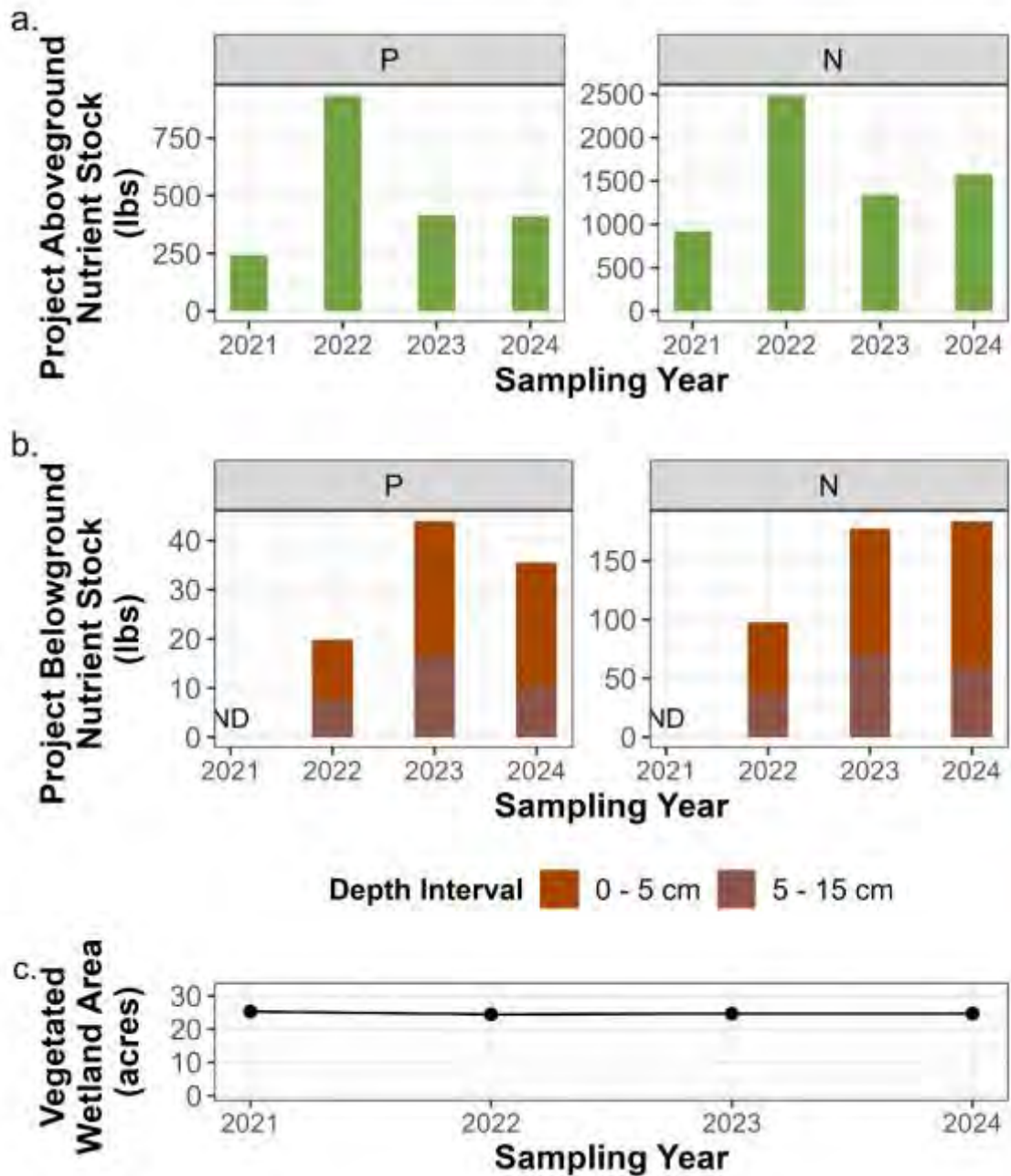


Figure 94. Nutrient stock in (a) above- and (b) belowground vegetation at Oakwoods Nature Preserve Wetland Restoration West. Estimates of the total mass of Phosphorus (P) and Nitrogen (N) stock in vegetation in the areas surveyed by the H2Ohio Wetland Monitoring Program for each year Oakwoods West was monitored for vegetation. (c) Vegetated Wetland Area refers to areas observed to have wetland-dominant species composition and all other Project areas were excluded from vegetation stock calculations. For more detailed information on how estimates were calculated, see Appendix II.

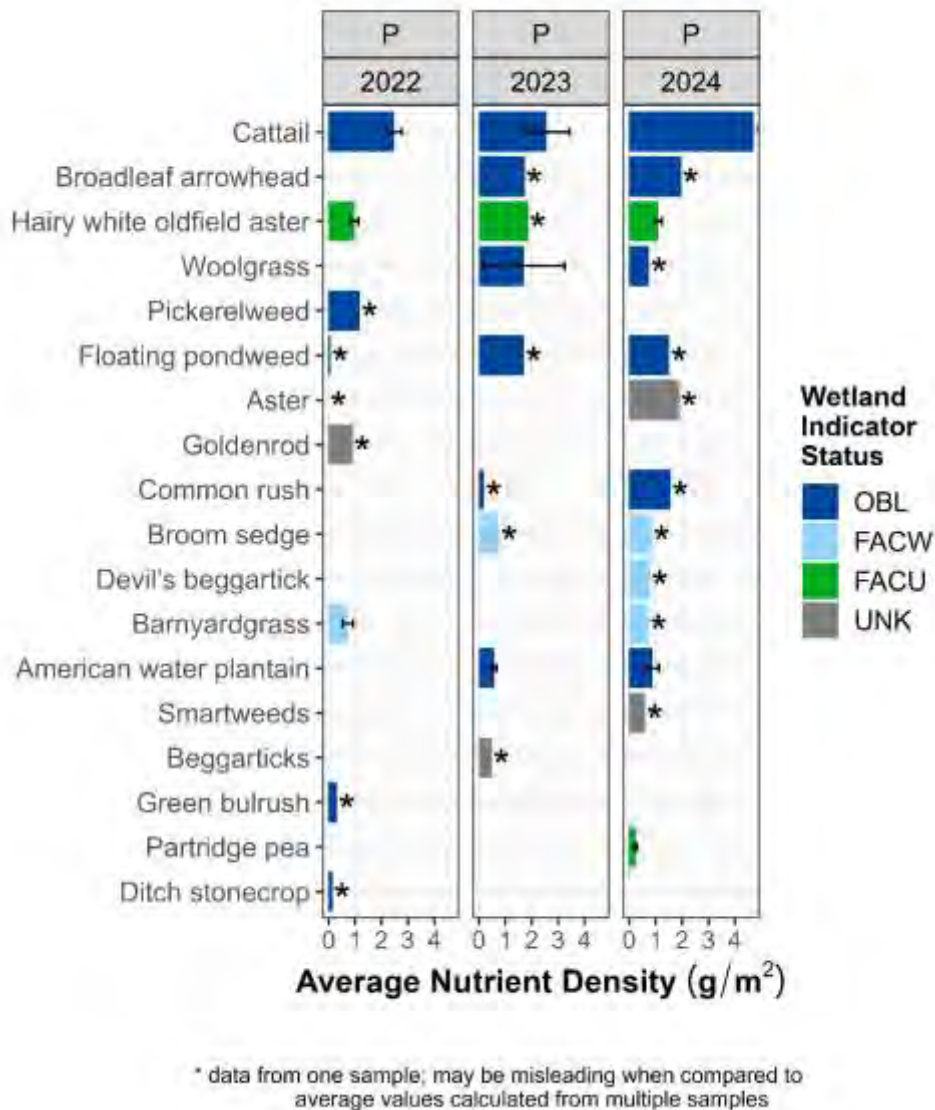
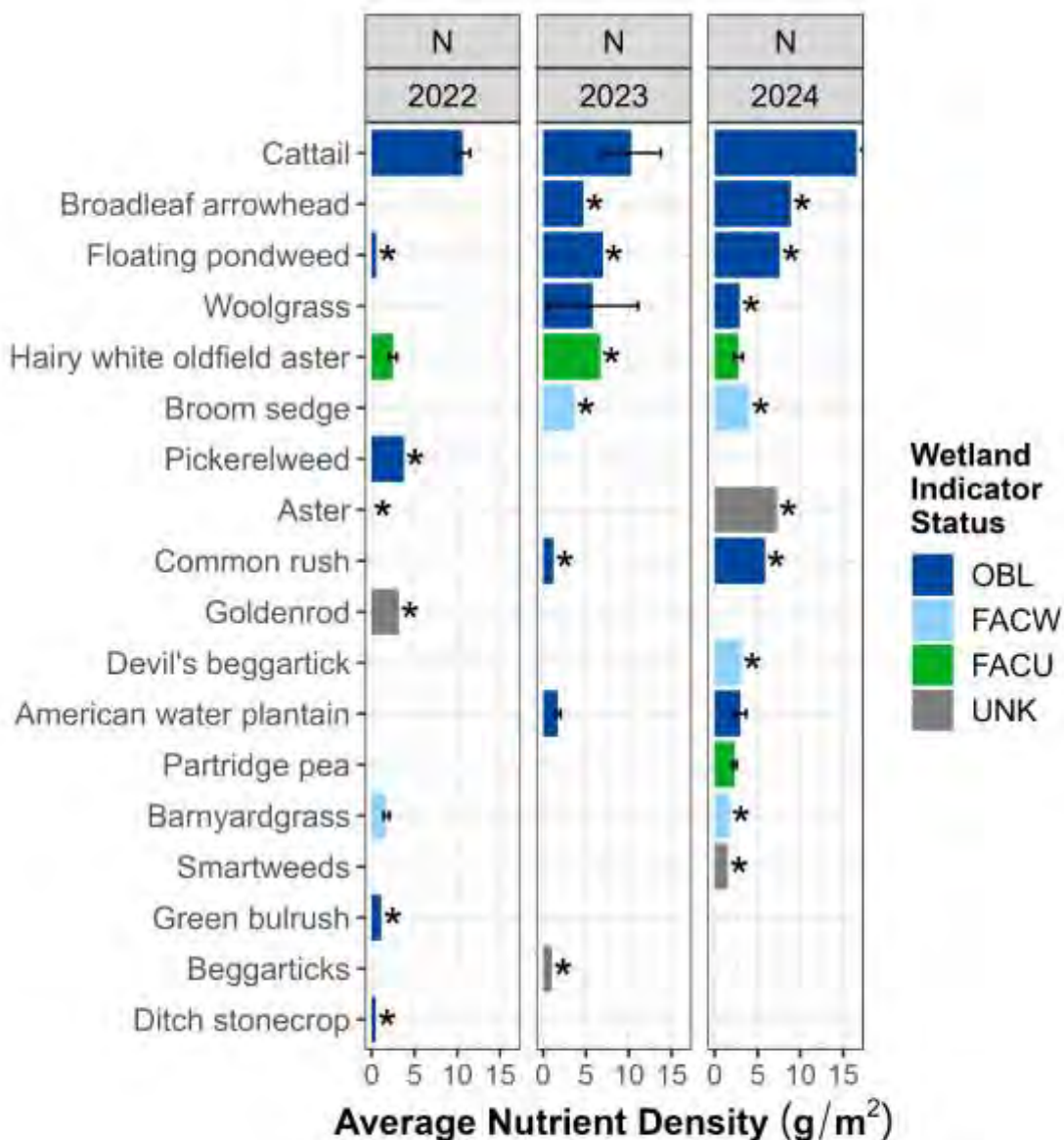


Figure 95. Average nutrient density of Phosphorus (P) in vegetation species at Oakwoods Nature Preserve Wetland Restoration West. The average mass of P stock in aboveground plant material per square meter for species sampled that covered more than 20% of sampling quadrat at Oakwoods West. Nutrient density is calculated by multiplying measured nutrient concentrations and aboveground dry biomass data, resulting in an estimate of the average aboveground nutrient mass observed in a species within a given area. Appendix II displays both common and scientific species names and Wetland Indicator Status (WIS) designations can be found in Appendix II.



* data from one sample; may be misleading when compared to average values calculated from multiple samples

Figure 96. Average nutrient density of Nitrogen (N) in vegetation species at Oakwoods Nature Preserve Wetland Restoration West. The average mass of N stock in aboveground plant material per square meter for species sampled that covered more than 20% of sampling quadrat at Oakwoods West. Nutrient density is calculated by multiplying measured nutrient concentrations and aboveground dry biomass data, resulting in an estimate of the average aboveground nutrient mass observed in a species within a given area. Appendix II displays both common and scientific species names and Wetland Indicator Status (WIS) designations can be found in Appendix II.

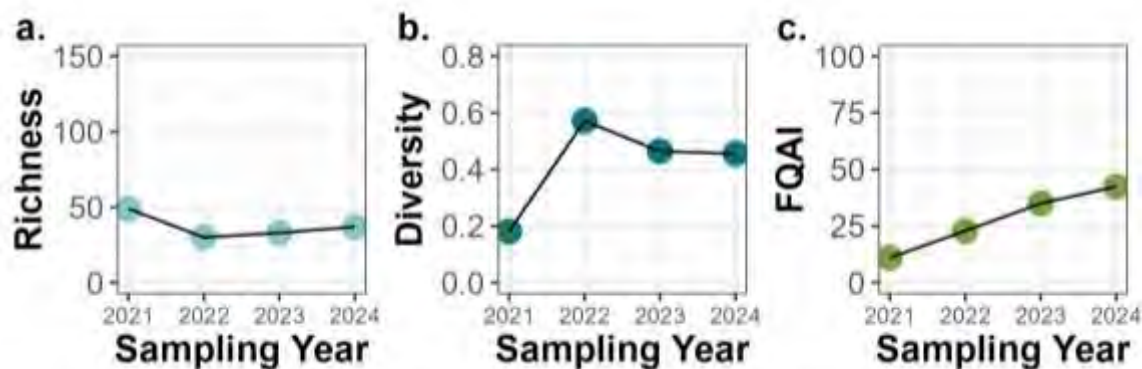


Figure 97. Species richness, diversity, & the Floristic Quality Assessment Index at Oakwoods Nature Preserve Wetland Restoration West. These graphs display (a) species richness, or a count of the total number of species, (b) species diversity calculated with Simpson's Diversity Index (See Appendix II), and (c) the floristic quality assessment index (FQAI), a measure of habitat quality based on vegetation present (See Appendix II), for Oakwoods West.

Next Steps to Strengthen Understanding

Eight new groundwater wells were drilled in 2024 for a total of nine wells at the Projects. Routine monitoring of the water level and water chemistry in these wells will broaden understanding of the Project and the possible connection to and movement of groundwater at this Project, which may play a part in nutrient transport. Because tile outlets are at the bottom of the tile-drain fed pools (Pools 1, 30, 31, 36, and 42), they are quickly submerged when water is flowing and filling the pools. This prevents direct measures of flow rates in the tile drains. Researchers plan to quantify flow into these pools using water level monitoring data and inferring flow rates from changes in pool volume over time. The installation and sampling from groundwater monitoring wells will aim to assess the role of subsurface water inputs to these seemingly isolated depressional wetlands pool.

Continuously logging water level sensors (Vegapuls, VEGA, Shiltach, Germany; Solinst, , Solinst Canada Ltd.) have been deployed in representative pools throughout Oakwoods East and West to fully capture seasonal and event-driven changes in hydrology and more accurately calculate water balances for the Project than can be generated by monthly water level measurements alone. Special attention will be given to observing differences between pools receiving tile drain inputs from those without tile drain inputs to assess the differential contributions of these two different pool types to overall nutrient load reduction. Pool 39 is noteworthy because it is located far from the northern pools; researchers plan to examine water levels in this location and others to compare rates of water level change in spring and determine whether the field tiles in the northern pools deliver water and to estimate the volume, if so.

To measure surface water nutrient concentrations during infrequent but important flooding events, an automated water sampler will be installed to collect water samples from Pool 1 during periods when water is exchanged with Aurand Run and when outflow from the

drainage tile is delivered. These concentrations and accompanying volume estimates will be critical to calculating a nutrient budget with finer resolution.

Starting in 2024, vegetation monitoring for the East and West sides of the Oakwoods Projects will alternate each year. In 2025, vegetation monitoring at Oakwoods East will take place. Cross-crew comparison of nutrient concentrations in vegetation, water, and soils should be coordinated to provide insight into the biogeochemical conditions which have resulted in different patterns of vegetation above- and belowground stocks of phosphorus and nitrogen, with the ultimate aim of understanding how biogeochemical conditions influence Project nutrient retention. Monitoring vegetation in locations of interest, where soil and water are sampled, will be prioritized in 2025 at Oakwoods East to better facilitate this goal. 3-D hydrodynamic model development and improvement will continue in Water Year 2025 as more data is collected at the Oakwoods Projects.

Redhorse Bend Preserve Wetland Restoration (REDB)

Project Description

Sandusky County | Sandusky River Watershed

Project size: 54 Acres

Partners: Black Swamp Conservancy, Sandusky County Parks, Biohabitats

The hydrology at this Project is passively managed. The Project has 54 acres restored wetland with two distinct features: a set of floodplain wetland pools that connect to each other in series but have limited connectivity to water inputs from the river itself; and a single pool meant to capture separate ditch water. A hydrologic event at this Project is operationally defined as a storm event in which the USGS gage (Sandusky River near Fremont OH - 04198000¹⁰) reaches 12,000 cfs, as this is when researchers estimate the river flows through the cut banks into the set of floodplain wetland pools. However, when the Sandusky River reaches a lower flow threshold of 3,200 cfs, water first enters a ditch and then the series of minor pools. At another location, a single pool intended to capture water from a separate drainage ditch, in fact, mostly receives inputs from rainwater and surface water runoff from an adjacent meadow.

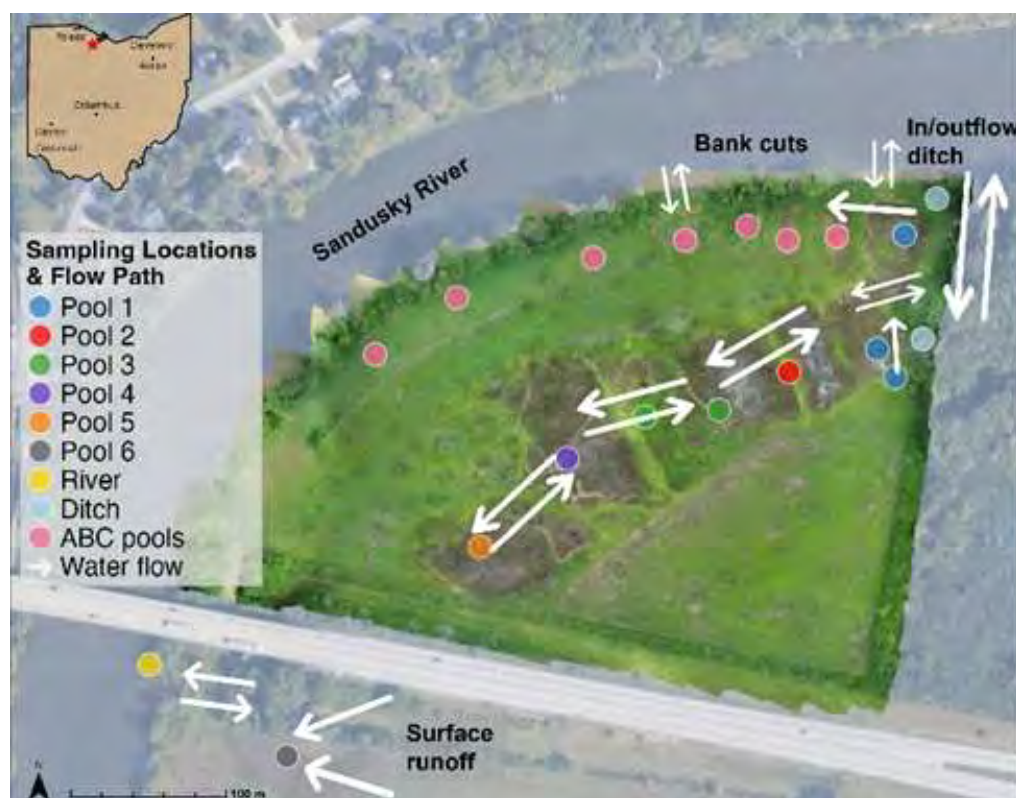


Figure 98. Aerial image showing surface water flow and sampling locations for the Redhorse Bend Preserve Wetland Restoration Project. Blue arrows indicate direction of surface water flow. Dots represent geographic base crew sampling locations, which are grouped by Project

¹⁰ "Sandusky River near Fremont OH - 04198000." [waterdata.usgs.gov](https://waterdata.usgs.gov/monitoring-location/04198000/). U.S. Department of Interior. <https://waterdata.usgs.gov/monitoring-location/04198000/>

features (fill color) where relevant. Text annotations provide additional context about the Project's watershed connection or other important features.

Management Considerations

Constrained Floodplain Connectivity Limits Wetland Nutrient Retention Potential

The capacity of the Redhorse Bend Preserve Wetland Restoration Project (hereafter Redhorse Bend) to receive water and filter nutrients as a floodplain wetland is limited by its current design. During extreme high flow events in which the river flow exceeds 12,000 cubic feet per second (cfs; last occurred April 2024), the Sandusky River floods its banks into wetland pools via cut banks, and floodwater is retained until the river water level begins to recede to base flow conditions. However, during typical high flow events at flow between 8,000 and 10,000 cfs, the Project's pools only flood through a northern ditch which connects the river to the main pools (Ditch 2 N). During these events, the main pools (Pools 1–5) are most inundated, while inundations at Pool 6 and many of the minor (ABC) pools vary (Figure 99). Increasing connectivity throughout the wetland would, in turn, allow more of the pools to be affected by floodwaters, resulting in improved nutrient load reductions.

In the southern portion of the Project on the opposite side of a major highway, Pool 6 was designed so that the Sandusky River would enter Pool 6 through a drainage ditch managed by a partnering agency (Ohio Department of Transportation) during high flow events (Figure 99). However, due to the elevation difference between the pool and the river, Pool 6 only receives water as direct input from rain events and runoff from the surrounding meadow, rather than the drainage ditch or river as the design originally intended. If the ditch berm were lowered and minor modifications made to Pool 6, there would be an increased chance for Pool 6 to capture runoff from the highway, potentially increasing nutrient filtration in Pool 6. The design of the southern portion also includes a depression to direct floodwater from the river to Pool 6. While floodwater has never reached the level where water enters Pool 6 through this connection, areas of the connection closer to the river get wet following precipitation events and from upland drainage. If connectivity between the partner-managed drainage ditch and Pool 6 cannot be improved, a location closer to the river might be an alternative to Pool 6 to capture more upland wet meadow drainage.

Much like the pools in Complex 2 at the Forder Bridge Floodplain Reconnection Project, the ABC pools at Redhorse Bend do not hold water and rarely receive any water from the river. This lack of retention is likely the result of the ABC pools being at a slightly higher elevation than the river and the main pools. Additionally, most events at Redhorse Bend rarely produced water depths in the ABC pools that were sufficient to sample (greater than 20 cm). These pools often dried before repeat monitoring events could be performed by base crews. These pools have dry, coarse soils that appear to drain water quicker than the other pools that hold water year-round. Making these pools deeper, with lower berms between them and the main pools, would increase the functionality of the Project by increasing overall Project hydrologic connectivity, increasing stormwater storage, and increasing nutrient storage capacity for flooding events rather than just precipitation events as they currently serve.

Nutrient Reduction Function Affected by Recent Climate Conditions

As was the case for much of Ohio, Redhorse Bend experienced drought conditions for the latter half of Water Year 2024, potentially contributing to lower-than-expected nutrient retention. The main pools (Pools 1–5) began drying in June and all pools were completely dry by September. Redhorse Bend did not receive the same number of storm and flooding events as in years past and researchers were able to sample less frequently as a result.



Figure 99. Aerial image of approximate locations of interest for water and soil sampling and discrete manual measurements of water depth and physicochemical parameters at Redhorse Bend Preserve Wetland Restoration Project during water year 2024 (Oct 1, 2023–Sep 30, 2024). The legend provides the name of each sampling point. Different shapes denote the types of wetland features represented by the locations of interest. If present, different colors represent locations of interest that belong to a group or complex of features (e.g., a treatment train).

Nutrient Budget Takeaways

Redhorse Bend received approximately 54,000 m³ of water in Water Year (WY) 2024. Monitoring results from the Project in WY 2024 indicate that the Project filtered 6.6 lbs. of total phosphorus, 1.6 lbs. of dissolved reactive phosphorus, 98 lbs. of total nitrogen, and 35 lbs. of nitrite+nitrate. The Project released 1.3 lbs. of total ammonium nitrogen in WY 2024. Conversion from agricultural land to wetland prevents 35 ± 24 lbs. of phosphorus runoff annually. Soils throughout the Project have moderate to high capacity to sorb phosphate, indicating that during storm events, when higher levels of dissolved reactive phosphorus (DRP) are typically present in river water samples, the soils inundated with flood waters have

the potential to help absorb and filter phosphate in the Project area (Figure 100). During baseflow conditions the ratio of DRP/TP is typically lower, indicating that the soils and plants within the Project are absorbing DRP that entered the Project during storm events (Figure 101). Since drought conditions persisted during much of WY 2024, the amount of both TP and DRP filtration in the Project area was reduced compared to previous years.

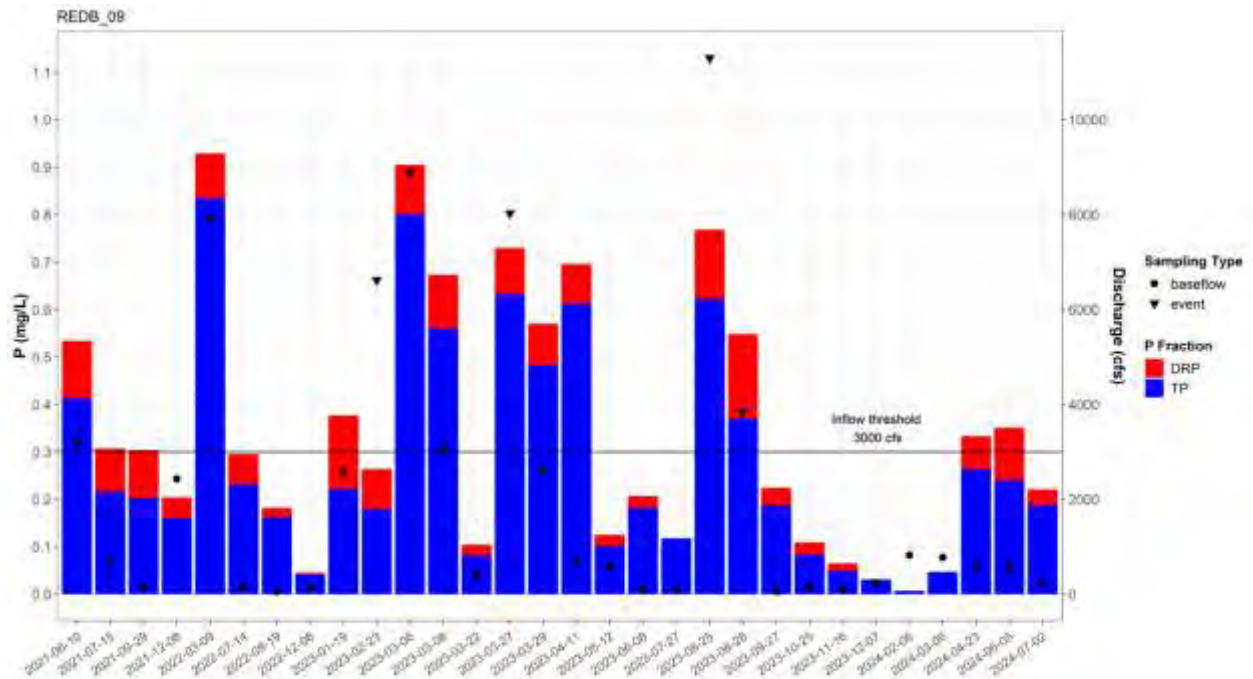


Figure 100. Sandusky River dissolved reactive phosphorus (DRP)/ total phosphorus (TP) Ratio (mg P/L) over time with the Sandusky River discharge in cubic feet per second (cfs) shown to indicate baseflow vs. event conditions. Triangles indicate event conditions and represent Sandusky River discharge greater than 3000 cfs. Baseflow conditions are indicated with a circle and represents conditions in which Sandusky River water is not entering the Redhorse Bend Preserve Wetland Restoration Project. Note that small storm events on the Sandusky River (cfs < 3000) will not enter the Project but may still indicate increased DRP levels in samples collected from the Sandusky River. Also, since this Project is just downstream of the City of Fremont Water Reclamation Center increased DRP values can still occur during baseflow conditions, especially in late Spring through Fall.

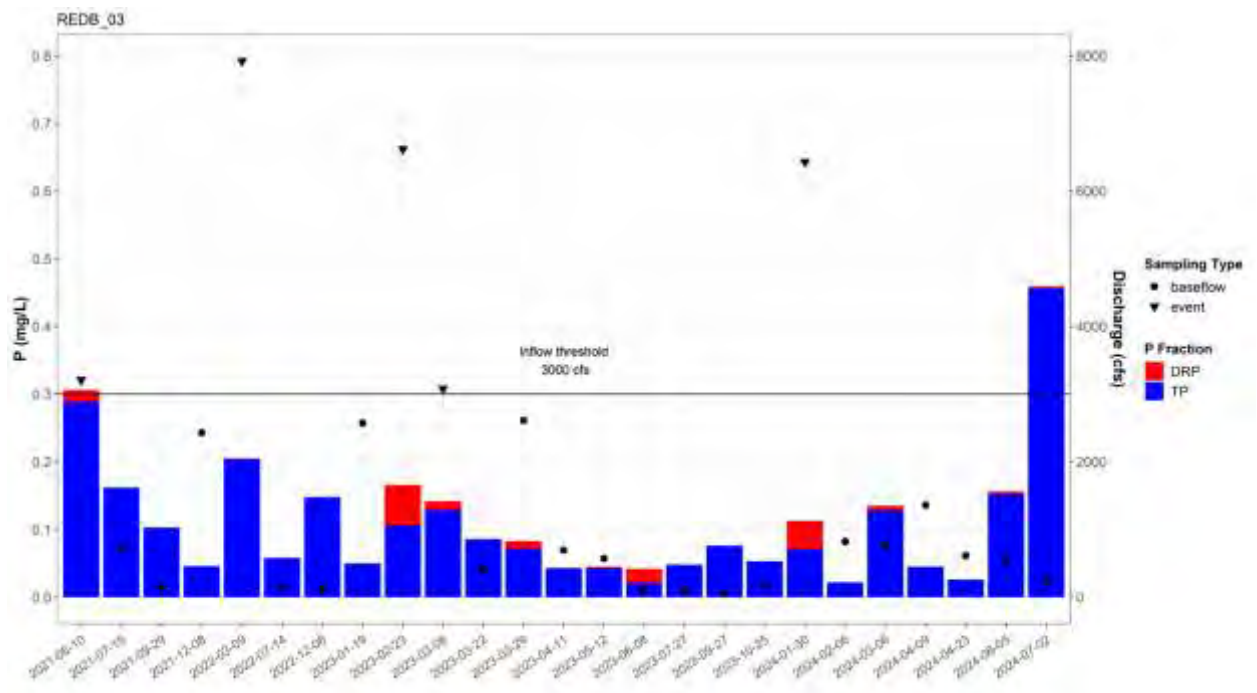


Figure 101. Pool 2 dissolved reactive phosphorus (DRP)/ total phosphorus (TP) Ratio (mg P/L) over time with the Sandusky River discharge in cubic feet per second (cfs) shown to indicate baseflow vs. event conditions. Triangles indicate event conditions and represent Sandusky River discharge greater than 3000 cfs. Baseflow conditions are indicated with a circle and represents conditions in which Sandusky River water is not entering the Redhorse Bend Preserve Wetland Restoration Project. Note that DRP levels are typically higher when sampled during events, and the majority of P in baseflow samples is represented by TP, not DRP.

Surface Water Hydrology and Nutrients

Redhorse Bend Wetland is a restored agricultural field within a river floodplain designed with several bank cuts to allow floodwaters to enter the wetland pools. Due to the elevation of those bank cuts in relation to the floodplain elevation, only storm events producing river flow in excess of 12,000 cubic feet per second (cfs, last occurred April 2024) will cause the Sandusky River to breach its banks at those cuts. During most flood events, floodwater enters the north Ditch 2 (Ditch 2 N), flowing to the southern portion of the ditch (Ditch 2 S) before flowing into Pool 1 and flooding in the direction of Pool 5 (Figure 98). During the falling limb of the flood, water leaves the Project from Pool 5 back in the direction of Pool 1 before draining into Ditch 2 and then flowing back into the Sandusky River.

Due to the design of the Project, pool inundation extent depends on the flood intensity.. For example, a flood event in which the Sandusky River flow exceeded 12,000–15,000 cfs, such as the event captured in April 2024, will result in complete pool connectivity across the northern portion of the Project (e.g., Pools 1–5, Pools A–D). Alternatively, during a flood event with river flows of 8,000–10,000 cfs, floodwaters might only result in Redhorse Bend inundation to Pool 3 and may leave the ABC pools (Pools A–D) relatively untouched by flood water. Pools 4 and 5 also sit more further from the Sandusky River than the ABC pools,

but due to a combination of their elevation and pool depth, the ABC pools are often dry. In Water Year (WY) 2024, four of 17 total H2Ohio Wetland Monitoring Program sampling events were classified as storm sampling events, and there was one sampling visit during which all pools were dry and were not sampled due to drought. Only the storm events in January and April produced flooding significant enough to cause pool connectivity. The April storm caused wetland areas that are typically dry to have 20–30 cm of water (Pools 1–5, Figure 102).

During most of the Water Year 2024, the main pools (Pools 1–5) held water, with the exception of drought conditions that impacted all the pools in the latter half of the year. In, Pools 1–5 had an average manual water depth ranged from 14 cm (Pools 4 and 5) to 35 cm (Pool 3), and all of these main Pools filtered water until September 2024 (Figure 102, Supplemental Information). The ABC pools did not hold water for nearly the same length of time that Pools 1–5 did and were not sampled after January 2024. Typically, Pools A, B and C will hold water following flood events, resulting in complete connectivity between all pools. Researchers observed the ABC pools hold approximately 20 cm of water at varying timespans following precipitation events (Figure 102).

Monitoring results suggest Pools 1–3 are the most responsive to changes in river physiochemistry and nutrient concentration. In WY 2024 there were two notable flooding events in January and April that caused elevated ($> 25 \mu\text{g/L}$) dissolved reactive phosphorus (DRP) values in the Sandusky River, Pools 1–3, and Pool 5 (Figure 104). Of Pools 1–5, Pool 5 had the highest average DRP concentration of 0.019 mg/L for WY 2024, followed by Pool 3 with an average concentration of 0.014 mg/L (Supplemental Information). These January and April storm events also generally led to elevated total phosphorus, total nitrogen (TN), nitrate-nitrite, pH, and turbidity, in Pool 1–5 (Figure 103, Figure 105, Figure 106). TN increases were also observed in June across the Project (Figure 105). Pool 4 had the greatest TN peak at nearly 10 mg/L (Figure 105). The increase in TN concentrations coincides with decreasing water levels due to drought conditions (Figure 102), which could explain the elevated TN values by concentrating the same amount (mass) of TN in a smaller volume of water within the pools.

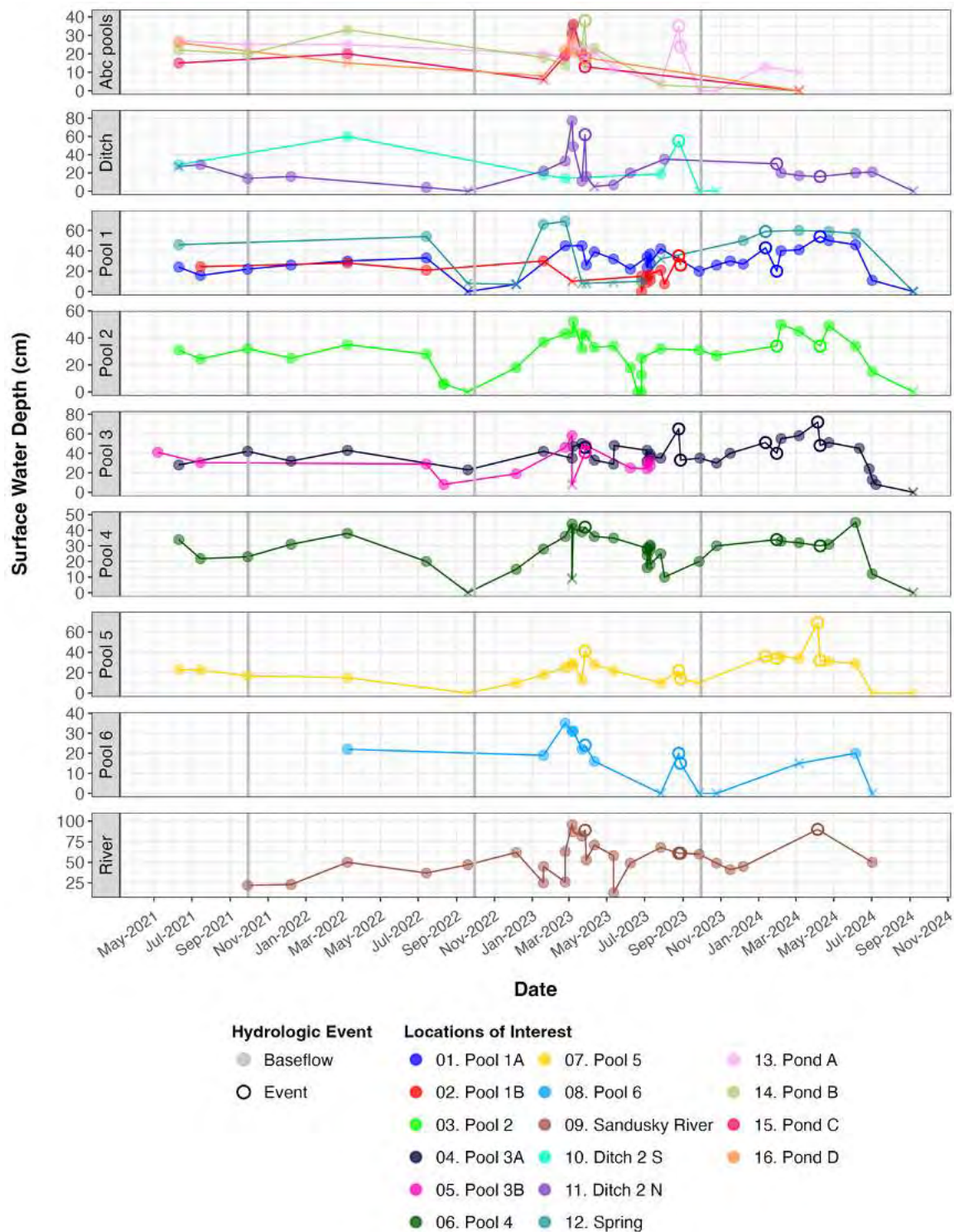


Figure 102. Time series of discrete, manually measured surface water depth at the Redhorse Bend Preserve Wetland Restoration Project. Depths were measured approximately monthly. Each point represents one measurement and colors denote the locations of interest, as indicated in the legend. Open symbols indicate samples that were collected during a hydrologic event (e.g., storm event) and filled symbols denote samples collected during baseflow. Crosses (×) represent instances when no surface water was detected during the visit. If present, different shapes denote the types of wetland features represented by the locations of interest. Gray vertical lines indicate the start of a water year (Oct 1–Sep 30).

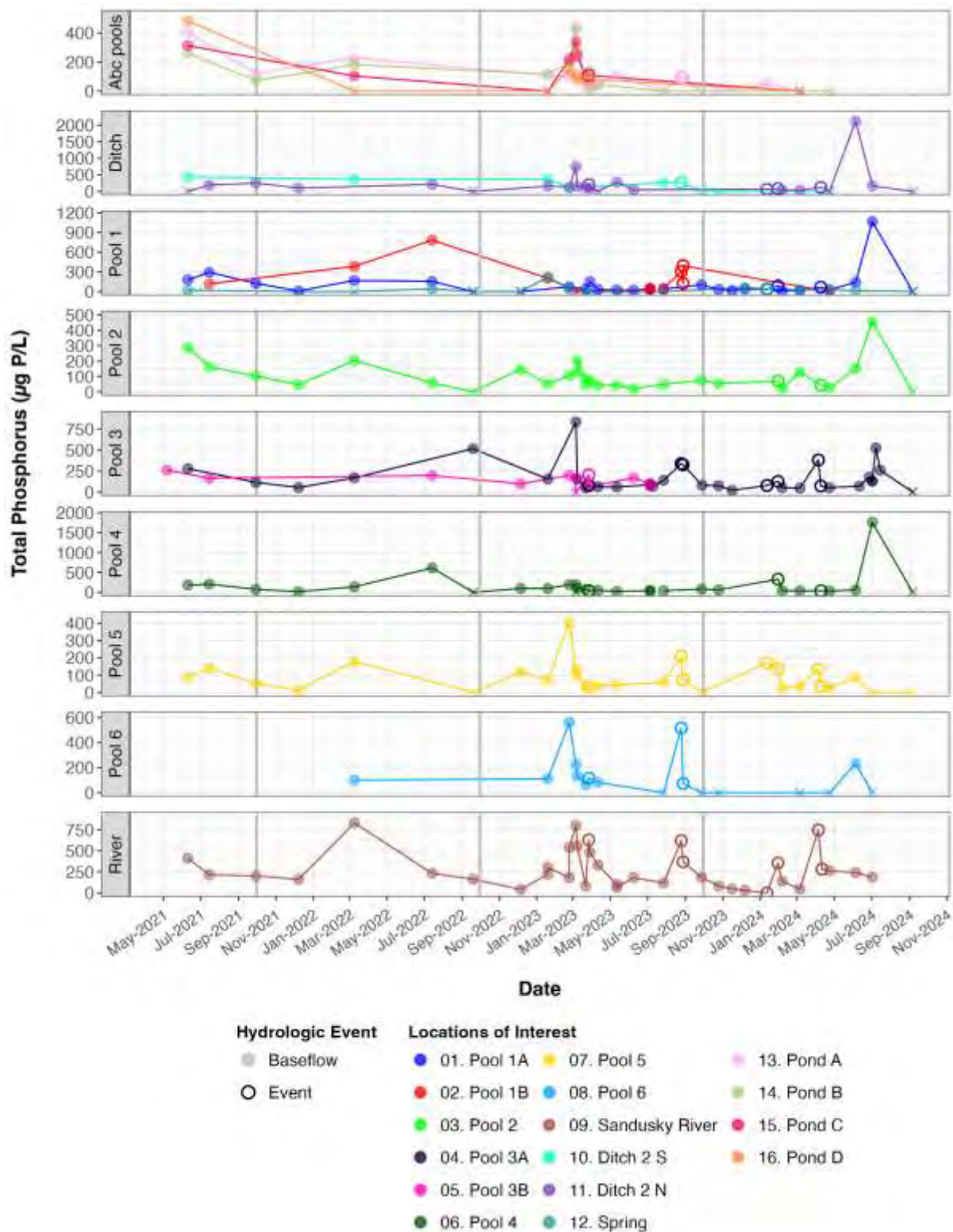


Figure 103. Time series of total phosphorus (TP) concentrations in surface water samples collected at the Redhorse Bend Preserve Wetland Restoration Project. Values below the detection limit of the analytical equipment were replaced with half the value of the detection limit. Each point represents one measurement and colors denote the locations of interest, as

indicated in the legend. Open symbols indicate that measurements were collected during a hydrologic event (e.g., storm event) and filled symbols denote measurements collected during baseflow. Crosses (×) represent instances when no surface water was detected during the visit. If present, different shapes denote the types of wetland features represented by the locations of interest. Gray vertical lines indicate the start of a water year (Oct 1–Sep 30).

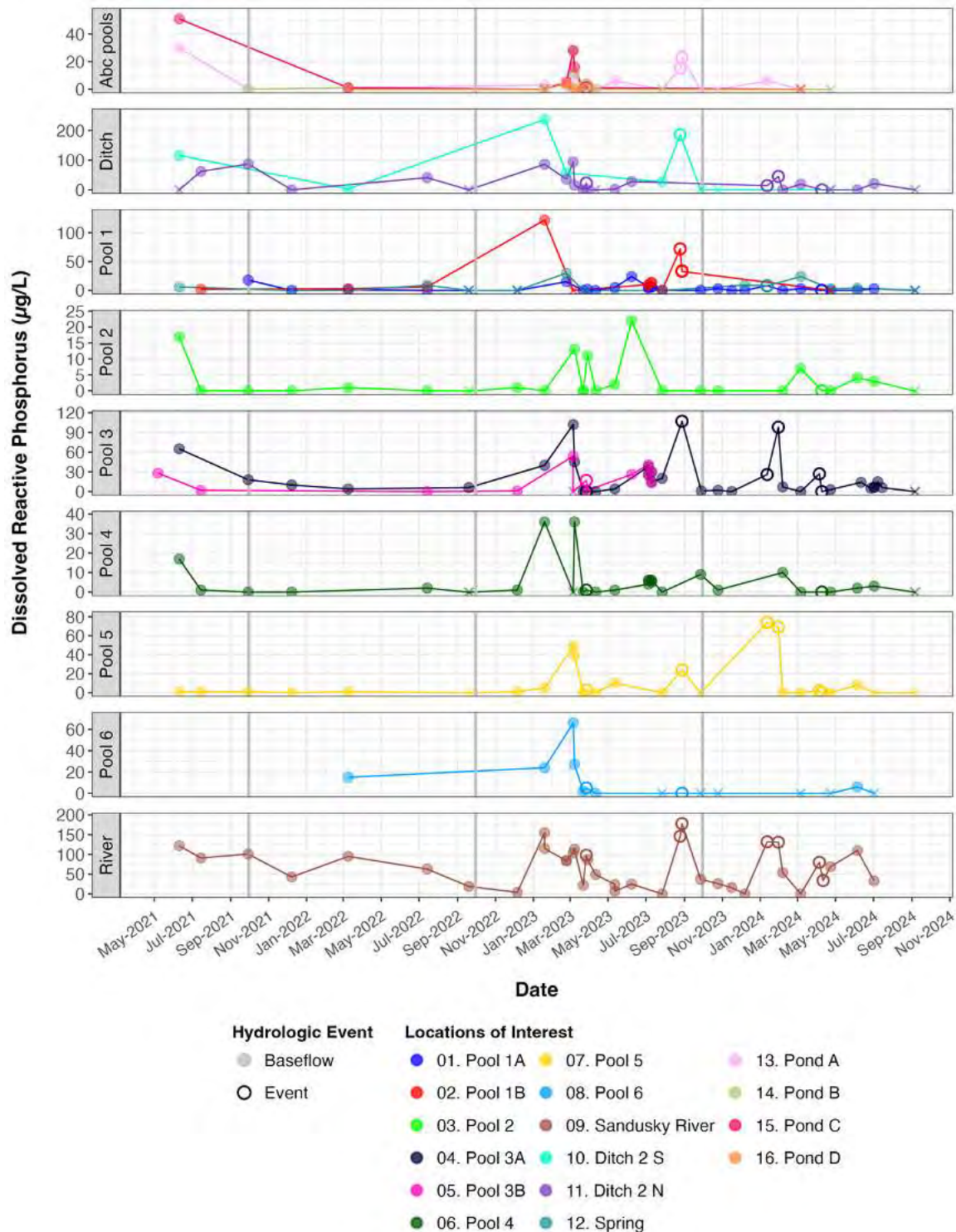


Figure 104. Time series of dissolved reactive phosphorus (DRP) concentrations in surface water samples collected at the Redhorse Bend Preserve Wetland Restoration Project. Values below the detection limit of the analytical equipment were replaced with half the value of the detection limit. Each point represents one measurement and colors denote the locations of interest, as indicated in the legend. Open symbols indicate that measurements were collected during a hydrologic event (e.g., storm event) and filled symbols denote measurements collected during baseflow. Crosses (×) represent instances when no surface water was detected during the visit. If present, different shapes denote the types of wetland features represented by the locations of interest. Gray vertical lines indicate the start of a water year (Oct 1–Sep 30)

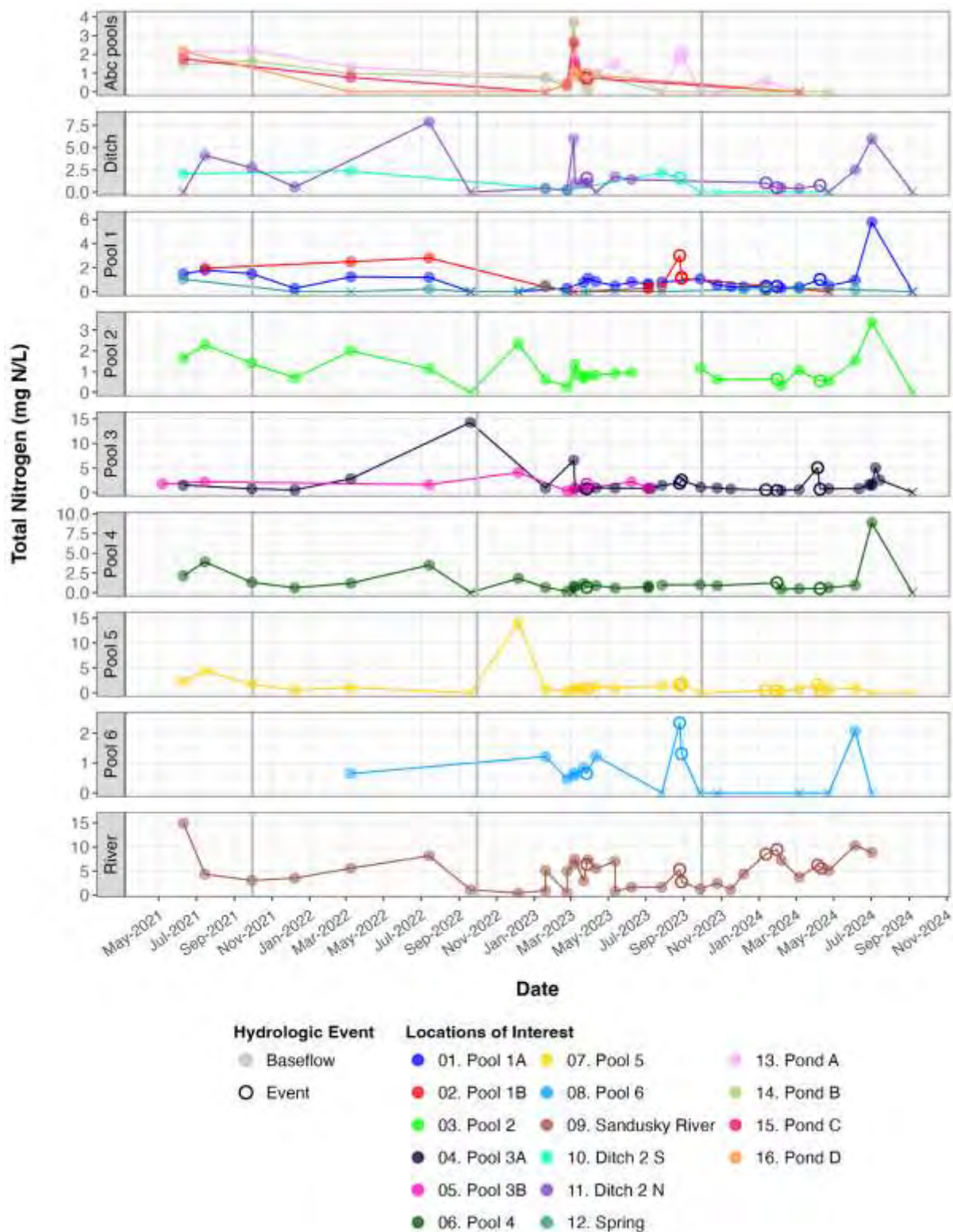


Figure 105. Time series of total nitrogen (TN) concentrations in surface water samples collected at the Redhorse Bend Preserve Wetland Restoration Project. Values below the detection limit of the analytical equipment were replaced with half the value of the detection limit. Each point represents one measurement and colors denote the locations of interest, as indicated in the legend. Open symbols indicate that measurements were collected during a

hydrologic event (e.g., storm event) and filled symbols denote measurements collected during baseflow. Crosses (×) represent instances when no surface water was detected during the visit. If present, different shapes denote the types of wetland features represented by the locations of interest. Gray vertical lines indicate the start of a water year (Oct 1–Sep 30).

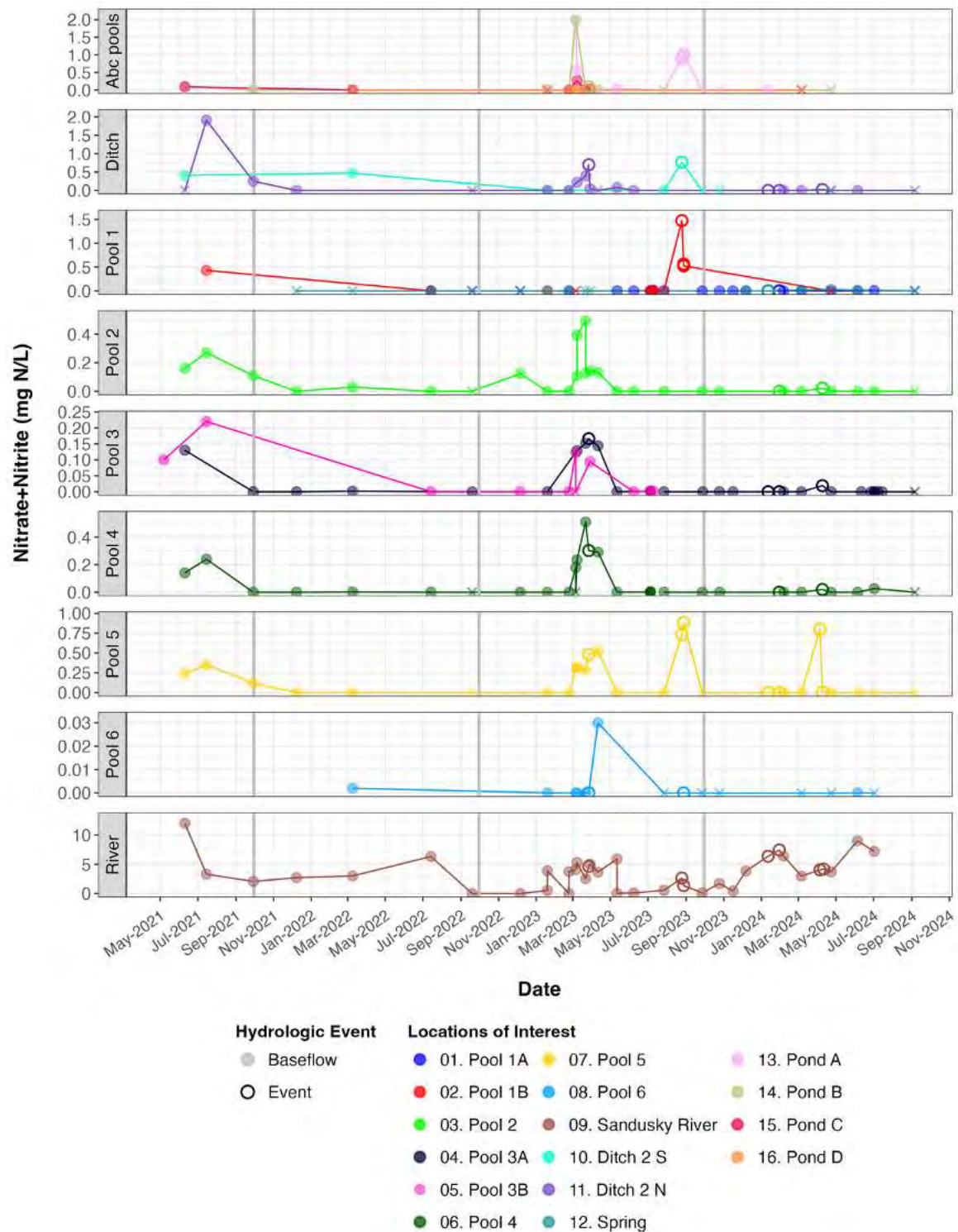


Figure 106. Time series of Nitrite+nitrate (NO_x) concentrations in surface water samples collected at the Redhorse Bend Preserve Wetland Restoration Project. Values below the detection limit of the analytical equipment were replaced with half the value of the detection limit. Each point represents one measurement and colors denote the locations of interest, as indicated in the legend. Open symbols indicate that measurements were collected during a hydrologic event (e.g., storm event) and filled symbols denote measurements collected during baseflow. Crosses (×) represent instances when no surface water was detected during the visit. If present, different shapes denote the types of wetland features represented by the locations of interest. Gray vertical lines indicate the start of a water year (Oct 1–Sep 30).

Soil Nutrient Status and Processes

Soil phosphate sorption capacity (SPSC) values in Water Year (WY) 2024 at Redhorse Bend were moderately high; the average value across the Project was 87 mg phosphorus/kg, indicating a capacity to sorb phosphate. Pool 2 had the highest SPSC value (230 mg/kg), and the floodplain transect north of Pool 5 and west of Pool 6 had the lowest value (31 mg/kg, Figure 107). Areas that typically retain water year-round, such as Ditch 2 or the deepest location within a pool, have higher SPSC values than areas without water. A comparison of Redhorse Bend's SPSC values from WY 2022 to WY 2024 illustrates a shift from some negative values to all positive values, suggesting the Project's increased capacity to sorb phosphate. In a wetland with established vegetation, this could be indicative of a release (i.e., decreased SPSC due to freeing up of soil binding sites due to release of phosphate from soil over time), however in the case of Redhorse Bend it is more likely that the lower SPSC values found in the WY 2022 data were the result of underdeveloped vegetation and underperforming soils. Thus, pool sedimentation and vegetation uptake (i.e., releasing phosphate from binding sites and decreasing SPSC from WY 2022 to WY 2024) are likely explanations for the shift in soil capacity, based on the age and design of the Project.



Figure 107. Soil Phosphate Sorption Capacity (SPSC) throughout the Redhorse Bend Preserve Wetland Restoration Project. Each point denotes a soil sample (0–5 cm) and different shapes indicate the wetland feature type, as shown in the legend. Colors indicate the SPSC value of each sample relative to the overall range of values observed at the wetland project, as shown in the color bar. Each panel shows the soil samples collected during a

respective water year (Oct 1–Sep 30), along with the minimum and maximum SPSC values observed during a given water year. Negative SPSC values indicate the potential for soils to release phosphate, while positive values indicate soils have capacity to sorb phosphate, based on Mehlich-3 extractions of phosphate, iron, and aluminum.

Next Steps to Strengthen Understanding

Determining the volume of water entering or exiting Redhorse Bend at any given moment is difficult, because the majority of water that enters the Project does so through Ditch 2. Improving measurements of input volumes to Redhorse Bend during storm-driven flooding events will improve the accuracy of nutrient budget estimates. In addition, characterizing the role of groundwater flow and subsurface-surface water exchange in nutrient processing may be of particular importance at this site, given observational evidence of groundwater seepage.

To address this knowledge gap, a trail camera was installed in 2025 and directed at the inflow/outflow of Ditch 2, which holds a staff gage designed to help researchers better understand flow conditions. Trail camera time stamps matched with USGS river flow data and sensor network pool levels will improve flow and nutrient load calculations by pinpointing when water enters and exits the wetland pools. Additional soil samples, collected throughout the year, will give researchers more insight into seasonal variability of plant nutrient uptake during the spring and release during the fall and winter months. Soil samples will continue to be taken from established locations of interest to facilitate long-term analyses. The data from these samples is crucial to better understanding Redhorse Bend's nutrient reduction capacity. Researchers plan to determine the role the ABC pools play in nutrient reduction by identifying which conditions cause the pools to fill with water and for how long the water is held.

Starting in 2024, vegetation monitoring at Redhorse Bend will occur every other year. In 2025, monitoring of vegetation in locations of interest will be prioritized at the Project to better facilitate comparison of nutrient levels in vegetation, water, and soil, with the aim of understanding how movement of nutrients within the wetland impact the annual Project nutrient retention outcomes.

St. Joseph River Restoration (SJRE)

Project Description

Williams County | St. Joseph Watershed

Project size: 94 Acres

Partners: Black Swamp Conservancy

The hydrology at this Project is passively managed. The Project has 33 acres of restored wetland, including multiple features: four tile-fed flowthrough pools (A, B, C, G), two of which also occasionally flood from an adjacent ditch (B, G); three depressional pools that function periodically as floodplains depending on water levels in the adjacent ditch or river (D, E, F); and the St. Joseph River. Water enters the Project via three drainage tiles discharging from upstream agricultural lands draining approximately 75 acres adjacent to the north and east of the Project. Water flows through the wetland features and exits into a ditch to the east. The ditch connects to the St. Joseph River, which flows west parallel to the south edge of the Project. A hydrologic event at this Project is operationally defined as a storm in which flow is expected from the three input tiles (North, Northeast, Northwest). Floodplain events are defined as periods when water level in the East Ditch or the St. Joseph River exceed their banks and flow into the Project.

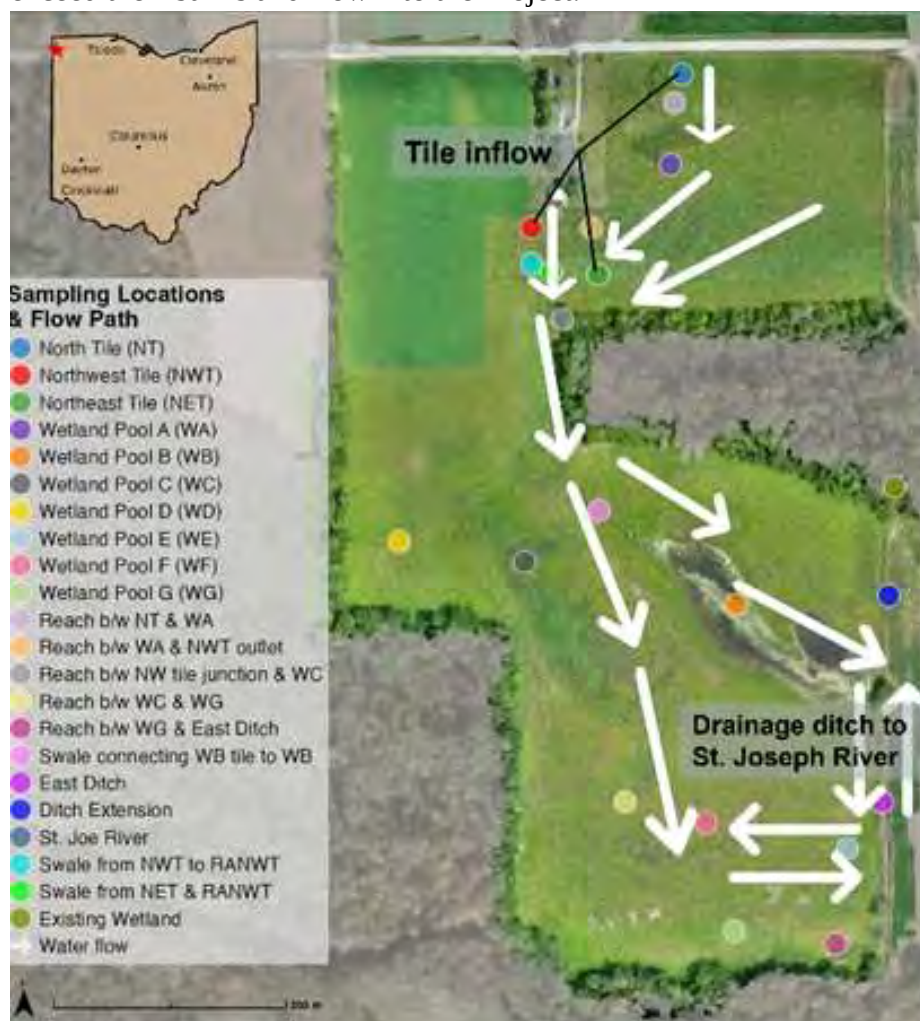


Figure 108. Aerial image showing surface water flow and sampling locations for the St. Joseph's River Restoration Project. Blue arrows indicate direction of surface water flow. Dots

represent geographic base crew sampling locations, which are grouped by Project features (fill color) where relevant. Text annotations provide additional context about the Project's watershed connection or other important features.

Management Considerations

Connectivity to Agricultural Drainage Drives Nutrient Reduction Potential, but Drought Conditions Dampen Actual Nutrient Reduction

St. Joseph's River Restoration Project (hereafter the St. Joseph's Restoration Project or St. Joseph's River Restoration) highlights the potential for wetland nutrient retention when connected to high concentration sources. Nutrient loading can be increased in two main ways: higher nutrient concentrations or more water. Water flows to the Project parcel directly from three agricultural tile drains with total nitrogen concentrations as high as 17 mg N/L, and total phosphorus concentrations as high as 1.1 mg P/L. The St. Joseph Restoration Project has the potential to mitigate substantial nutrient loads because of its connectivity to agricultural drainage. There is no active water level management at this Project, so water and nutrient delivery is entirely reliant on agricultural drainage and flood events, and dry years have a large effect on nutrient delivery to the Project. Water Year (WY) 2024 was another relatively dry year with especially dry conditions in the fall, so overall wetland function was likely sub-optimal. Floodplain hydrologic events influence much of the southern portion of the Project (Pools E, F, G) and Pool B via the East Ditch, all of which fill with water from the St. Joseph River during periods of high water level, often in late winter or early spring. In WY 2024, Pools E and F filled only once during a major flood event in February and did not receive floodwater again for the rest of the year.

Floodplain Connectivity Refreshes Phosphorus Sorption Capacity of Soils, Perhaps Due to Sediment Accumulation

One of the pools connected to the ditch (Pool B) had the highest capacity to sorb phosphate of all the features within St. Joseph Restoration and aligned with the high concentrations of phosphorus in the water column during the summer. In particular, the soil at the outlet of Pool B had the highest soil phosphate sorption capacity across multiple years of monitoring. Researchers also observed that Pool B accretes sediment at a far higher rate than any of the other pools in the Project, but sediment markers were also washed away at the outlet of Pool B. This suggests that the connection of Pool B to the floodplain is refreshing the capacity to store phosphorus of soil in the pool. However, further study is needed to confirm that the increase in SPSC is related to sediment accretion and not caused by anoxic conditions at the outlet of pool B leading to the release and subsequent export of phosphorus (P) from Pool B sediments.

P Concentrations Increase Under Specific Conditions, but Ultimate Cause and Effect Not Certain

At the largest pool (Pool B), researchers have observed higher P concentrations at the outlet compared to the inlet during conditions of high temperatures, low dissolved oxygen (DO), and high pH. Researchers suggest that the potential internal sediment P release to Pool B surface waters could be due to transient low-oxygen conditions, causing a release of iron- and manganese-bound sedimentary P. These low DO conditions are possibly caused by the decomposition of plant material that accumulates near the outlet of Pool B because of the

steep elevation increase from the bottom of the pool to the outlet. The increased P at the outlet compared to the inlet may not indicate that the Pool B Outlet is consistently releasing nutrients, though, because this trend is most often observed when water is not flowing out. Additional assessment is needed to determine whether transiently high P concentrations in this wetland pool contribute to net P export from the system and if so, whether that is due to accumulation of decomposing plant matter or not. If the cause of the high P, and subsequent P release is determined to be the accumulation of decomposing plant matter, it suggests that the performance of this pool could be substantively improved by periodic dredging of the accumulated plant detritus.

High Nutrient Retention and High Biodiversity

Vegetation at St. Joseph's River Restoration suggests that it is possible to have both high nutrient retention and high biodiversity. The Project is unique in its relatively low cover of Cattails (*Typha spp.*) compared to all other H2Ohio Focal Projects. Thus, managers may consider taking actions to preserve or promote biodiversity, such as controlling Cattail or other invasive species. Future H2Ohio restorations may use this Project as an example for maximizing both nutrient retention and vegetation habitat quality.



Figure 109. Aerial image of approximate locations of interest for water and soil sampling and discrete manual measurements of water depth and physicochemical parameters at St. Joseph's River Restoration Project during water year 2024 (Oct 1, 2023–Sep 30, 2024). The legend provides the name of each sampling point. Different shapes denote the types of wetland features represented by the locations of interest. If present, different colors represent locations of interest that belong to a group or complex of features (e.g., a treatment train).

Nutrient Budget Takeaways

In Water Year (WY) 2024, the St. Joe Restoration Project received approximately 31,000 m³ of water. The predominant flow path of the Project filtered 5 lbs. of dissolved reactive phosphorus, 410 lbs. of total nitrogen, 88 lbs. of nitrite+nitrate, and 18 lbs. of total ammonium nitrogen. The Project released 3 lbs. of total phosphorus in WY 2024. The conversion from agricultural land to wetland prevents 52 ± 24 lbs. phosphorus runoff annually. Soils throughout the Project have moderate capacity to sorb phosphate, as suggested by soil phosphate sorption capacity values.

Surface Water Hydrology and Nutrients

Pool B functions both as a flow-through system and as a floodplain wetland. Researchers observed Pool B held water from January through September and is the only pool at St. Joseph River Restoration to do so (Figure 110). High resolution water level data from Vegapuls (VEGA, Shiltach, Germany) sensors show two large spikes that indicate times when the St. Joseph River and the East Ditch flooded Pool B and substantively increased water level for short periods of time in late winter and early spring (Figure 111), during which the water height reached approximately 1.5-m. Considering that Pool B remained inundated all year after the initial flooding, despite relatively dry conditions in 2024, it is likely that this pool would exhibit a near-permanent inundation regime under non-drought conditions.

Other pools at this Project vary in degree of inundation. Pools D, E, G, and F receive water annually during late winter and early spring floodplain events but become dry shortly after; these pools are shallower and receive less water than Pool B, which may account for the difference in water retention. Pools A and C are intermediate by comparison (Figure 111). Under non-drought conditions researchers infer these two pools (A, C) would exhibit a seasonal regime with water levels persisting for several months of the year.

Researchers observed similar patterns of water levels and nutrient concentration at St. Joseph Restoration in Water Year 2024 as in previous years. Across sampling locations, average total phosphorus (TP) concentrations ranged from 0.027 to 0.372 mg P/L while average total nitrogen (TN) concentrations ranged from 0.595 to 11.065 mg N/L (Figure 112, Figure 114, Supplemental Information). Of all the sampling locations, the inputs (North Tile, Northeast Tile, Northwest Tile) to this wetland Project had some of the highest average TN concentrations (9.12–14.21 mg N/L, Supplemental Information). Pools and Reaches connected to these tile-fed flow paths were also found to have high average TN concentrations (Pool A, 12.19 mg N/L; Pool C, 9.81 mg N/L; and the Reach between the NW Tile Junction and Pool C, 8.62 mg N/L, Supplemental Information) compared to other wetland features. The TN concentrations found in pools disconnected from the tile-fed flow paths were lower, such as Pool E (0.59 mg N/L) and Pool D (0.62 mg N/L, Supplemental Information). The elevated TN concentrations are often associated with storm events. Event samples taken in January and July of 2024 showed a spike in TN delivery via the three tiles, and this TN spike in July was also reflected in TN concentrations in Pool A (Figure 114).

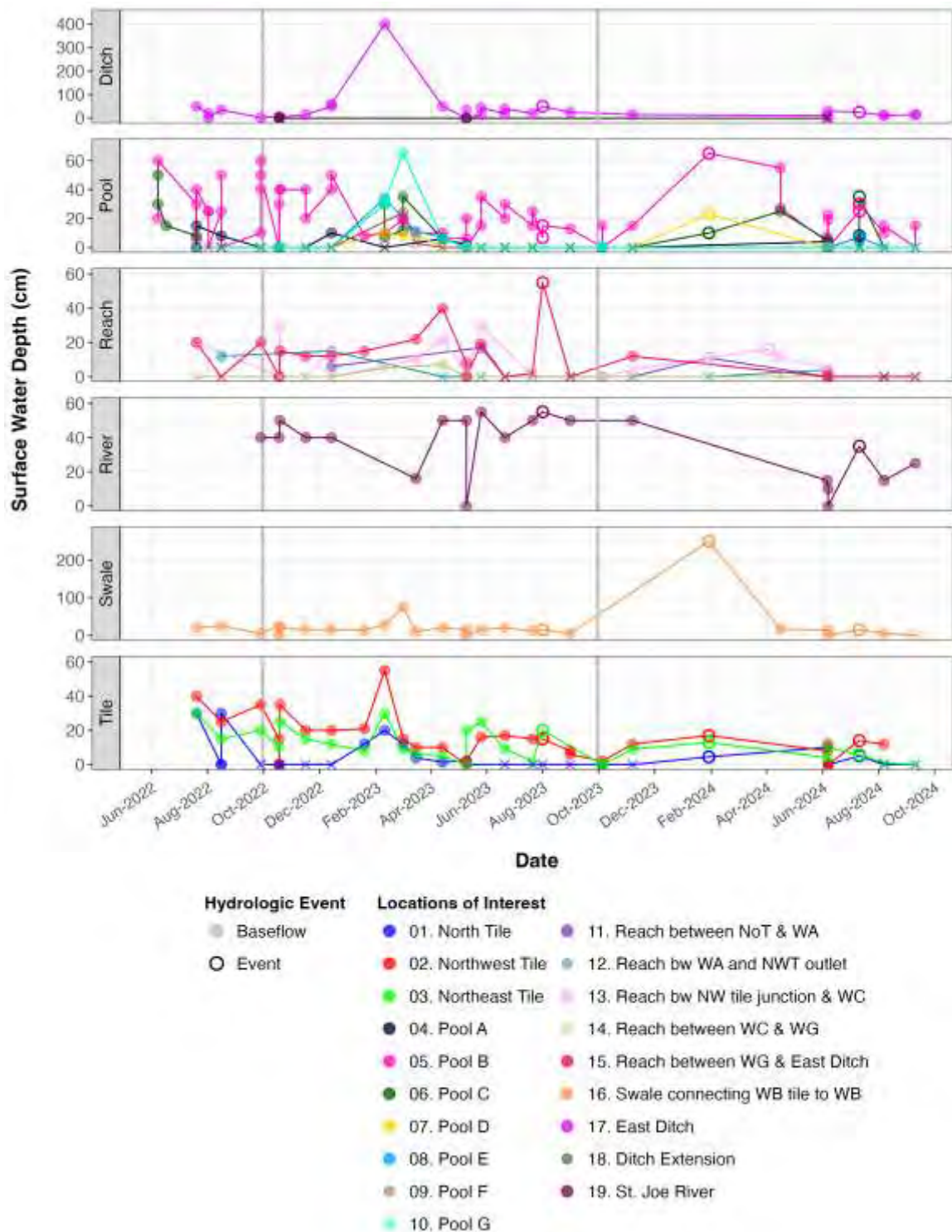


Figure 110. Time series of discrete, manually measured surface water depth at the St. Joseph's River Restoration Project. Depths were measured approximately monthly. Each point represents one measurement and colors denote the locations of interest, as indicated in the legend. Open symbols indicate samples that were collected during a hydrologic event (e.g., storm event) and filled symbols denote samples collected during baseflow. Crosses (x) represent instances when no surface water was detected during the visit. If present, different shapes denote the types of wetland features represented by the locations of interest. Gray

vertical lines indicate the start of a water year (Oct 1–Sep 30). **Note:** The Location of Interest Pool B is a large pool, and at times sampled at multiple locations within the pool.

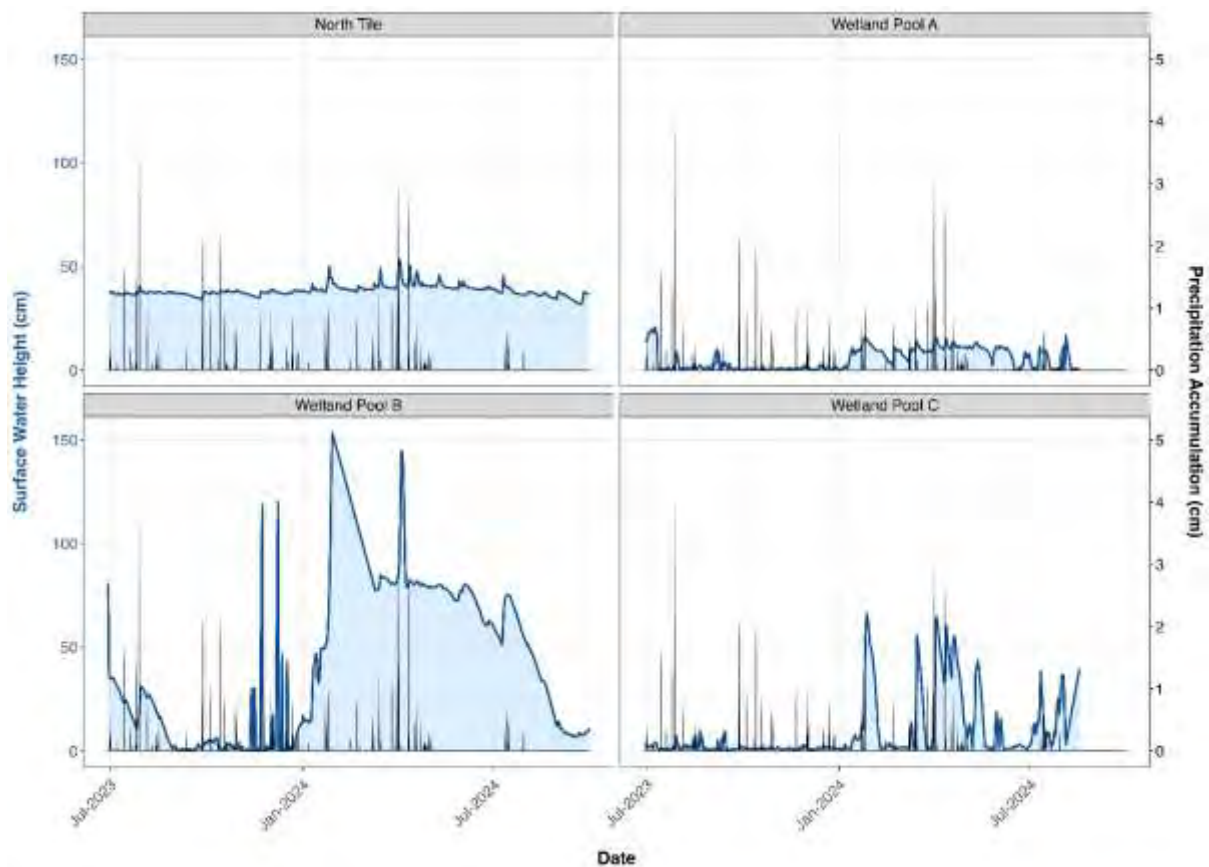


Figure 111. Time series of continuously measured surface water depth for the St. Joseph's River Restoration Project. Depths were measured by sensors deployed at select locations of interest that report live observations. Values are reported as daily averages. Where available, daily precipitation accumulation is reported on the secondary y-axis. For information on the locations of interest, please refer to the aerial map above. Note that measurements in some locations are missing or were interrupted due to sensor malfunction.

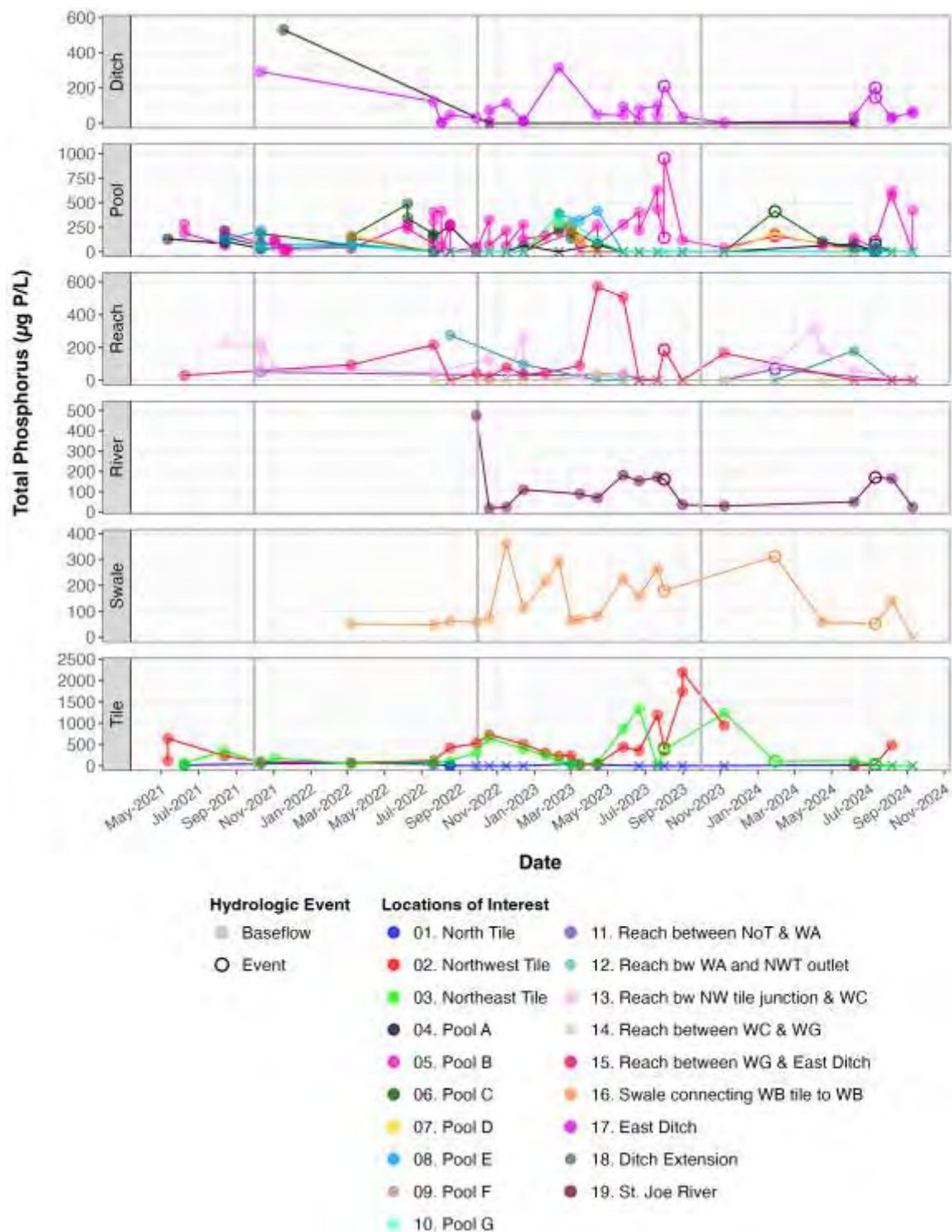


Figure 112. Time series of total phosphorus (TP) concentrations in surface water samples collected at the St. Joseph's River Restoration Project. Values below the detection limit of the analytical equipment were replaced with half the value of the detection limit. Each point represents one measurement and colors denote the locations of interest, as indicated in the legend. Open symbols indicate that measurements were collected during a hydrologic event (e.g., storm event) and filled symbols denote measurements collected during baseflow. Crosses (x) represent instances when no surface water was detected during the visit. If

present, different shapes denote the types of wetland features represented by the locations of interest. Gray vertical lines indicate the start of a water year (Oct 1–Sep 30).

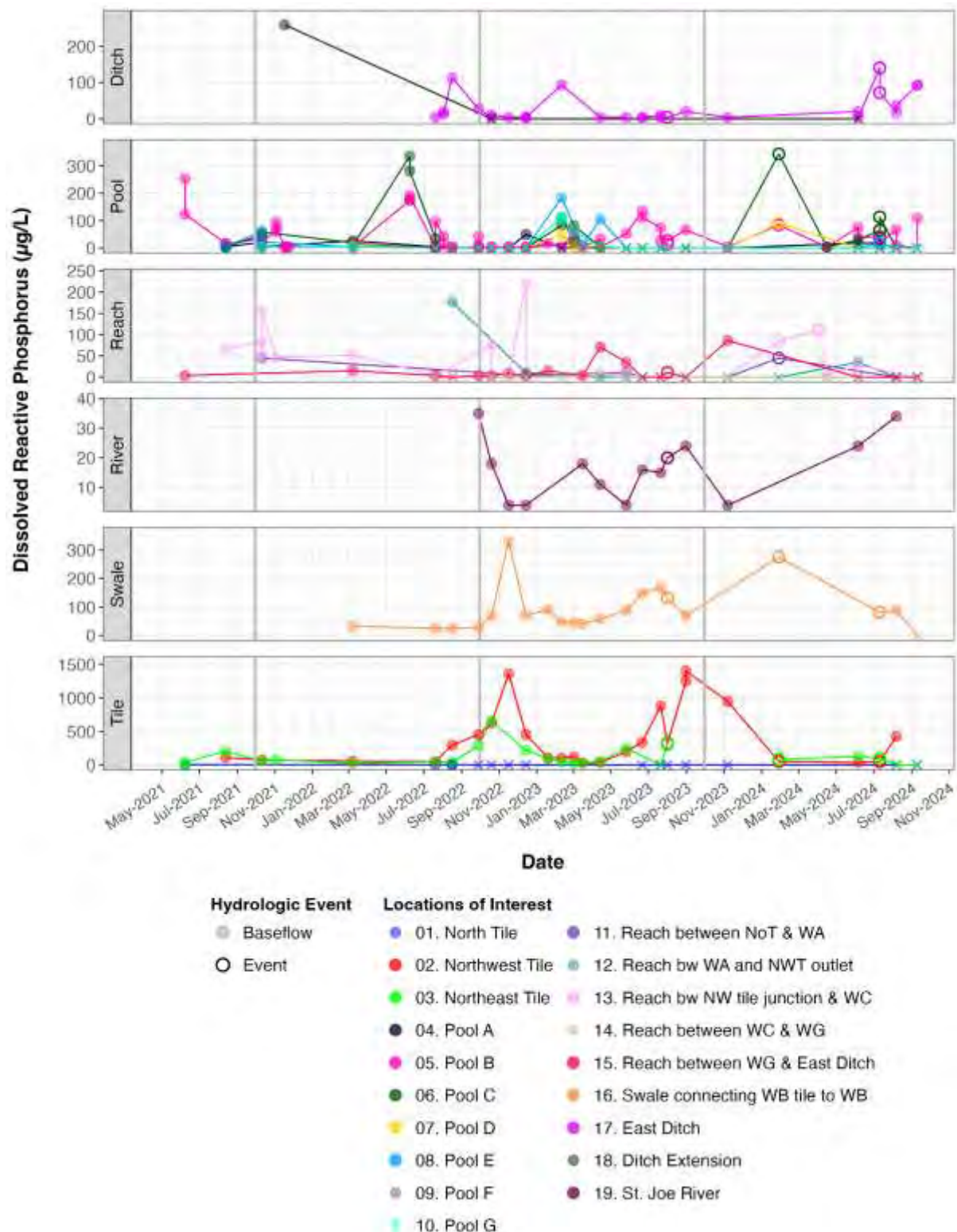


Figure 113. Time series of dissolved reactive phosphorus (DRP) concentrations in surface water samples collected at the St. Joseph's River Restoration Project. Values below detection limit were replaced with half the detection limit. Each point represents one measurement and

colors denote the locations of interest, as indicated in the legend. Open symbols indicate that measurements were collected during a hydrologic event (e.g., storm event) and filled symbols denote measurements collected during baseflow. Crosses represent instances when no surface water was detected during the visit. If present, different shapes denote the types of wetland features represented by the locations of interest. Gray vertical lines indicate the start of a water year (Oct 1–Sep 30).

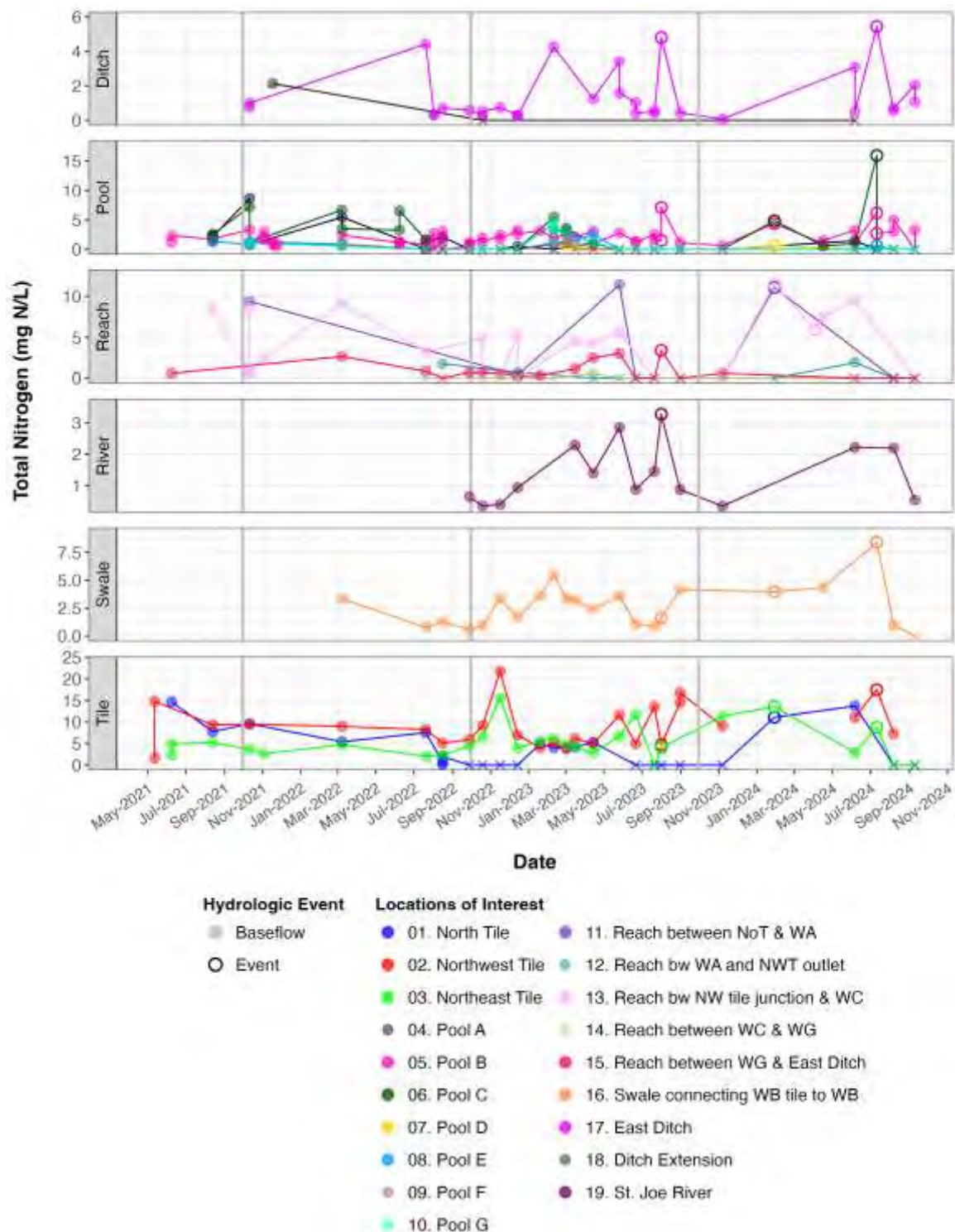


Figure 114. Time series of total nitrogen (TN) concentrations in surface water samples collected at the St. Joseph's River Restoration Project. Values below the detection limit of the analytical equipment were replaced with half the value of the detection limit. Each point represents one measurement and colors denote the locations of interest, as indicated in the legend. Open symbols indicate that measurements were collected during a hydrologic event (e.g., storm event) and filled symbols denote measurements collected during baseflow. Crosses (×) represent instances when no surface water was detected during the visit. If present, different shapes denote the types of wetland features represented by the locations of interest. Gray vertical lines indicate the start of a water year (Oct 1–Sep 30).

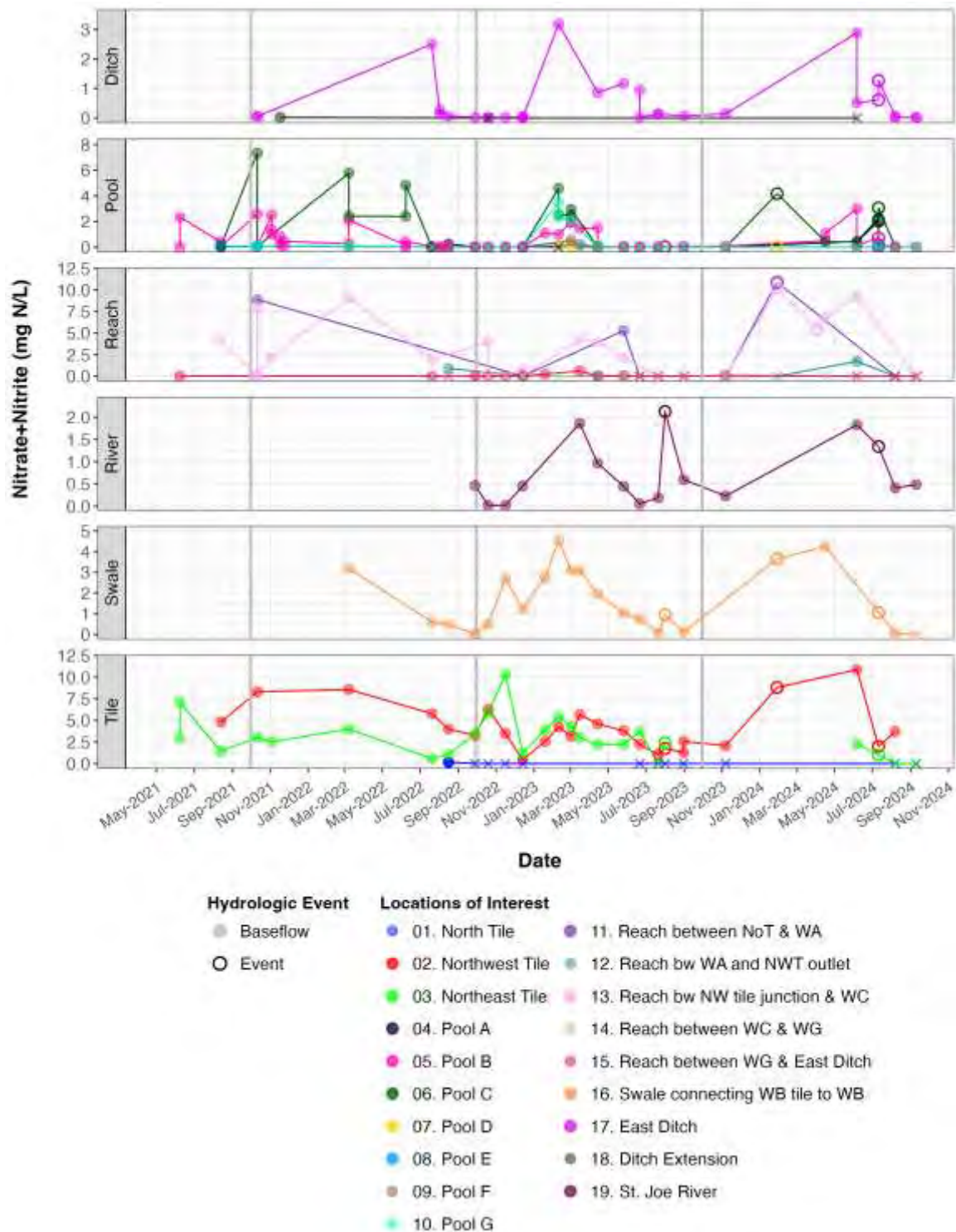


Figure 115. Time series of Nitrite+nitrate (NO_x) concentrations in surface water samples collected at the St. Joseph's River Restoration Project. Values below the detection limit of the analytical equipment were replaced with half the value of the detection limit. Each point represents one measurement and colors denote the locations of interest, as indicated in the legend. Open symbols indicate that measurements were collected during a hydrologic event (e.g., storm event) and filled symbols denote measurements collected during baseflow. Crosses (x) represent instances when no surface water was detected during the visit. If

present, different shapes denote the types of wetland features represented by the locations of interest. Gray vertical lines indicate the start of a water year (Oct 1–Sep 30).

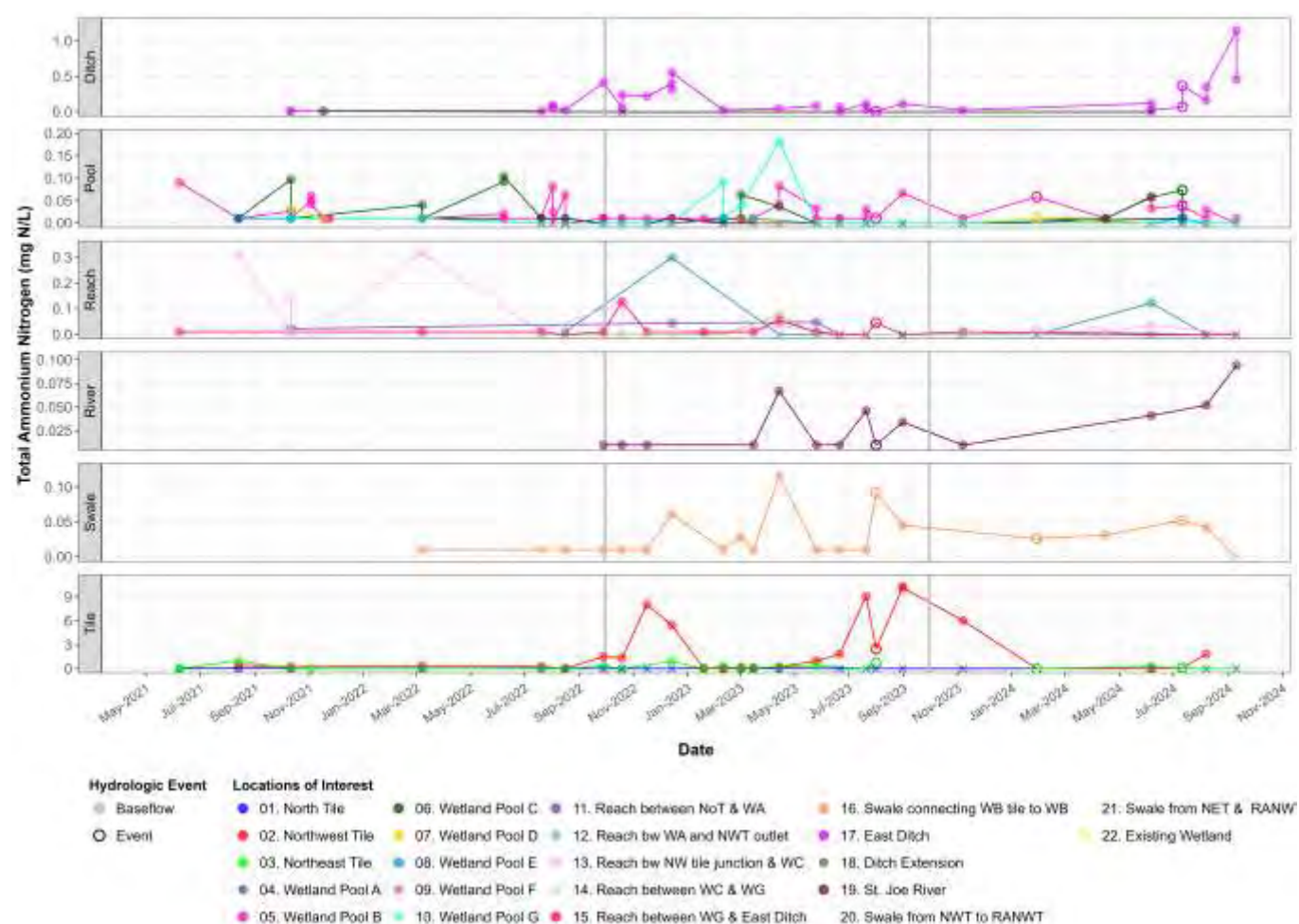


Figure 116. Time series of total ammonium nitrogen ($\text{NH}_4\text{-N}$) concentrations in surface water samples collected at the St. Joseph's River Restoration Project. Values below detection limit were replaced with half the detection limit. Each point represents one measurement and colors denote the locations of interest, as indicated in the legend. Open symbols indicate that measurements were collected during a hydrologic event (e.g., storm event) and filled symbols denote measurements collected during baseflow. Crosses represent instances when no surface water was detected during the visit. If present, different shapes denote the types of wetland features represented by the locations of interest. Gray vertical lines indicate the start of a water year (Oct 1–Sep 30).

Soil Nutrient Status and Processes

The broad soil phosphate sorption capacity (SPSC) pattern at St. Joseph Restoration in Water Year 2024 is similar to past Water Years (Figure 118). Most sampling locations remain moderately positive, indicating a capacity to sorb phosphate. In particular, soil at the outlet of Pool B had the highest SPSC (up to 163 mg phosphorus/kg), which is the highest recorded SPSC value in the three years of sampling (compared to 143 mg/kg in 2022, 126 mg/kg in 2023). The Northeast Tile (15 mg/kg) and the Swale connecting WB tile to WB (22 mg/kg),

which receives Northeast Tile water, had the lowest average SPSC of all wetland features at this Project.

Soil electrical conductivity (measured in lab on field collected soils) was greatest at the Northwest Tile ($2592 \pm 1654 \mu\text{S/cm}$), Northeast Tile ($2889 \pm 1822 \mu\text{S/cm}$), Pool B ($3537 \pm 3393 \mu\text{S/cm}$), and the Swale connecting the WB Tile to WB ($2539 \pm 2628 \mu\text{S/cm}$, Supplemental Information). Three of these features had maximums above $4200 \mu\text{S/cm}$ (NW Tile, NE Tile, Swale), and Pool B had a maximum of $8741 \mu\text{S/cm}$ (Supplemental Information). Field-measured Bulk apparent Electrical Soil Conductivity (ECa) values for both the 0.5-m and the 1.0-m coil spacing (which correspond to different soil depth readings) ranged from 2 to 39 mS/m ($2000\text{--}39000 \mu\text{S/cm}$) with the highest values recorded in the northeastern portion of the Project directly east of the North Tile. Generally, higher ECa values for both surveys correspond to lower elevation areas at locations where higher moisture could collect.

Feldspar horizon markers were installed at this Project in December 2023 to estimate rates of sediment accretion. At each marker location, a layer of white feldspar was placed in a rectangular plot on the soil surface and were left for one year. In December 2024, soil cores were taken from the plots in Pools A, B, and C. Relative rates of sediment accretion varied drastically between pools. Cores from Pool C had deposited soil depths of only about 1.0 mm above the horizon. Cores from Pool A had accretion depths ranging from 2.4 mm to 15 mm. Pool B had the most sediment accretion, with depths ranging from 13 mm to 37 mm, which is consistent with observations that appear to indicate it receives more water than Pools A and C. Results of the chemical analysis of the soil above and below the feldspar horizons is underway and will inform researchers about the nutrient content and SPSC of soil deposited before December 2023 and new soil that was delivered to the pools during the December 2023–December 2024.

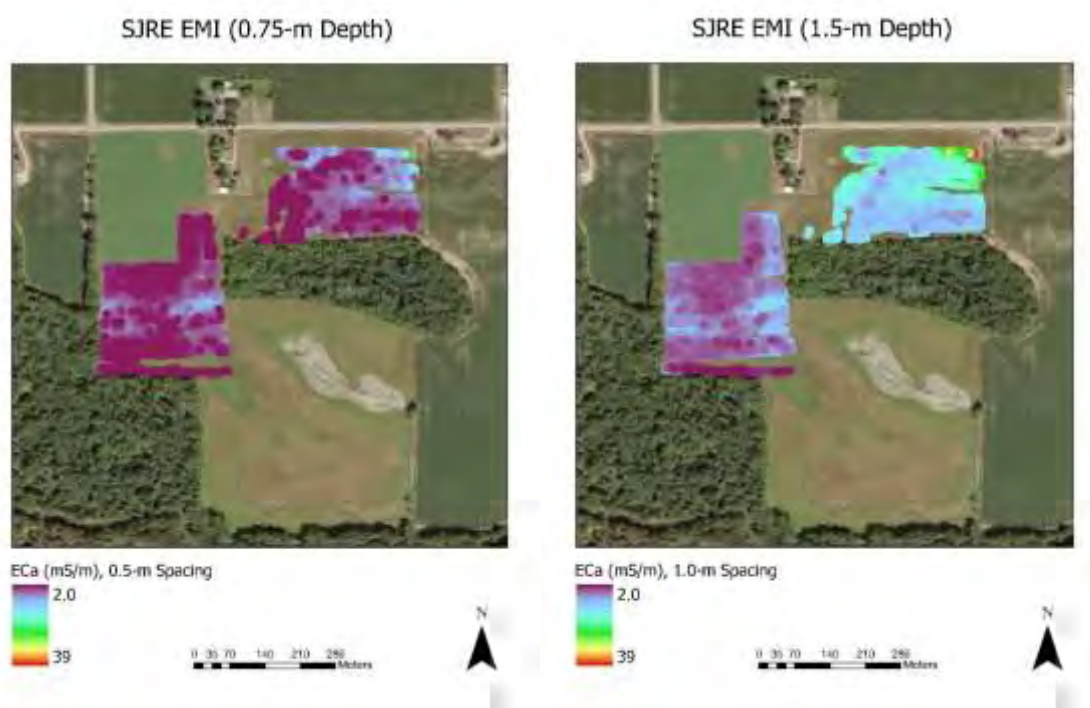


Figure 117. Bulk Electrical Soil Conductivity (ECa) measured at St. Joseph's River Restoration Project during September 2024 for the 0.5-m (left) and 1.0-m (right) coil spacings. Note that the 0.5-m and 1.0-m correspond with 0.75m and 1.5m, respectively, for approximate depth of investigation.

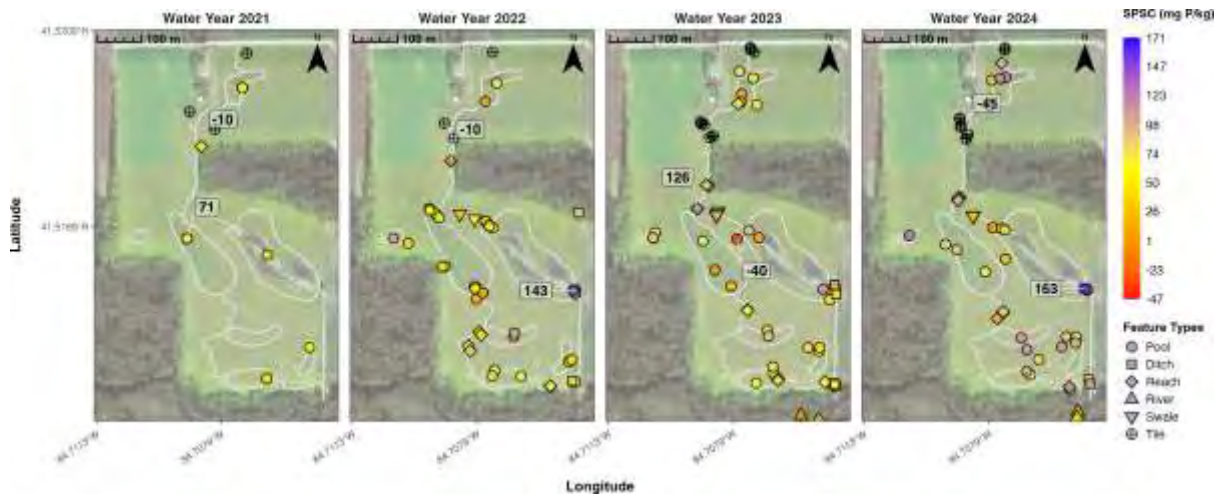


Figure 118. Soil Phosphate Sorption Capacity (SPSC) throughout the St. Joseph's River Restoration Project. Each point denotes a soil sample (0–5 cm) and different shapes indicate the wetland feature type, as shown in the legend. Colors indicate the SPSC value of each sample relative to the overall range of values observed at the wetland project, as shown in the color bar. Each panel shows the soil samples collected during a respective water year (Oct 1–Sep 30), along with the minimum and maximum SPSC values observed during a given water year. Negative SPSC values indicate the potential for soils to release phosphate, while positive values indicate soils have capacity to sorb phosphate, based on Mehlich-3 extractions of phosphate, iron, and aluminum.

Vegetation Results

In 2024, researchers estimate vegetation nutrient stocks were 191 lbs. phosphorus (P, 903 lbs. aboveground and 16 lbs. belowground) and 4,879 lbs. nitrogen (N, 4798 lbs. aboveground and 81 lbs. belowground) at peak biomass (July–August, Figure 120). This is an estimated decrease of 1,258 lbs. P and 2,983 lbs. N, largely due to the decrease in active vegetated wetland area from relatively dry conditions over the past two years. Despite dry conditions, St. Joseph's River Restoration continues to have the highest average aboveground nutrient stock per acre for both P and N, as well as the highest plant richness, diversity, and floristic quality assessment index of all H2Ohio Focal Projects (Figure 121, Figure 122, Figure 123). Biodiversity at the Project is high because relatively little habitat is dominated by Cattails (*Typha spp.*). This demonstrates that prioritizing high wetland vegetation nutrient stocks and plant biodiversity is possible in wetland restorations. Species such as Common rush (*Juncus effusus*), Woolgrass (*Scirpus cyperinus*), Beggarticks (*Bidens cernua* or *B. frondosa*), Swamp milkweed (*Asclepias incarnata*), and Virginia wild rye (*Elymus virginicus*) are some of the native wetland plants that contribute heavily to nutrient stock at the Project.

While vegetation at St. Joseph's River Restoration continues to perform well in comparison to other H2Ohio Focal Projects, from 2023 to 2024, total above- and belowground nutrient

stock declined (Figure 120). The decline is likely caused by drought conditions in 2023 and 2024 leading to a decline in the active vegetated wetland area and a slight decline in P stock per acre. Average aboveground N stock per acre increased in 2024, but the decrease in area was significant enough that the overall N stock was reduced, possibly indicating that nutrient acquisition in established plants is not negatively impacted by drought conditions. Rather it may be that nutrient stock losses are primarily from losses of suitable habitat for wetland plants and stocks will recover in wetter conditions.

However, there are year-to-year changes in terms of the overall nutrient density of the various wetland species that contribute highly to vegetation nutrient stock at St. Joseph's River Restoration. For instance, the average P density of Common rush (*Juncus effusus*) decreased from approximately 3 g P/m² in 2023 to approximately 1 g P/m² in 2024. The impact of the individual species on the Project-level vegetation nutrient stock estimate is not yet understood, along with the seasonal changes in the vegetative nutrient stock that may impact nutrient retention at the Project. While the H2Ohio Wetland Monitoring Program has provided species planting recommendations using data on individual species' nutrient densities observed at St. Joseph's River Restoration (Figure 121, Figure 122), supplementary research and future Monitoring Program activities aim to provide more context related to which plant species promote long-term nutrient storage and how vegetation nutrient stocks impact annual nutrient retention.

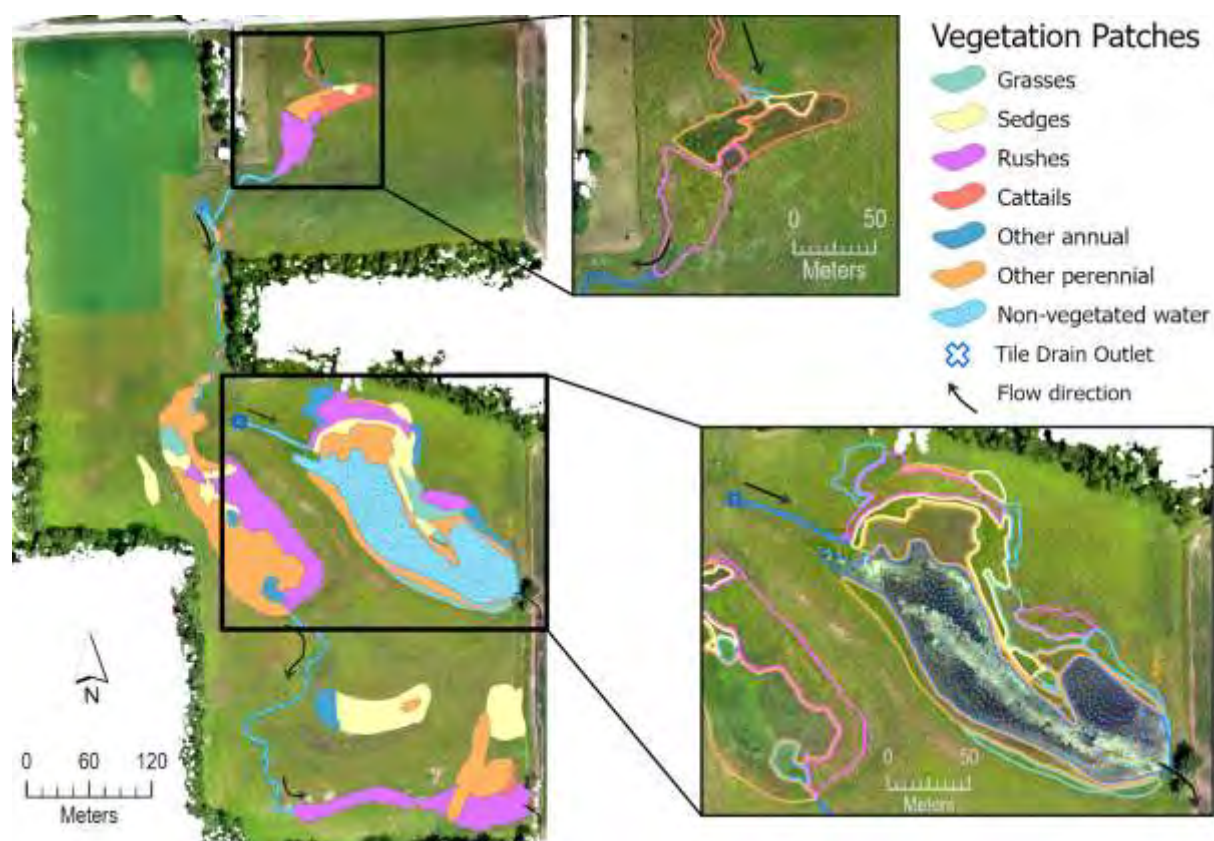


Figure 119. Aerial imagery (collected July 2024) with simplified vegetation patches based on expert-drawn vegetation maps (based on data collected July 2024) at St. Joseph River Restoration. The magnified sections show the outlines of the vegetation patches. Vegetation patch types used in analyses have been combined in this image to visually simplify patch categories. Flow Direction (black arrows) indicates the general flow direction of surface

water, and the Tile Drain Outlet (blue cross) indicates the location of tile drains from which water flows into the pools.

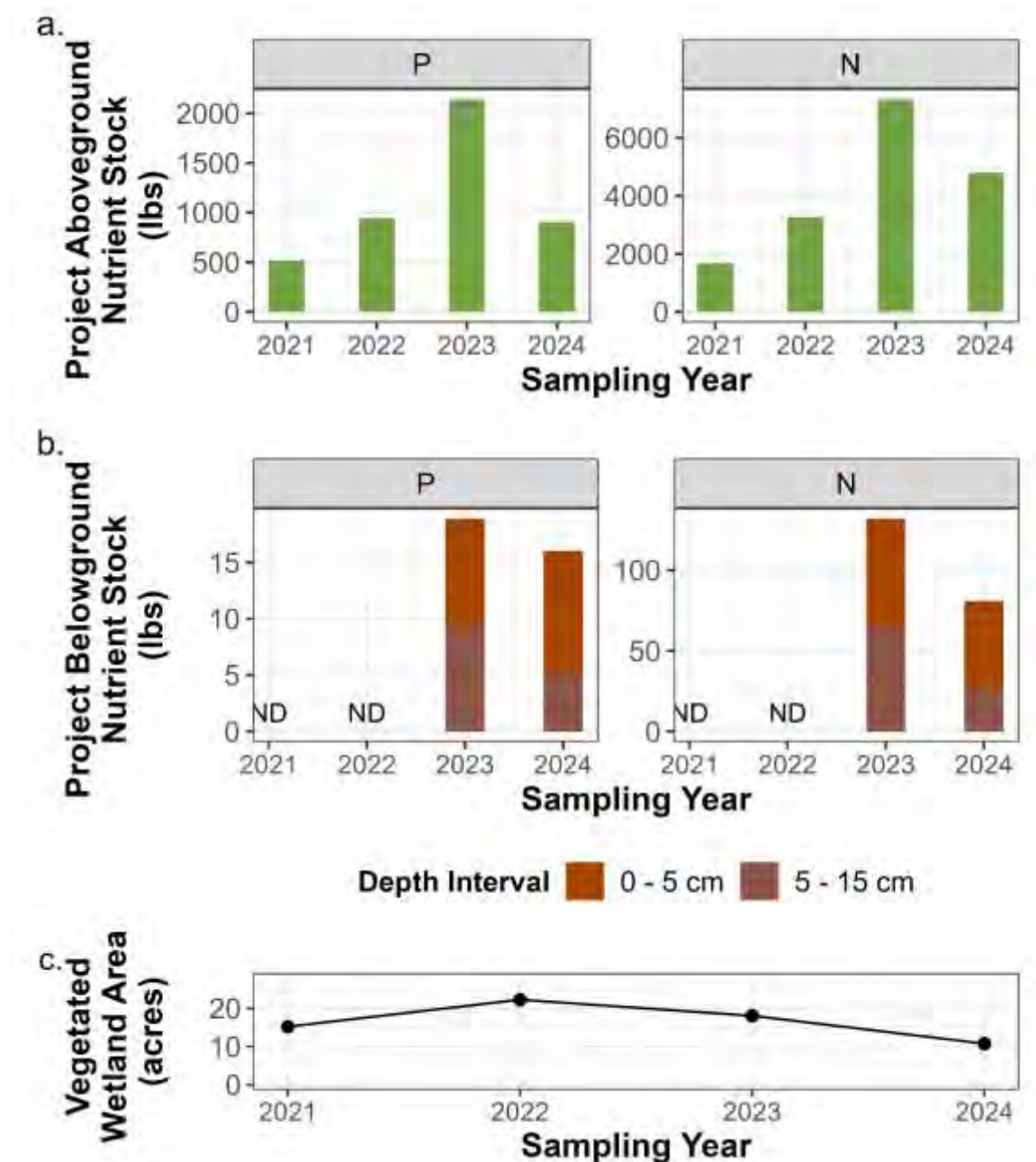


Figure 120. Nutrient stock in (a) above- and (b) belowground vegetation at St. Joseph's River Restoration. Estimates of the total mass of Phosphorus (P) and Nitrogen (N) stock in vegetation in the areas surveyed by the H2Ohio Wetland Monitoring Program for each year St. Joseph's River Restoration was monitored for vegetation. (c) Vegetated Wetland Area refers to areas observed to have wetland-dominant species composition and all other Project areas were excluded from vegetation stock calculations. For more detailed information on how estimates were calculated, see Appendix II.

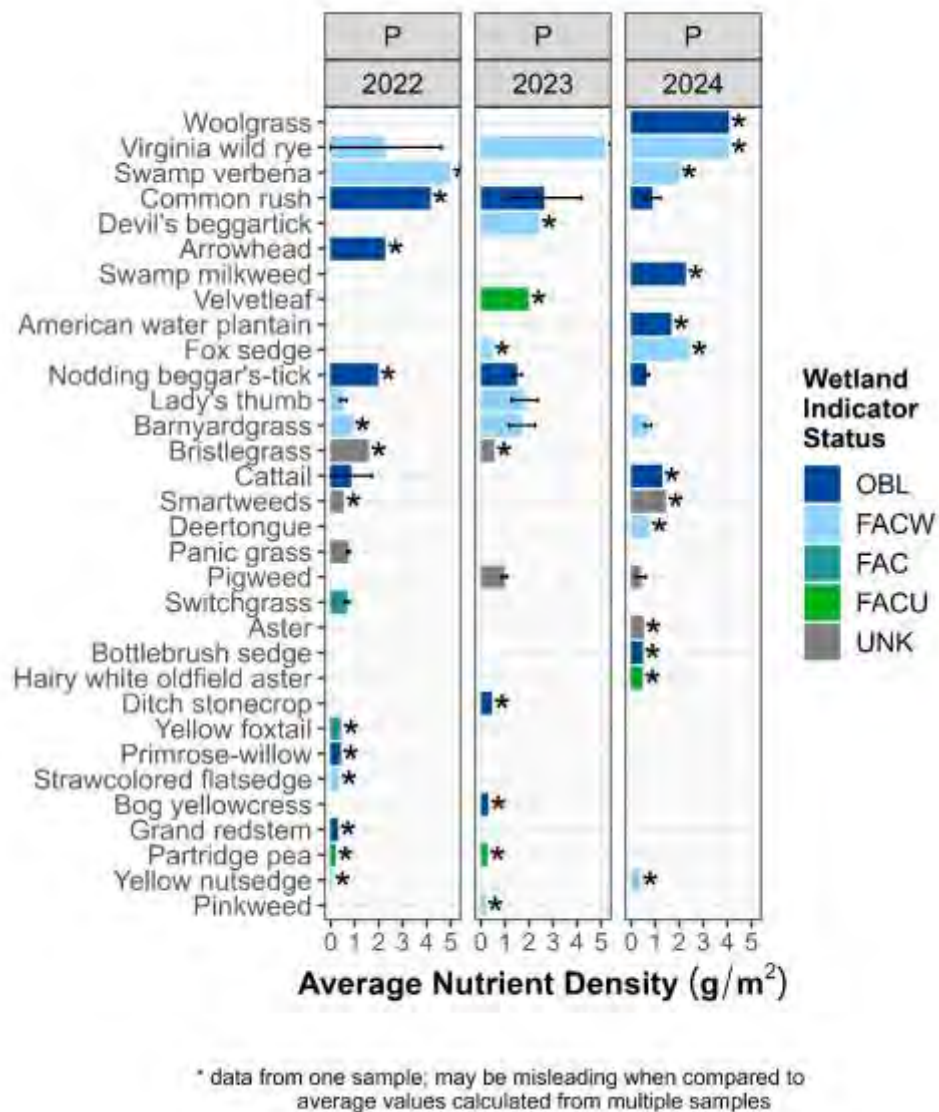


Figure 121. Average nutrient density of phosphorus in vegetation species at St. Joseph's River Restoration. The average mass of Phosphorus (P) stock in aboveground plant material per square meter for species sampled that covered more than 20% of a sampling quadrat at St. Joseph's River Restoration. Nutrient density is calculated by multiplying measured nutrient concentrations and aboveground dry biomass data, resulting in an estimate of the average aboveground nutrient mass observed in a species within a given area. Appendix II displays both common and scientific species names and Wetland Indicator Status (WIS) designations can be found in Appendix II.

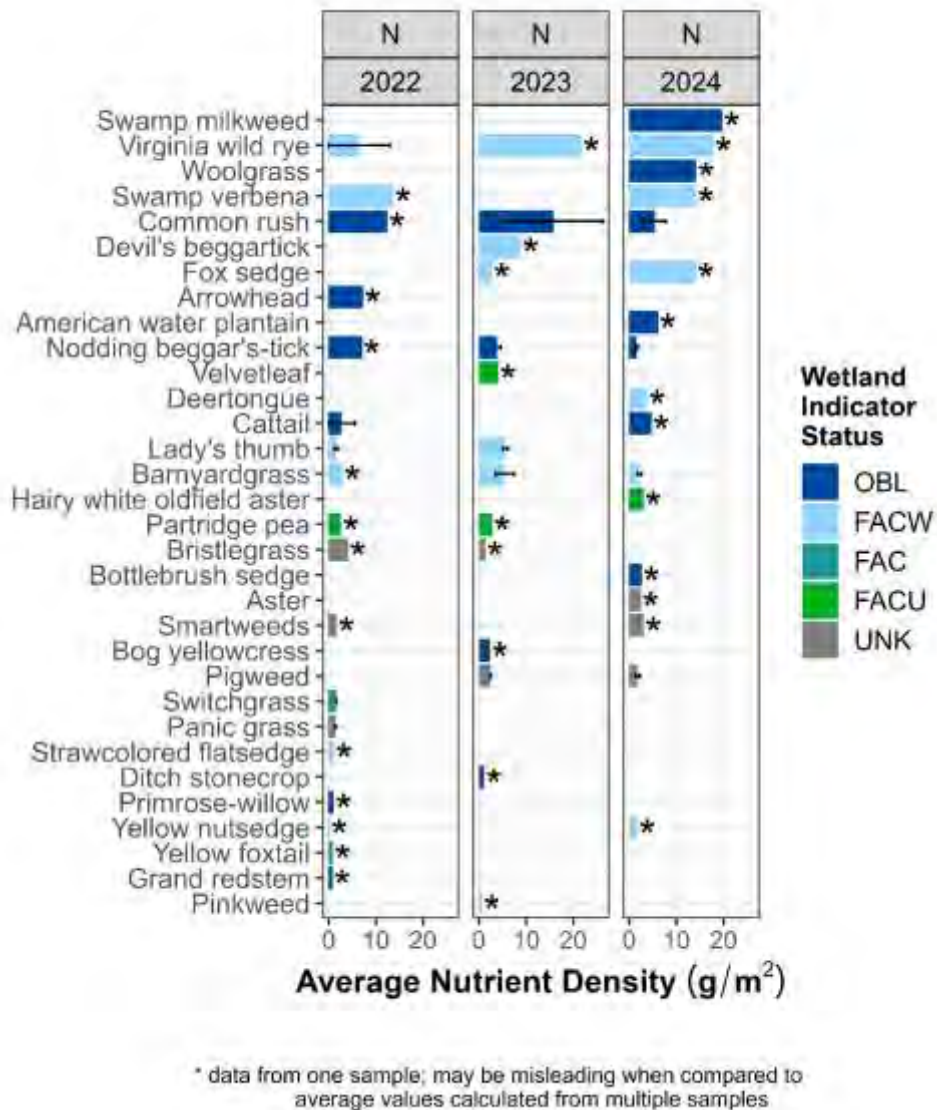


Figure 122. Average nutrient density of nitrogen in vegetation species at St. Joseph's River Restoration. The average mass of Nitrogen (N) stock in aboveground plant material per square meter for species sampled that covered more than 20% of sampling quadrat. at St. Joseph's River Restoration. Nutrient density is calculated by multiplying measured nutrient concentrations and aboveground dry biomass data, resulting in an estimate of the average aboveground nutrient mass observed in a species within a given area. Appendix II displays both common and scientific species names and Wetland Indicator Status (WIS) designations can be found in Appendix II.

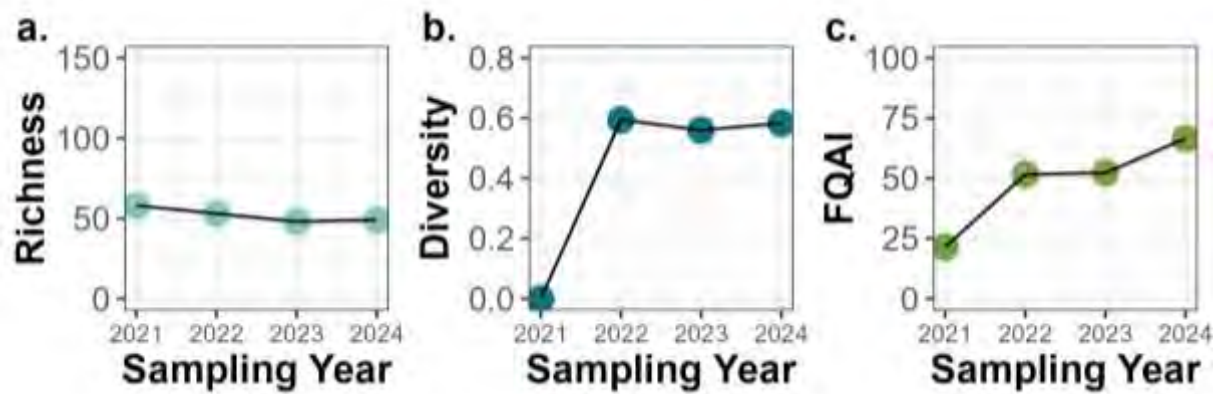


Figure 123. Species richness, diversity, & the Floristic Quality Assessment Index at St. Joseph's River Restoration. These graphs display (a) species richness, or a count of the total number of species, (b) species diversity calculated with Simpson's Diversity Index (See Appendix II), and (c) the floristic quality assessment index (FQAI), a measure of habitat quality based on vegetation present (See Appendix II), for St. Joseph's River Restoration.

Next Steps to Strengthen Understanding

As the H2Ohio Project with the some of the most complex hydrology being monitored, the St. Joseph Restoration is a model for the development of hydrological monitoring that can either inform monitoring of Non-Focal sites. To fully understand the hydrology of the Project in 2025, researchers plan to use one or two ISCO autosamplers to capture hydrologic event water samples and acoustic velocity (A/V) sensors to measure water velocity so that the nutrient flow profiles and water flow can be more accurately assessed. Paired with flow data, these event samples will allow researchers to calculate a much more robust nutrient reduction estimate for this Project.

Additionally, in winter of 2024, the base crew discovered a change in tile drainage delivery at St. Joseph River Restoration. The Northeast Tile delivers water to both Pool C and Pool B under normal conditions. It delivers water to Pool C via a Reach that flows south from the NE Tile outlet to Pool C. A riser near the outlet of the Northeast Tile also delivers a portion of the tile outflow water to Pool B when the water in the outflow basin reaches sufficient level. On December 30, 2024, the base crew discovered that erosion or animal burrowing had occurred around the base of this riser and 100% of the water from the Northeast Tile now goes directly via an underground tile to Pool B. None of the water from the Northeast Tile is being delivered to Pool C. This will likely reduce the water volume and nutrient load delivered to Pool C for Water Year 2025. Continued monitoring efforts are critical for advancing understanding of wetland nutrient reduction function as this system matures post-construction.

Researchers will continue to collect water samples at the Project monthly and sample soil twice per year. Continued data collection from the remote sensor system will inform a 3D hydrological model, which will eventually enable more accurate estimates of water volumes entering this Project and also contribute to improving estimates of nutrient load reduction.

Results of the chemical analysis of the soil above and below feldspar horizons in Pools A and B are underway and will inform researchers about the nutrient content and SPSC of soil deposited before December 2023 and new soil that was delivered to the pools during Water Year (WY) 2024. Future feldspar horizon installations will enable similar estimates over time or in other pools.

To better understand hydrologic patterns at the St. Joseph Restoration Project, and to build a framework that can be applied to Non-Focal sites with less intensive monitoring, an undergraduate student researcher (Hana Esber, Kent State University) applied remotely sensed data to track hydrology via satellite imagery. Satellite imagery from Sentinel at 10-meter resolution was captured for WY 2024 and analyzed for moisture content using the Automated Water Extraction Index (AWEI). Sentinel satellite imagery yielded 23 images with usable data and no cloud cover but was not frequent enough to capture storm and flooding events (Figure 124). However, the imagery allowed researchers to detect the wetting and drying of Pool B over the course of the year at a Project which is validated by the sensor systems at place at the St. Joseph Restoration. H2Ohio Wetland Monitoring Program researchers or affiliate researchers may be able to expand this method to track hydrologic patterns at Non-Focal sites where the Base Crews do not have the capacity to regularly sample.

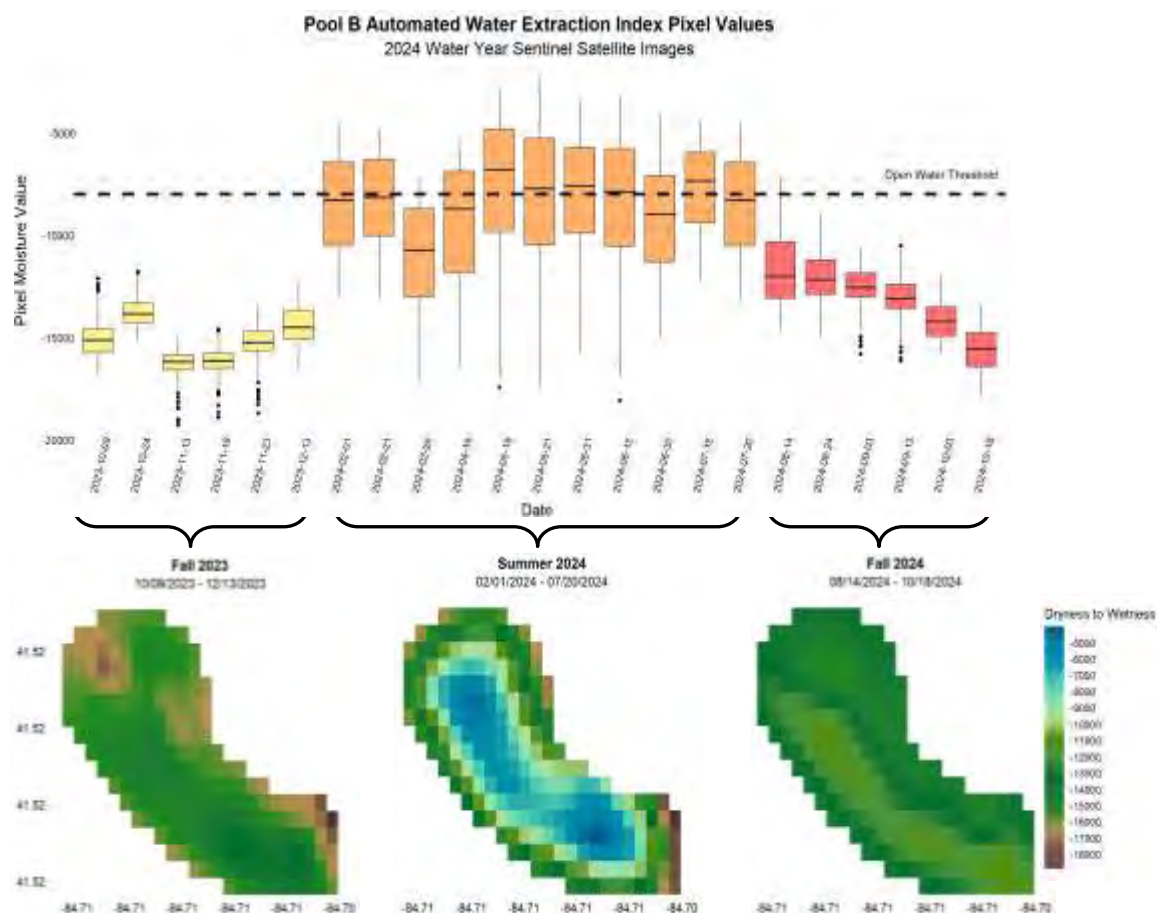


Figure 124. Average pixel moisture for Pool B at St. Joseph's River Restoration Project throughout water year 2024. More negative values (-18,000– -16,000) indicate less moisture or bare soil, increasing negative values transition into healthy vegetation (-15,000– -13,000), then aquatic or submerged vegetation (-10,000– -9,000), and open water (values > -8000).

The average water pixels recorded only for Pool B during 10/24/2023–12/13/2023 (bottom left) has large amounts of vegetation (green pixels) surrounding the pool and throughout it. Bottom middle image (summer 2024) has vegetation surrounding the pool and there are signs of aquatic vegetation in light green pixels on the outer portions with open water in the more interior areas denoted by the brightest blue pixels. Bottom left and right images (fall 2023 and 2024) have a small strip of vegetation through the middle of the pool and generally less moisture in the entire area.

Non-Focal Projects

Non-Focal Projects are sampled at lower frequency than Focal Projects, and with fewer to no specialty crew (e.g., vegetation, hydrogeophysics) collected metrics, though some Non-Focal Projects receive water level sensors⁵.

Coastal (University of Toledo)

Projects in coastal region (Figure 1) are primarily monitored by the geographic base crew centered at the University of Toledo's Lake Erie Center (Thomas Bridgeman, Principal Investigator).

Darby Refuge Wetland Reconnection (DARR)

Project Description

Ottawa County | La Carpe Creek Watershed | Coastal

Project Size: 352.2 Acres

Partners: Ottawa Soil & Water Conservation District, U.S. Fish and Wildlife Service

The hydrology at this Project is actively managed. This coastal Project has 352 acres of restored wetland featuring two major pools: a large western pool (Pool 1) and a smaller eastern pool (Pool 4). The Project receives water from a ditch that runs adjacent to Pools 1 and 4, as well as LaCarpe Creek that flows from south to north along the west side of the wetland. There are three WLCSs along LaCarpe Creek and the adjacent ditch, connecting them to Pools 1 and 4. A hydrologic event at this Project is operationally defined as an event where WLCSs are open, and water can flow into or out of Pools 1 and 4.



Figure 125. Aerial image showing surface water flow and sampling locations for the Darby Refuge Wetland Reconnection Project. Blue arrows indicate direction of surface water flow. Dots represent geographic base crew sampling locations, which are grouped by Project features (fill color) where relevant. Text annotations provide additional context about the Project's watershed connection or other important features.

Management Considerations

The source water inputs and resulting nutrient reduction impact of the Darby Refuge Wetland Reconnection Project (hereafter the Darby Project) have been limited by management that prioritizes enhancing wildlife habitat. The Darby Project is an actively managed coastal Project located within the Ottawa National Wildlife Refuge, on the southern shore of Lake Erie and east of LaCarpe Creek. The Darby Project consists of two separate wetland units, Pool 1 on the western side and Pool 4 on the eastern side, which are surrounded by dikes. The dikes isolate the wetland units from the surrounding landscape except through three water level control structures (WLCSs) connecting them to LaCarpe Creek: two in Pool 1 and one in Pool 4.

Water was released from both units, Pools 1 and 4, during the month of March 2024. Subsequently, the WLCS in Pool 4 was left open to allow water to move in and out freely between the ditch and Pool 4, potentially leading to some nutrient retention. WLCSs in Pool 1 were closed and Pool 1 was isolated from the watershed from April through September. In September 2024, water was added to Pool 1 from LaCarpe Creek or the ditch. In November, Pool 4 was isolated from the watershed to stabilize water levels for wildlife. Based on this activity, Pool 1 did not capture water during the growing season, which is when runoff has the highest nutrient concentrations. The wetland could be managed more intentionally for nutrient sequestration by “cycling” LaCarpe Creek water through the wetland once or a few times per year, especially by allowing water to enter the wetland in spring when nutrient sequestration is most impactful for preventing harmful algal blooms in nearby Lake Erie. However, there may be trade-offs between nutrient sequestration actions and wildlife habitat considerations.

Unless a WLCS is opened when the water level in the creek is higher than the water level in the wetland unit, it will not receive inputs from the surrounding landscape. Therefore, punctual or advance notification of management actions is critical for analysis of the nutrient content of water entering or leaving the wetland. In general, the federal agency in charge of management (U.S. Fish and Wildlife Service) achieves its primary goal of providing wildlife habitat by removing water from the wetland in the spring and adding water in the fall. Water levels are maintained for ideal habitat conditions whenever possible while accommodating maintenance needs, regardless of external weather conditions.



Figure 126. Aerial image of approximate locations of interest for water and soil sampling and discrete manual measurements of water depth and physicochemical parameters at Darby Refuge Wetland Reconnection Project during water year 2024 (Oct 1, 2023–Sep 30, 2024). The legend provides the name of each sampling point. Different shapes denote the types of wetland features represented by the locations of interest. If present, different colors represent locations of interest that belong to a group or complex of features (e.g., a treatment train).

Surface Water Hydrology and Nutrients

Both units within the Darby Project, Pool 1 on the west side and Pool 4 on the east side, remained permanently inundated throughout Water Year (WY) 2024 as in past years, but water levels varied seasonally based on management goals. Water levels in both units decreased in September and November 2023 adjacent to the water level control structures (WLCSs) that connect them to the ditch south of Pool 1 and west of Pool 4, suggesting that either water evaporated, or it was actively removed from the units through the WLCSs (Pool 1 WCS2, Pool 4 WCS3, Figure 127). While records of management actions do not exist for the Darby Project for 2023, matching dissolved oxygen and pH levels between the ditch and Pool 4 during the water level decrease suggests potential connectivity between them, while Pool 1 was likely isolated because physical characteristics in the unit deviated from ditch levels (Supplemental Information). Water in Pool 1 of the Darby Project was released directly to LaCarpe Creek for one month in March 2024, then the WLCS connecting it to the creek was closed and water levels adjacent to the creek remained stable through September 2024.

(Pool 1 WCS1, Figure 127). Water levels near the WLCSs adjacent to the ditch in both units fluctuated in similar patterns as ditch and creek water levels in May and July 2024, suggesting runoff flowed into the units for treatment when water levels increased.

In May 2024, runoff from the ditch that contained an increased concentration of total phosphorus (TP) and dissolved reactive phosphorus appeared to be captured by both pools, as concentrations increased with water levels at adjacent sampling locations (Pool 1 WCS2 and Pool 4 WCS3), and subsequently the concentration of TP at those locations increased (Figure 128, Figure 129). Water in LaCarpe Creek contained elevated concentrations of total nitrogen and NO_x in May 2024, however it was not captured by the Darby Project because WCS1 was likely closed during that time (Figure 130, Figure 131).

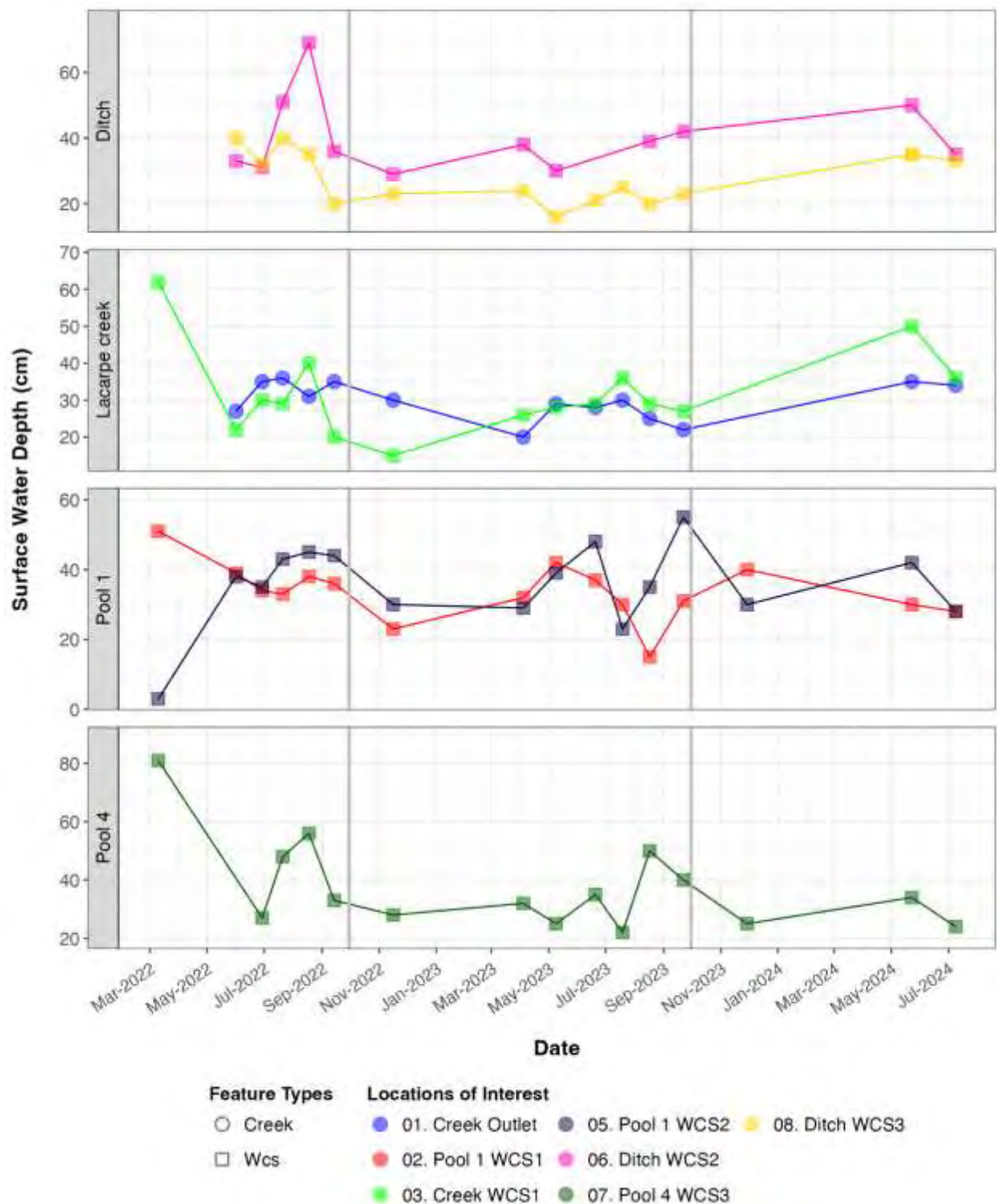


Figure 127. Time series of discrete, manually measured surface water depth at the Darby Refuge Wetland Reconnection Project. Depths were measured approximately monthly. Each point represents one measurement and colors denote the locations of interest, as indicated in the legend. Open symbols indicate samples that were collected during a hydrologic event (e.g., storm event) and filled symbols denote samples collected during baseflow. Crosses (×) represent instances when no surface water was detected during the visit. If present, different

shapes denote the types of wetland features represented by the locations of interest. Gray vertical lines indicate the start of a water year (Oct 1–Sep 30).

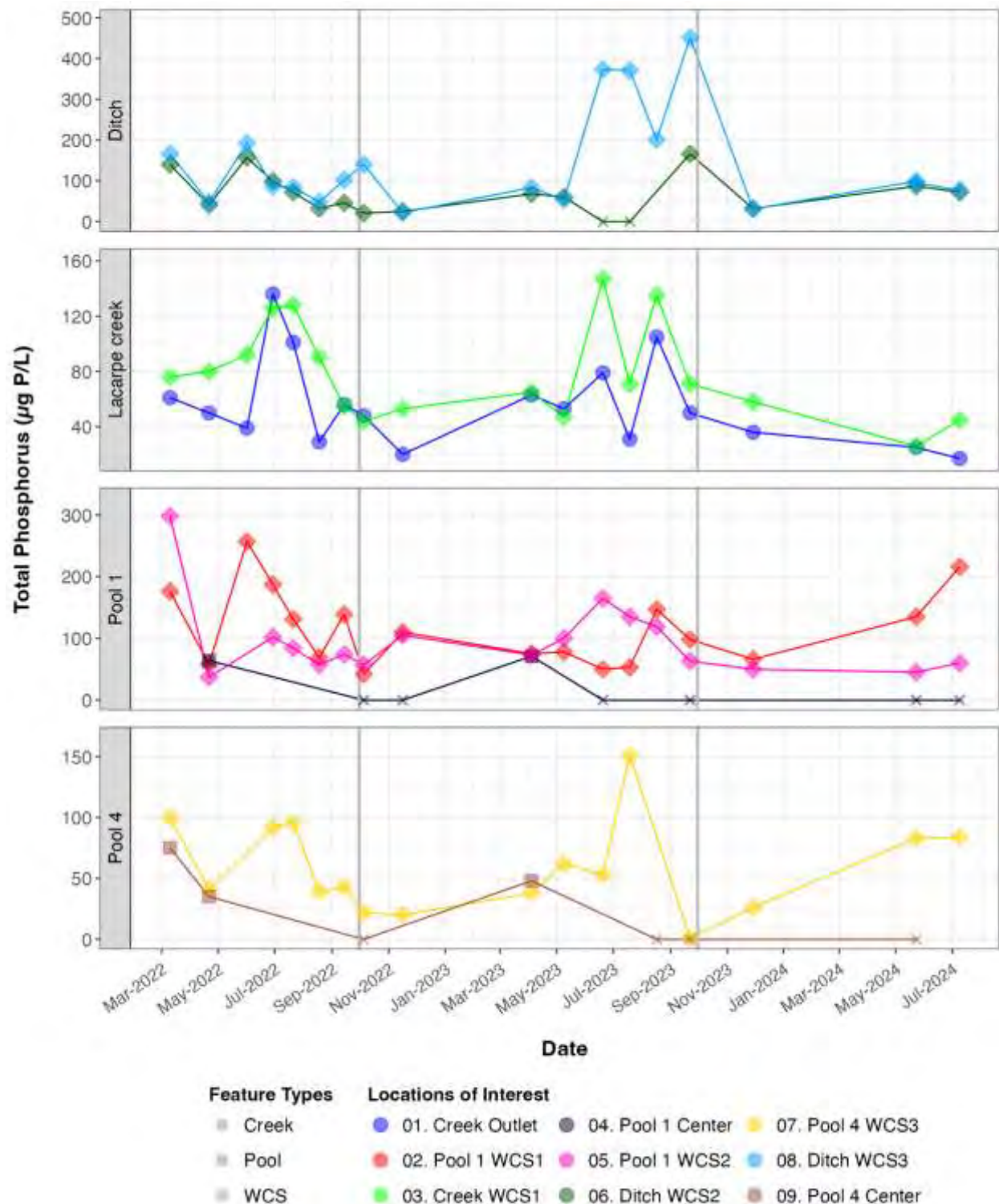


Figure 128. Time series of total phosphorus (TP) concentrations in surface water samples collected at the Darby Refuge Wetland Reconnection Project. Values below the detection limit of the analytical equipment were replaced with half the value of the detection limit. Each point represents one measurement, and colors denote the locations of interest, as

indicated in the legend. Open symbols indicate that measurements were collected during a hydrologic event (e.g., storm event) and filled symbols denote measurements collected during baseflow. Crosses (×) represent instances when no surface water was detected during the visit. If present, different shapes denote the types of wetland features represented by the locations of interest. Gray vertical lines indicate the start of a water year (Oct 1–Sep 30).

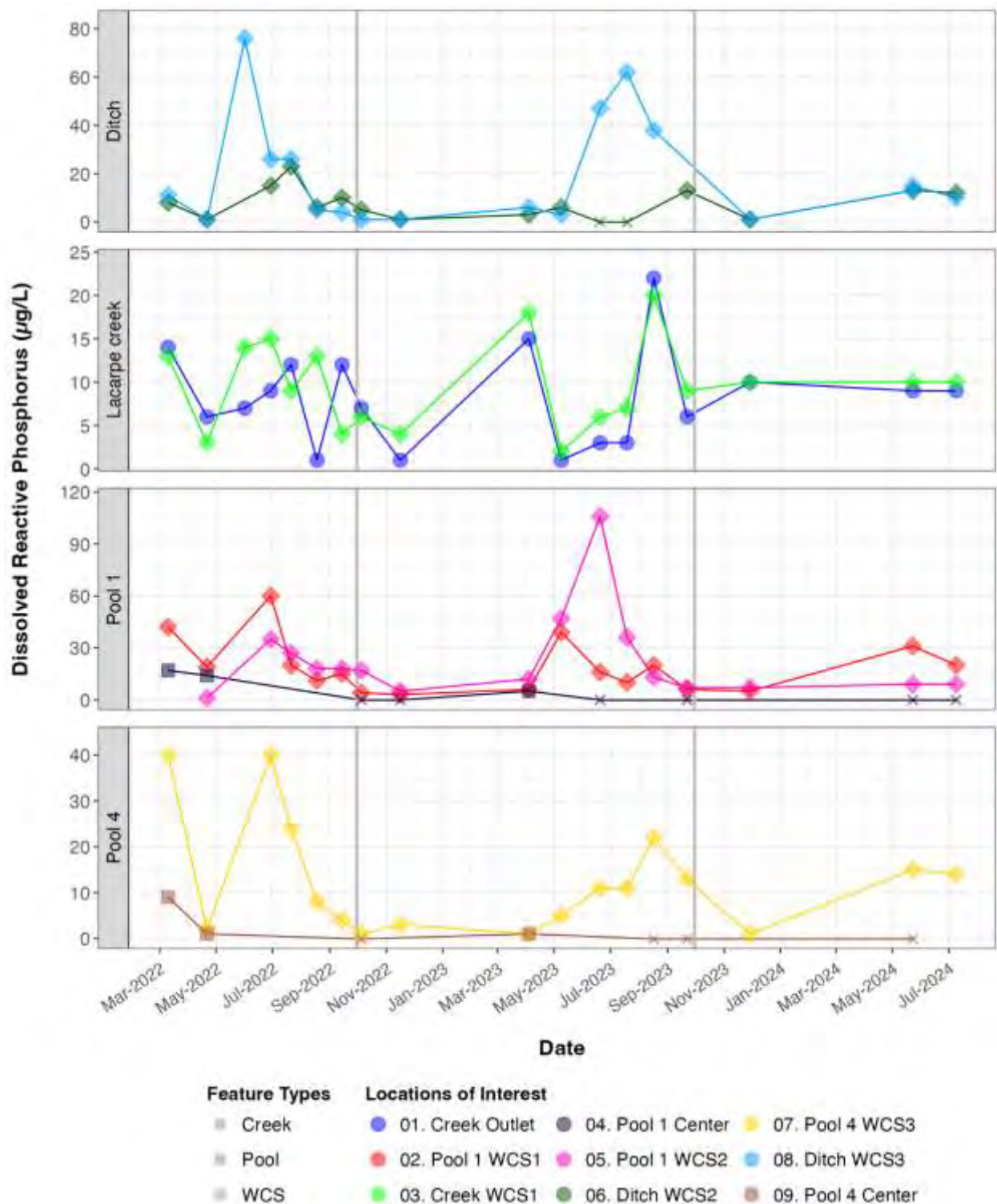


Figure 129. Time series of dissolved reactive phosphorus (DRP) concentrations in surface water samples collected at the Darby Refuge Wetland Reconnection Project. Values below the detection limit of the analytical equipment were replaced with half the value of the detection limit. Each point represents one measurement, and colors denote the locations of interest, as indicated in the legend. Open symbols indicate that measurements were collected during a hydrologic event (e.g., storm event) and filled symbols denote measurements collected during baseflow. Crosses (x) represent instances when no surface water was

detected during the visit. If present, different shapes denote the types of wetland features represented by the locations of interest. Gray vertical lines indicate the start of a water year (Oct 1–Sep 30).

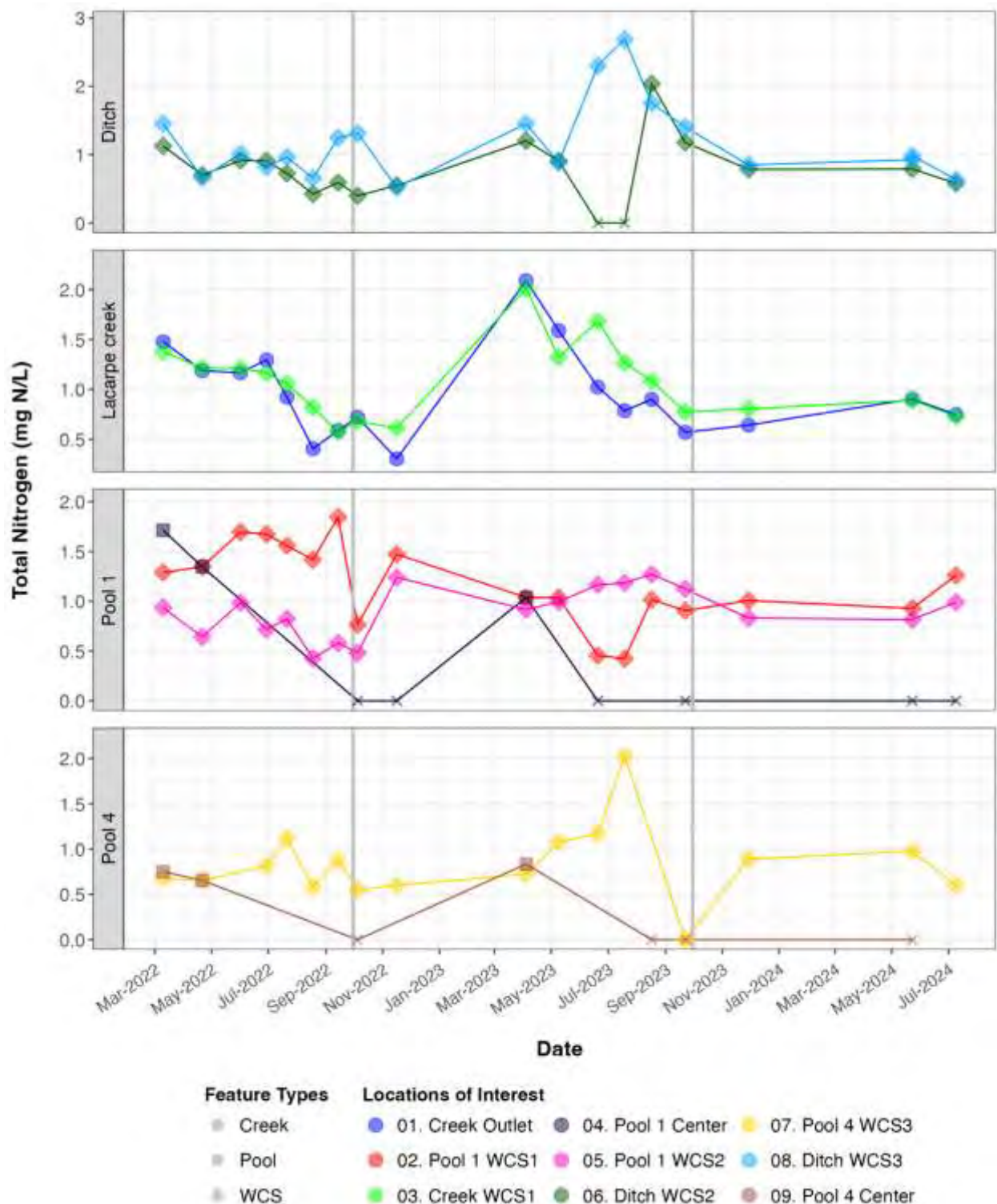


Figure 130. Time series of total nitrogen (TN) concentrations in surface water samples collected at the Darby Refuge Wetland Reconnection Project. Values below the detection limit of the analytical equipment were replaced with half the value of the detection limit.

Each point represents one measurement, and colors denote the locations of interest, as indicated in the legend. Open symbols indicate that measurements were collected during a hydrologic event (e.g., storm event) and filled symbols denote measurements collected during baseflow. Crosses (×) represent instances when no surface water was detected during the visit. If present, different shapes denote the types of wetland features represented by the locations of interest. Gray vertical lines indicate the start of a water year (Oct 1–Sep 30).

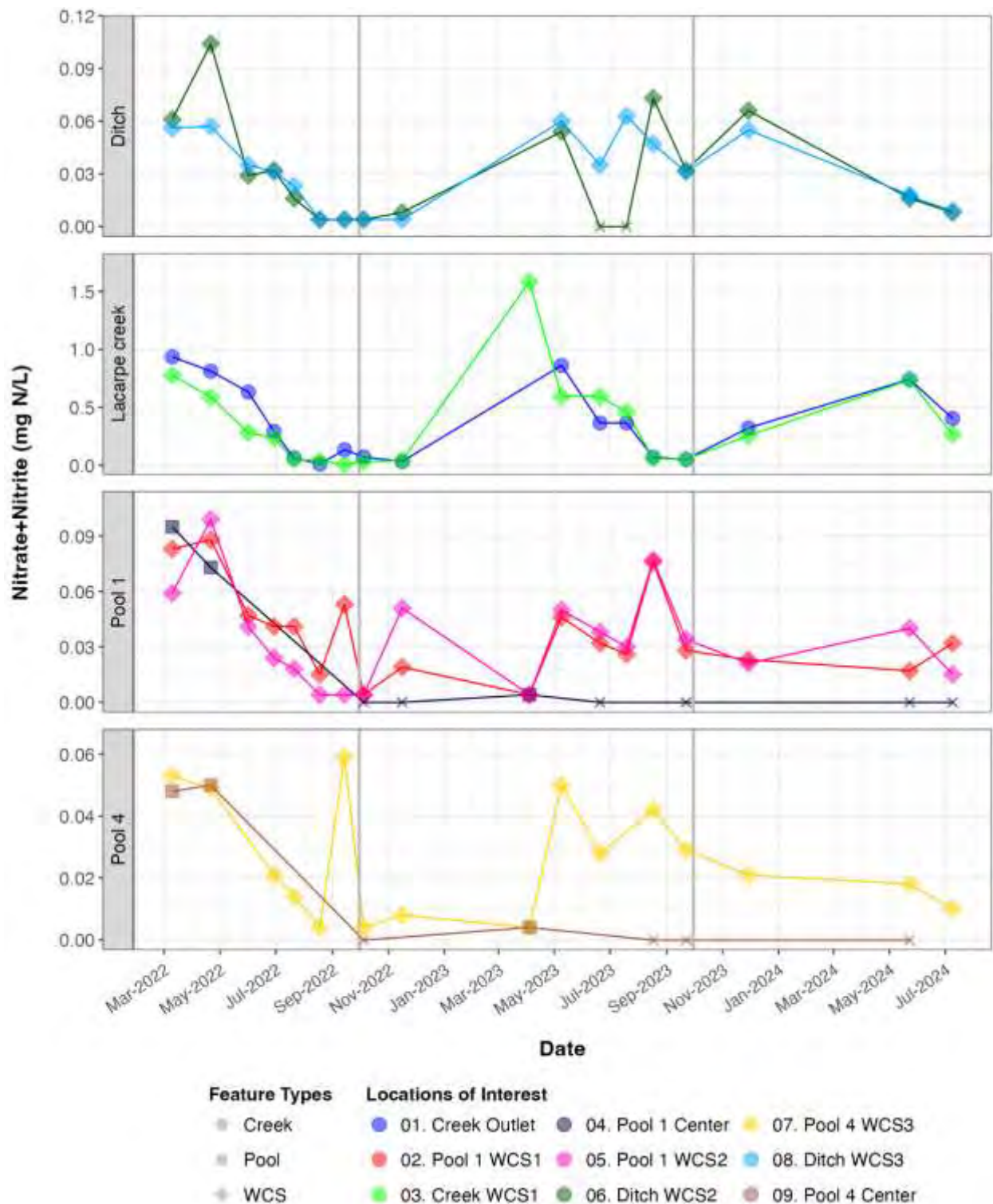


Figure 131. Time series of Nitrite+nitrate (NO_x) concentrations in surface water samples collected at the Darby Refuge Wetland Reconnection Project. Values below the detection limit of the analytical equipment were replaced with half the value of the detection limit. Each point represents one measurement, and colors denote the locations of interest, as indicated in the legend. Open symbols indicate that measurements were collected during a hydrologic event (e.g., storm event) and filled symbols denote measurements collected during baseflow. Crosses (x) represent instances when no surface water was detected during the

visit. If present, different shapes denote the types of wetland features represented by the locations of interest. Gray vertical lines indicate the start of a water year (Oct 1–Sep 30).

Soil Nutrient Status and Processes

There is no soil data available for Water Year (WY) 2024 due to a delay in soil sample analysis. However, soil samples collected within Pool 1, Pool 3, and LaCarpe Creek near the water level control structures (WLCSs) during WY 2023 have been analyzed. Soil phosphate sorption capacity (SPSC) values at all sampling locations within the Darby Project were positive in those samples, indicating a capacity to sorb additional phosphate that entered the Darby Project after August of 2023 (Figure 132).

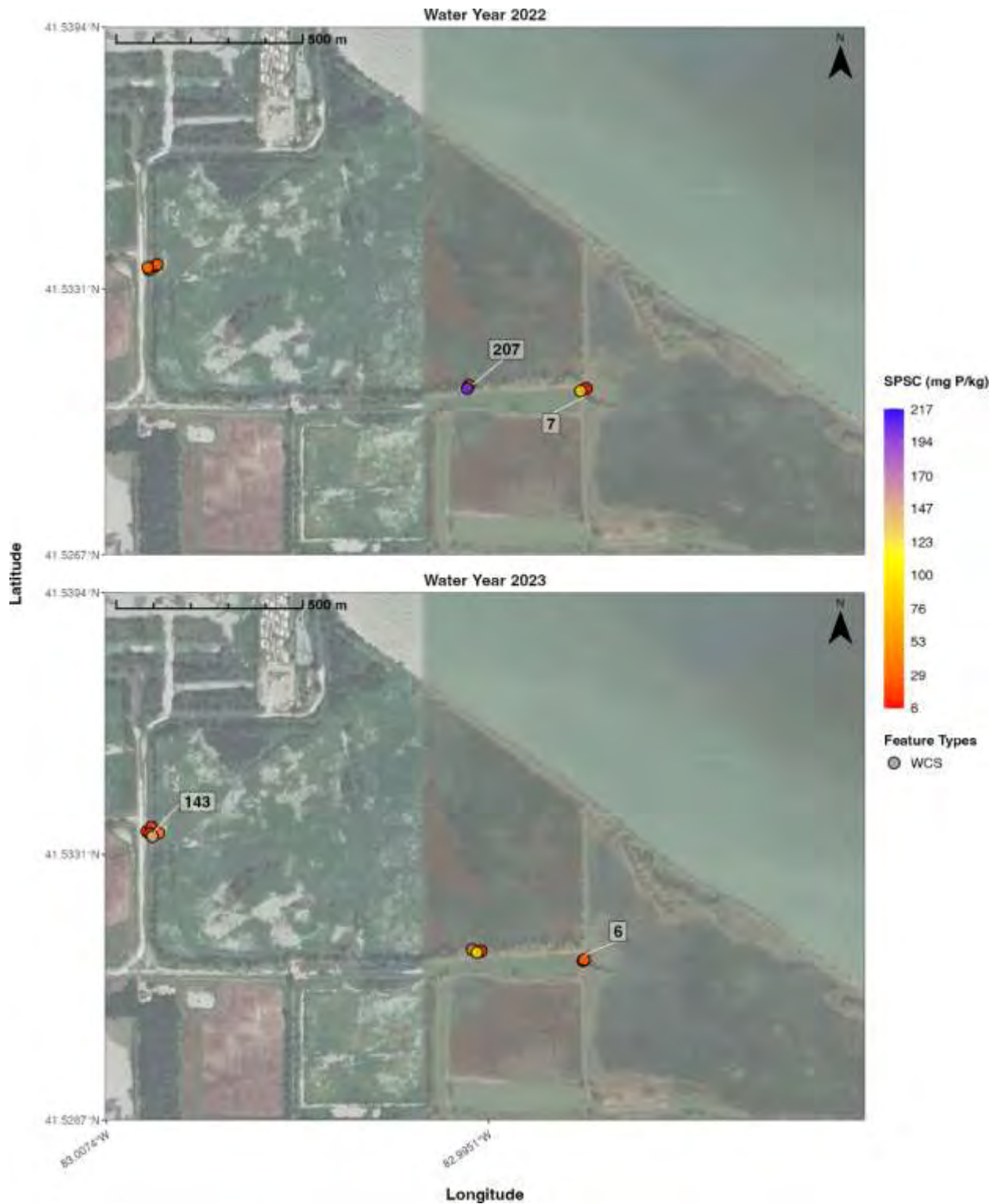


Figure 132. Soil Phosphate Sorption Capacity (SPSC) throughout the Darby Refuge Wetland Reconnection Project. Each point denotes a soil sample (0–5 cm) and different shapes indicate the wetland feature type, as shown in the legend. Colors indicate the SPSC value of each sample relative to the overall range of values observed at the wetland project, as shown in the color bar. Each panel shows the soil samples collected during a respective water year (Oct 1–Sep 30), along with the minimum and maximum SPSC values observed during a given water year. Negative SPSC values indicate the potential for soils to release phosphate,

while positive values indicate soils have capacity to sorb phosphate, based on Mehlich-3 extractions of phosphate, iron, and aluminum.

Next Steps to Strengthen Understanding

Sampling frequency at the Darby Project will be decreased in Water Year 2025 due to Project restrictions, barriers to access, and complex flow paths, which prevent accurate nutrient budget calculations. Lack of permission for sensor installations and drone flights make it difficult to calculate water volume and flow. Reduced Project access due to active bald eagle nests and hunting activity prevent frequent sampling visits to measure nutrient concentrations in water over time. Finally, without knowledge of water levels within the wetland units and LaCarpe Creek, it is difficult to determine when and how much water enters or leaves the wetlands

Duck and Otter Creek Wetland and Stream Restoration (DUCO)

Project Description

County: Lucas | Duck Creek Watershed

Project size: 69 Acres

Partners: Toledo–Lucas County Port Authority

The hydrology at this coastal flowthrough Project is passively managed. The Project has 10.56 acres of restored or created wetland and features several wetland pools situated along reconfigured meandering natural stream channel. Water enters from Duck Creek upstream and flows slowly through the Project before outflowing to Duck Creek downstream.

Note: The Duck and Otter Creek H2Ohio Project was sampled directly by the Ohio Department of Natural Resources personnel. The H2Ohio Wetland Monitoring Program provided standardized data summary figures following the conventions used elsewhere in this report. The data interpretation here in this Project summary was contributed by ODNR staff (Steven McMurray, Old Woman Creek NERR Research Coordinator).



Figure 133. Aerial image showing surface water flow and sampling locations for the Duck and Otter Creek Wetland and Stream Restoration Project. Blue arrows indicate direction of surface water flow. Dots represent geographic base crew sampling locations, which are grouped by Project features (fill color) where relevant. Text annotations provide additional context about the Project's watershed connection or other important features.

Management Considerations

Monitoring of the Duck and Otter Creek Project began in fall 2022 at stations upstream and downstream of the Project (Figure 134). Surface water nutrient concentration estimates suggest that the Project wetland is functioning as a sink for phosphorus and has had a variable influence on reducing nitrogen concentrations. However, flow measurements are needed to validate these conclusions. Water levels were lower than expected in an average water year, either due to drought conditions over Water Year (WY) 2024 or the re-grading of the Project that occurred during construction to slow flow and increase water retention. This suggests that the Project has the potential to receive and interact with greater volumes of water. Future measurements of water flow at the monitoring stations are needed to evaluate nutrient load filtration for the Project.

The Duck and Otter Creek Project is a small portion of a potential larger series of floodplain wetland restoration and stream channel naturalization projects along Duck and Otter Creeks. The upstream watershed (approximately 851 acres) is highly urbanized, and the Project has a large industrial influence given its location at the Port of Toledo. The entire length of Duck Creek has been altered or culverted over time. Restoration of this portion of the Project, which occurred from March through June 2023, involved replacing 1,440 linear feet (LF) of channelized Duck Creek with 2,055 LF of reconfigured meandering natural channel to slow the velocity of the stream and thus aid sediment deposition and nutrient removal. The Project also involved the restoration of 8.25 acres of degraded wetland as well as the creation of 2.31 acres of additional wetland and 10.37 acres of upland prairie to increase infiltration and nutrient processing (Figure 134).

Fertilizers from residences and the Collins Park Golf Course (located immediately upstream) are likely sources of nutrients into the Project. The Collins Park Toledo Water Treatment Plant lagoons also have outlets into Duck Creek, and treated water may enter the Project during storm events. The Project is an unmanaged coastal flow-through wetland that empties into the mouth of Maumee River and is therefore also likely to be influenced by lake level fluctuations.



Figure 134. Post-construction (June 2023) aerial image of the Duck and Otter Creek Project wetland, depicting the reconfigured meandering natural channel and wetland pools. Photo credit: EnviroScience.

Nutrient Budget Takeaways

More information is needed to calculate the volume of water that the Duck and Otter Creek Project receives. There is currently not enough data to calculate filtration values for this Project. However, preliminary nutrient concentration data has been collected. For both Water Year (WY) 2023 and WY 2024, concentrations of dissolved reactive phosphorus (DRP) and total phosphorus (TP) were generally higher upstream of the Project relative to the downstream station. For WY 2023, the mean differences in the concentrations upstream and downstream stations were 0.137 mg/L (TP) and 0.0914 mg/L (DRP). For 2024, the differences in concentrations were 0.07 mg/L (TP) and 0.062 mg/L (DRP, Figure 137). The smaller difference in phosphorus concentrations between upstream and downstream sites in 2024 may be attributed to reduced precipitation for that year but may also be an artifact of unequal sample sizes between years. There was less consistent a difference in the concentrations of nitrite+nitrate, total ammonium nitrogen, and total nitrogen between upstream and downstream sites (Figure 138), suggesting that the Project had a small and more variable influence on reducing nitrogen concentrations (Figure 139). Further monitoring is needed to better assess the Project's influence on nitrogen dynamics. No land within the

Project was previously used for agriculture, thus the Project does not prevent any additional phosphorus runoff. There is no soil data for this Project.



Figure 135. Aerial image of approximate locations of interest for water and soil sampling and discrete manual measurements of water depth and physicochemical parameters at Duck and Otter Creek Wetland and Stream Restoration Project during water year 2024 (Oct 1, 2023–Sep 30, 2024). The legend provides the name of each sampling point. Different shapes denote the types of wetland features represented by the locations of interest. If present, different colors represent locations of interest that belong to a group or complex of features (e.g., a treatment train).

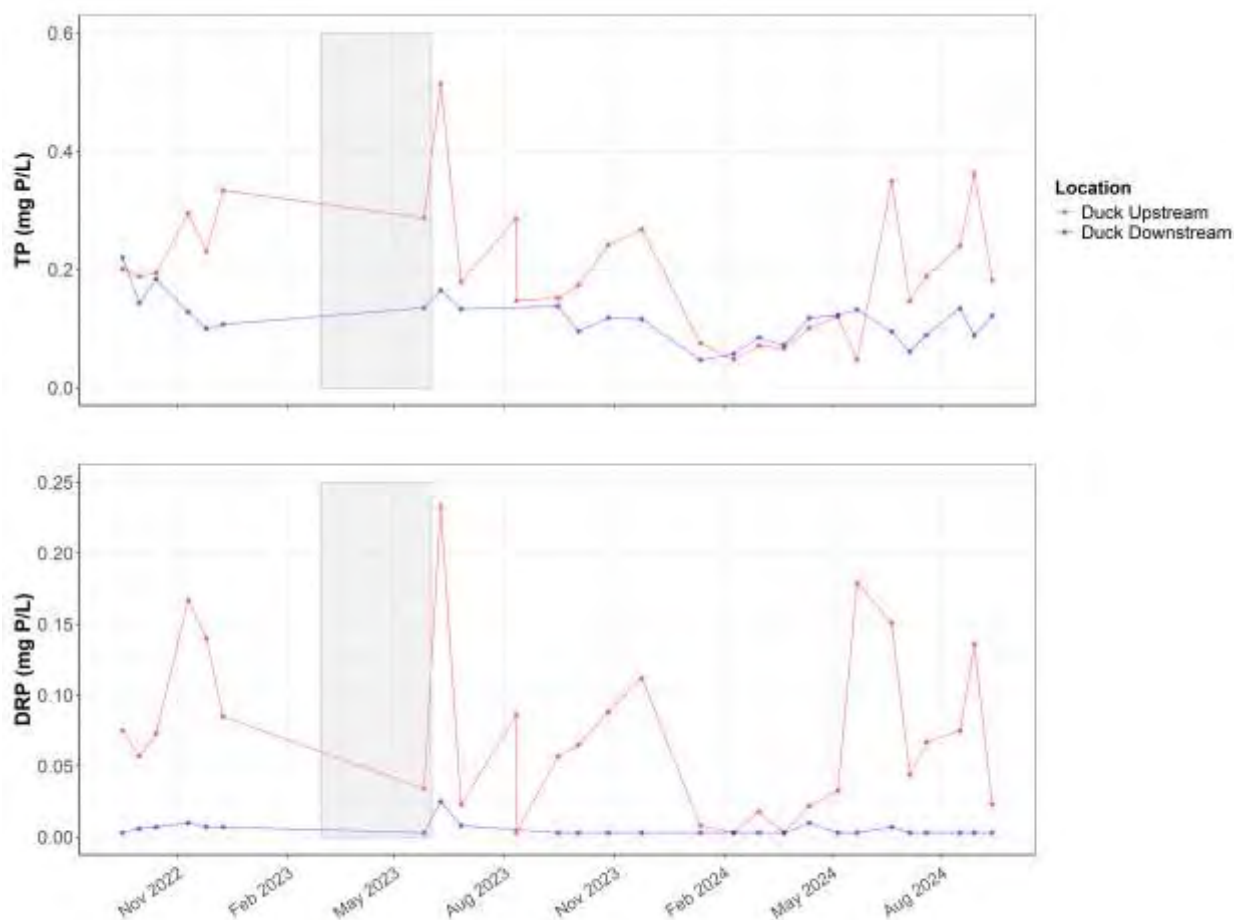


Figure 136. Time series of dissolved reactive phosphorus (DRP, top panel) and total phosphorus (TP, bottom panel) concentrations in surface water samples collected at the Duck and Otter Creek Wetland and Stream Restoration Project from 2022 to 2024. Each symbol represents one sample point and colors denote the sampling locations as indicated in the legend. Values below detection limit were replaced with zero. Gray vertical lines indicate the start of a water year (Oct 1–Sep 30) and the period shaded in gray (March through June 2023) denotes the approximate dates of construction.

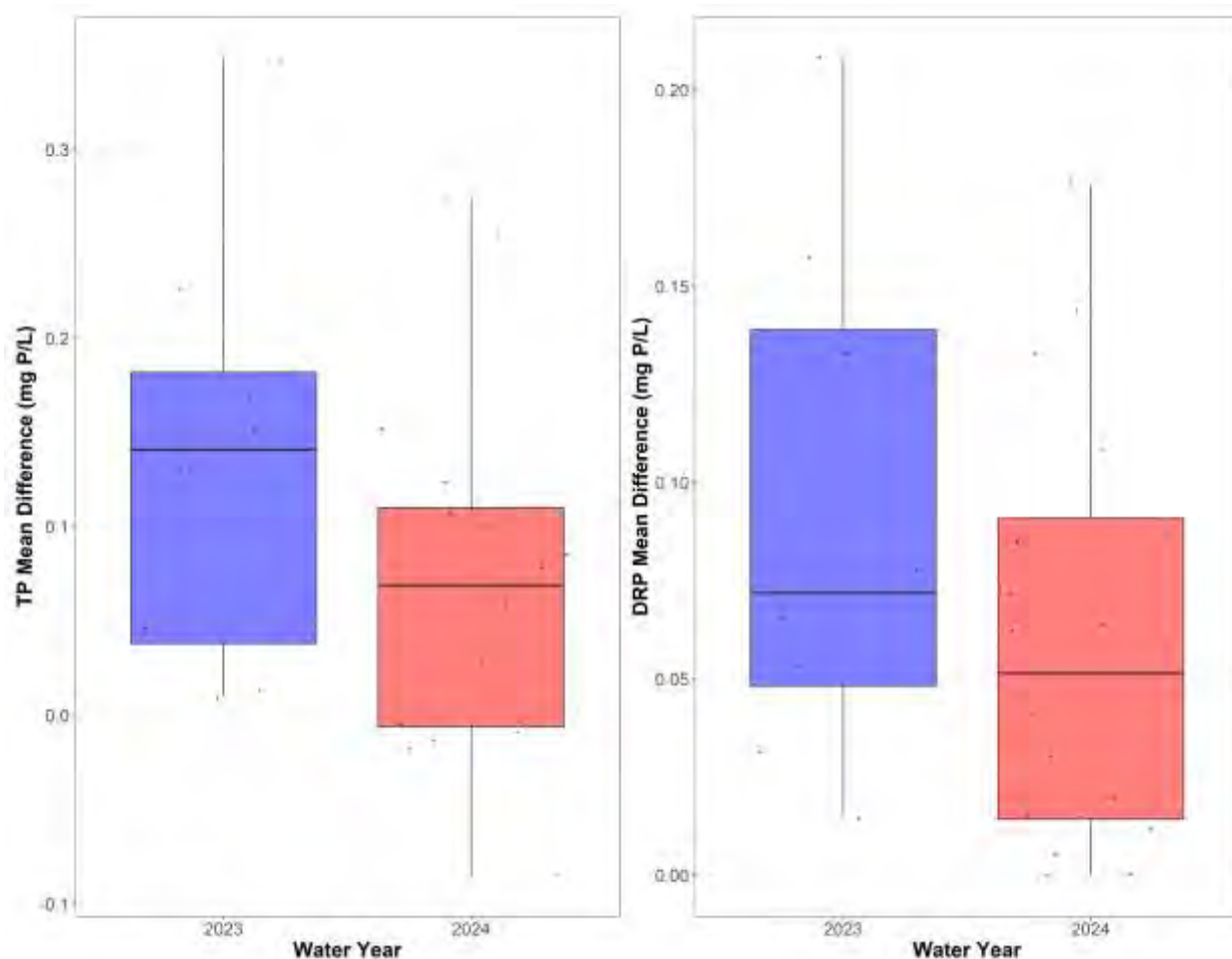


Figure 137. Mean ($\pm$ SD) difference in total phosphorus (TP) and dissolved reactive phosphorus (DRP) concentrations in surface water samples between upstream and downstream sites collected at the Duck and Otter Creek Wetland and Stream Restoration Project for water years 2023 and 2024. Positive values denote wetland nutrient filtration and negative values indicate nutrient release.

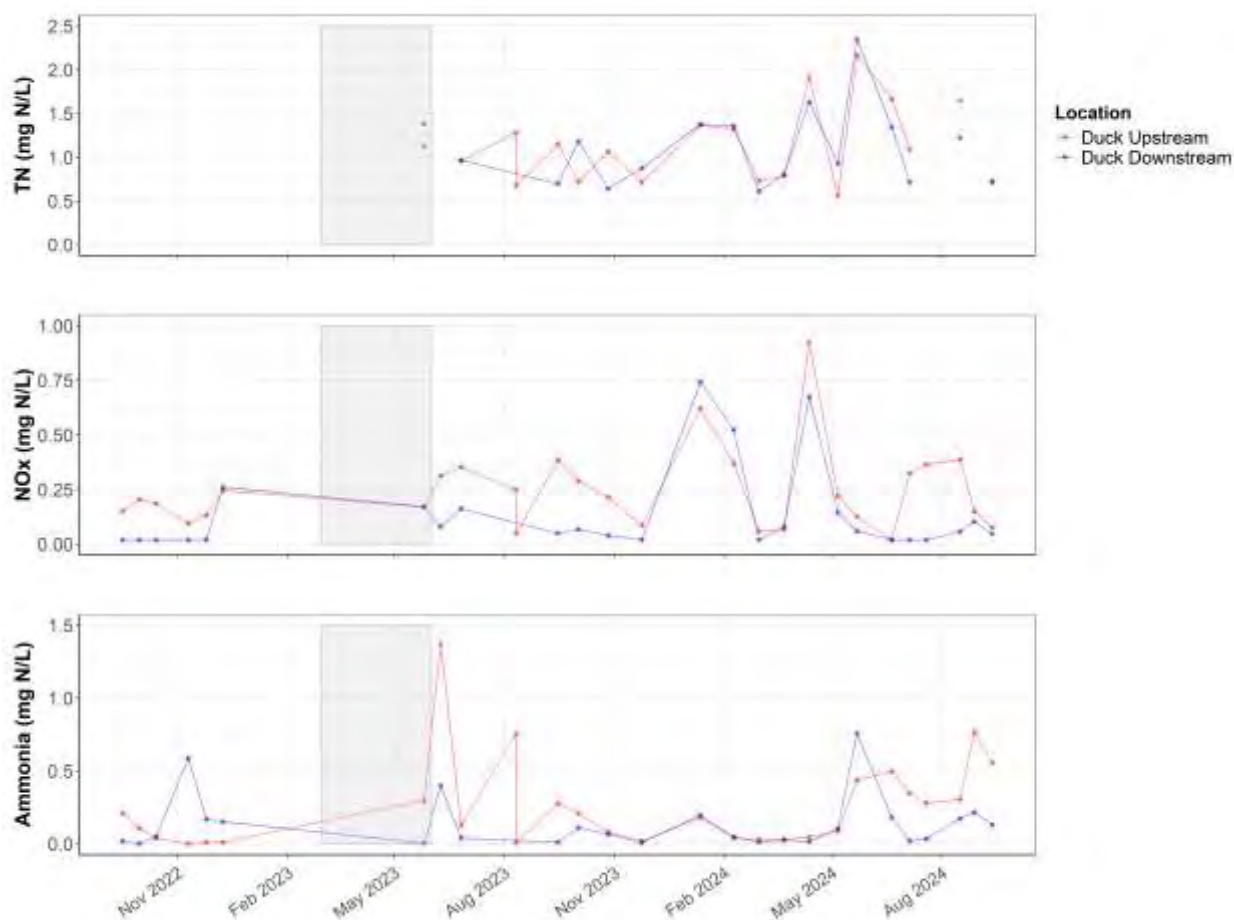


Figure 138. Time series of nitrite+nitrate (NO_x, top panel) total ammonium nitrogen (NH₄-N, middle panel), and total nitrogen (TN, bottom panel) concentrations in surface water samples collected at the Duck and Otter Creek Wetland and Stream Restoration Project from 2022 to 2024. Each symbol represents one sample point and colors denote the sampling locations as indicated in the legend. Values below detection limit were replaced with zero. Gray vertical lines indicate the start of a water year (Oct 1–Sep 30) and the period shaded in gray (March through June 2023) denotes the approximate dates of construction.

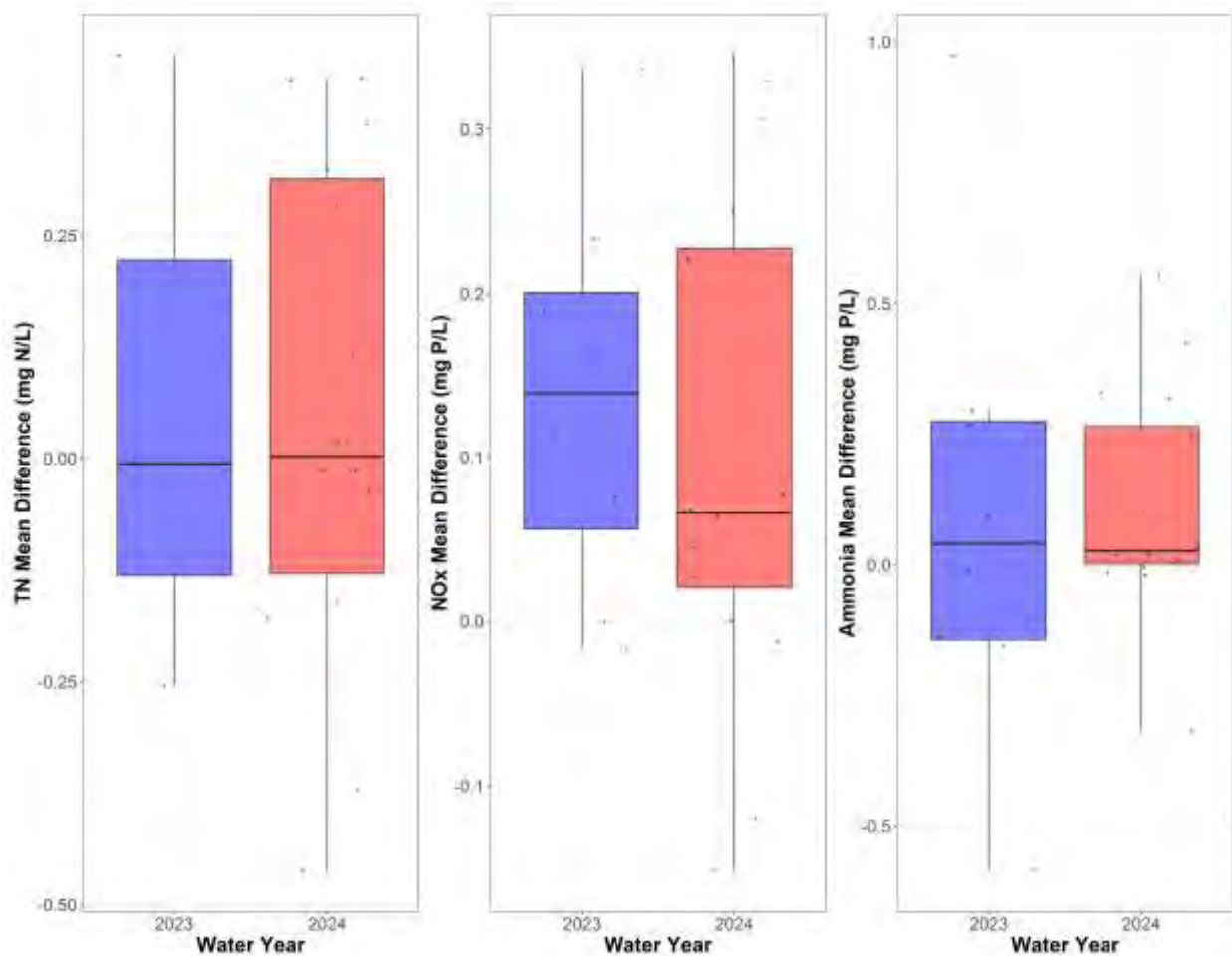


Figure 139. Mean ($\pm$ SD) difference in total ammonium nitrogen ($\text{NH}_4\text{-N}$), Nitrite+nitrate (NO_x), and total nitrogen (TN) concentrations in surface water samples between upstream and downstream sites collected at the Duck and Otter Creek Wetland and Stream Restoration Project for water years 2023 and 2024. Positive values denote wetland nutrient retention and negative values indicate nutrient release.

Surface Water Hydrology and Nutrients

Water levels at the Project are monitored using a permanent staff gauge that was installed before construction at the downstream monitoring station. Since construction ended in June 2023, water levels within the Project were observed to be lower than the staff gauge for the majority (76 %) of Project visits, suggesting that the wetland could retain and process higher volumes of water than what has been typically observed. This suggests that the Project's design has been successful in slowing flow and retaining water, but lower water levels may also be due to decreased precipitation in Water Year (WY) 2024 relative to WY 2023. No notable high flow events have been sampled for this Project to date.

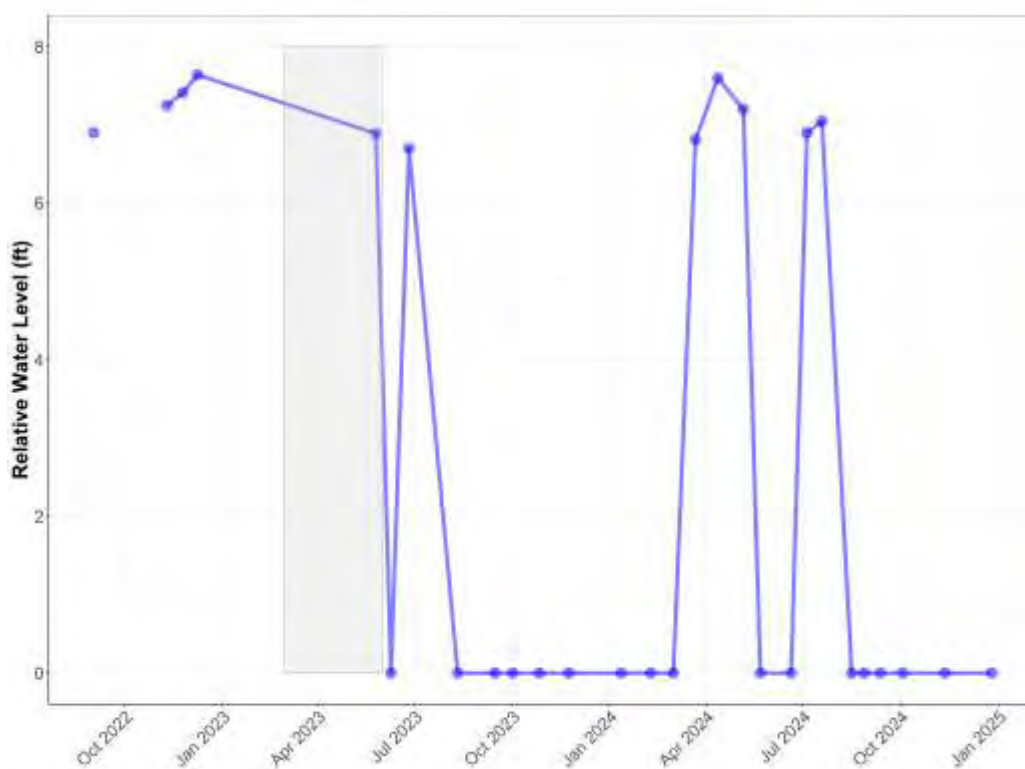


Figure 140. Time series of discrete, manually measured water levels at the Duck and Otter Creek Wetland and Stream Restoration Project. Water levels were measured approximately monthly from 2022 to 2024 via a permanent staff gauge installed at the downstream monitoring location. Each circle represents one measurement. Measurements of zero indicate that water level was below the gauge. Gray vertical lines indicate the start of a water year (Oct 1–Sep 30) and the period shaded in gray (March through June 2023) denotes the approximate dates of construction.

Soil Nutrient Status and Processes

There is no soil data available for this Project.

Next Steps to Strengthen Understanding

Current monitoring data based on concentrations alone suggest that the wetland is retaining some phosphorus and relatively less nitrogen. However, flow measurements are needed to reliably assess the volume of water received and, therefore, nutrient load. Additionally, no significant high-flow events have been sampled for the Project, and event-based storm sampling should be prioritized during subsequent monitoring to characterize the wetland's nutrient filtration and loading over a larger range of hydrological regimes.

North Ridge Hunt Club Wetland Restoration (NORR)

Project Description

Ottawa County | Packer Creek Watershed

Project size: 23 Acres

Partner: Ducks Unlimited

The hydrology of this Project is actively managed. This Project has 23 acres of restored wetland consisting of three wetland pools: Center, East, and West. Water inputs come from tile drainage in the farm field to the north flowing into the “L” shaped ditch around the wetland site. The pump at the southern point of the ditch pumps ditch water into the wetland pools. Water outflows from the Project through a WLCS to Packer Creek. A hydrologic event at this Project is operationally defined as a pumping event where water is actively pumped from the drainage ditch into the wetland pools.



Figure 141. Aerial image showing surface water flow and sampling locations for the North Ridge Hunt Club Wetland Restoration Project. Blue arrows indicate direction of surface water flow. Dots represent geographic base crew sampling locations, which are grouped by Project features (fill color) where relevant. Text annotations provide additional context about the Project's watershed connection or other important features.

Management Considerations

The North Ridge Hunt Club Wetland Restoration Project (hereafter North Ridge Project) has potential for nutrient reduction because water is pumped into the wetland from a ditch that receives agricultural runoff. The North Ridge Project is a privately owned property in Ottawa County, Ohio that is actively managed to support wildlife habitat and reduce nutrient loads to Packer Creek. Tile drainage from the surrounding agricultural land is directed into a ditch that borders the Project on the northern and eastern sides. Typically, water is pumped into the North Ridge Project when the ditch fills with runoff and is released into Packer Creek through a water level control structure (WLCS) when the manager lowers it at least four days after water is pumped in. These management actions trigger a hydrologic event, which is defined at this Project as the adjustment or activation of a WLCS that alters water flow speed and/or direction. Given the importance of water level and connectivity information to determine the potential of the wetland to retain nutrients, accurate and prompt reporting of water level management actions by the property owner allows researchers to document water

level and physicochemical changes in the wetland pool over time and in response to management. The information reported includes when the pump is activated, how long the pump is on, and when the WLCS is managed to allow the North Ridge Project to retain or release water.

In Water Year 2024, water was pumped into the North Ridge Project from the agricultural ditch throughout the year but was allowed to flow out to Packer Creek through the WLCS only between May 2024 and July 2024. The pump automatically activates when the ditch reaches a certain level in response to filling from runoff, especially following precipitation events, which allows the North Ridge Project to treat that runoff. Tile drainage from the surrounding farmland provides a steady source of water to pump into the wetland even during drought conditions. The water levels in the wetland are carefully managed to provide the proper habitat and food access to wildlife in the spring, which is also when agricultural runoff is likely to contain the most nutrients, however the ideal residence time to effectively reduce nutrient content in water has not been determined.

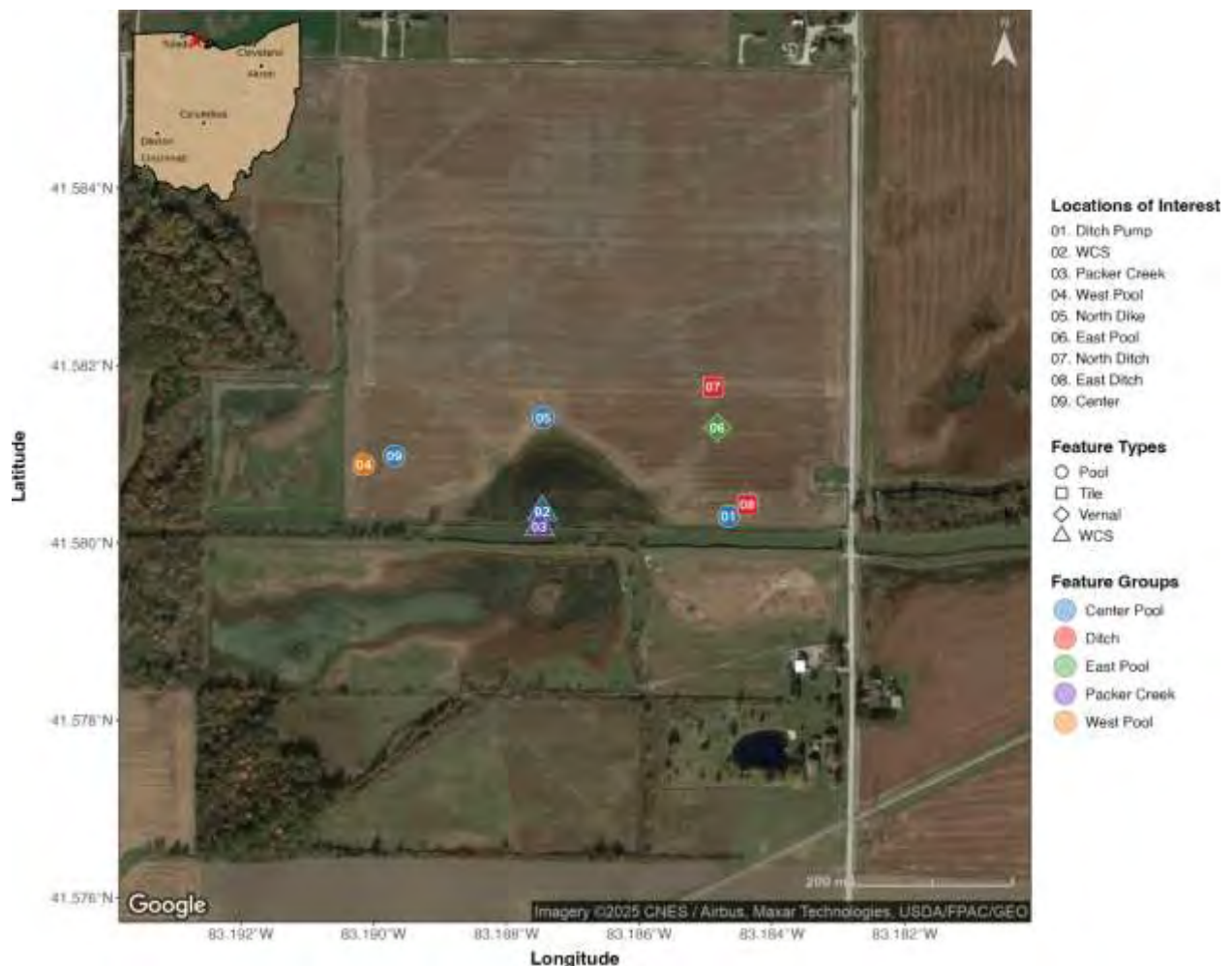


Figure 142. Aerial image of approximate locations of interest for water and soil sampling and discrete manual measurements of water depth and physicochemical parameters at North Ridge Hunt Club Wetland Restoration Project during water year 2024 (Oct 1, 2023–Sep 30, 2024). The legend provides the name of each sampling point. Different shapes denote the

types of wetland features represented by the locations of interest. If present, different colors represent locations of interest that belong to a group or complex of features (e.g., a treatment train).

Surface Water Hydrology and Nutrients

The North Ridge Project is a permanently inundated wetland that experiences seasonal water level patterns based on management by an individual property owner. Agricultural runoff is automatically pumped into the wetland from an adjacent tile-fed ditch when it reaches a certain level, creating relatively stable water levels at sampling locations within the ditch over time (North Ditch and East Ditch; Figure 143). Runoff from the ditch first flows through the Ditch Pump before entering the Center Pool and may flow into the West Pool if water levels are exceptionally high. Water will remain in the wetland until it is released to Packer Creek through the stoplog water level control structure (WLCS) when the water level exceeds the height of the stoplogs within the structure at a given time.

Water levels increased within the wetland in November 2023 and remained high through December 2024, then steadily declined (Center Pool, Figure 140). Agricultural runoff containing increased concentrations of total phosphorus (TP), total nitrogen (TN), total ammonium nitrogen (NH₄-N) was present in the agricultural ditches in October 2023 (Figure 144, Figure 145, Figure 146, Supplemental Information). . Similarly to previous years, dissolved oxygen reached the lowest annual point at all sampling locations in September and October of 2023, before increasing throughout the year as water flow resumed outside and within the wetland (Supplemental Information).

Center Pool water levels decreased when water was released into Packer Creek and considerably less water was pumped in from the ditch from May to July 2024 (Figure 143). TP, DRP, TN, nitrite+nitrate (NO_x), and NH₄-N concentrations increased in July 2024 in the East Ditch, as well as in Packer Creek (Figure 144, Figure 145, Figure 146, Figure 147; Supplemental Information). An increase in concentrations of TP, TN, NO_x, and NH₄-N, were also observed at the Ditch Pump sampling location at the same time (July 2024), indicating that the water was pumped into the wetland, however the DRP concentration increased at the north dike rather than in the Ditch Pump (Figure 144, Figure 145, Figure 146, Figure 147, Supplemental Information). Although water levels fluctuated over time in the West Pool and center of the Center Pool, nutrient concentrations did not vary greatly over time; these two locations are the farthest locations from the inlet (pump) and beyond the outlet WLCS, so it is possible that nutrients became adsorbed to sediments or were taken up by organisms by the time water reached those points.

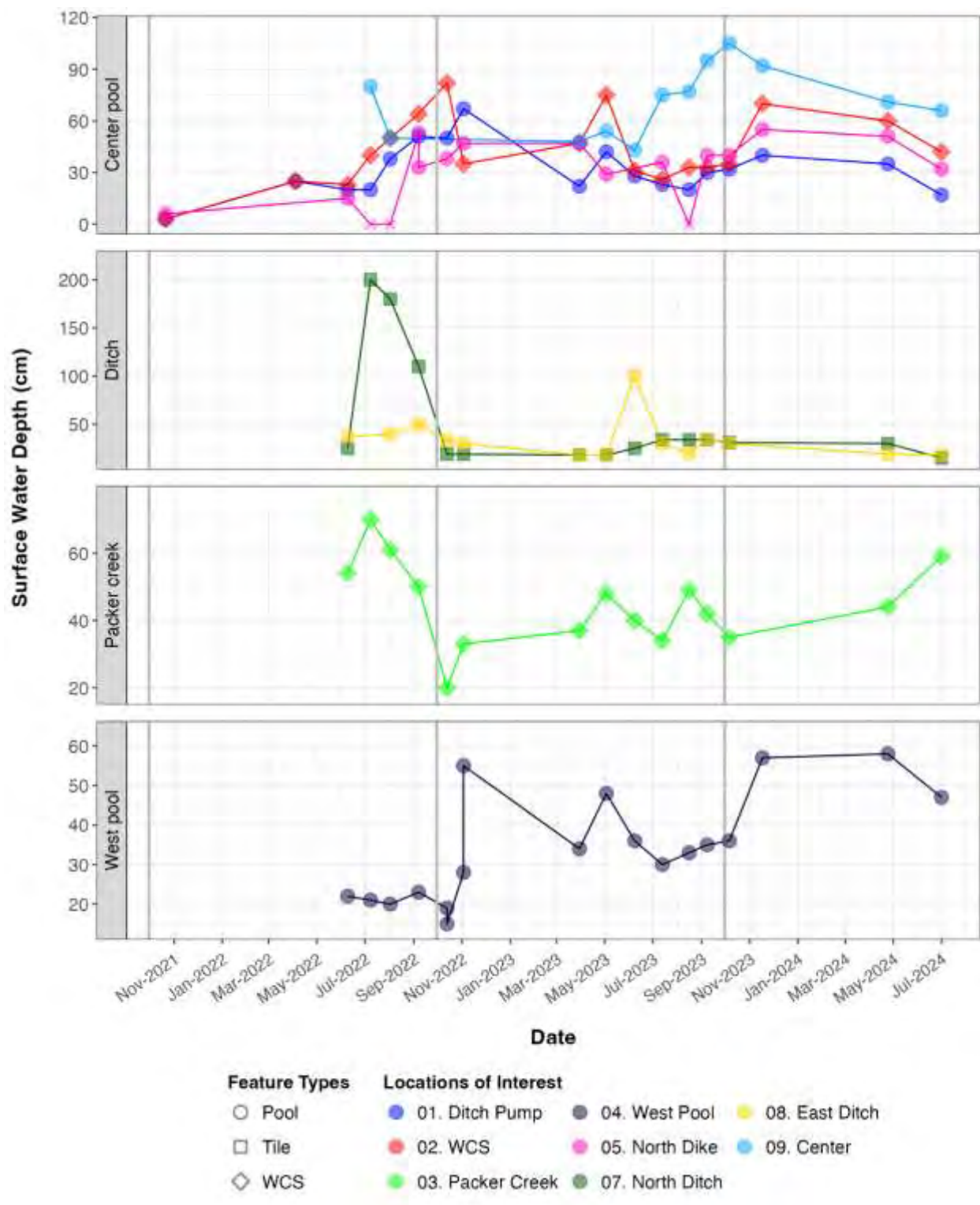


Figure 143. Time series of discrete, manually measured surface water depth at the North Ridge Hunt Club Wetland Restoration Project. Depths were measured approximately monthly. Each point represents one measurement and colors denote the locations of interest, as indicated in the legend. Open symbols indicate samples that were collected during a hydrologic event (e.g., storm event) and filled symbols denote samples collected during baseflow. Crosses (x) represent instances when no surface water was detected during the

visit. If present, different shapes denote the types of wetland features represented by the locations of interest. Gray vertical lines indicate the start of a water year (Oct 1–Sep 30).

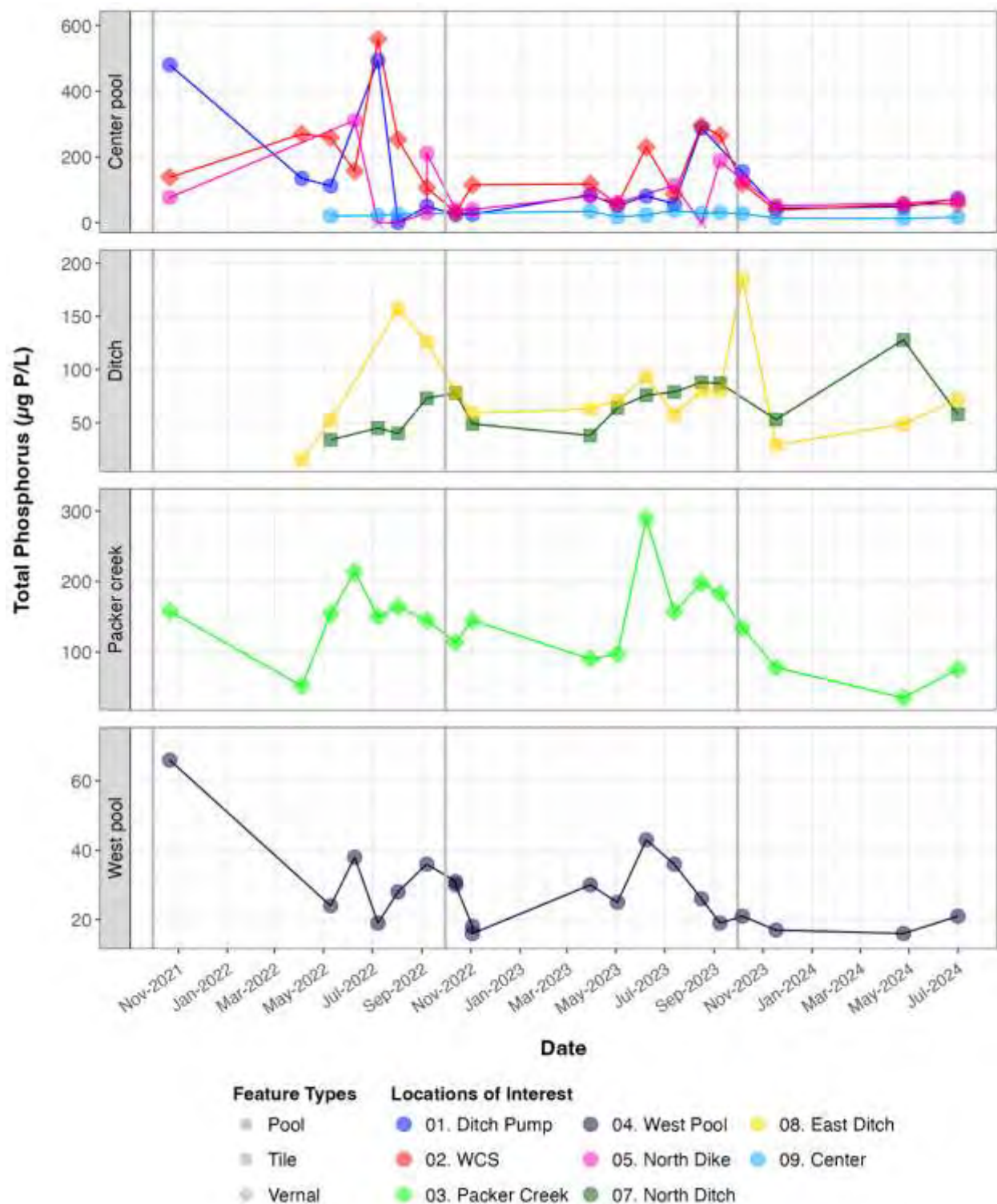


Figure 144. Time series of total phosphorus (TP) concentrations in surface water samples collected at the North Ridge Hunt Club Wetland Restoration Project. Values below the detection limit of the analytical equipment were replaced with half the value of the detection limit. Each point represents one measurement, and colors denote the locations of interest, as indicated in the legend. Open symbols indicate that measurements were collected during a

hydrologic event (e.g., storm event) and filled symbols denote measurements collected during baseflow. Crosses (×) represent instances when no surface water was detected during the visit. If present, different shapes denote the types of wetland features represented by the locations of interest. Gray vertical lines indicate the start of a water year (Oct 1–Sep 30).

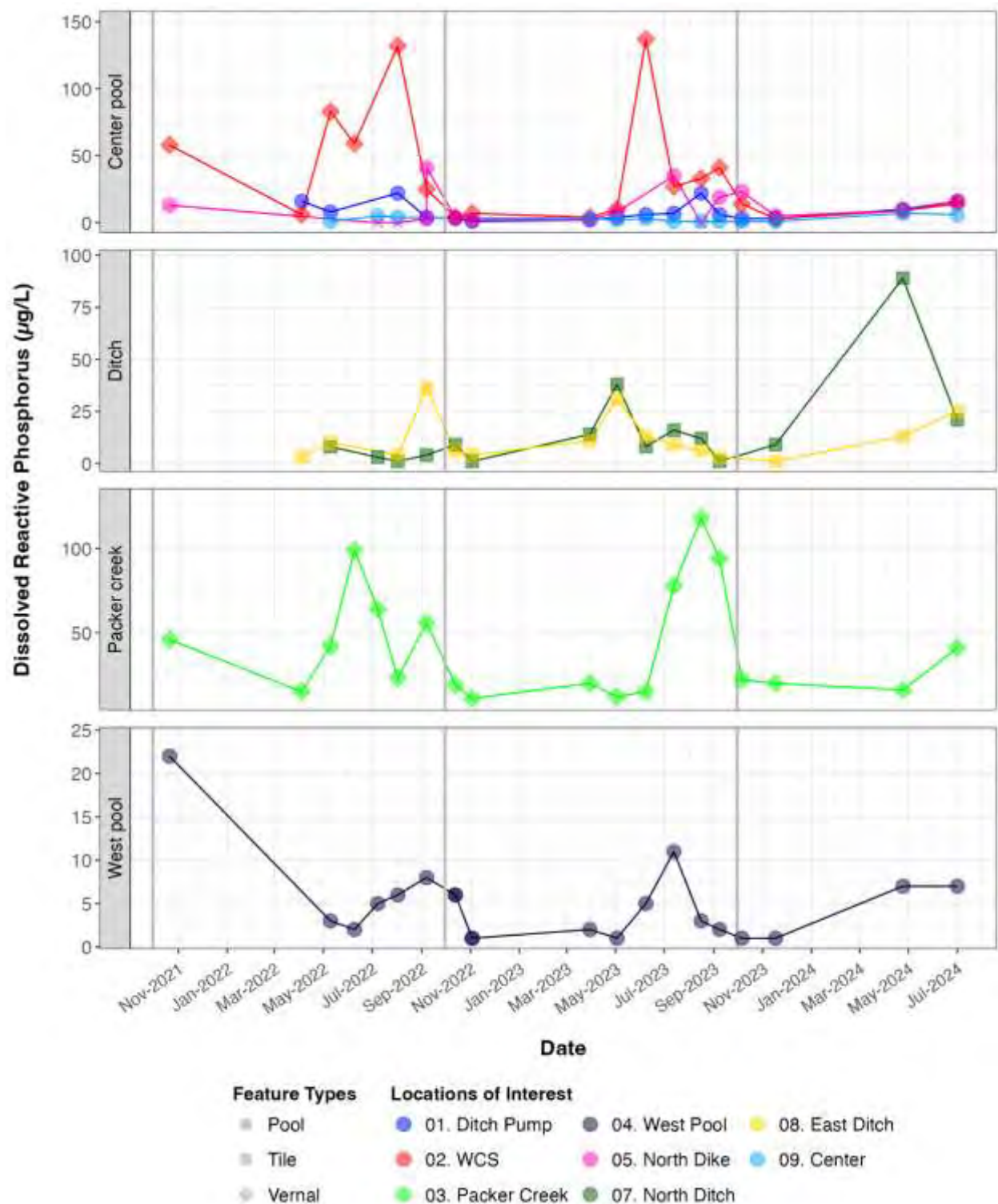


Figure 145. Time series of dissolved reactive phosphorus (DRP) concentrations in surface water samples collected at the North Ridge Hunt Club Wetland Restoration Project. Values

below the detection limit of the analytical equipment were replaced with half the value of the detection limit. Each point represents one measurement, and colors denote the locations of interest, as indicated in the legend. Open symbols indicate that measurements were collected during a hydrologic event (e.g., storm event) and filled symbols denote measurements collected during baseflow. Crosses (×) represent instances when no surface water was detected during the visit. If present, different shapes denote the types of wetland features represented by the locations of interest. Gray vertical lines indicate the start of a water year (Oct 1–Sep 30).

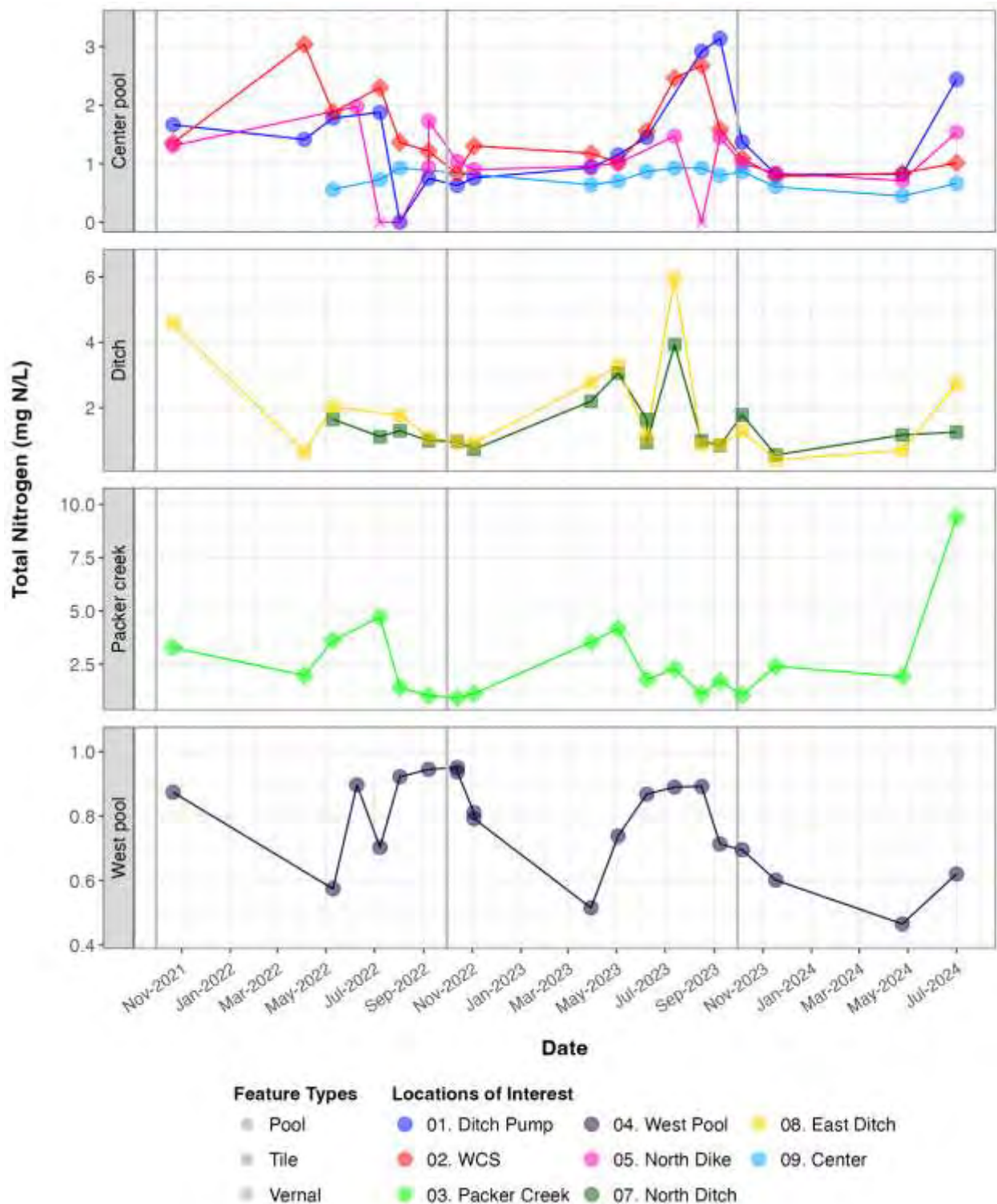


Figure 146. Time series of total nitrogen (TN) concentrations in surface water samples collected at the North Ridge Hunt Club Wetland Restoration Project. Values below the detection limit of the analytical equipment were replaced with half the value of the detection limit. Each point represents one measurement, and colors denote the locations of interest, as indicated in the legend. Open symbols indicate that measurements were collected during a hydrologic event (e.g., storm event) and filled symbols denote measurements collected during baseflow. Crosses (x) represent instances when no surface water was detected during the

visit. If present, different shapes denote the types of wetland features represented by the locations of interest. Gray vertical lines indicate the start of a water year (Oct 1–Sep 30).

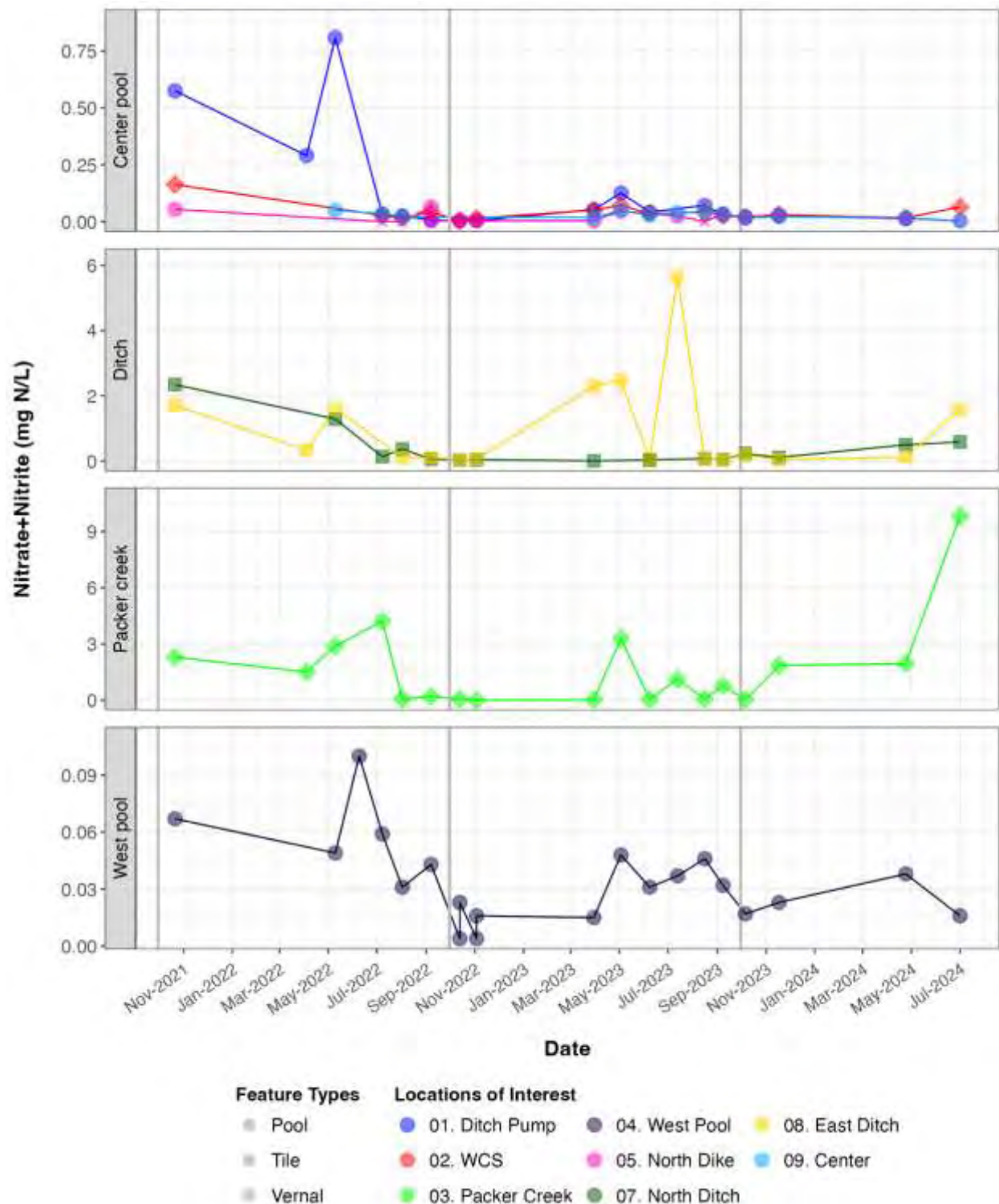


Figure 147. Time series of Nitrite+nitrate (NO_x) concentrations in surface water samples collected at the North Ridge Hunt Club Wetland Restoration Project. Values below the detection limit of the analytical equipment were replaced with half the value of the detection limit. Each point represents one measurement, and colors denote the locations of interest, as

indicated in the legend. Open symbols indicate that measurements were collected during a hydrologic event (e.g., storm event) and filled symbols denote measurements collected during baseflow. Crosses (×) represent instances when no surface water was detected during the visit. If present, different shapes denote the types of wetland features represented by the locations of interest. Gray vertical lines indicate the start of a water year (Oct 1–Sep 30).

Soil Nutrient Status and Processes

Soil phosphate sorption capacity (SPSC) values at all sampling locations within the North Ridge Project were positive in Water Year 2024, indicating a capacity to sorb additional phosphate (Figure 148). Areas with highest values (and therefore greatest capacity to sorb additional phosphate) were within the West Pool along the western edge of the Project. The lowest value was observed at the water level control structure (WLCS) along the southern edge of the Project where water is released into Packer Creek, indicating a limited capacity of soil in that area to sorb additional phosphate. SPSC values at most locations have tended to increase over time from 2022 to 2024, regardless of changes in water level. Across the Project, soil total nitrogen and total phosphorus were lowest in the center of the West Pool and greatest near the WLCS (Supplemental Information).

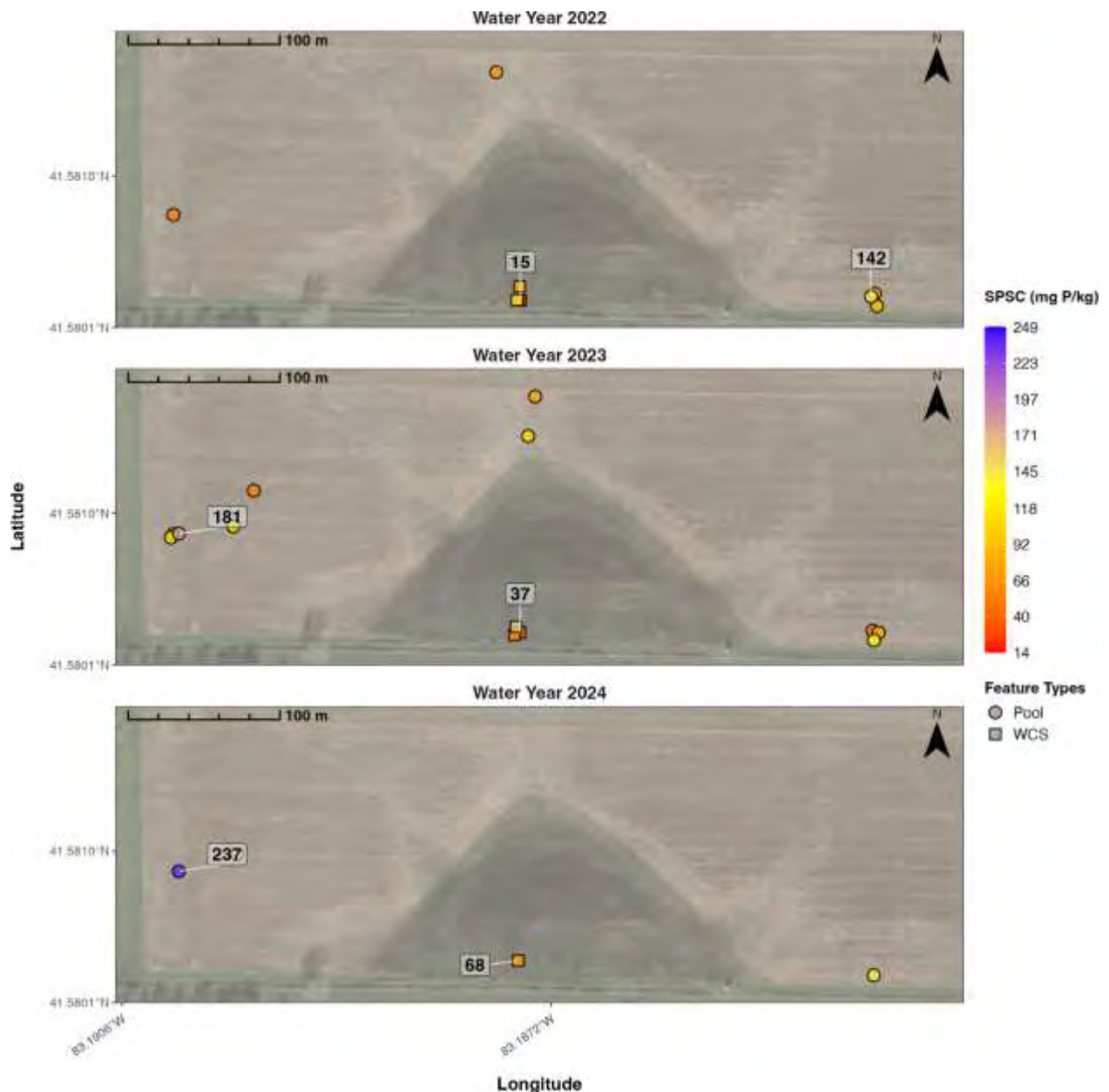


Figure 148. Soil Phosphate Sorption Capacity (SPSC) throughout the North Ridge Hunt Club Wetland Restoration Project. Each point denotes a soil sample (0–5 cm) and different shapes indicate the wetland feature type, as shown in the legend. Colors indicate the SPSC value of each sample relative to the overall range of values observed at the wetland project, as shown in the color bar. Each panel shows the soil samples collected during a respective water year (Oct 1–Sep 30), along with the minimum and maximum SPSC values observed during a given water year. Negative SPSC values indicate the potential for soils to release phosphate, while positive values indicate soils have capacity to sorb phosphate, based on Mehlich-3 extractions of phosphate, iron, and aluminum.

Next Steps to Strengthen Understanding

Researchers need more data across time, particularly during hydrologic events, to improve nutrient budget calculations in Water Year (WY) 2025. Sampling during hydrologic events, defined at the actively managed North Ridge Project as the activation or modification of a

water level control structure that alters the direction or speed of flow, will be added to the sampling approach in WY 2025. This will allow researchers to sample during hydrologic events and analyze the nutrient content and physical characteristics of water entering and leaving the wetland. Difficulty in identifying hydrologic events has prevented event sampling in the past, but efforts are being made to improve communication between managers and researchers to better understand water flow patterns at this Project. Researchers also need specialized data, specifically the measurement of flow through the agricultural pump, to calculate water inputs into the wetland. Water inputs from the pump will be calculated on, at minimum, a monthly basis, when combined with regular updates on pump usage from both managers and researchers to improve nutrient budget estimates.

Ottawa National Wildlife Refuge Wetland Reconnection Project (OTTN)

Project Description

Lucas County | Crane Creek Estuary | Coastal

Project size: 586.3 Acres

Partner: Ottawa Soil & Water Conservation District

The hydrology at this Project is actively managed. This Project has 586 acres of restored wetland, and its hydrologic features consist of a northern portion (Pool 3) and a southern portion (MS5), separated by Veler Road and its adjacent ditch. Ditch water flows west to east and can enter the northern and southern portions of the wetland complex through WLCs. Water is released back into Veler Ditch or out into Crane Creek (ultimately outflowing directly to Lake Erie) during overflow events or in instances where water level is higher in the wetlands and the WLCs gates are opened. A hydrologic event at this Project is operationally defined as an overflow event where water flows between the wetland units and Veler Ditch after WLCs are opened.

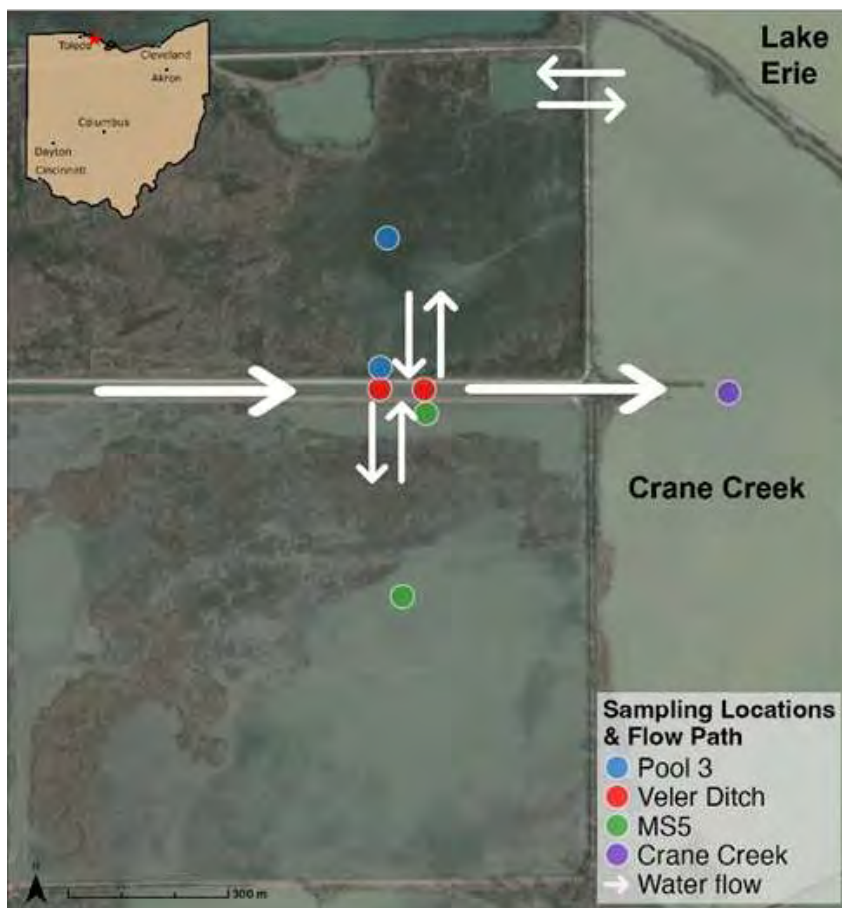


Figure 149. Aerial image showing surface water flow and sampling locations for the Ottawa National Wildlife Refuge Wetland Reconnection Project. Blue arrows indicate direction of surface water flow. Dots represent geographic base crew sampling locations, which are grouped by Project features (fill color) where relevant. Text annotations provide additional context about the Project's watershed connection or other important features.

Management Considerations

The source water inputs and resulting nutrient reduction impact of the Ottawa National Wildlife Refuge Wetland Reconnection Project (hereafter Ottawa NWR Project) have been limited by management that has prioritized infrastructure maintenance and enhancing wildlife habitat in the Water Year 2024. The Ottawa NWR Project is an actively managed coastal Project located within the Ottawa National Wildlife Refuge, near the point where Crane Creek flows into Lake Erie. The Ottawa NWR Project consists of two separate wetland units surrounded by dikes, which hydrologically isolate them from the surrounding landscape except through two water level control structures (WLCS) that allow water exchange to a ditch connected to Crane Creek: one WLCS in the northern unit (Pool 3) and another in the southern unit (MS5).

A federal agency partner (U.S. Fish and Wildlife Service) typically manages water levels in the Ottawa NWR Project with the goal of providing wildlife habitat, creating a seasonal pattern in water levels regardless of external weather conditions. Water was fully removed from MS5 in May 2024 for dike maintenance. Water was added back to MS5 in September 2024 for waterfowl migration. The wetland could be managed more intentionally for nutrient sequestration by “cycling” nutrient-rich water from the ditch through the wetland once or a few times per year, especially during the spring when nutrient sequestration is most impactful for preventing harmful algal blooms in nearby Lake Erie. However, there may be trade-offs between nutrient sequestration actions, wildlife habitat considerations, and needs for maintenance and construction at the Ottawa NWR Project.

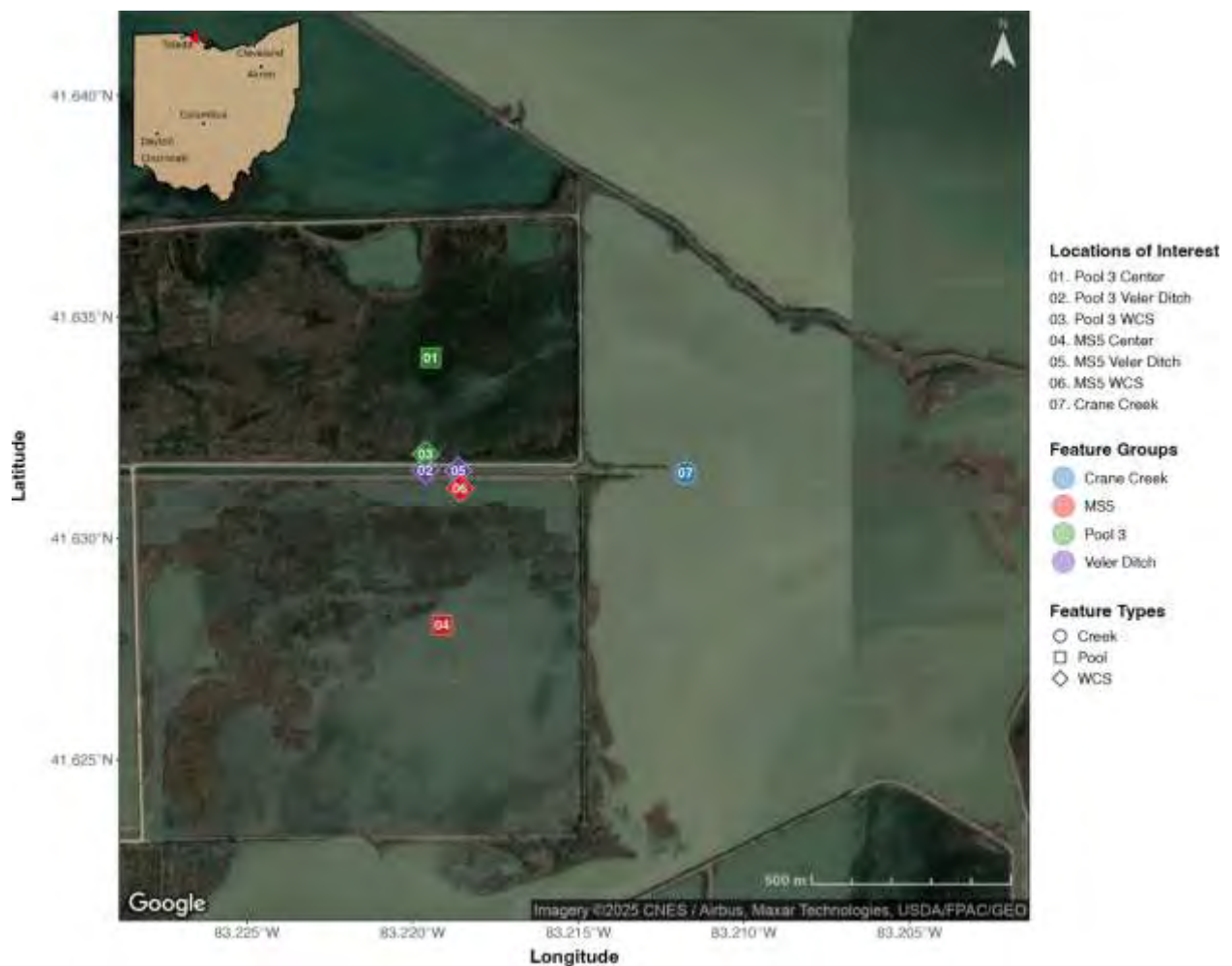


Figure 150. Aerial image of approximate locations of interest for water and soil sampling and discrete manual measurements of water depth and physicochemical parameters at Ottawa National Wildlife Refuge Wetland Reconnections Project during water year 2024 (Oct 1, 2023–Sep 30, 2024). The legend provides the name of each sampling point. Different shapes denote the types of wetland features represented by the locations of interest. If present, different colors represent locations of interest that belong to a group or complex of features (e.g., a treatment train).

Surface Water Hydrology and Nutrients

The full drawdown of the southern wetland unit (MS5) in May 2024 completely dried the unit at the MS5 sampling location by late May while the northern wetland unit (Pool 3) remained inundated throughout the year (Figure 151). The ditch that flows between the units and connects to Crane Creek (Veler Ditch) had high concentrations of total phosphorus (TP), dissolved reactive phosphorus (DRP), and total nitrogen (TN), in November 2023 relative to other sampling locations (Figure 152, Figure 153, Figure 154). There was no concurrent increase in nutrient concentrations at sampling locations in either wetland unit, indicating the nutrient-rich runoff was not captured by the Project because the closed water level control structures isolated the units from Veler Ditch. There was some water exchanged between Veler Ditch and Pool 3 between May and July 2024, suggested by concurrent increases in turbidity, decreases in dissolved oxygen, and increases in TP, DRP, TN, and nitrite+nitrate

concentrations in both areas (Supplemental Information, Figure 152, Figure 153, Figure 154, Figure 155).

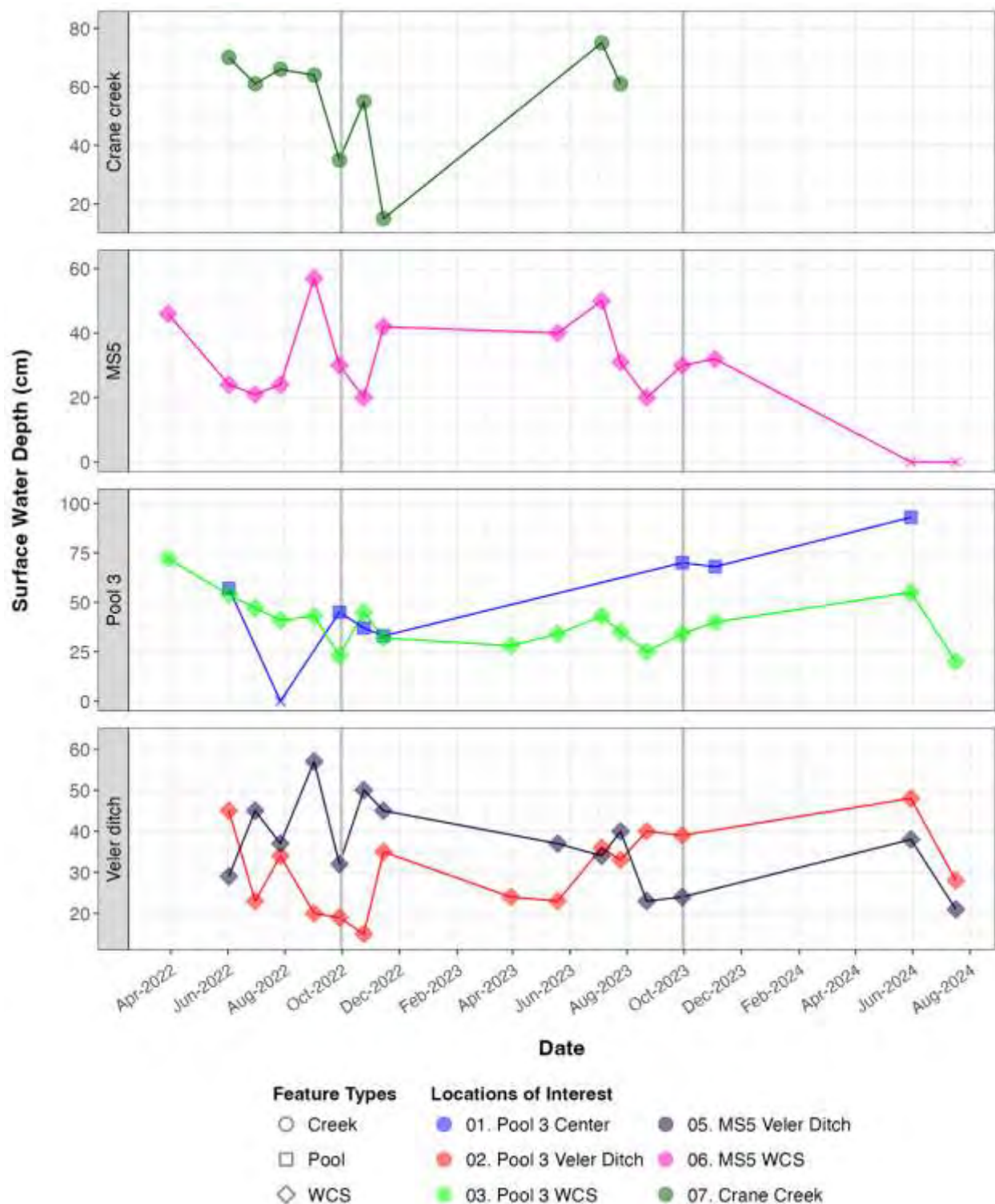


Figure 151. Time series of discrete, manually measured surface water depth at the Ottawa National Wildlife Refuge Wetland Reconnections Project. Depths were measured approximately monthly. Each point represents one measurement and colors denote the locations of interest, as indicated in the legend. Open symbols indicate samples that were collected during a hydrologic event (e.g., storm event) and filled symbols denote samples

collected during baseflow. Crosses (×) represent instances when no surface water was detected during the visit. If present, different shapes denote the types of wetland features represented by the locations of interest. Gray vertical lines indicate the start of a water year (Oct 1–Sep 30).

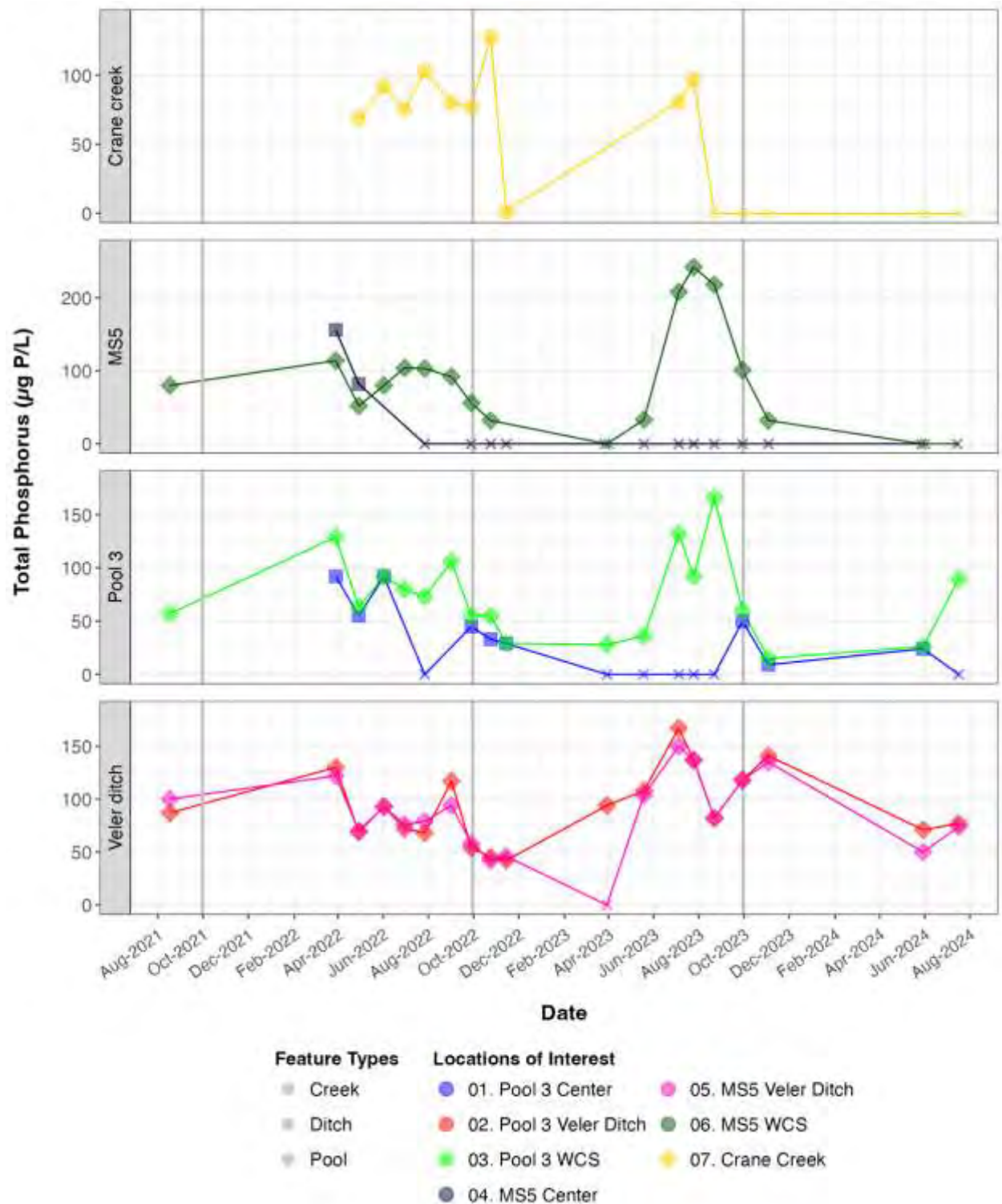


Figure 152. Time series of total phosphorus (TP) concentrations in surface water samples collected at the Ottawa National Wildlife Refuge Wetland Reconnections Project. Values

below the detection limit of the analytical equipment were replaced with half the value of the detection limit. Each point represents one measurement, and colors denote the locations of interest, as indicated in the legend. Open symbols indicate that measurements were collected during a hydrologic event (e.g., storm event) and filled symbols denote measurements collected during baseflow. Crosses (×) represent instances when no surface water was detected during the visit. If present, different shapes denote the types of wetland features represented by the locations of interest. Gray vertical lines indicate the start of a water year (Oct 1–Sep 30).

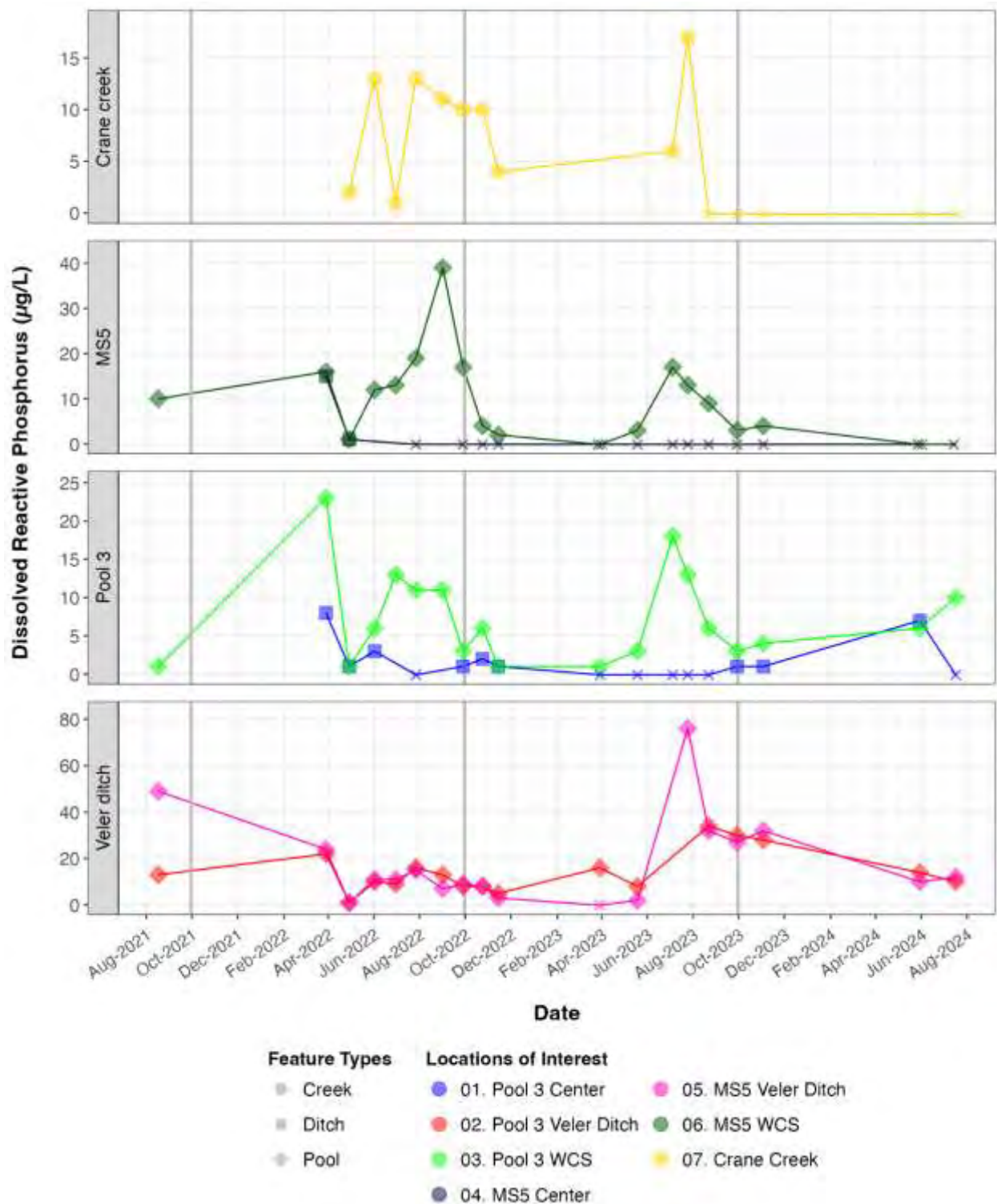


Figure 153. Time series of dissolved reactive phosphorus (DRP) concentrations in surface water samples collected at the Ottawa National Wildlife Refuge Wetland Reconnections Project. Values below the detection limit of the analytical equipment were replaced with half the value of the detection limit. Each point represents one measurement, and colors denote the locations of interest, as indicated in the legend. Open symbols indicate that measurements were collected during a hydrologic event (e.g., storm event) and filled symbols denote measurements collected during baseflow. Crosses (x) represent instances when no surface

water was detected during the visit. If present, different shapes denote the types of wetland features represented by the locations of interest. Gray vertical lines indicate the start of a water year (Oct 1–Sep 30).

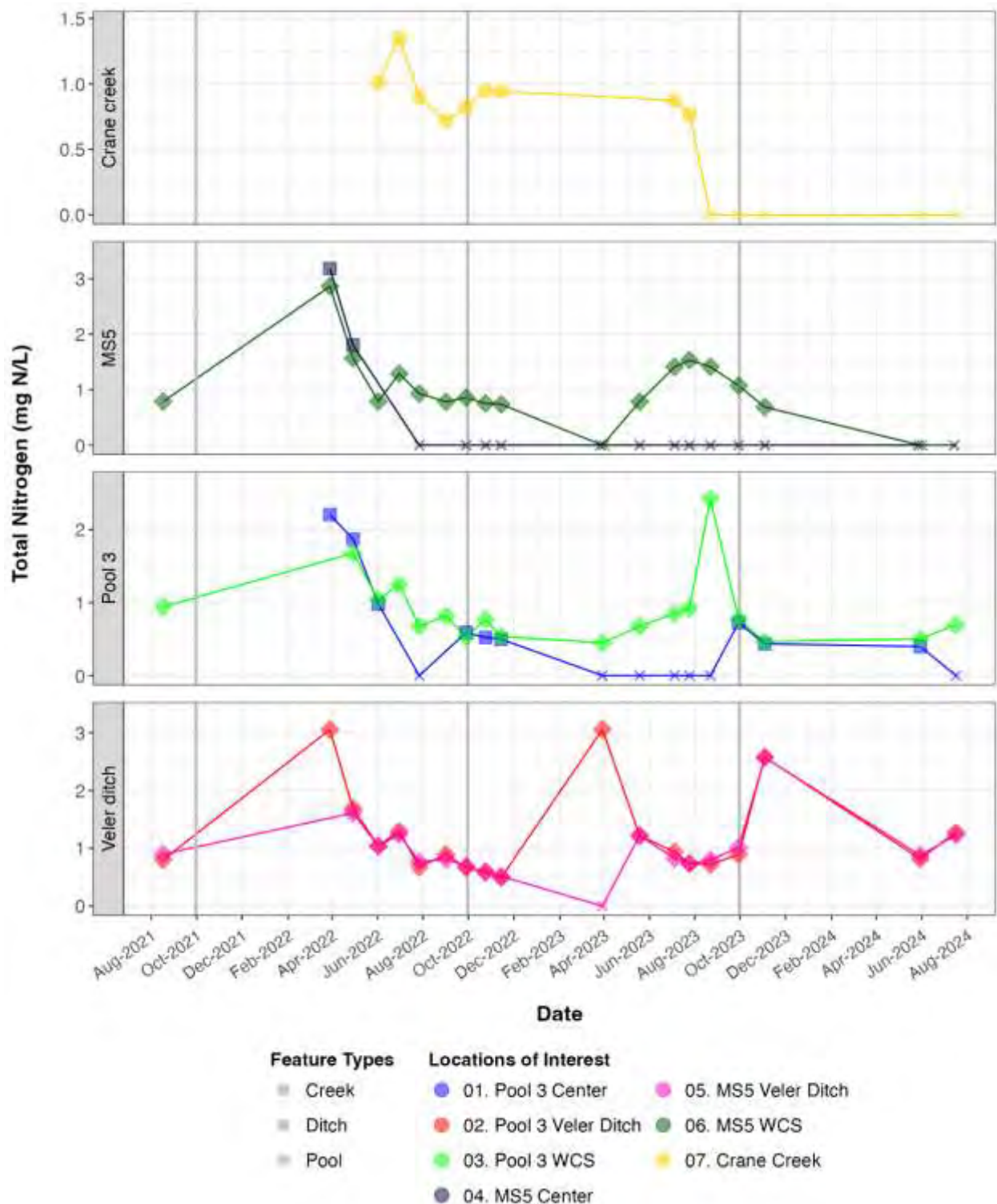


Figure 154. Time series of total nitrogen (TN) concentrations in surface water samples collected at the Ottawa National Wildlife Refuge Wetland Reconnections Project. Values below the detection limit of the analytical equipment were replaced with half the value of the

detection limit. Each point represents one measurement, and colors denote the locations of interest, as indicated in the legend. Open symbols indicate that measurements were collected during a hydrologic event (e.g., storm event) and filled symbols denote measurements collected during baseflow. Crosses (×) represent instances when no surface water was detected during the visit. If present, different shapes denote the types of wetland features represented by the locations of interest. Gray vertical lines indicate the start of a water year (Oct 1–Sep 30).

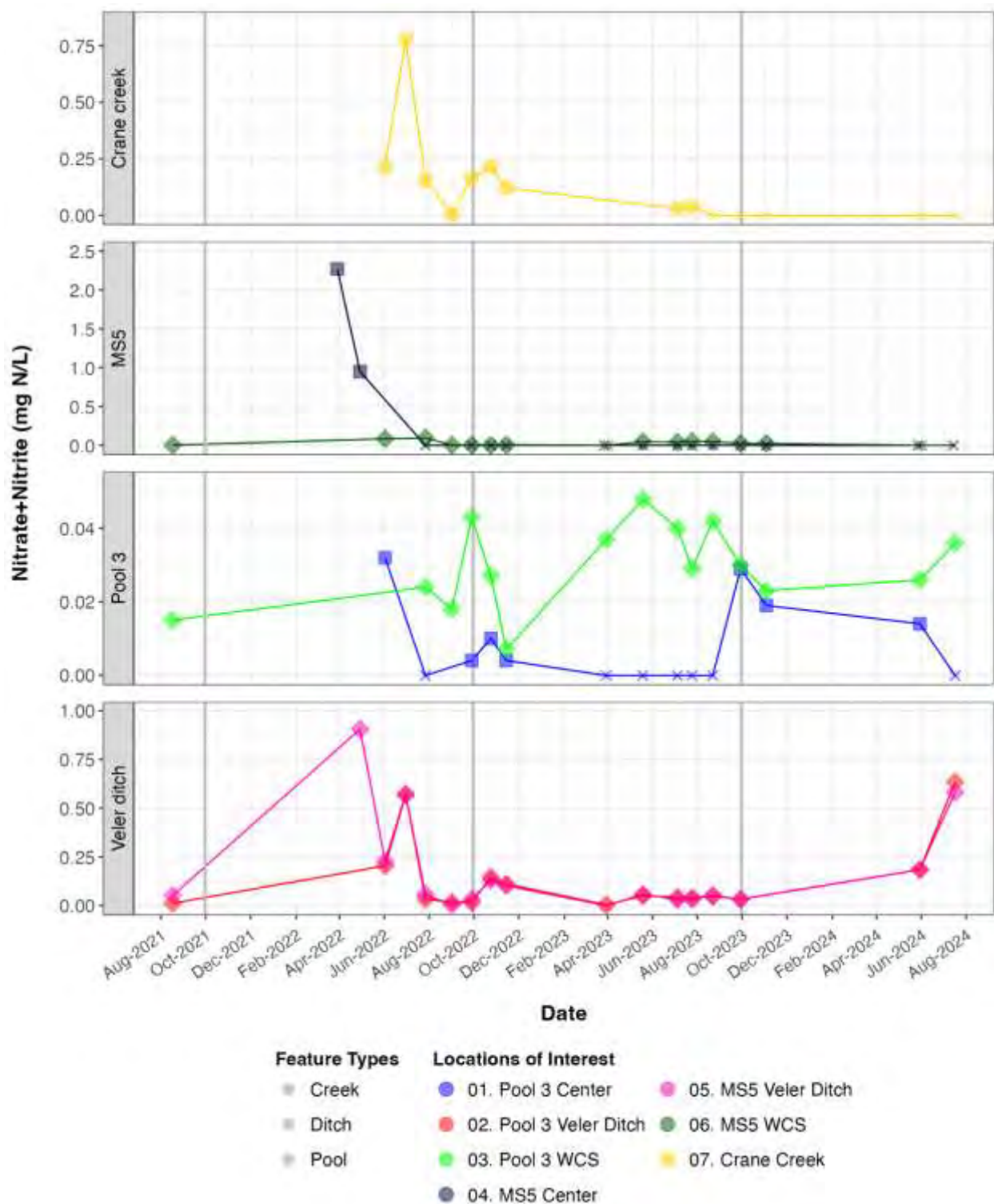


Figure 155. Time series of Nitrite+nitrate (NO_x) concentrations in surface water samples collected at the Ottawa National Wildlife Refuge Wetland Reconnections Project. Values below the detection limit of the analytical equipment were replaced with half the value of the detection limit. Each point represents one measurement, and colors denote the locations of interest, as indicated in the legend. Open symbols indicate that measurements were collected during a hydrologic event (e.g., storm event) and filled symbols denote measurements collected during baseflow. Crosses (x) represent instances when no surface water was

detected during the visit. If present, different shapes denote the types of wetland features represented by the locations of interest. Gray vertical lines indicate the start of a water year (Oct 1–Sep 30).

Soil Nutrient Status and Processes

There is no data available for Water Year (WY) 2024 due to a delay in soil sample analysis. However, soil samples collected during WY 2023 within Pool 3, MS5, and Veler Ditch near the two water level control structures during have been analyzed. Soil phosphate sorption capacity (SPSC) values at all sampling locations within the Ottawa NWR Project were positive in those samples, indicating a capacity to sorb additional phosphate that entered the Project after August of 2023 (Figure 156). Generally, sampling locations within Pool 3 (northern portion of the Project) had greater SPSC than in MS5 (southern portion of the Project; Figure 156).



Figure 156. Soil Phosphate Sorption Capacity (SPSC) throughout the Ottawa National Wildlife Refuge Wetland Reconnections Project. Each point denotes a soil sample (0–5 cm) and different shapes indicate the wetland feature type, as shown in the legend. Colors indicate the SPSC value of each sample relative to the overall range of values observed at the wetland project, as shown in the color bar. Each panel shows the soil samples collected during a respective water year (Oct 1–Sep 30), along with the minimum and maximum SPSC values observed during a given water year. Negative SPSC values indicate the potential for soils to release phosphate, while positive values indicate soils have capacity to sorb phosphate, based on Mehlich-3 extractions of phosphate, iron, and aluminum.

Next Steps to Strengthen Understanding

Researchers need more data across time, particularly during hydrologic events, to improve nutrient budget calculations in Water Year (WY) 2025. Sampling during hydrologic events, defined at the actively managed Ottawa NWR as the activation or modification of a water level control structure that alters the direction or speed of flow, will be added to the sampling

approach in WY 2025. This will allow researchers to analyze the nutrient content and physical characteristics of water entering and leaving the wetland to supplement current understanding of seasonal conditions within the wetlands between hydrologic events. Difficulty in identifying hydrologic events has prevented event sampling in the past, but efforts are being made to improve communication between managers and researchers to better understand water flow patterns at this Project.

Northeast (Kent State University)

Projects in northeast region (Figure 1) are primarily monitored by the geographic base crew centered at Kent State University (Lauren Kinsman-Costello, Principal Investigator).

Trumbull Creek H2Ohio (TRUC)

Project Description

Ashtabula County | Grand River Watershed

Project size: 30 acres

Partners: Stream + Wetlands Foundation

The hydrology at this Project is passively managed. The Project has 30 acres of restored wetland. Water enters as precipitation and moves slowly across constructed hummock-hollow microtopography towards the outlet at the north of the Project, ultimately flowing into a tributary of Mill Creek in the Grand River watershed. Although water generally flows south to north, there are no discrete flow paths within this Project. The outflow water level control structure is an Agri Drain which maintains the maximum height of the water in the wetland. A hydrologic event at this Project is operationally defined as > 1.3 cm of rain within 48 hours as tracked by the USGS weather station near Headlands State Park OH - 414514081174400¹¹.



Figure 157. Aerial image showing surface water flow and sampling locations for the Trumbull Creek H2Ohio Project. Blue arrows indicate direction of surface water flow. Dots represent geographic base crew sampling locations, which are grouped by Project features

¹¹ “Weather station near Headlands State Park OH - 414514081174400.” [waterdata.usgs.gov](https://waterdata.usgs.gov/monitoring-location/414514081174400/). U.S. Department of Interior. <https://waterdata.usgs.gov/monitoring-location/414514081174400/>

(fill color) where relevant. Text annotations provide additional context about the Project's watershed connection or other important features.

Management Considerations

The Trumbull Creek Project receives no major nutrient loads, and the primary nutrient retention benefit of the Project is its conversion from agricultural land use to wetland. The Project is located in the middle of a watershed divide between Mill Creek and Bronson Creek and is not directly connected to any streams, tile drain outlets, or other potential nutrient inputs. Precipitation is the primary input of water to the Project. The outflow is a passively managed water level control structure (WLCS). The WLCS has not been altered in any way since construction in 2021. Any future alterations to the WLCS set height or management style would change the nutrient storage capacity of the Project by altering the water retention capacity of the wetland.

Soil analysis indicates little to no evidence that this formerly agricultural area is vulnerable to releasing and exporting legacy P. However, there is some evidence of transient nutrient release from sediments into surface waters during precipitation-driven reflooding events. There is evidence from core incubation experiments that the soil near the outlet is sorbing phosphate at a rate of 0.103 mg/m²/day and may be filtering phosphorus during storm events. The drought conditions of 2024 decreased the likelihood of nutrient export as water levels were seldom high enough for water to leave the Project. If the Project were more connected to nutrient inputs, such as via tile inputs or a ditch or stream, its nutrient retention capabilities would increase.

Nutrient Budget Takeaways

The main nutrient benefit of the Trumbull Creek Project is its conversion from an agricultural field and mitigation as a nutrient source, preventing 19 ± 13 lbs. of phosphorus runoff per year. The Trumbull Creek Project receives no major nutrient loads because it is in the middle of a watershed divide, between Mill Creek and Bronson Creek, and is not directly connected to any nutrient inputs. Water at this Project is passively managed, and the primary input is precipitation. Little to no “new” nutrient inputs are filtered by this Project. Soils throughout the Project have moderate to high capacity to sorb phosphate, as suggested by soil phosphate sorption capacity values.



Figure 158. Aerial image of approximate location of sampling for water and soil samples and discrete manual measurements of water depth and physicochemical measurements at Trumbull Creek H2Ohio Project. The legend provides a brief description of each sampling location. Symbols denote the types of wetland features represented by the locations of interest.

Surface Water Hydrology and Nutrients

The Trumbull Creek wetland was designed so that water enters the Project via precipitation and moves slowly across the upland hummock-hollow microtopography towards the outlet at the north of the Project. The outflow water level control structure (WLCS) is an Agri Drain which passively maintains the maximum height of the water in the wetland. This WLCS has not been altered since the construction of the wetland in 2021. The upland pools (Hummock Pool and Borrow Pool 1 sampling locations) are shallower and retain less water than the lowland pools nearest the outlet (Borrow Pool 2 and WCS sampling locations). There was less precipitation in 2024 than in 2023, which allows researchers to compare how water levels in the Project react to varying precipitation regimes.

The Hummock Pool was completely dry several times throughout 2024, which never occurred in 2023. The temporal variation in water level in the Hummock Pool suggests it is most dependent on recent precipitation events for it to be inundated. (Figure 159). During a storm event that re-inundated the mostly dry Project in August 2024, researchers observed a spike in concentration in all three dissolved nutrients, dissolved reactive phosphorus (DRP),

nitrite+nitrate (NO_x), and total ammonium nitrogen ($\text{NH}_4\text{-N}$), within the Hummock Pool. This spike occurred in all monitored pools but was most pronounced in the Hummock Pool. These concentrations are the highest observed across the monitored period for each of the dissolved nutrients (Figure 160 & Figure 161).

Despite the temporary increase in depth during and immediately after the August 2024 storm, the water level in the Hummock Pool after this storm event was lower than any measured level in 2023, when there was more precipitation overall (Figure 159). Thus, the volume of this closed pool declined while at the same time nutrient concentrations (mass per volume) increased, suggesting a net input of nutrients (mass) to the pool, potentially via a flux (resuspension or diffusive) of nutrients from the sediment during and after reflooding. Researchers observed a positive flux of both DRP and ammonium from sediments into surface waters during experiments incubations from the upland portion of the Project (Borrow Pool 1 not the Hummock Pool; Figure 162, Figure 163). Therefore, at least a portion of the nutrient concentration spike may be from a flux from the sediment following the reflooding of soils in the pool in August.

Dissolved reactive phosphorus (DRP) sorption is a mechanism by which the wetland functions as a nutrient sink. The Project's capacity as a nutrient sink is limited by both the sorption capacity of the soils and the connectivity to nutrient inputs into the Project. Surface water DRP concentrations did not change much from 2023 to 2024 (Figure 160). However, there was more water present in 2023 than in 2024. Since concentration is a function of mass and water volume, and water volume decreased, DRP mass must have decreased from 2023 to 2024, given that the concentrations do not change. This decrease could be a result of DRP leaving through the outflow, via groundwater transport, or through sorption to sediments. It is unlikely that DRP left through the outflow, as water is seldom observed to be flowing out. It is also unlikely that DRP is being transported through groundwater as the soil in the Project has a lot of clay and very little pore space.

There is evidence to suggest that DRP is sorbing to the sediment. All soil samples collected since monitoring began in Water Year 2023 contain positive SPSC values, indicating that iron and aluminum oxides in soils throughout the Project have the capacity to sorb additional phosphate. Researchers observed a negative flux of DRP (indicating sorption) in sediment cores from within the lowland pool near the WLCS (Figure 162). One thing to consider is that a shift in the redox conditions would likely lead to a net desorption of DRP from the sediment, shifting it from a potential sink to a source of nutrients. Researchers did not observe the dissolved oxygen (DO) concentrations within the WCS pool reach anoxic levels during the summer of 2024 (Fig A1.4). However, during a winter sampling date in 2025, the Base Crew did observe hypoxic DO concentrations in the WCS pool under a layer of ice. Air temperatures had risen, thawing the ice and allowing water from beneath the ice to flow out of the Project through the WLCS. This may represent a potential release of DRP from the Project, with shifted redox conditions more favorable for DRP flux from the sediment, and then the increased flow of water leaving the wetland from the ice conditions. Therefore, the filtration of DRP in Trumbull Creek may change seasonally.

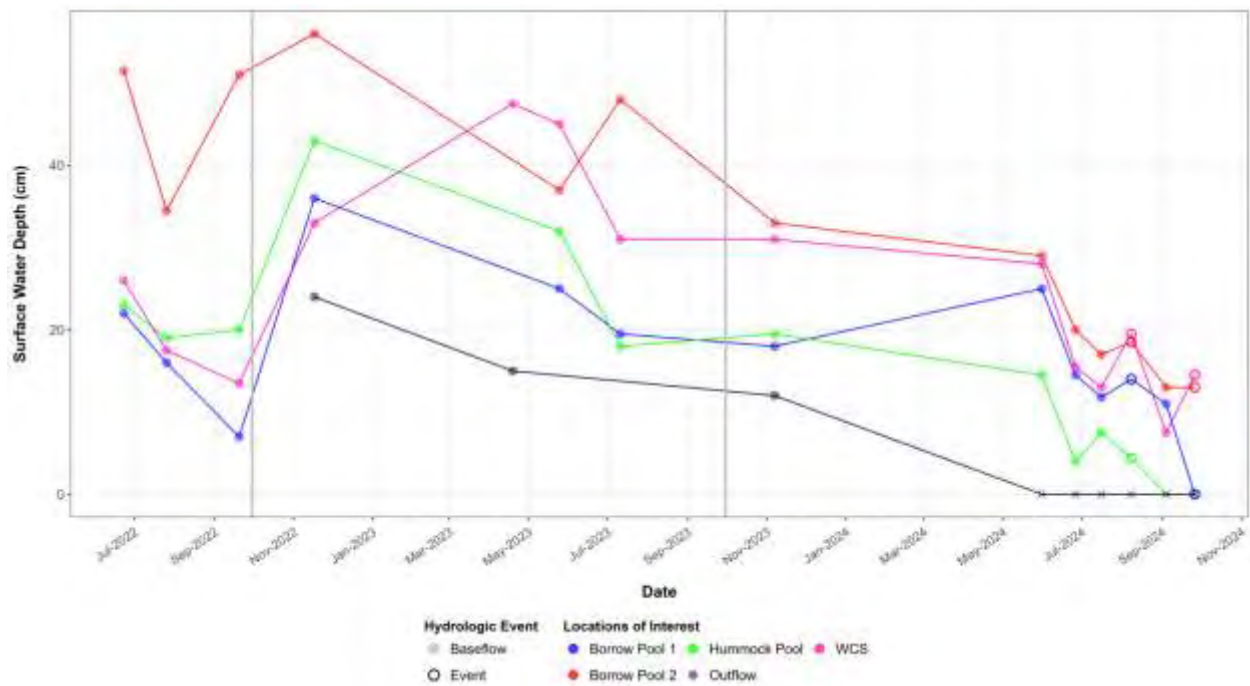


Figure 159. Time series of discrete, manually measured water depth at the Trumbull Creek H2Ohio Project. Depths were measured approximately monthly from 2022 to 2024. Each circle represents one measurement, and colors denote the sampling locations, as indicated in the legend. Open circles represent samples that were collected during a hydrologic event (e.g., storm event), filled circles indicate samples collected during baseflow, and denote represent instances when no surface water was detected during the visit. Gray vertical lines indicate the start of a water year (Oct 1–Sep 30).

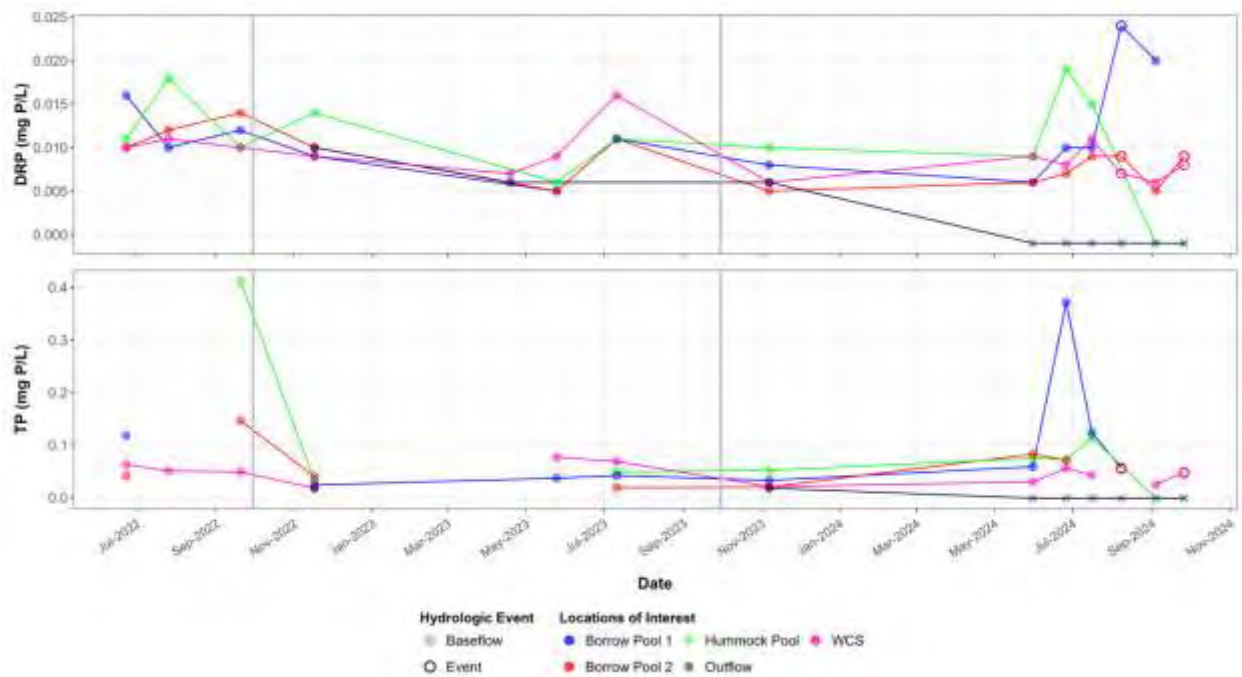


Figure 160. Time series of dissolved reactive phosphorus (DRP, top panel) and total phosphorus (TP, bottom panel) concentrations in surface water samples collected at the Trumbull Creek H2Ohio Project from 2022 to 2024. Each circle represents one sample point, and colors denote the sampling locations, as indicated in the legend. Open circles represent samples that were collected during a hydrologic event (e.g., storm event), filled circles indicate samples collected during baseflow, and crosses denote instances when no surface water was detected during the visit. Values below detection limit were replaced with half the detection limit. Gray vertical lines indicate the start of a water year (Oct 1–Sep 30).

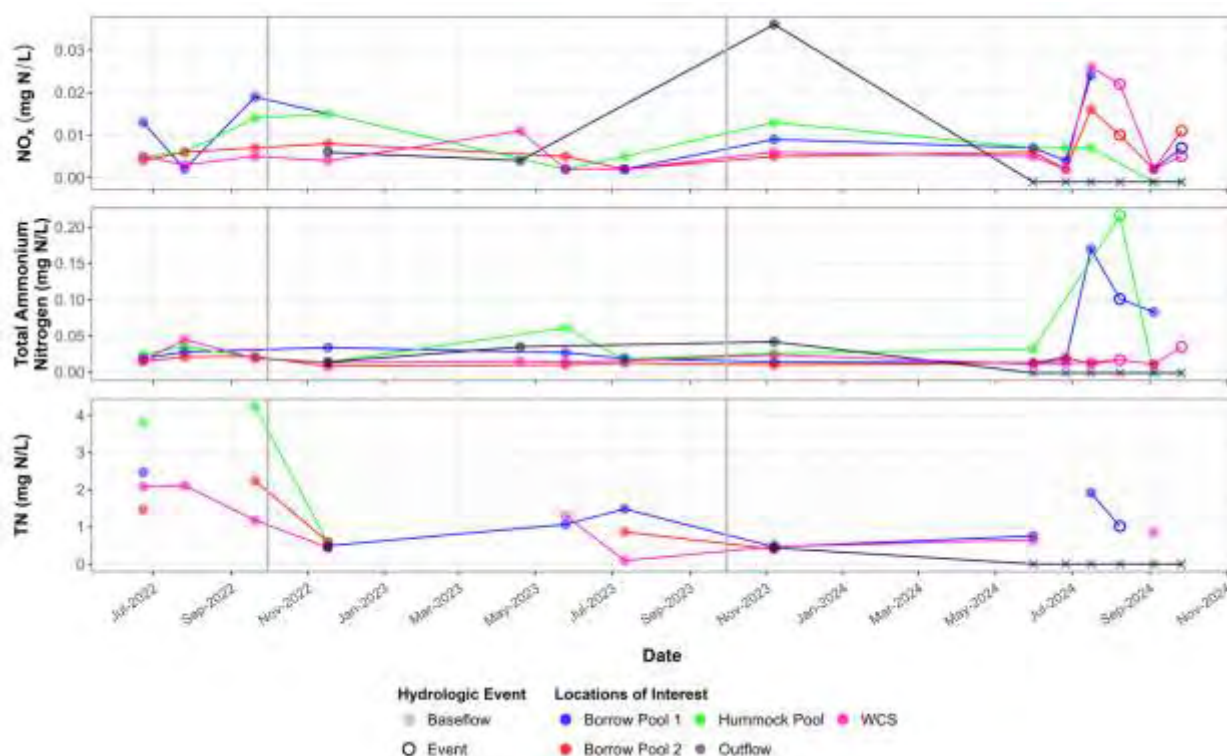


Figure 161. Time series of Nitrite+nitrate (NO_x , top panel), total ammonium nitrogen ($\text{NH}_4\text{-N}$, middle panel), and total nitrogen (TN, bottom panel) concentrations in surface water samples collected at the Trumbull Creek H2Ohio Project from 2022 to 2024. Each circle represents one sample point, and colors denote the sampling locations, as indicated in the legend. Open circles represent samples that were collected during a hydrologic event (e.g., storm event), filled circles indicate samples collected during baseflow, and crosses denote instances when no surface water was detected during the visit. Values below detection limit were replaced with half the detection limit. Gray vertical lines indicate the start of a water year (Oct 1–Sep 30)

Soil Nutrient Status and Processes

Soil phosphate sorption capacity (SPSC) values suggest that there is potential for sorption of phosphate to soils across the Trumbull Creek Project (Figure 164). This holds true for both 2023 and 2024 samples. There is little spatial variation across the Project, though the soils in the inundated areas (to the north of the site) seem to have higher SPSC values, indicating a higher capacity for sorbing phosphate. The differences in SPSC between the upland and lowland area may be because of differences in soil characteristics from the dugout pools or because of different hydroperiods leading to varying nutrient exposure. The lack of variation between 2023 and 2024 suggests that the soils will retain their capacity to sorb phosphate over a longer period of time. This makes sense given the minimal nutrient input into the Project. Not much phosphate gets into the Project to take up the sorption sites and potentially convert the Project into a source of phosphate.

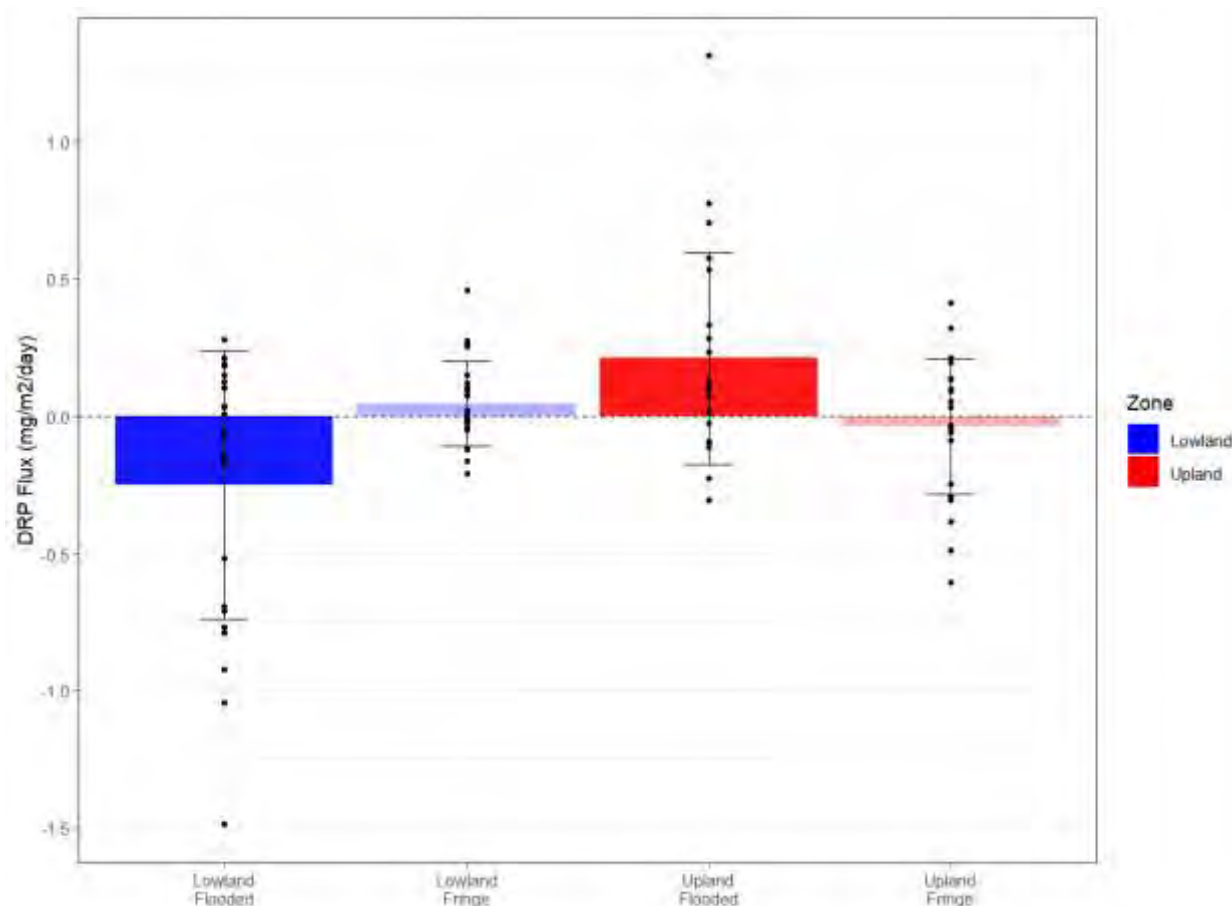


Figure 162. Bar graph representing the mean flux of dissolved reactive phosphorus (DRP) from incubated sediment cores ($n = 4$ cores per zone) over a period of 6 days, including a simulated drying event during the incubation. Bar magnitude represents the mean flux over the course of the experiment and error bars represent the standard deviation of the flux measurements over time and across replicates. The graph is overlaid by points representing the actual measured flux values during the experiment ($n = 24$ flux measurements per Zone). Lowland samples were collected near the WCS sampling location and upland samples were collected near the Borrow Pool 1 sampling location. Positive values indicate a flux from sediment to the surface water, while negative values indicate a flux from surface waters into the sediment.

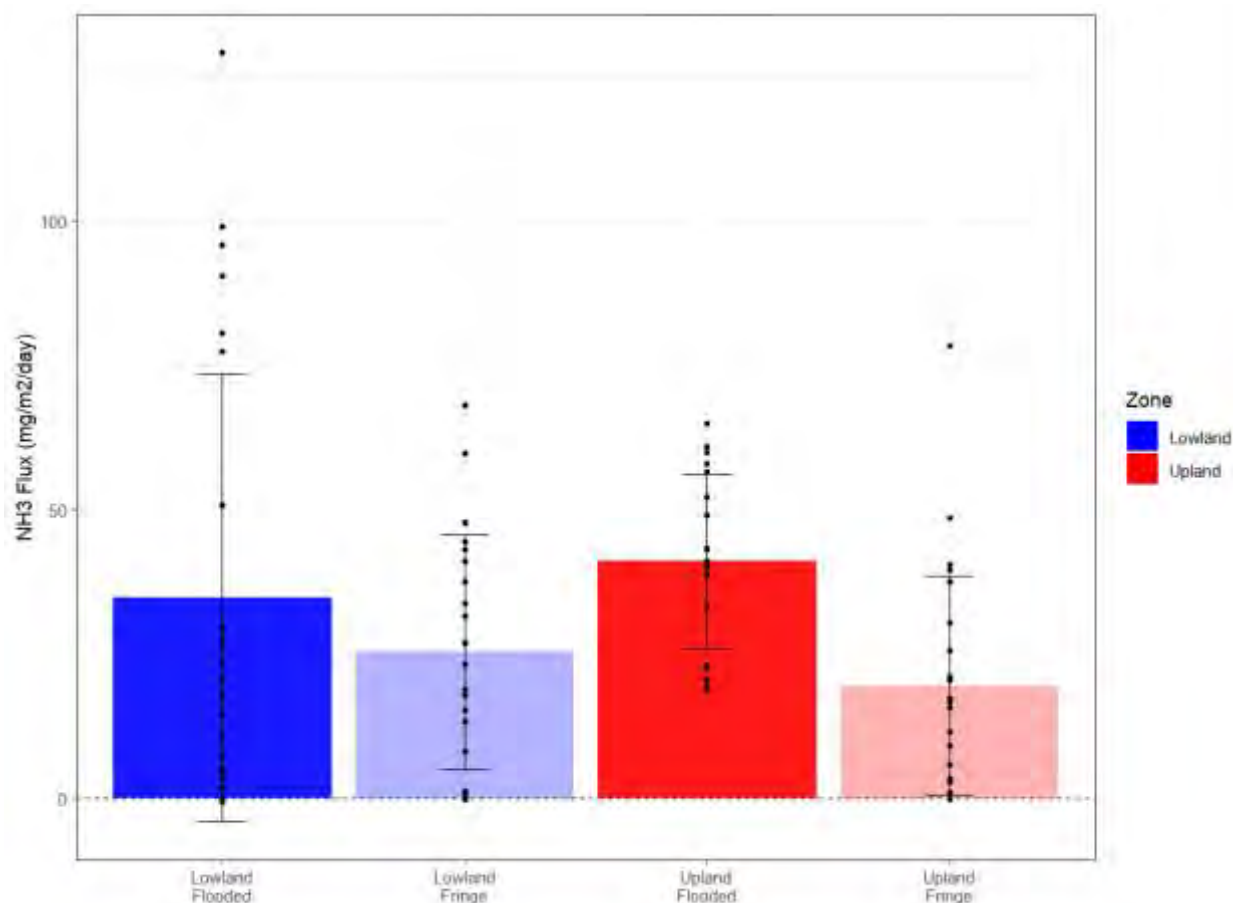


Figure 163. Bar graph representing the mean flux of total ammonium nitrogen ($\text{NH}_4\text{-N}$) from incubated sediment cores ($n = 4$ cores per Zone) over a period of 6 days, including a simulated drying event during the incubation. Bar magnitude represents the mean flux over the course of the experiment and error bars represent the standard deviation of the flux measurements over time and across replicates. The graph is overlaid by points representing the actual measured flux values during the experiment ($n = 24$ flux measurements per Zone). Lowland samples were collected near the WCS sampling location and upland samples were collected near the Borrow Pool 1 sampling location. Positive values indicate a flux from sediment to the surface water, while negative values indicate a flux from surface waters into the sediment.

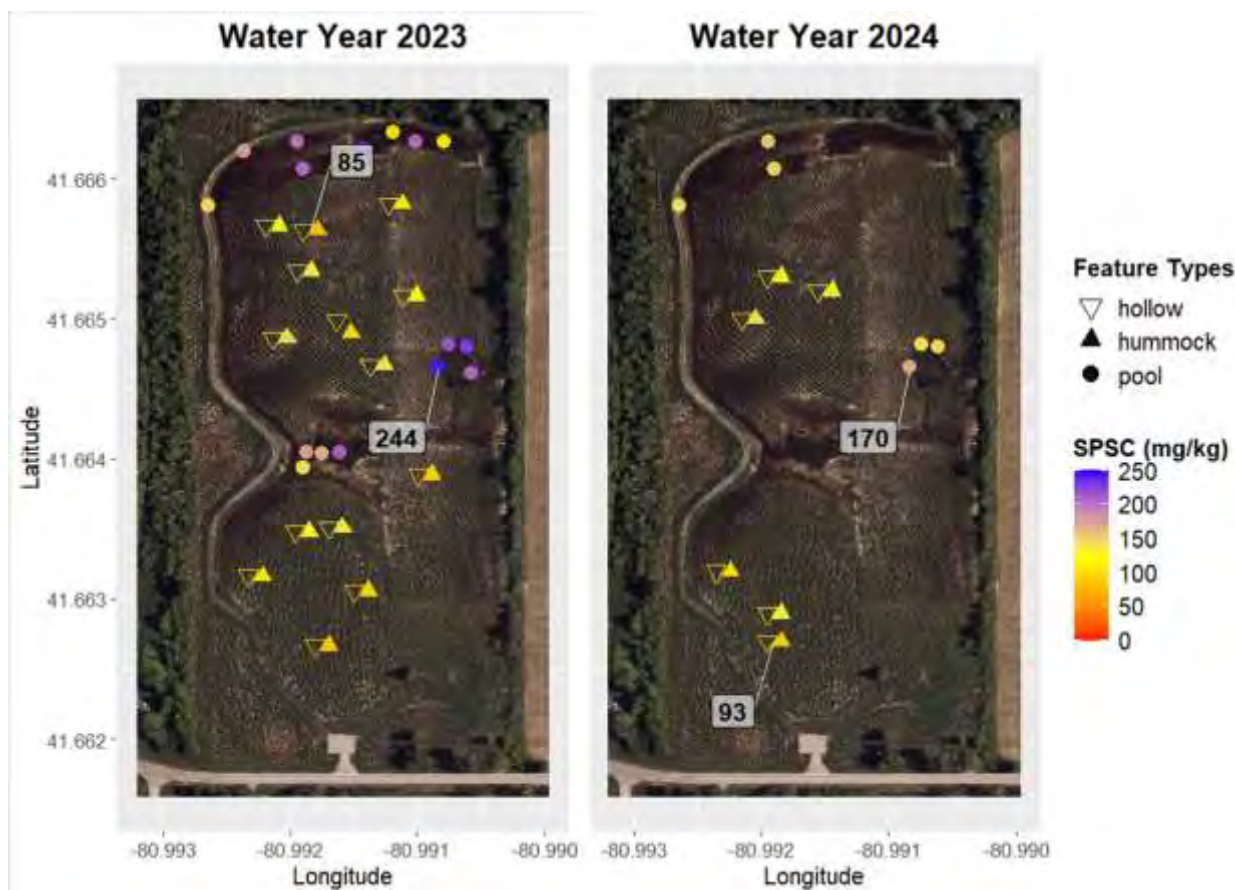


Figure 164. Average Soil Phosphate Sorption Capacity (SPSC) throughout the H2Ohio Trumbull Creek Wetland Project in 2023 and 2024. Each symbol represents an approximate sampling location and is annotated with the mean SPSC for spatially clustered soil samples (0-5cm). The shape marks if the sample was taken from pool (circle), hummock (up-oriented triangle) or hollow (down-oriented triangle) sediment. The color corresponds to the range of SPSC values, as indicated by the legend. Negative SPSC values indicate potential for soils to release phosphate, while positive values indicate soils have capacity to sorb phosphate, based on Mehlich-3 extractions of P, Fe, and Al.

Northwest (Bowling Green State University)

Projects in the northwest region (Figure 1) are primarily monitored by the geographic base crew centered at Bowling Green State University (W. Robert Midden, Principal Investigator).

Maumee River Floodplain (MAUR)

*Also known as Rotary Riverside Preserve Restoration

Project Description

Lucas County | Maumee River Watershed

Project size: 137 acres

Partners: The Nature Conservancy

The hydrology at this Project is passively managed. The Project has 35 acres of restored wetland and consists of a single large central wetland, three northern pools of varying depths (one of which was constructed to meet habitat needs of a specific endangered fish), and many hummock-hollow pools in the southwest area. The large central wetland acts as an occasional floodplain pool. The smaller pools normally act as depressional wetlands but also receive water from the Maumee or existing oxbow wetland at very high water levels. A hydrologic event at this Project is operationally defined as a storm event in which the Maumee River floods the central pool via the existing oxbow wetland.



Figure 165. Aerial image showing surface water flow and sampling locations for the Maumee River Floodplain: H2Ohio Restoration Project. Blue arrows indicate direction of surface water flow. Dots represent geographic base crew sampling locations, which are grouped by Project features (fill color) where relevant. Text annotations provide additional context about the Project's watershed connection or other important features.

Management Considerations

Overall wetland function of the Maumee River Floodplain Project in Water Year (WY) 2024 was likely limited by low-rainfall conditions similar to those in WY 2023. The Project is situated close to the bank of the Maumee River and functions as a connected floodplain for the Maumee during wetter years. The Project can receive extensive flooding during late winter and early spring, providing the opportunity for nutrient filtration if there is enough water. There is no active water level management at this Project; changes in water level are

due largely to floodplain events. During periods of elevated water levels, two of the Project's features, the Existing Oxbow Wetland and the Central Pool, connect via two cuts, but otherwise there are no flow paths and the pools function more or less as isolated pools.

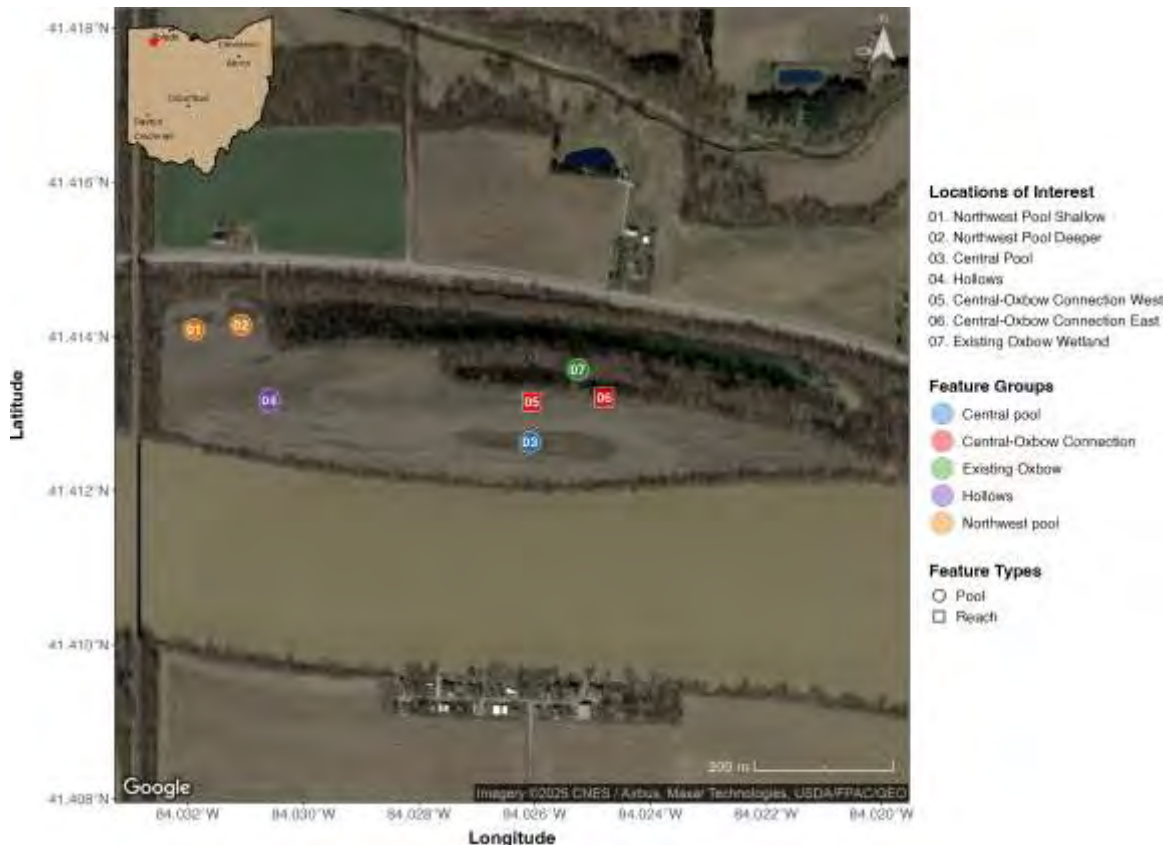


Figure 166. Aerial image of approximate locations of interest for water and soil sampling and discrete manual measurements of water depth and physicochemical parameters at Maumee River Floodplain: H2Ohio Restoration Project (Rotary Riverside Preserve Restoration Project) during water year 2024 (Oct 1, 2023–Sep 30, 2024). The legend provides the name of each sampling point. Different shapes denote the types of wetland features represented by the locations of interest. If present, different colors represent locations of interest that belong to a group or complex of features (e.g., a treatment train).

Surface Water Hydrology and Nutrients

The Northwest Pools (Shallower and Deeper) held water for longer periods than other sampling locations at this Project and also had the greatest depths, commonly over 50 cm. Like other pools at the Project, they reached peak depths in spring, and water level dropped through summer and fall. Most sampling locations at this Project were totally dry by summer in both Water Years (WYs) 2023 and 2024. The connection of the Maumee River Floodplain Project to the Maumee River appeared to be relatively brief but significant. The frequency of floodplain events is unknown because the Project was visited only three times per year. However, based on lack of water during summer and fall visits, it is likely that the Project did not have significant floodplain function after spring. This may be different during wetter

years. An initial Project visit in early 2023 during a floodplain event experienced water levels high enough that only the northwest corner of the Project could be safely accessed.

The Northwest Shallower and Deeper Pools had minimal dissolved reactive phosphorous (DRP) concentrations (< 0.05 mg phosphorus (P)/L). The Existing Oxbow Wetland was the only pool to have detectable DRP concentrations, and it had a maximum DRP (0.3 mg P/L) during the summer of WY 2024. Northwest Pool Shallower had a maximum total phosphorous (TP) concentration (1.0 mg P/L) in September 2024. The Northwest Pool Deeper had a maximum TP (0.6 mg P/L) in the summer at the same time as the Existing Oxbow Wetland maximum TP (0.9 mg P/L). Northwest Pool Shallower had a maximum total nitrogen (TN, 1.75 mg N/L) in September 2024. The Northwest Pool Deeper had a maximum TN (0.9 mg N/L) in the summer at the same time as The Existing Oxbow Wetland maximum TN (5 mg N/L). Higher nutrient concentrations late in Water Year 2024 may occur because concentrations increase as water levels decrease via evapotranspiration. These higher concentrations are likely not due to new water inputs in the latter half of Water Year 2024.

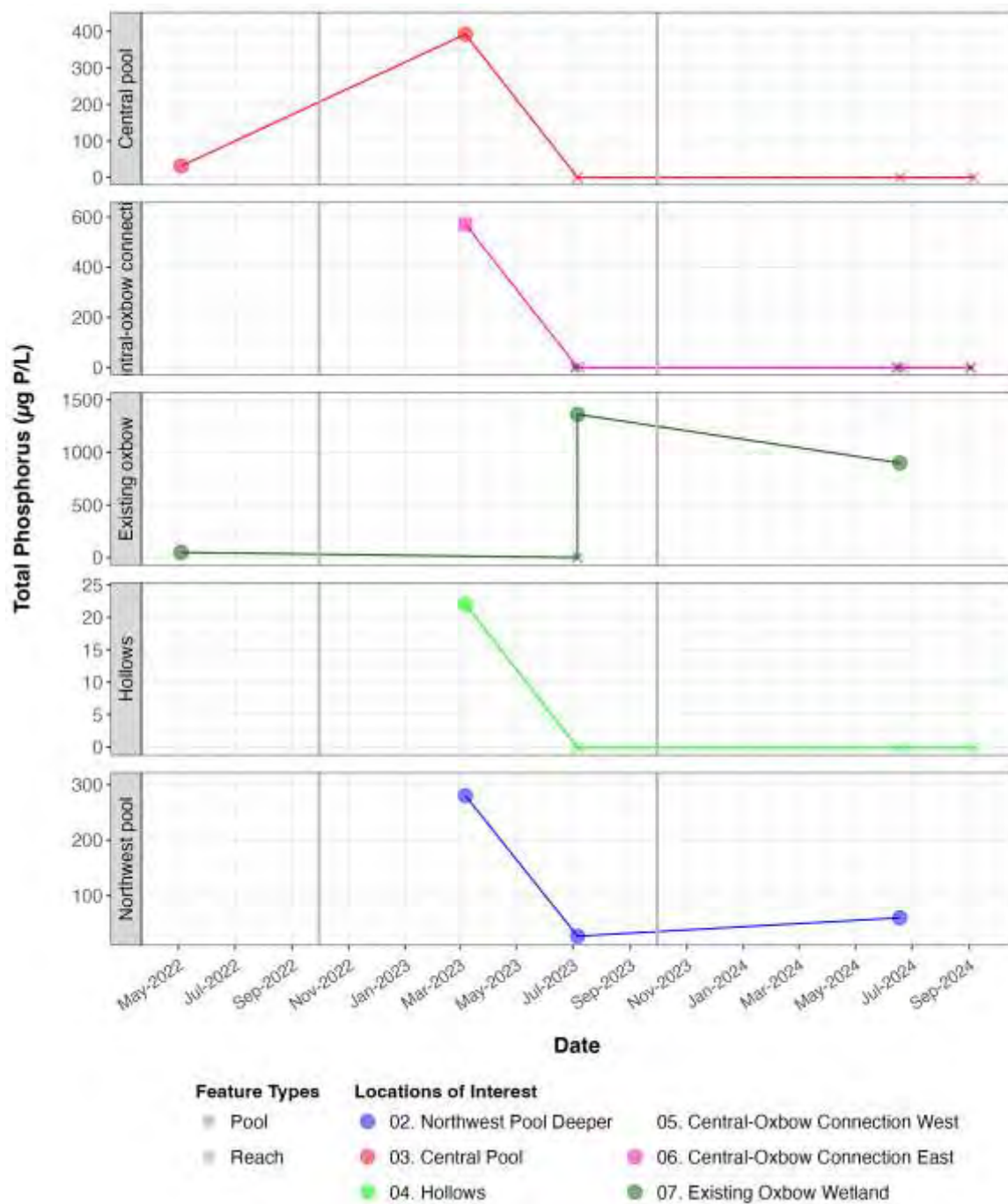


Figure 167. Time series of total phosphorus (TP) concentrations in surface water samples collected at Maumee River Floodplain: H2Ohio Restoration Project (Rotary Riverside Preserve Restoration Project). Values below the detection limit of the analytical equipment were replaced with half the value of the detection limit. Each point represents one measurement, and colors denote the locations of interest, as indicated in the legend. Open symbols indicate that measurements were collected during a hydrologic event (e.g., storm event) and filled symbols denote measurements collected during baseflow. Crosses (×) represent instances when no surface water was detected during the visit. If present, different shapes denote the types of wetland features represented by the locations of interest. Gray vertical lines indicate the start of a water year (Oct 1–Sep 30).

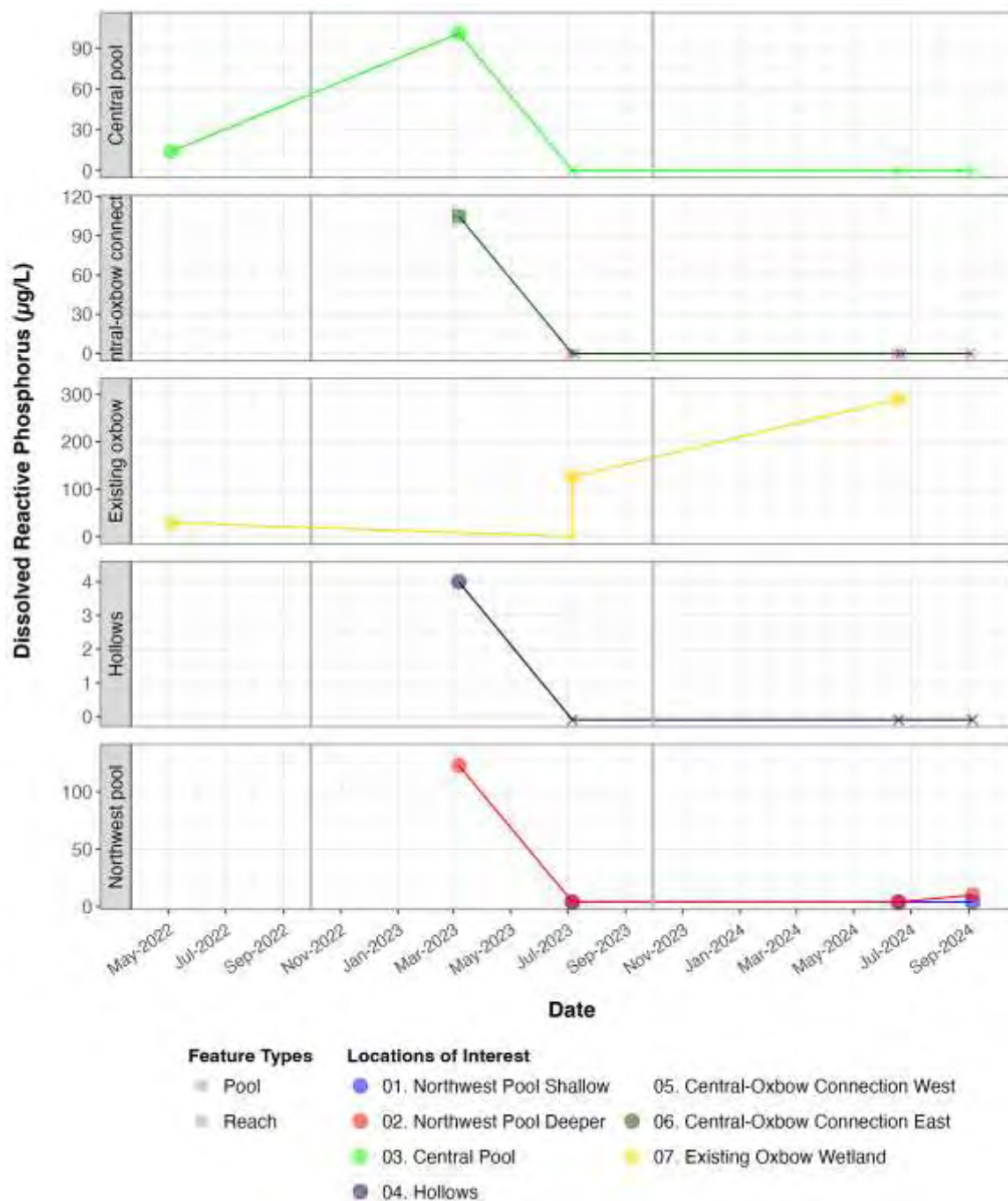


Figure 168. Time series of dissolved reactive phosphorus (DRP) concentrations in surface water samples collected at Maumee River Floodplain: H2Ohio Restoration Project (Rotary Riverside Preserve Restoration Project). Values below the detection limit of the analytical equipment were replaced with half the value of the detection limit. Each point represents one measurement, and colors denote the locations of interest, as indicated in the legend. Open symbols indicate that measurements were collected during a hydrologic event (e.g., storm event) and filled symbols denote measurements collected during baseflow. Crosses (×) represent instances when no surface water was detected during the visit. If present, different shapes denote the types of wetland features represented by the locations of interest. Gray vertical lines indicate the start of a water year (Oct 1–Sep 30).

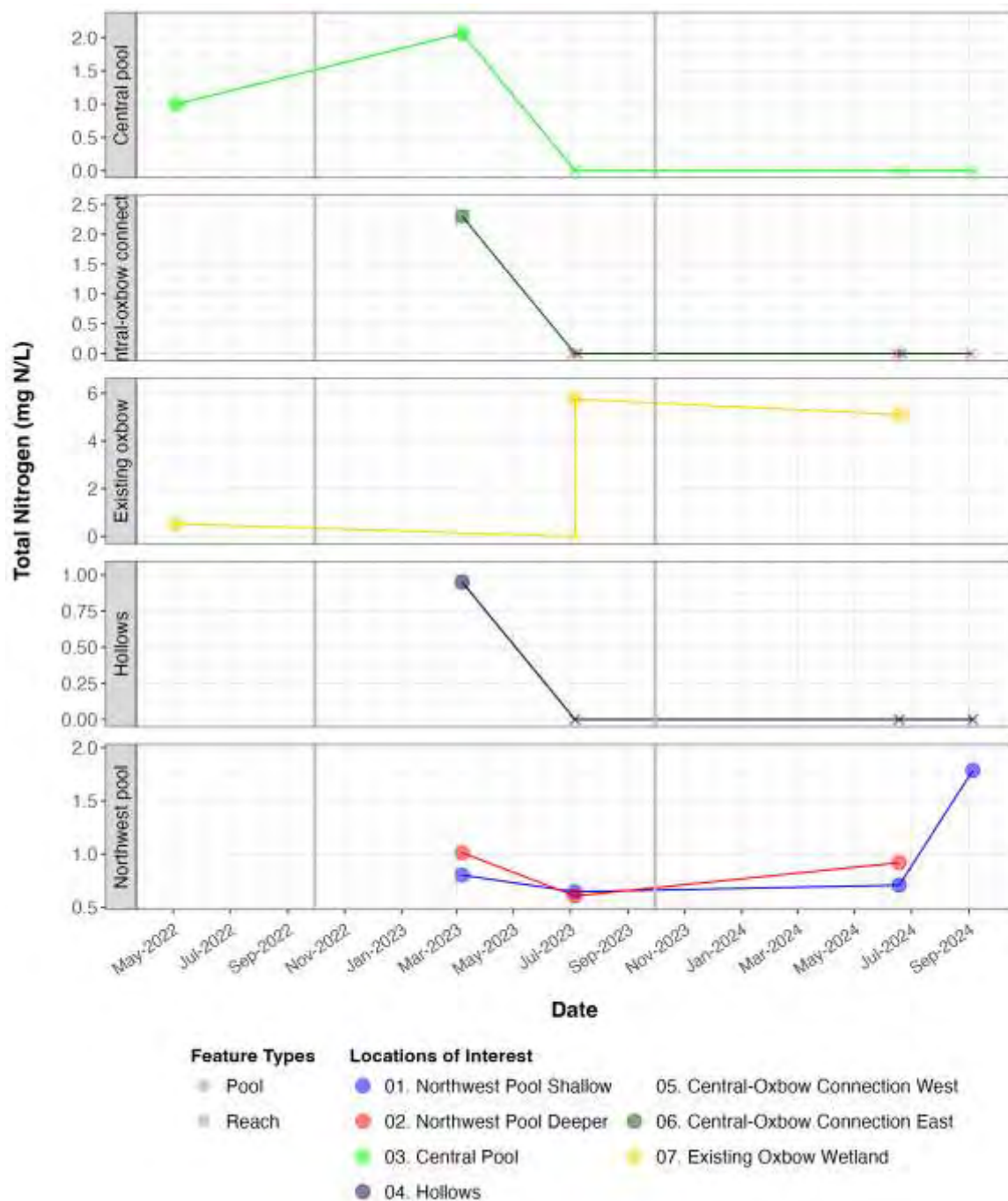


Figure 169. Time series of total nitrogen (TN) concentrations in surface water samples collected at Maumee River Floodplain: H2Ohio Restoration Project (Rotary Riverside Preserve Restoration Project). Values below the detection limit of the analytical equipment were replaced with half the value of the detection limit. Each point represents one measurement, and colors denote the locations of interest, as indicated in the legend. Open symbols indicate that measurements were collected during a hydrologic event (e.g., storm event) and filled symbols denote measurements collected during baseflow. Crosses (×) represent instances when no surface water was detected during the visit. If present, different shapes denote the types of wetland features represented by the locations of interest. Gray vertical lines indicate the start of a water year (Oct 1–Sep 30).

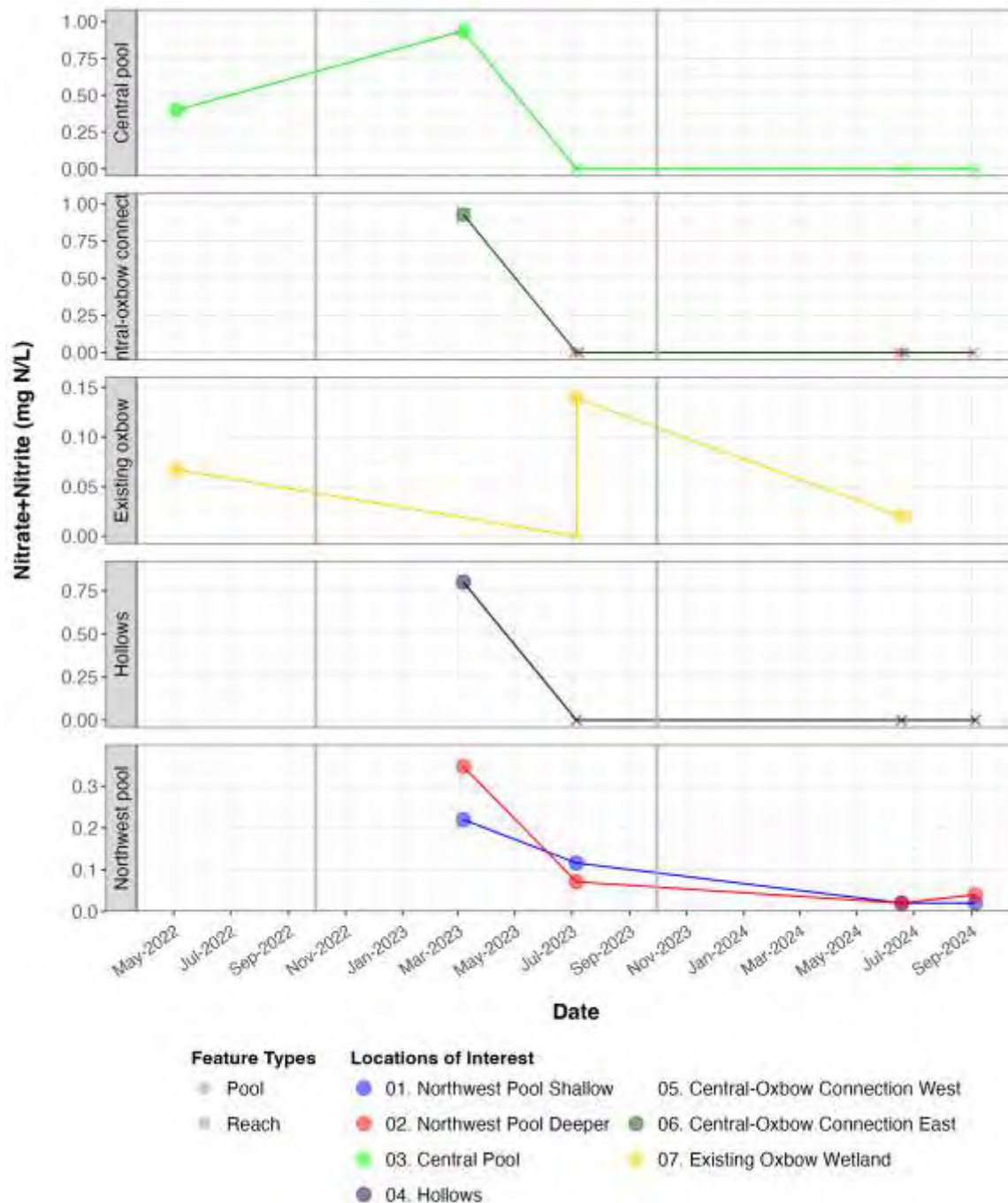


Figure 170. Time series of Nitrite+nitrate (NO_x) concentrations in surface water samples collected at the Maumee River Floodplain: H2Ohio Restoration Project (Rotary Riverside Preserve Restoration Project). Values below the detection limit of the analytical equipment were replaced with half the value of the detection limit. Each point represents one measurement, and colors denote the locations of interest, as indicated in the legend. Open symbols indicate that measurements were collected during a hydrologic event (e.g., storm event) and filled symbols denote measurements collected during baseflow. Crosses (×) represent instances when no surface

water was detected during the visit. If present, different shapes denote the types of wetland features represented by the locations of interest. Gray vertical lines indicate the start of a water year (Oct 1–Sep 30).

Soil Nutrient Status and Processes

Soil samples were collected once per year in 2023 and 2024. Soil phosphate sorption capacity (SPSC) was variable at the Maumee River Floodplain Project and ranged into the negative in some locations (Figure 171). The lowest SPSC value in 2023 was -26 mg phosphorus/kg, and in 2024, the lowest SPSC value was -57 mg/kg. Negative values indicate a potential for release of phosphorus from the soil. There were also areas with positive SPSC values, with maximums of 188 mg/kg in 2023 and 83 mg/kg in 2024. The decrease in SPSC could be because this Project is very highly connected and receives extreme flooding from the Maumee River, which delivers significant nutrient loads during flood events, which may sorb to the soil and decrease SPSC, and/or deliver new sediment with decreased SPSC.

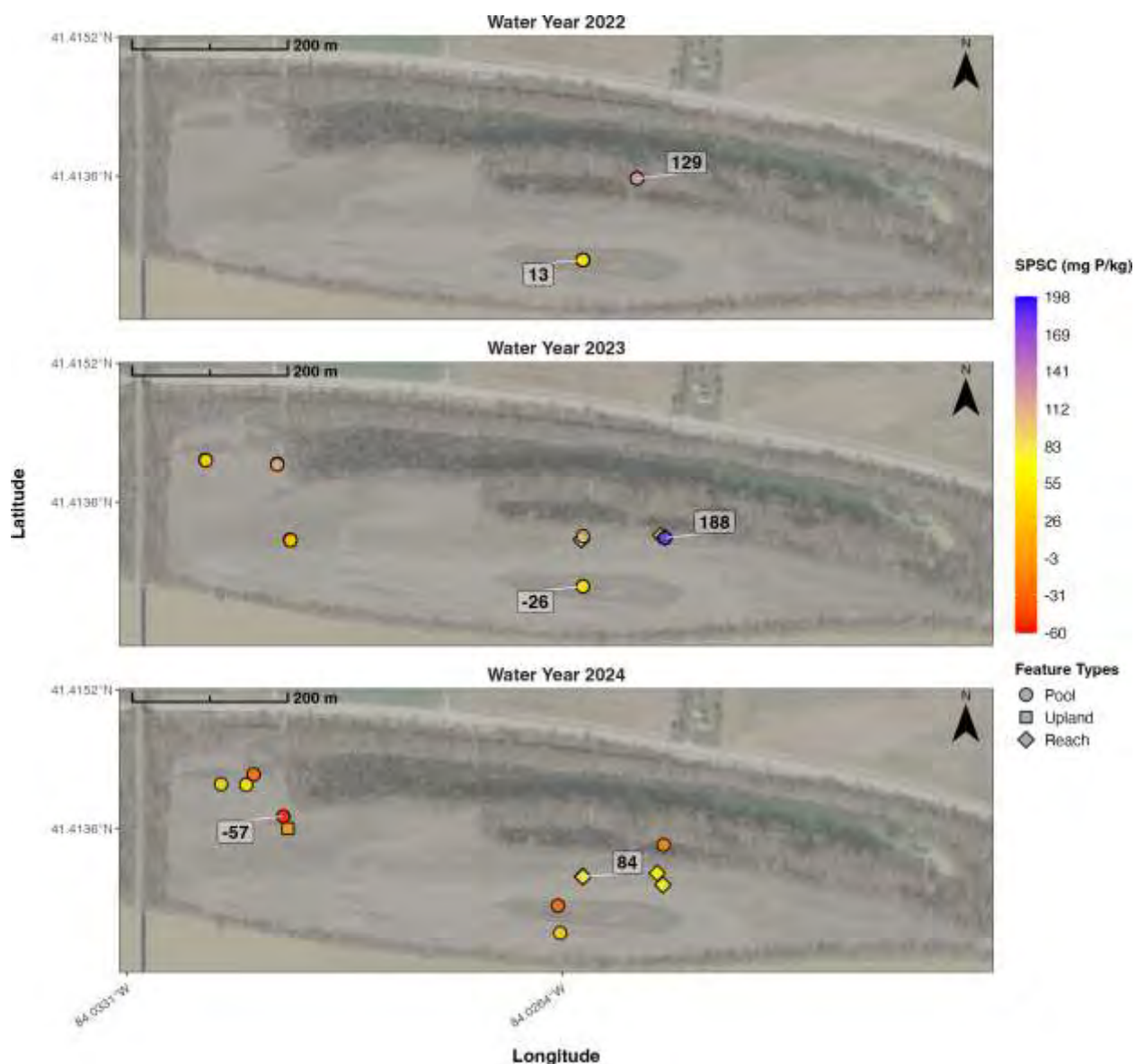


Figure 171. Soil Phosphate Sorption Capacity (SPSC) throughout the Maumee River Floodplain: H2Ohio Restoration Project (Rotary Riverside Preserve Restoration Project). Each point denotes a soil sample (0–5 cm) and different shapes indicate the wetland feature type, as shown in the legend. Colors indicate the SPSC value of each sample relative to the overall range of values observed at the wetland project, as shown in the color bar. Each panel shows the soil samples collected during a respective water year (Oct 1–Sep 30), along with the minimum and maximum SPSC values observed during a given water year. Negative SPSC values indicate the potential for soils to release phosphate, while positive values indicate soils have capacity to sorb phosphate, based on Mehlich-3 extractions of phosphate, iron, and aluminum.

Next Steps to Strengthen Understanding

Annual soil samples will enable continued monitoring of soil phosphate sorption capacity (SPSC). SPSC data in particular will be critical to monitoring this Project for potential nutrient release, given some locations have negative SPSC values. SPSC data across time is also needed because the Project is relatively young and still developing; SPSC is likely to change and variably impact nutrient retention over time. Water samples will be collected only if feasible and if considered a priority amidst resource constraints. Water samples will enable researchers to at least get a snapshot of Project nutrient status and surveil for any major changes over time.

Montpelier Wetland (MONW)

Project Description

Williams County | Maumee River Watershed

Project size: 98 acres

Partners: Ohio State University

The hydrology at this Project is passively managed. The Project has approximately 8.5 acres of restored wetland and consists of a southern wetland with a flow-through wetland system, and a northern wetland with a series of small depressional wetlands. The southern wetland receives water through a tile outlet on the eastern side and outlets into an underground phosphorus filter which outflows into a ditch, while the northern wetland receives water from surface runoff. A hydrologic event at this Project is operationally defined as a storm event in which the eastern tile delivers water to the flow-through wetland system.

Note: The hydrology and surface water chemistry of the Montpelier Wetland Project was monitored by researchers from Ohio State University with support from the H2Ohio Wetland Monitoring Program to sample and analyze soils¹². There are no non-Monitoring Program results to report at this time aside from 2024 nitrogen and phosphorus filtration calculations.

¹² Stoltzfus, Brooker, and Martin, Unpublished Results, 2025



Figure 172. Aerial image showing surface water flow and sampling locations for the OSU Montpelier High-P Wetland. Blue arrows indicate direction of surface water flow. Dots represent geographic base crew sampling locations, which are grouped by Project features (fill color) where relevant. Text annotations provide additional context about the Project's watershed connection or other important features.

Management Considerations

Soil phosphate sorption capacity (SPSC) levels in the Montpelier Wetland remained similar from Water Year (WY) 2023 to WY 2024, indicating a potential for soils to sorb phosphate. The H2Ohio Wetland Monitoring Program does not collect water samples or water level data at this Project, but water was present in the South Wetland Tiled Pool and soils were moist during the July 2024 soil sampling visit, which suggests Montpelier Wetland is receiving water to treat, likely from nearby overland flow and rainfall. WY 2024 was a relatively dry year, so the overall treatment magnitude was likely limited.



Figure 173. Aerial image of approximate locations of interest for water and soil sampling and discrete manual measurements of water depth and physicochemical parameters at OSU Montpelier High-P Wetland Project during Water Year 2024 (Oct 1, 2023–Sep 30, 2024). The legend provides the name of each sampling point. Different shapes denote the types of wetland features represented by the locations of interest. If present, different colors represent locations of interest that belong to a group or complex of features (e.g., a treatment train).

Nutrient Budget Takeaways

The Montpelier Project received approximately 16,000 m³ of water in Water Year 2024. The H2Ohio Wetland Monitoring Program does not collect water samples at this Project, but surface water was collected by affiliate researchers. Though the dry conditions throughout 2024 likely limited its overall efficacy, the Project filtered 28 lbs. of total phosphorus, 3.2 lbs. of dissolved reactive phosphorus, and 163 lbs. of total nitrogen. The conversion from agricultural land to wetland prevents 25 ± 12 lbs. phosphorus runoff annually. Soils throughout the Project have a wide range in capacity to sorb phosphate, as suggested by soil phosphate sorption capacity values, although all values were positive in WY 2024.

Soil Nutrient Status and Processes

Annual soil samples at Montpelier Wetland showed a wide range of soil phosphate sorption capacity (SPSC) values. All SPSC values were positive, which suggests an overall capacity to

sorb phosphate throughout the Project¹². However, some sampling locations had low values, such as North Wetland A (9 mg phosphorus (P)/kg; Figure 174). This value represents the lowest SPSC value at Montpelier Wetland. North Wetland A is suspected to have water inputs from a tile drain, which may explain the low SPSC value if the pool is consistently inundated with nutrient-rich water. The highest SPSC value in 2024 was measured in the South Wetland Middle (179 mg/kg), at approximately the midpoint of the serpentine channel that directs water towards the P filter outlet (Figure 174). The maximum SPSC observed in 2023 (229 mg/kg) was also highly positive. These two maximums are spatially close together, both part of the serpentine channel in the South Wetland. This indicates potentially strong treatment potential of the South Wetland, as positive values indicate a capacity to sorb phosphate. The minimal change in SPSC between years may suggest that this portion of the Project will likely continue to sorb phosphate, though analysis from affiliate researchers this Project will better clarify this potential¹².



Figure 174. Soil Phosphate Sorption Capacity (SPSC) throughout the OSU Montpelier Wetland Restoration Project. Each point denotes a soil sample (0–5 cm) and different shapes indicate the wetland feature type, as shown in the legend. Colors indicate the SPSC value of each sample relative to the overall range of values observed at the wetland project, as shown in the color bar. Each panel shows the soil samples collected during a respective water year (Oct 1–Sep 30), along with the minimum and maximum SPSC values observed during a given water year. Negative SPSC values indicate the potential for soils to release phosphate, while positive values indicate soils have capacity to sorb phosphate, based on Mehlich-3 extractions of phosphate, iron, and aluminum.

Next Steps to Strengthen Understanding

Annual soil samples will enable continued monitoring of soil phosphate sorption capacity (SPSC). SPSC data across time is needed because the Project is relatively young and still developing and SPSC is likely to change and variably impact nutrient retention over time. Water samples will be taken by partners of the H2Ohio Wetland Monitoring Program.

Oak Openings Preserve Wetland Restoration (OOPR)

Project Description

Lucas County | Maumee River Watershed

Project size: 48 acres

Partner: MetroParks Toledo

The hydrology at this Project is passively managed. The Project has 22 acres of restored wetland, consisting of 15 wetland pools that are arranged into four main flow paths (watershed areas 1–4). All four flow paths receive water from surface runoff, and they all drain into the same stream-seep wetland outflow that flows into a nearby stream. A hydrologic event at this Project is operationally defined as a storm event in which the flow paths receive surface runoff.



Figure 175. Aerial image showing surface water flow and sampling locations for the Oak Openings Preserve Wetland Restoration Project. Blue arrows indicate direction of surface water flow. Dots represent geographic base crew sampling locations, which are grouped by Project features (fill color) where relevant. Text annotations provide additional context about the Project's watershed connection or other important features.

Management Considerations

Overall wetland function of the Oak Openings Preserve Project in Water Year (WY) 2024 was likely limited by dry conditions like those in WY 2023. However, several pools did hold 10 – 20 cm of water throughout the year. Pool 12 was the deepest pool and held water throughout the year. This contrasts with early predictions that Pool 8 would be the deepest pool and hold water the longest. The sources of water for this Project remain unclear. It may receive some water from the roadside ditch at the west end of the Project, or it may get its water solely from precipitation and surface runoff from the land within the Project. The soils are sandy, which may limit water and/or nutrient retention, or could potentially increase connection to groundwater sources. There are no tile connections or water level control structures at this Project.



Figure 176. Aerial image of approximate locations of interest for water and soil sampling and discrete manual measurements of water depth and physicochemical parameters at Oak Openings Preserve Wetland Restoration Project during water year 2024 (Oct 1, 2023–Sep 30, 2024). The legend provides the name of each sampling point. Different shapes denote the types of wetland features represented by the locations of interest. If present, different colors represent locations of interest that belong to a group or complex of features (e.g., a treatment train).

Surface Water Hydrology and Nutrients

Pool 12 is the final pool of the treatment train at Oak Openings Preserve. It is the deepest pool and holds water for the longest period during the year. The highest total phosphorus (TP) and dissolved reactive phosphorus (DRP) concentrations were in Pools 14 and 15, which are part of the treatment train (Figure 178). Pool 3 also had somewhat higher than average TP concentrations and tended to be deeper than other pools and hold water for longer periods. Pool 8 is the largest in terms of footprint, but it doesn't appear to hold water longer than pools in the treatment train. Pools 3 and 12 have the most hydrological activity throughout the year. The highest DRP concentrations were observed in Pool 14 (0.05 mg P/L) at the end of the Water Year (WY) 2024. Pool 14 was sampled twice with an average of 0.027 mg P/L. All other pools had DRP concentrations below the minimum detection limit (MDL). The highest TP was in Pool 14 (0.48 mg P/L) and had an average of $(0.278 \pm 0.3 \text{ mg P/L})$. Pool 15 had the second highest TP (0.091 mg P/L) but was only sampled once over the summer of WY 2024 before it dried out. Pool 14 had the highest total nitrogen in September of WY 2024 (5.11 mg nitrogen (N)/L) and averaged $(3.35 \pm 2.5 \text{ mg N/L})$.

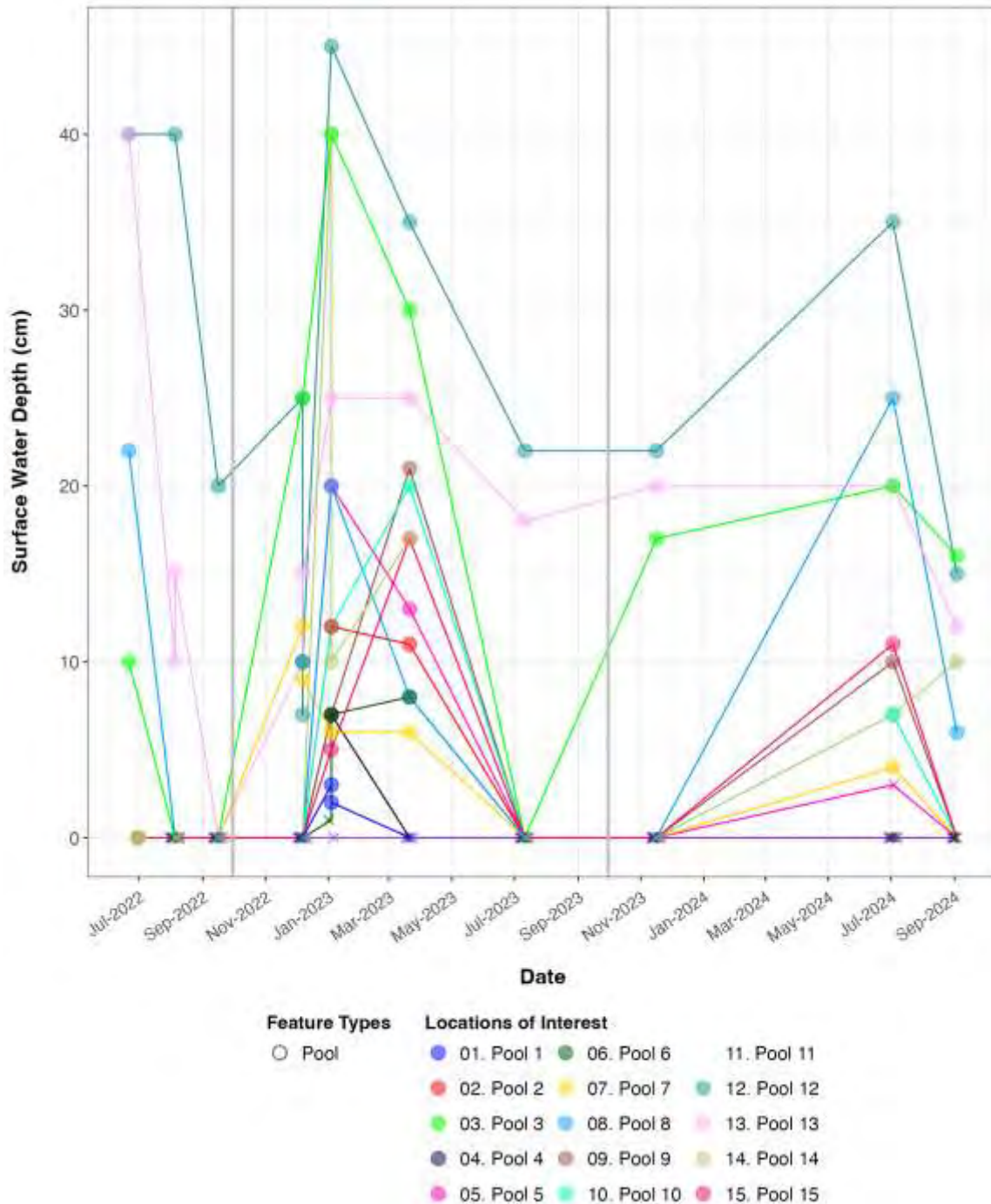


Figure 177. Time series of discrete, manually measured surface water depth at the Oak Openings Preserve Wetland Restoration Project. Depths were measured approximately monthly. Each point represents one measurement and colors denote the locations of interest, as indicated in the legend. Open symbols indicate samples that were collected during a hydrologic event (e.g., storm event) and filled symbols denote samples collected during baseflow. Crosses (x) represent instances when no surface water was detected during the visit. If present, different shapes denote

the types of wetland features represented by the locations of interest. Gray vertical lines indicate the start of a water year (Oct 1–Sep 30).

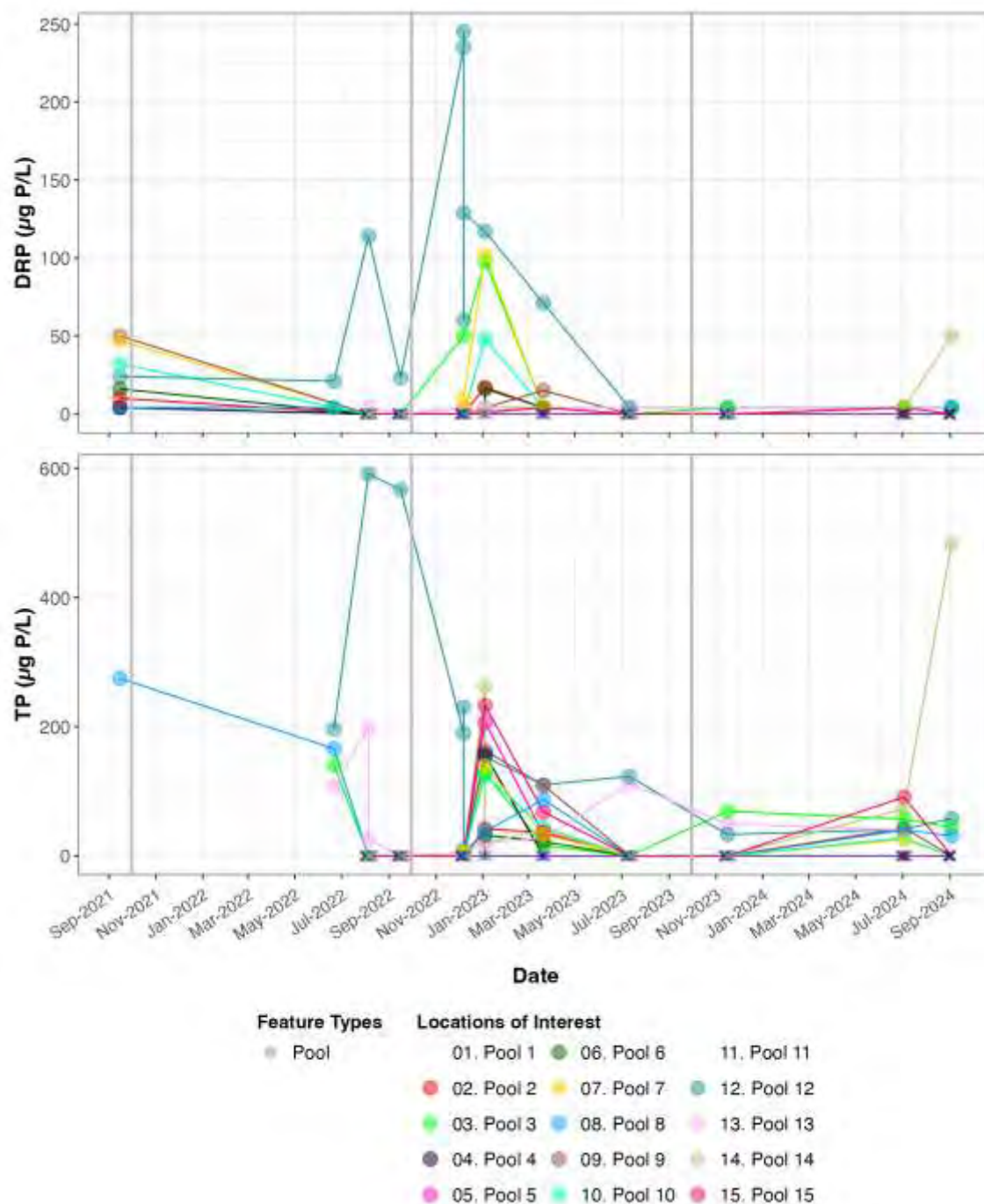


Figure 178. Time series of dissolved reactive phosphorus (DRP, top panel) and total phosphorus (TP, bottom panel) concentrations in surface water samples collected at the Oak Openings Preserve Wetland Restoration Project. Values below the detection limit of the analytical equipment were replaced with half the value of the detection limit. Each point represents one

measurement, and colors denote the locations of interest, as indicated in the legend. Open symbols indicate that measurements were collected during a hydrologic event (e.g., storm event) and filled symbols denote measurements collected during baseflow. Crosses (×) represent instances when no surface water was detected during the visit. If present, different shapes denote the types of wetland features represented by the locations of interest. Gray vertical lines indicate the start of a water year (Oct 1–Sep 30).

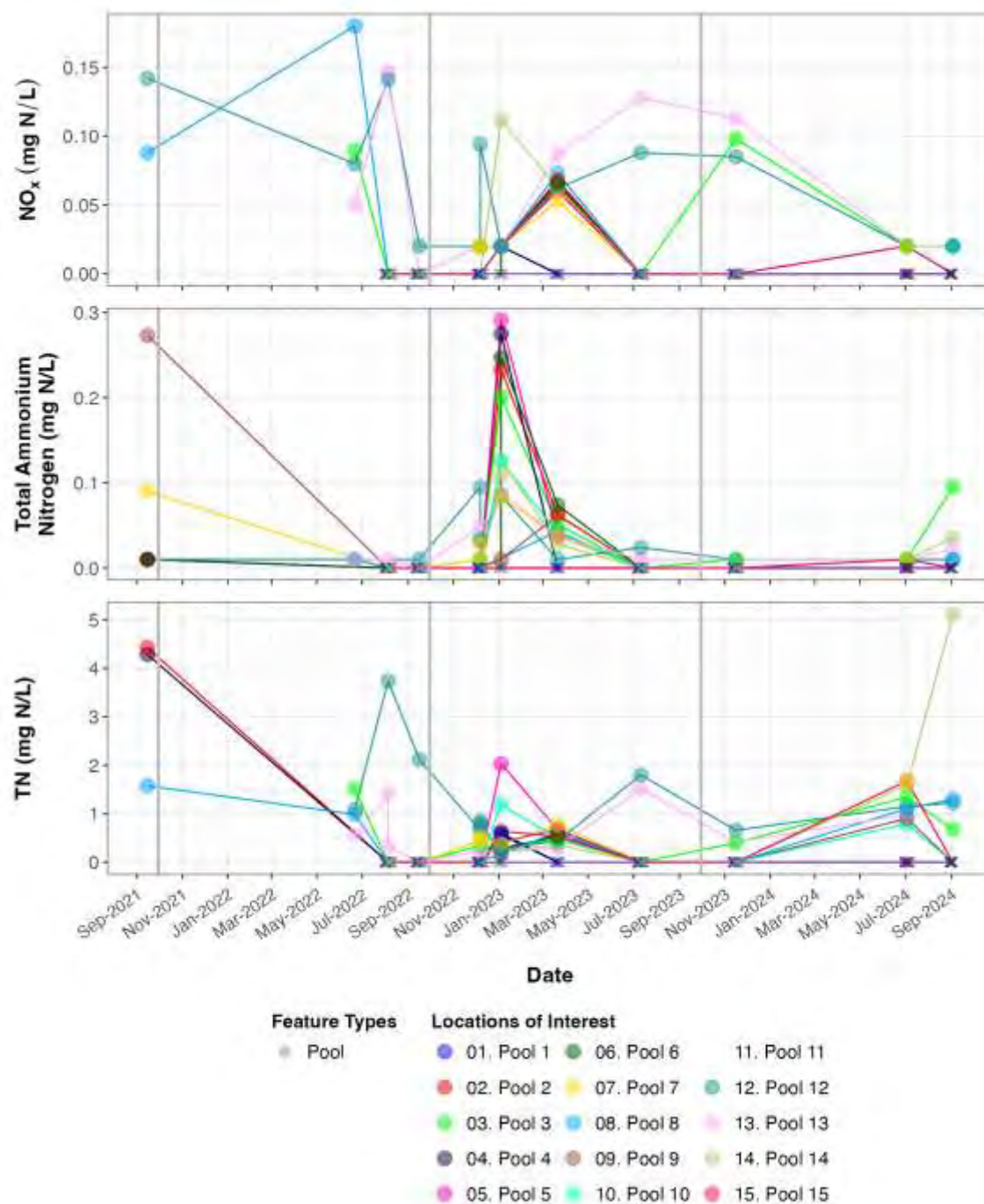


Figure 179. Time series of Nitrite+nitrate (NO_x , top panel) total ammonium nitrogen ($\text{NH}_4\text{-N}$, middle panel), and total nitrogen (TN, bottom panel) concentrations in surface water samples collected at the Oak Openings Preserve Wetland Restoration Project. Values below the detection limit of the analytical equipment were replaced with half the value of the detection limit. Each point represents one measurement, and colors denote the locations of interest, as indicated in the legend. Open symbols indicate that measurements were collected during a hydrologic event (e.g., storm event) and filled symbols denote measurements collected during baseflow. Crosses ($\times$)

represent instances when no surface water was detected during the visit. If present, different shapes denote the types of wetland features represented by the locations of interest. Gray vertical lines indicate the start of a water year (Oct 1–Sep 30).

Soil Nutrient Status and Processes

The soil at Oak Openings Preserve has high sand content, which might impact the Project’s capacity to hold water and nutrients. The highest soil phosphate sorption capacity (SPSC) value was measured in Pool 6 (148 mg phosphorus/kg; Figure 180). This pool is relatively shallow and does not appear to hold water for much of the year. The general southwest area of the Oak Openings Preserve, where Pool 6 is located, consistently had higher SPSC values than elsewhere in the Project. SPSC values in the treatment train were highest in the first pool of the train (Pool 15, 89 mg/kg) and decreased in successive pools (Pool 14, 49 mg/kg; Pools 13 and 12, 0.0 mg/kg).

The lowest SPSC values were shared by the final two treatment train pools (13 and 12) and Pools 9 and 5. SPSC at the Oak Openings Project appears to be holding steady across years from 2022 to 2024 (Figure 180).

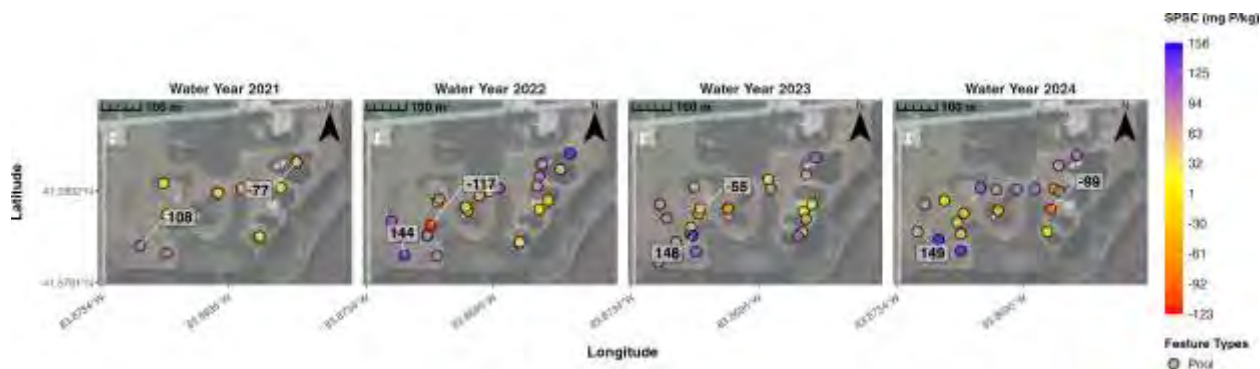


Figure 180. Soil Phosphate Sorption Capacity (SPSC) throughout the Oak Openings Preserve Wetland Restoration Project. Each point denotes a soil sample (0–5 cm) and different shapes indicate the wetland feature type, as shown in the legend. Colors indicate the SPSC value of each sample relative to the overall range of values observed at the wetland project, as shown in the color bar. Each panel shows the soil samples collected during a respective water year (Oct 1–Sep 30), along with the minimum and maximum SPSC values observed during a given water year. Negative SPSC values indicate the potential for soils to release phosphate, while positive values indicate soils have capacity to sorb phosphate, based on Mehlich-3 extractions of phosphate, iron, and aluminum.

Next Steps to Strengthen Understanding

Annual soil samples will enable continued monitoring of soil phosphate sorption capacity. A small sensor network will collect data about water level, conductivity, and turbidity in select

pools. Water samples will be collected only if feasible amidst resource constraints. Water samples will enable researchers to at least get a snapshot of Project nutrient status and surveil for any major changes over time.

Otsego Schools' Fox-Shank Living Laboratory (OTSS)

Project Description

Wood County | Maumee River Watershed

Project size: 16 acres

Partner: Black Swamp Conservancy

The hydrology at this Project is passively managed. The Project has 6 acres of restored wetland and consists of a depressional pool complex. There are two emergent wetland pools at the north end that rarely flood, a deep vernal pool in the southwest of the site, and numerous small hummock-hollow pools throughout the southern portion of the site. The Project receives water from surface water runoff and typically does not outflow. The emergent pools receive water from Tontogany Creek when water level rises. A hydrologic event at this Project is operationally defined as a storm event that causes surface water runoff within the Project and raises water level in Tontogany Creek to flood-stage.



Figure 181. Aerial image showing surface water flow and sampling locations for Otsego Schools' Fox-Shank Living Laboratory Project. Blue arrows indicate direction of surface water flow. Dots represent geographic base crew sampling locations, which are grouped by Project

features (fill color) where relevant. Text annotations provide additional context about the Project's watershed connection or other important features.

Management Considerations

The Otsego Schools' Fox-Shank Living Laboratory Project is a wetland used primarily for educational purposes. Although the Project lacks structures for active hydrologic management, its inclusion of a small agricultural field in the center of the Project provides unique opportunities to test drivers of the agricultural-wetland system function collectively and may provide insights into the functioning of larger, similar systems. The Project's connection to the watershed is limited, particularly under the dry conditions of 2024, though its soils do have moderate capacity to sorb phosphorus inputs if received. Future sampling to capture hydrologic events will help researchers assess the extent of the floodplain function of the emergent wetland and estimate any resulting nutrient transport reduction.



Figure 182. Aerial image of approximate locations of interest for water and soil sampling and discrete manual measurements of water depth and physicochemical parameters at Fox-Shank Living Laboratory Project during water year 2024 (Oct 1, 2023–Sep 30, 2024). The legend provides the name of each sampling point. Different shapes denote the types of wetland features represented by the locations of interest. If present, different colors represent locations of interest that belong to a group or complex of features (e.g., a treatment train).

Surface Water Hydrology and Nutrients

Otsego Schools' Fox-Shank Living Laboratory has a relatively large number of small vernal wetland pools and two emergent wetland pools, as well as a wet meadow. The majority of pools that had water in Water Year (WY) 2024 had comparable average water depths (19–32 cm). Emergent Wetland West pool had the lowest average water depth (14 ± 7 cm) but still had water throughout WY 2024 and had a maximum manually measured depth of 22 cm. The Vernal Pool had the highest average water depth (32 cm). It also had a small range in depth (29–35 cm). The Deadwood Hollow had a comparable average (30 cm) and maximum (32 cm) to the Vernal Pool. The Southeast Hollow had the highest maximum depth (40 cm) but ranged from 0 to 40 cm throughout the year.

Emergent Wetland West and Deadwood Hollow had dissolved reactive phosphorous (DRP) concentrations at the minimum detectable limit (MDL, 0.004 mg P/L, Figure 185). Emergent Wetland East, Southeast Hollow, and Vernal Pool had comparable average DRP concentrations (0.023–0.026 mg P/L). The Root Wad Hollow had the highest average DRP concentrations (0.087 mg P/L). The majority of the pools at the Project had comparable average total phosphorous (TP) concentrations (0.122–0.177 mg P/L). Emergent Wetlands East and West had the same average TP (0.122 mg P/L). The Root Wad Hollow had the highest average TP (0.229 mg P/L) and ranged from 0.06 to 0.42 mg P/L throughout WY 2024. The pools also had comparable average total nitrogen (TN) concentrations (0.476–0.789 mg N/L). The Root Wad Hollow had the highest average TN concentrations (0.789 mg N/L).

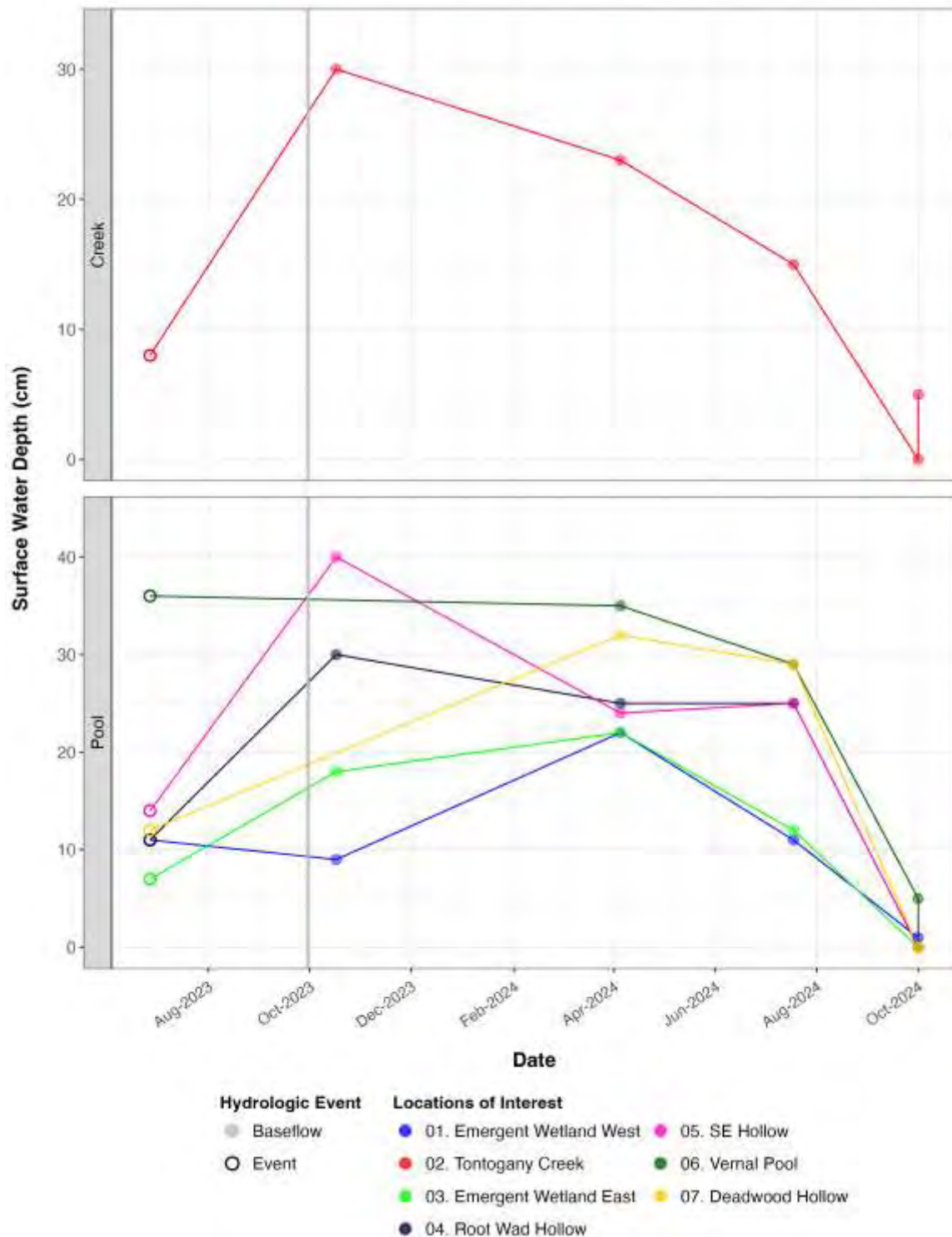


Figure 183. Time series of discrete, manually-measured surface water depth at the Fox-Shank Living Laboratory Project. Depths were measured approximately monthly. Each point represents one measurement and colors denote the locations of interest, as indicated in the legend. Open symbols indicate samples that were collected during a hydrologic event (e.g., storm event) and

filled symbols denote samples collected during baseflow. Crosses (×) represent instances when no surface water was detected during the visit. If present, different shapes denote the types of wetland features represented by the locations of interest. Gray vertical lines indicate the start of a water year (Oct 1–Sep 30).

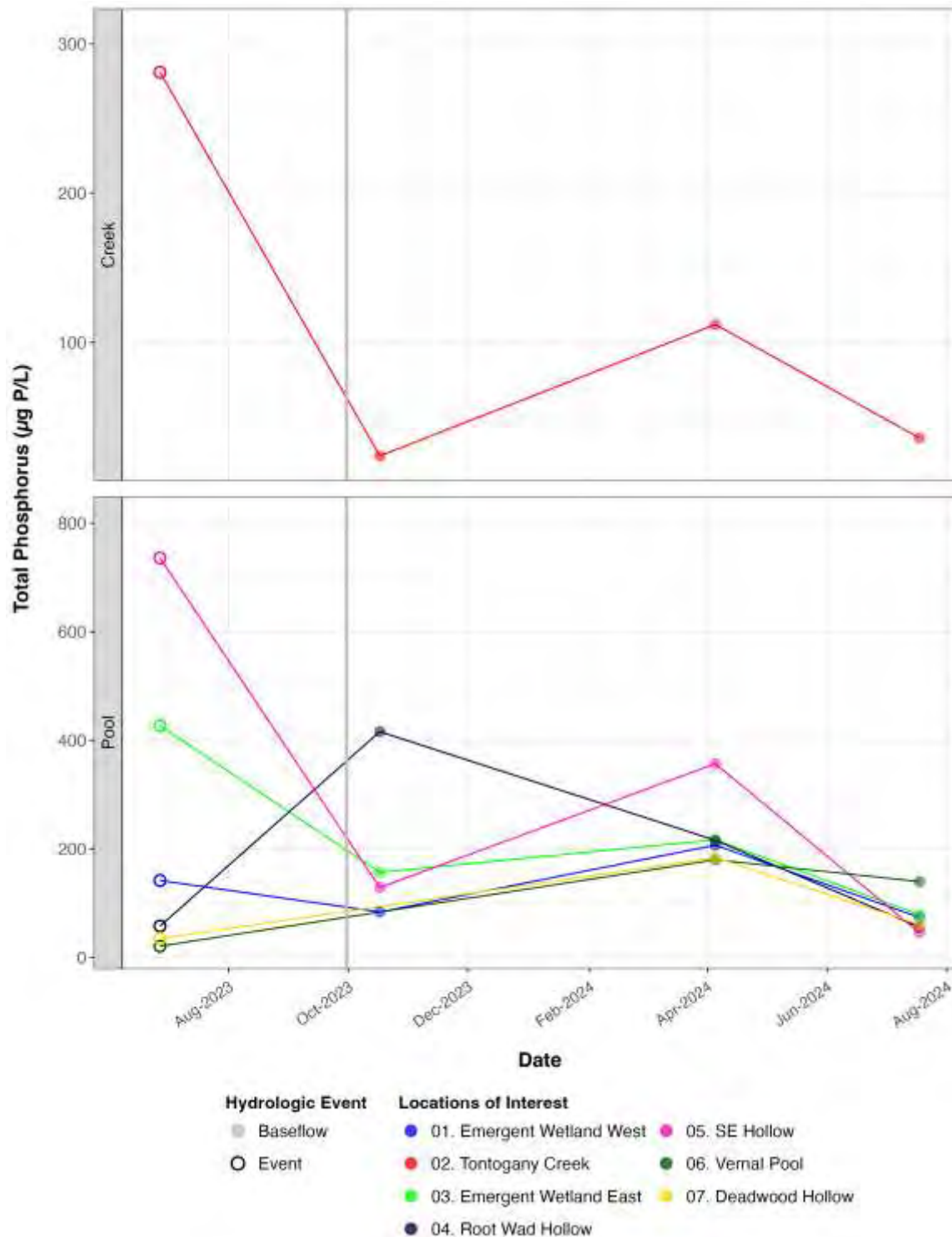


Figure 184. Time series of total phosphorus (TP) concentrations in surface water samples collected at the Fox-Shank Living Laboratory Project. Values below the detection limit of the analytical equipment were replaced with half the value of the detection limit. Each point represents one measurement, and colors denote the locations of interest, as indicated in the

legend. Open symbols indicate that measurements were collected during a hydrologic event (e.g., storm event) and filled symbols denote measurements collected during baseflow. Crosses (×) represent instances when no surface water was detected during the visit. If present, different shapes denote the types of wetland features represented by the locations of interest. Gray vertical lines indicate the start of a water year (Oct 1–Sep 30).

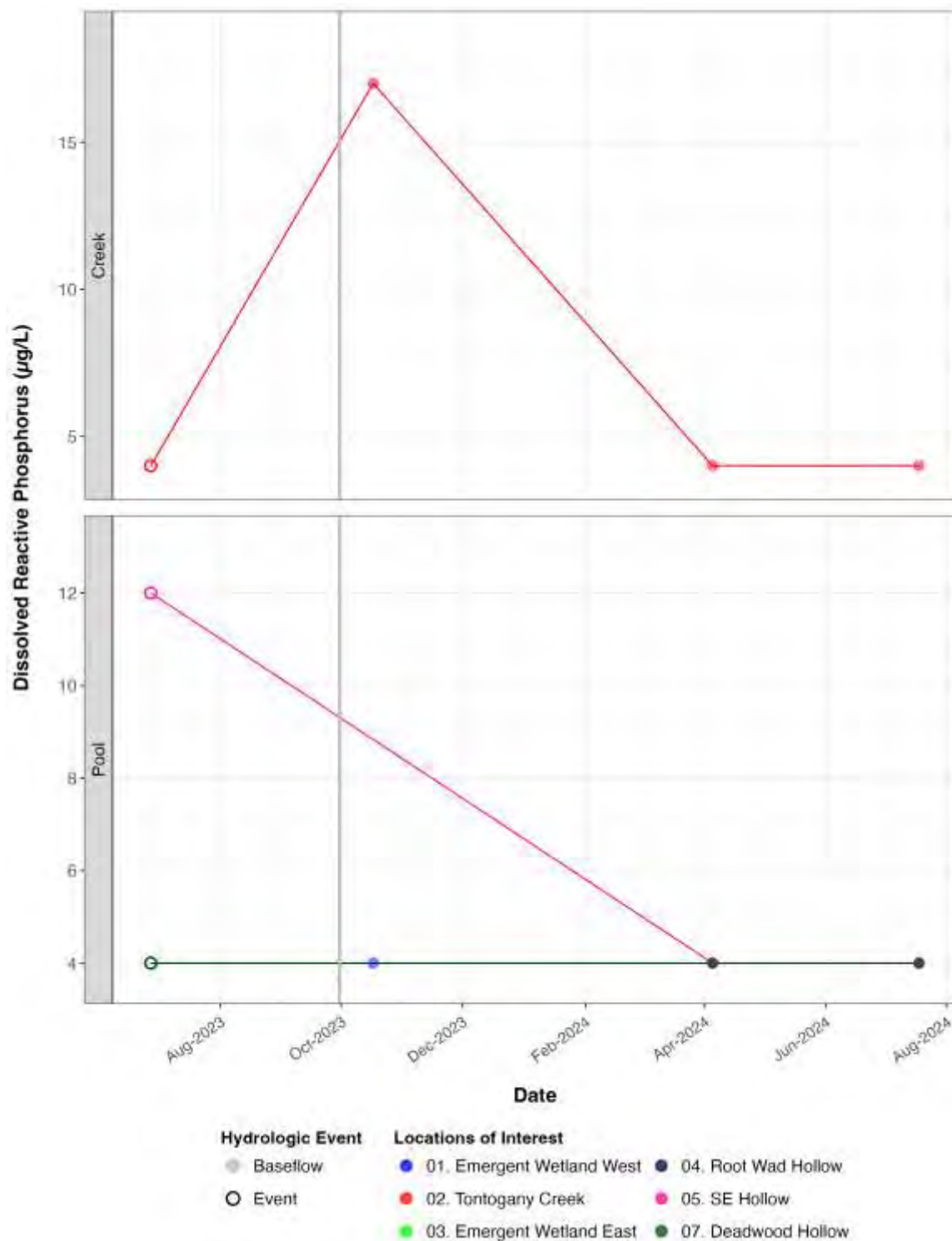


Figure 185. Time series of dissolved reactive phosphorus (DRP) concentrations in surface water samples collected at the Fox-Shank Living Laboratory Project. Values below the detection limit of the analytical equipment were replaced with half the value of the detection limit. Each point represents one measurement, and colors denote the locations of interest, as indicated in the

legend. Open symbols indicate that measurements were collected during a hydrologic event (e.g., storm event) and filled symbols denote measurements collected during baseflow. Crosses (×) represent instances when no surface water was detected during the visit. If present, different shapes denote the types of wetland features represented by the locations of interest. Gray vertical lines indicate the start of a water year (Oct 1–Sep 30).

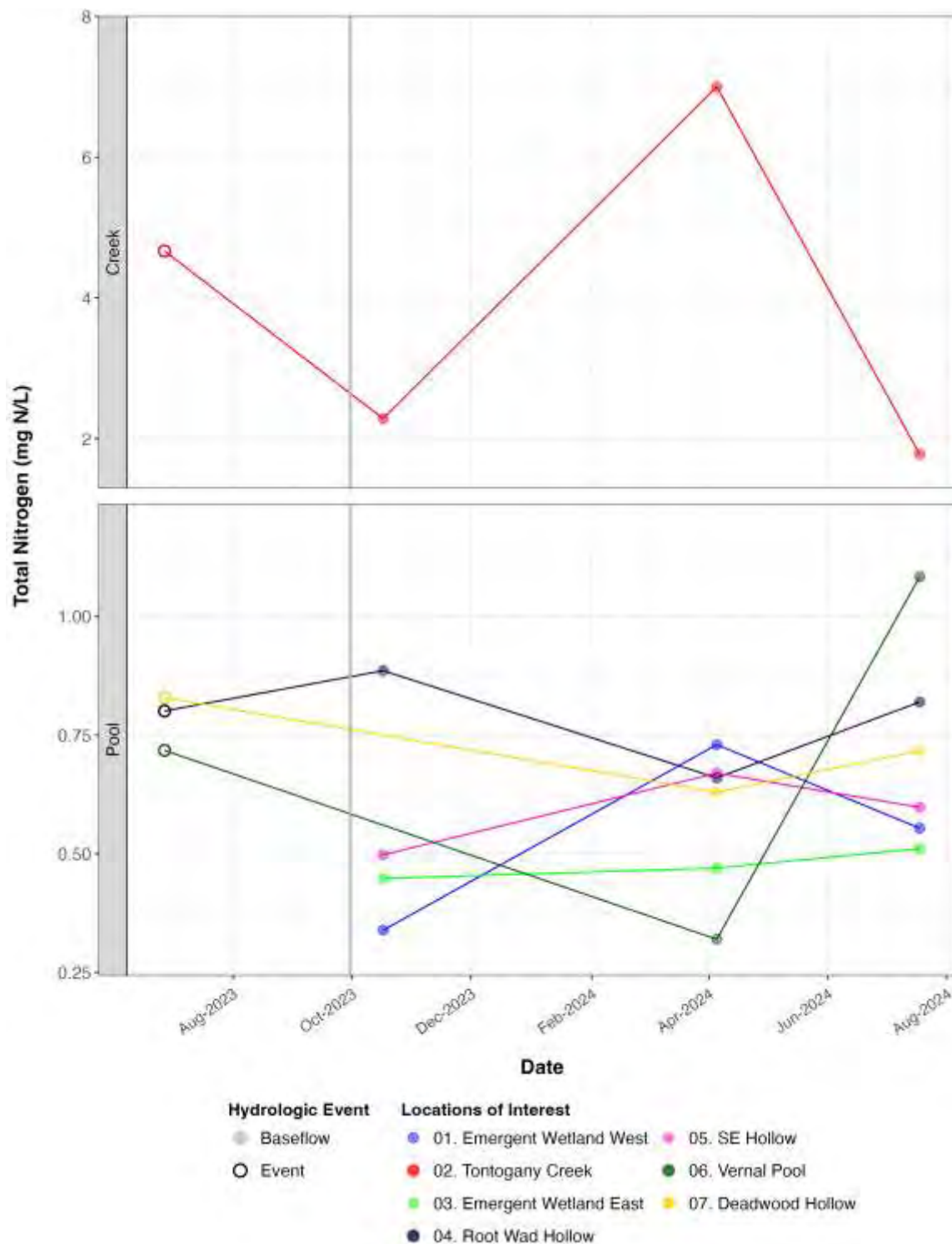


Figure 186. Time series of total nitrogen (TN) concentrations in surface water samples collected at the Fox-Shank Living Laboratory Project. Values below the detection limit of the analytical equipment were replaced with half the value of the detection limit. Each point represents one measurement, and colors denote the locations of interest, as indicated in the legend. Open

symbols indicate that measurements were collected during a hydrologic event (e.g., storm event) and filled symbols denote measurements collected during baseflow. Crosses (×) represent instances when no surface water was detected during the visit. If present, different shapes denote the types of wetland features represented by the locations of interest. Gray vertical lines indicate the start of a water year (Oct 1–Sep 30).

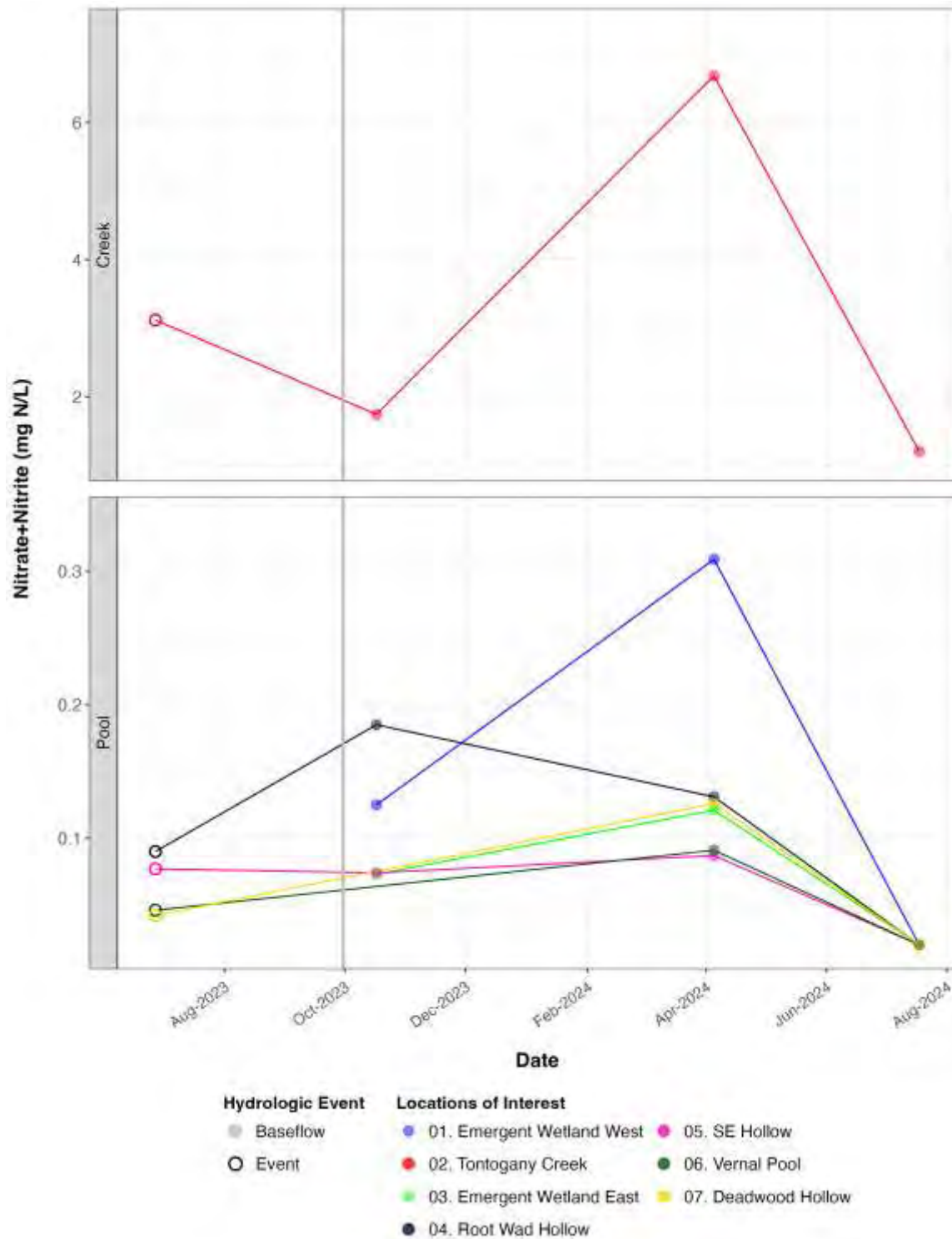


Figure 187. Time series of Nitrite+nitrate (NO_x) concentrations in surface water samples collected at the Fox-Shank Living Laboratory Project. Values below the detection limit of the analytical equipment were replaced with half the value of the detection limit. Each point represents one measurement, and colors denote the locations of interest, as indicated in the

legend. Open symbols indicate that measurements were collected during a hydrologic event (e.g., storm event) and filled symbols denote measurements collected during baseflow. Crosses (×) represent instances when no surface water was detected during the visit. If present, different shapes denote the types of wetland features represented by the locations of interest. Gray vertical lines indicate the start of a water year (Oct 1–Sep 30).

Soil Nutrient Status and Processes

The soils at the Otsego Project have moderate phosphate sorption capacity, suggesting a capacity to retain nutrients through infiltration of water and sorption of phosphate to soil particles. The soil phosphate sorption capacity (SPSC) values were positive for all samples (Figure 188, Figure 206). Tontogany Creek had the lowest average SPSC (28 mg phosphorus/kg). Emergent Wetland East had double the SPSC average of Tontogany Creek (49 mg/kg). The Southeast Hollow had the highest average SPSC value (120 mg/kg). Notably, Southeast Hollow had a relatively high maximum SPSC value (141 mg/kg) in Water Year 2024 compared to 2023. Overall, SPSC values at the Project remain relatively constant between water years.

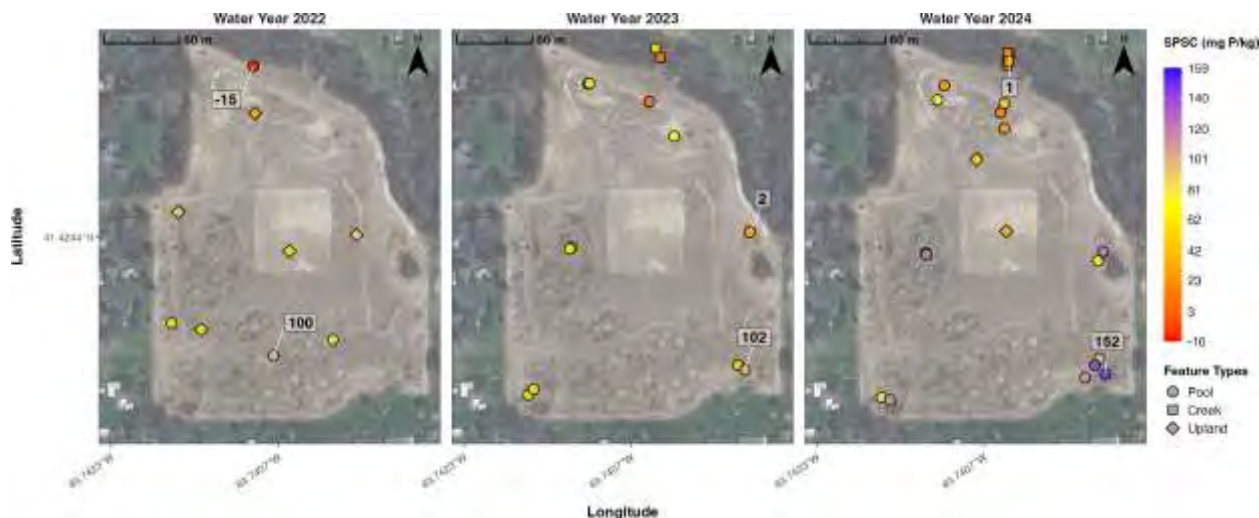


Figure 188. Soil Phosphate Sorption Capacity (SPSC) throughout the Fox-Shank Living Laboratory Project. Each point denotes a soil sample (0–5 cm) and different shapes indicate the wetland feature type, as shown in the legend. Colors indicate the SPSC value of each sample relative to the overall range of values observed at the wetland project, as shown in the color bar. Each panel shows the soil samples collected during a respective water year (Oct 1–Sep 30), along with the minimum and maximum SPSC values observed during a given water year. Negative SPSC values indicate the potential for soils to release phosphate, while positive values indicate soils have capacity to sorb phosphate, based on Mehlich-3 extractions of phosphate, iron, and aluminum.

Next Steps to Strengthen Understanding

Annual soil samples will enable continued monitoring of soil phosphate sorption capacity. A sensor network is collecting data about water level in the Emergent Wetland and Tontogany Creek and will detect flooding events and enable assessing this wetland's function as a floodplain wetland. Water samples will be collected only if feasible and if a priority amidst resource constraints. Water samples will enable researchers to at least get a snapshot of Project nutrient status and surveil for any major changes over time.

St. Joseph Confluence (SJCO)

Project Description

Williams County | Maumee River Watershed

Project size: 140 acres

Partner: Black Swamp Conservancy

The hydrology at this Project is passively managed. The Project has 31 acres of restored wetland, consisting of a northern and a southern pool complex. There are eight wetland pools plus one oxbow wetland, all of which receive flow from surface water runoff throughout the year, and act as floodplain pools when the St. Joseph River branches overflow their banks. A hydrologic event at this Project is operationally defined as a storm event where the St. Joseph River exceeds its banks and flows into the pools.

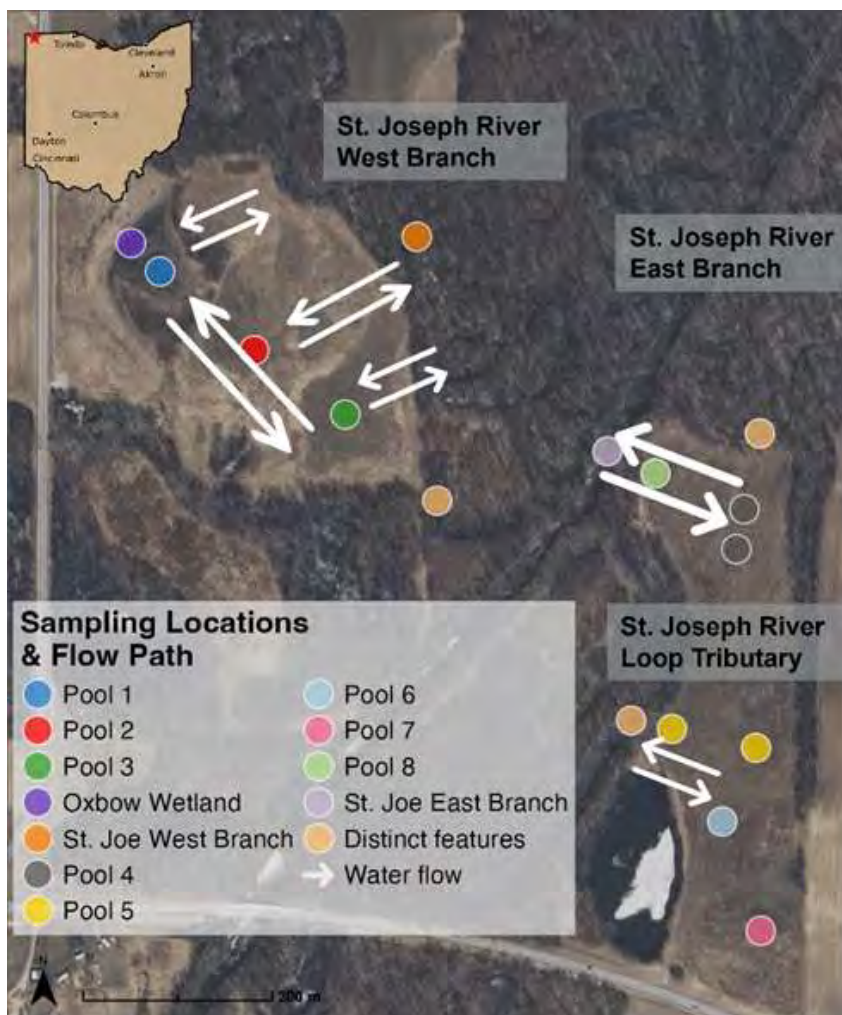


Figure 189. Aerial image showing surface water flow and sampling locations for the St. Joseph Confluence Wetland Reconnection Project. Blue arrows indicate direction of surface water flow.

Dots represent geographic base crew sampling locations, which are grouped by Project features (fill color) where relevant. Text annotations provide additional context about the Project's watershed connection or other important features.

Management Considerations

The Project converted an agricultural field as well as land previously enrolled in the Conservation Reserve Program (CRP). The CRP field includes areas of hydric soils that were converted to wetlands and portions that were not disturbed.

The soil has relatively high soil phosphate storage capacity (SPSC), suggesting it should be able to capture and hold a relatively large amount of P. SPSC increased at many sampling locations in Water Year (WY) 2024. The maximum SPSC value was 145 mg/kg, up from 108 in WY 2023. The minimum value has similarly increased from 8 mg/kg in 2022 to 29 mg/kg in 2024.

Dry conditions in WY 2024 limited the function of the St. Joseph Confluence Project. Pools were observed to be totally dry by July and remained dry throughout the summer and fall. There is no active water level management, and the only major water sources for this wetland are the branches of the St. Joseph River. Most of the pools at this Project function as floodplain wetlands only briefly (a few days or less) when the branches of the St. Joseph River flood. Otherwise, they hold relatively little water and serve as geographically isolated pools that decrease surface water runoff. However, there would be very little P and nitrogen (N) export in runoff because the soil P and N content is so low, so this is a minor effect with respect to nutrient export reduction.

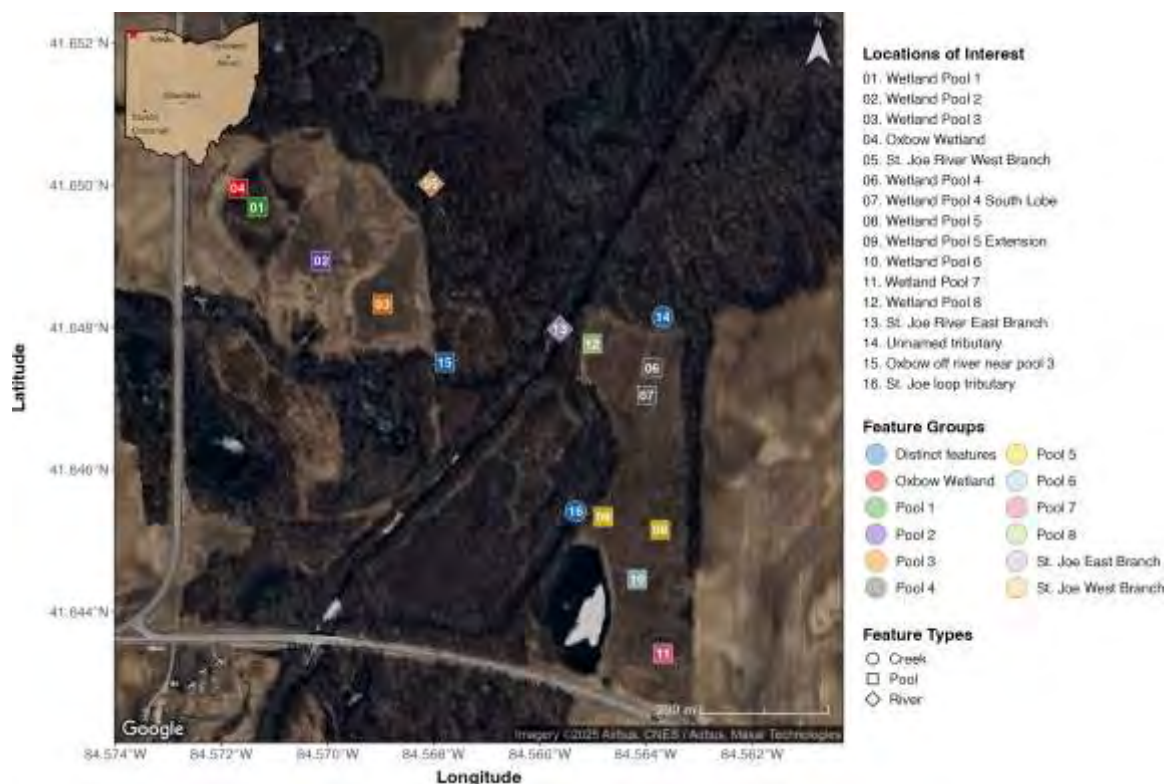


Figure 190. Aerial image of approximate locations of interest for water and soil sampling and discrete manual measurements of water depth and physicochemical parameters at St. Joseph Confluence Wetland Reconnection Project during water year 2024 (Oct 1, 2023–Sep 30, 2024). The legend provides the name of each sampling point. Different shapes denote the types of wetland features represented by the locations of interest. If present, different colors represent locations of interest that belong to a group or complex of features (e.g., a treatment train).

Surface Water Hydrology and Nutrients

The pools at the St. Joseph Confluence Project act as floodplain wetlands when the river branches flood. This typically occurs in late winter and early to late spring, and the pools completely dry shortly after. The Project has relatively low connectivity, so it is dry throughout the summer unless a floodplain event occurs during these months. Due to this low connectivity and drier-than-average conditions in Water Year 2024, water samples were only obtained at the St. Joseph West Branch and the Unnamed Tributary (Figure 191). All wetland pools were dry during all sampling visits in 2024 and exhibit a short-term seasonal flooding regime.

Total phosphorus (TP) concentration in the St. Joseph West Branch was 0.16 mg P/L and dissolved reactive phosphorus (DRP) was 0.011 mg P/L (Figure 192). The Unnamed Tributary at the north end of the southeast former ag field had a similar TP concentration (0.186 mg P/L) but a higher DRP concentration (0.096 mg P/L).

St. Joseph West Branch had a nitrite+nitrate (NO_x) concentration of 0.162 mg N/L, total ammonium nitrogen ($\text{NH}_4\text{-N}$) 0.042 mg N/L, and total nitrogen (TN) concentration of 1.276 mg

N/L (Figure 193). The Unnamed Tributary had a somewhat lower nitrite+nitrate NO_x concentration (0.075 mg N/L) but higher $\text{NH}_4\text{-N}$ (1.65 mg N/L) and TN (2.33 mg N/L). These are lower concentrations than often seen in rivers that receive runoff and drainage from agricultural fields in NW Ohio.

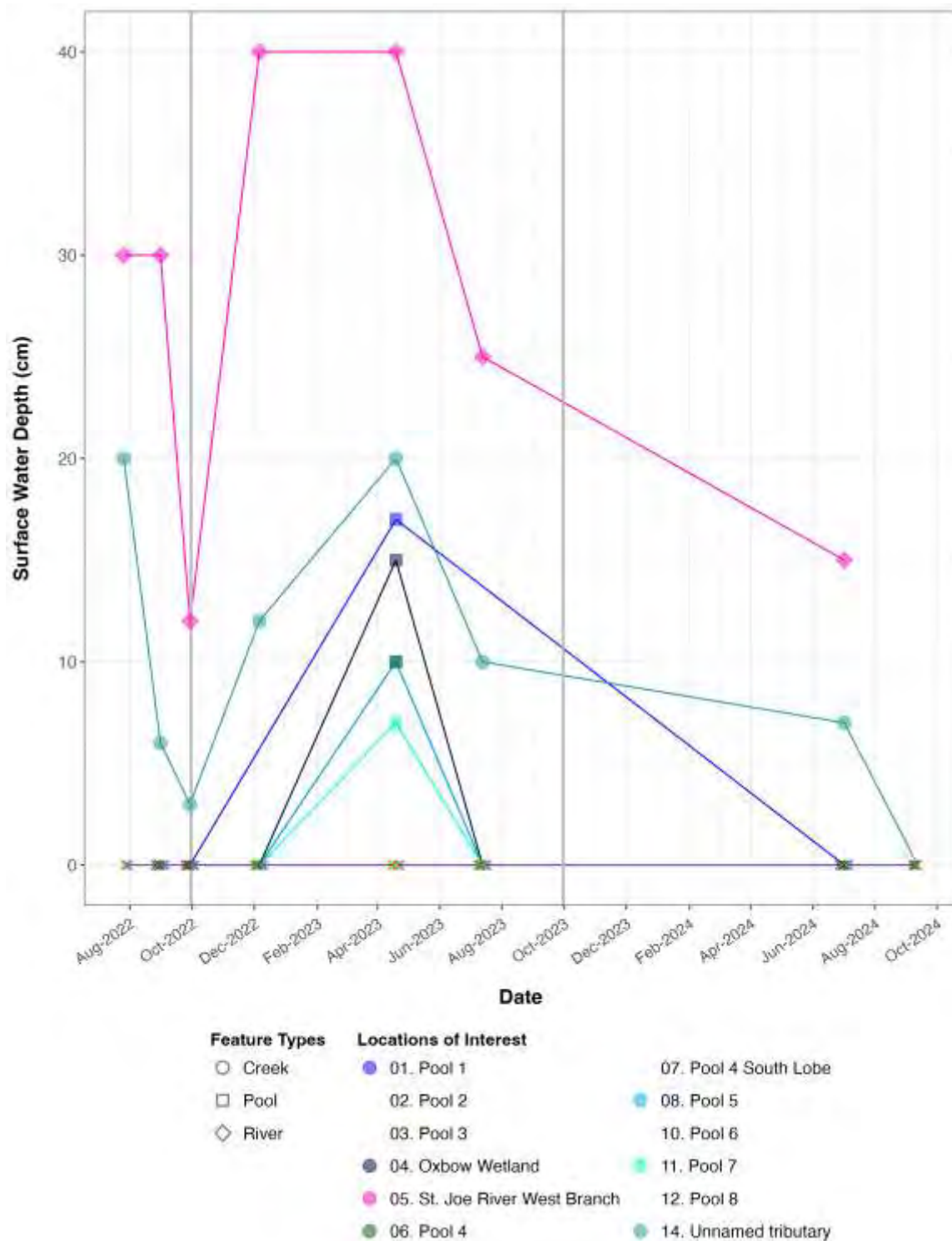


Figure 191. Time series of discrete, manually measured surface water depth at the St. Joseph Confluence Wetland Reconnection Project. Depths were measured approximately monthly. Each point represents one measurement and colors denote the locations of interest, as indicated in the legend. Open symbols indicate samples that were collected during a hydrologic event (e.g., storm

event) and filled symbols denote samples collected during baseflow. Crosses (×) represent instances when no surface water was detected during the visit. If present, different shapes denote the types of wetland features represented by the locations of interest. Gray vertical lines indicate the start of a water year (Oct 1–Sep 30).

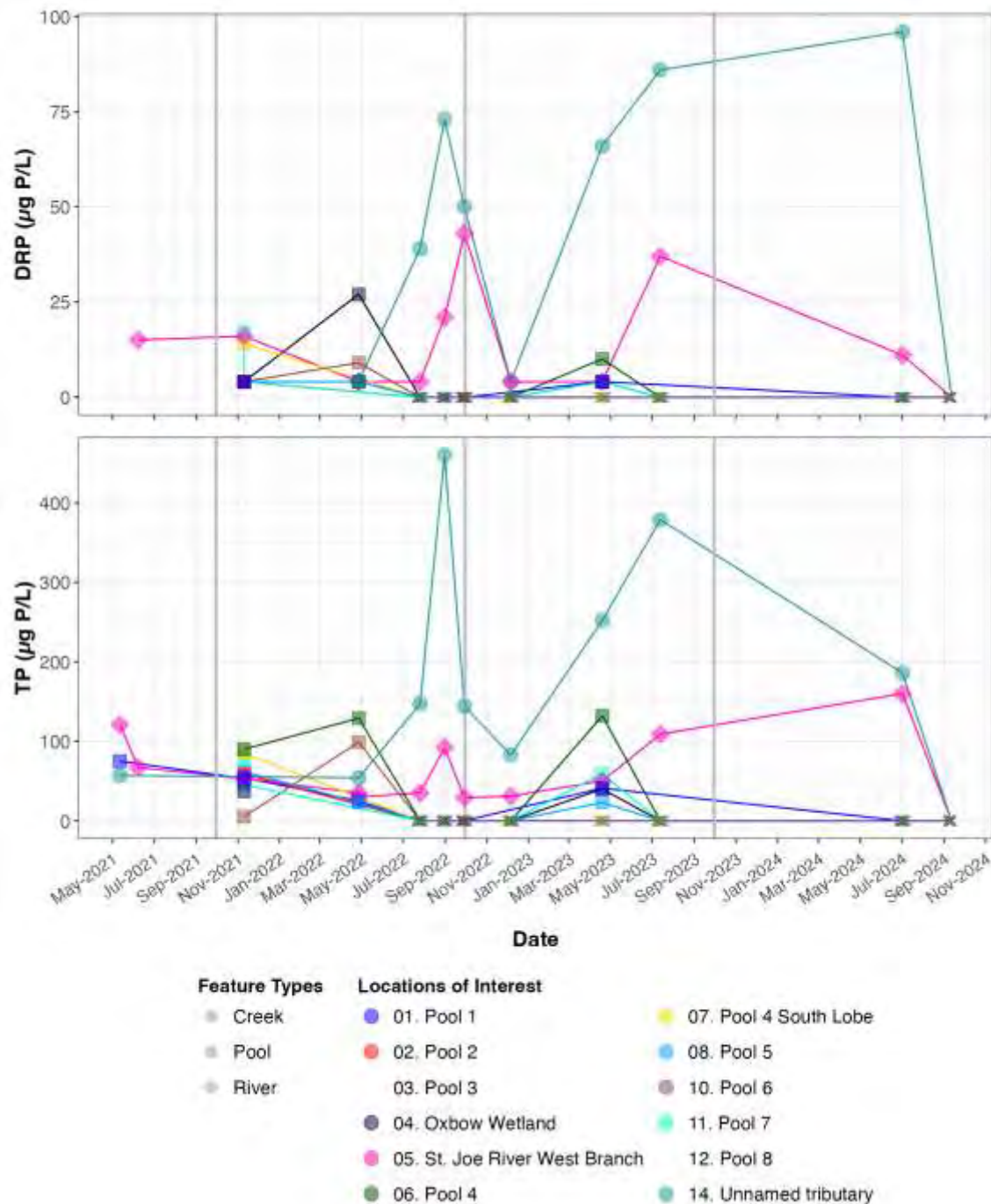


Figure 192. Time series of dissolved reactive phosphorus (DRP, top panel) and total phosphorus (TP, bottom panel) concentrations in surface water samples collected at the St. Joseph Confluence Wetland Reconnection Project. Values below the detection limit of the analytical equipment were replaced with half the value of the detection limit. Each point represents one measurement, and colors denote the locations of interest, as indicated in the legend. Open symbols indicate that measurements were collected during a hydrologic event (e.g., storm event) and filled symbols denote measurements collected during baseflow. Crosses (×) represent

instances when no surface water was detected during the visit. If present, different shapes denote the types of wetland features represented by the locations of interest. Gray vertical lines indicate the start of a water year (Oct 1–Sep 30).

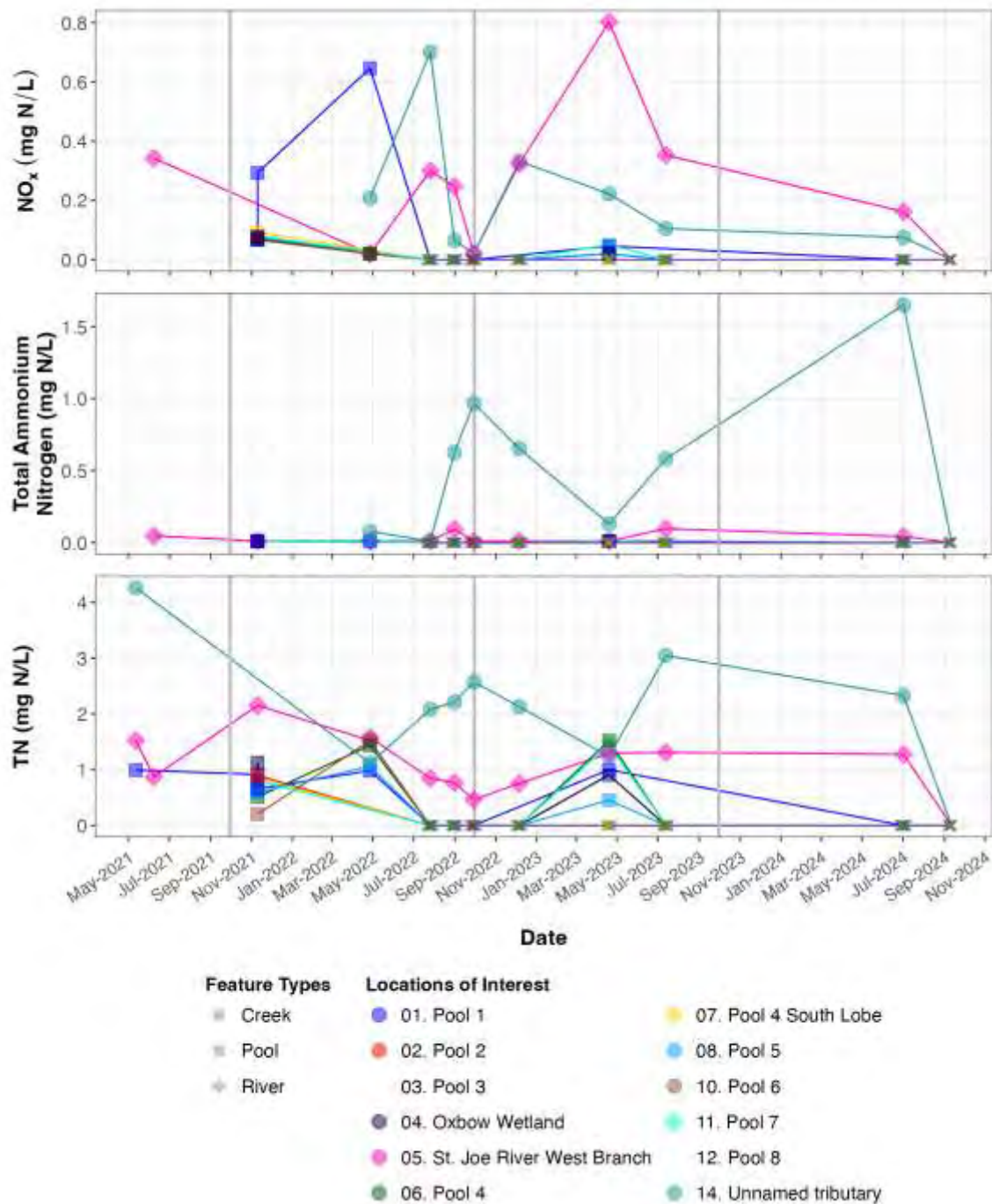


Figure 193. Time series of Nitrite+nitrate (NO_x , top panel) total ammonium nitrogen ($\text{NH}_4\text{-N}$, middle panel), and total nitrogen (TN, bottom panel) concentrations in surface water samples

collected at the St. Joseph Confluence Wetland Reconnection Project. Values below the detection limit of the analytical equipment were replaced with half the value of the detection limit. Each point represents one measurement, and colors denote the locations of interest, as indicated in the legend. Open symbols indicate that measurements were collected during a hydrologic event (e.g., storm event) and filled symbols denote measurements collected during baseflow. Crosses (×) represent instances when no surface water was detected during the visit. If present, different shapes denote the types of wetland features represented by the locations of interest. Gray vertical lines indicate the start of a water year (Oct 1–Sep 30).

Soil Nutrient Status and Processes

Soil phosphate sorption capacity (SPSC) increased at many sampling locations in 2024. The maximum SPSC value was 145 mg phosphorus/kg, up from 108 mg/kg in 2023. The minimum value has similarly increased from 9 mg/kg in Water Year (WY) 2022 to 29 mg/kg in WY 2024 (Figure 194). Wetland Pool 7 had the maximum SPSC value (145 mg/kg) and had an average of 119 mg/kg. Most of the wetland pools had comparable SPSC value averages (105–120 mg/kg). The Oxbow Wetland Pool and the Wetland Pool 4 South Lobe had slightly lower average SPSC values (86–87 mg/kg) than the other wetland pools. Wetland Pool 8 had the lowest SPSC value of the wetland pools (56 mg/kg).



Figure 194. Soil Phosphate Sorption Capacity (SPSC) throughout the St. Joseph Confluence Wetland Reconnection Project. Each point denotes a soil sample (0–5 cm) and different shapes indicate the wetland feature type, as shown in the legend. Colors indicate the SPSC value of each sample relative to the overall range of values observed at the wetland project, as shown in the color bar. Each panel shows the soil samples collected during a respective water year (Oct 1–Sep 30), along with the minimum and maximum SPSC values observed during a given water year. Negative SPSC values indicate the potential for soils to release phosphate, while positive values indicate soils have capacity to sorb phosphate, based on Mehlich-3 extractions of phosphate, iron, and aluminum.

Next Steps to Strengthen Understanding

Annual soil samples will enable continued monitoring of soil phosphate sorption capacity. A sensor network will collect data about water level, conductivity, and turbidity in select pools to measure the degree to which the pools function as a floodplain. Water samples will be collected only if feasible and if a priority amidst resource constraints. Water samples will enable researchers to get a snapshot of Project nutrient status and surveil for any major changes over time. Further evaluation and comparison of these two portions of this Project should improve understanding about the wetland performance of agricultural fields relative to Conservation Reserve Program fields as isolated wetlands. This could provide information that would be useful for decisions about which sites are best for conversion to specific types of wetlands given former land use.

Van Order Wetland & Forest Restoration (VANO)

Project Description

Henry County | Maumee River Watershed

Project size: 31 acres

Partner: ODNR Division of Forestry

The hydrology at this Project is passively managed. The Project has 5 acres of restored wetland and consists of eight isolated wetland pools. Pools 1–7 receive flow only from surface water runoff, while the southernmost pool (Pool 8) might receive flood water from a nearby agricultural ditch. A hydrologic event at this Project is operationally defined as a storm event where surface water runoff is delivered to the pools.



Figure 195. Aerial image showing surface water flow and sampling locations for the Van Order Wetland & Forest Restoration Project. Blue arrows indicate direction of surface water flow. Dots represent geographic base crew sampling locations, which are grouped by Project features (fill

color) where relevant. Text annotations provide additional context about the Project's watershed connection or other important features.

Management Considerations

All pools at the Van Order Project appear to be functioning as intended, holding water during the wet season (late winter into spring) and drying in the summer and fall. Dry conditions impacting part of Water Year (WY) 2024 likely limited the total volume of the pools. However, the sandy soil may hold water poorly in any year and researchers are uncertain how connected the Van Order Project is to the watershed for nutrient delivery. Pools 1–7 are likely fed by surface water runoff only from the surrounding land within the Project. Meanwhile, Pool 8 may receive some water from the South Ditch at peak water levels, but comparison of nutrient concentrations between Pool 8 and the South Ditch indicates this connection was likely not engaged in WY 2024. Overall extent and timing of inundation is comparable across all pools. Soil phosphate sorption capacity appears to be increasing across the Project across years, indicating potential for soils to capture and hold phosphate when water/nutrient inputs are present.



Figure 196. Aerial image of approximate locations of interest for water and soil sampling and discrete manual measurements of water depth and physicochemical parameters at Van Order Wetland & Forest Restoration Project during water year 2024 (Oct 1, 2023–Sep 30, 2024). The

legend provides the name of each sampling point. Different shapes denote the types of wetland features represented by the locations of interest. If present, different colors represent locations of interest that belong to a group or complex of features (e.g., a treatment train).

Surface Water Hydrology and Nutrients

Overall, the water levels among the different pools at Van Order are similar to each other. All pools also exhibited a seasonal flooding regime during the last two Water Years (WYs, 2023 and 2024) filling with water each year in the late winter or early spring and gradually going dry through the summer and fall. Pools 3–6 all hold water for extended periods of time throughout the year, whereas Pools 7 and 8 periodically dried out completely (Figure 197).

Pool 8 potentially receives flow from the South Ditch. Water nutrient levels in Pool 8 were not always similar to the South Ditch in WY 2024. Pools 3, 4, and 6 seemed to have elevated surface water phosphorus (P) and nitrogen (N) nutrient content compared to the other pools. Pools 3, 4, and 6 are relatively close together, but Pools 3 and 4 are separated by a ridge that prevents merging.

Pool 4 had the highest dissolved reactive phosphorus concentration (DRP, 0.119 mg P/L; Figure 198). Pool 6 was the only other pool to have DRP above the minimum detection limit for the analytical equipment (DRP; 0.013 mg P/L). Pool 6 also had the highest maximum total phosphorus (TP; 1.16 mg P/L) and had an average TP of 0.597 P/L. Pool 3 also had a relatively high TP (0.72 mg P/L) toward the end of WY 2024. Wetland Pools 3, 4, and 6 had had elevated TN concentrations (~ 1.44–1.78 mg N/L) compared to other wetland pools and features. It should be noted that there was variability around each of these averages, warranting further investigation of current data into temporal patterns in nutrients as the pools seasonally flood and dry.

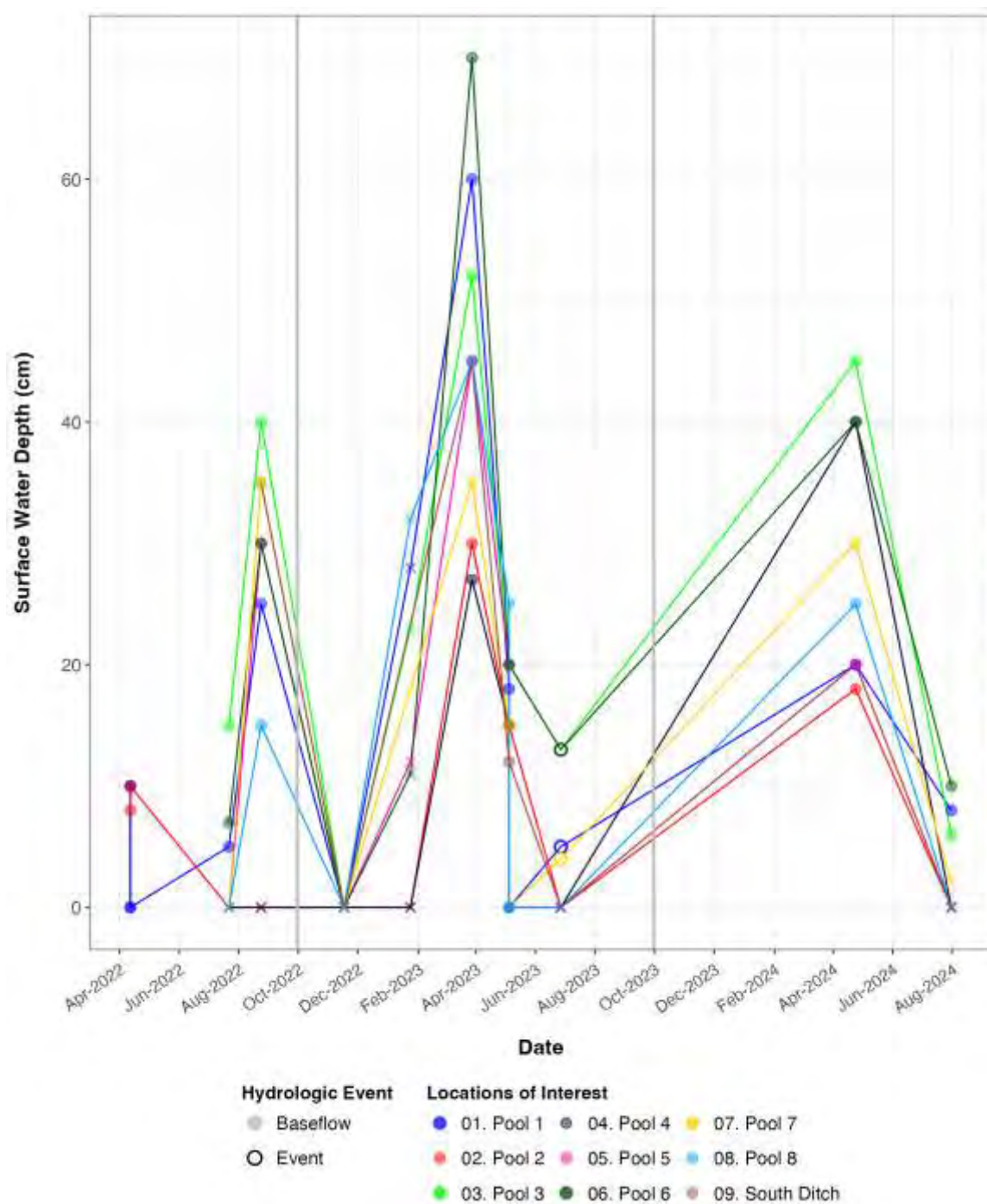


Figure 197. Time series of discrete, manually measured surface water depth at the Van Order Wetland & Forest Restoration Project. Depths were measured approximately monthly. Each point represents one measurement and colors denote the locations of interest, as indicated in the legend. Open symbols indicate samples that were collected during a hydrologic event (e.g., storm event) and filled symbols denote samples collected during baseflow. Crosses (x) represent

instances when no surface water was detected during the visit. If present, different shapes denote the types of wetland features represented by the locations of interest. Gray vertical lines indicate the start of a water year (Oct 1–Sep 30).

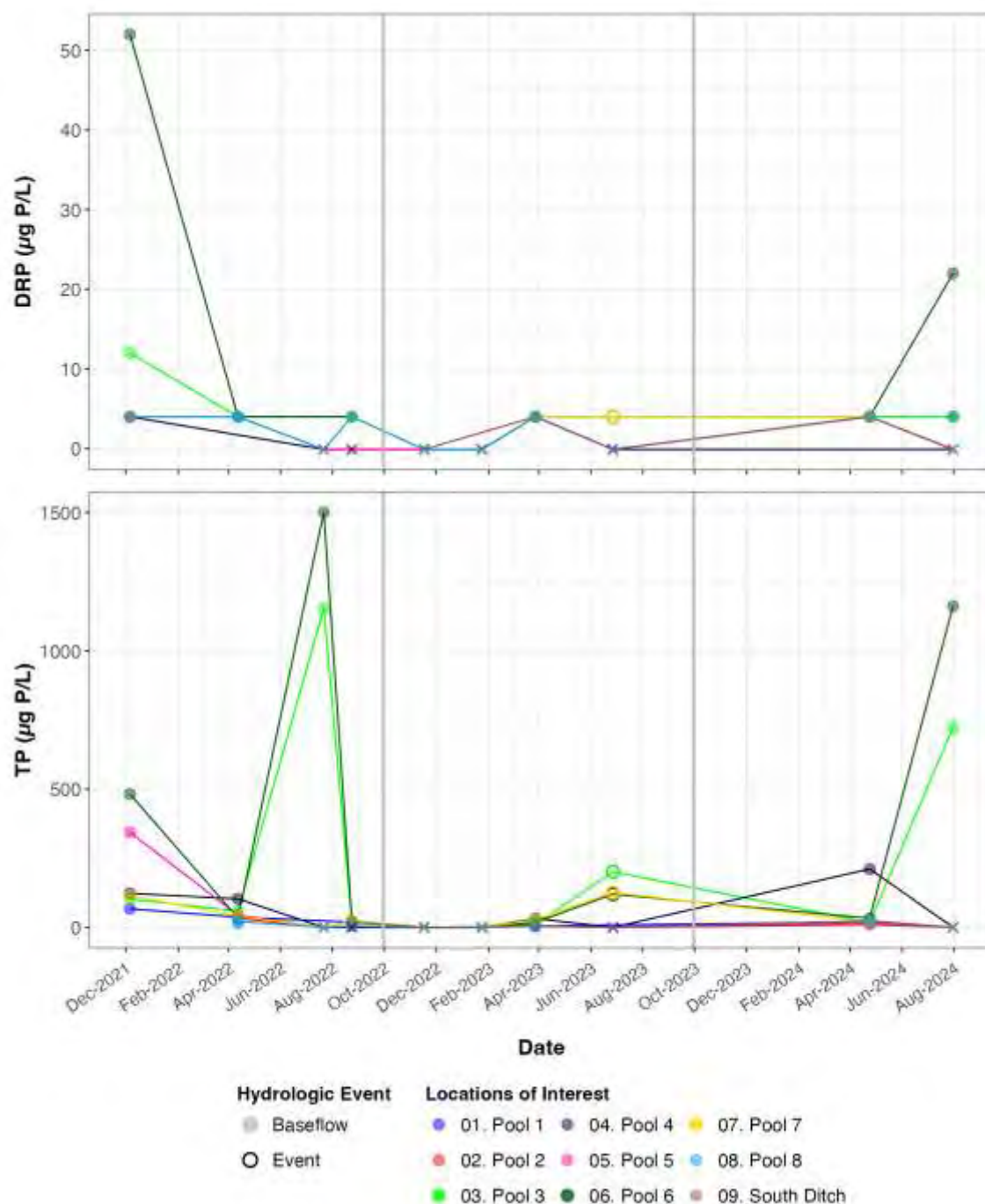


Figure 198. Time series of dissolved reactive phosphorus (DRP, top panel) and total phosphorus (TP, bottom panel) concentrations in surface water samples collected at the Van Order Wetland & Forest Restoration Project. Values below the detection limit of the analytical equipment were replaced with half the value of the detection limit. Each point represents one measurement, and colors denote the locations of interest, as indicated in the legend. Open symbols indicate that measurements were collected during a hydrologic event (e.g., storm event) and filled symbols denote measurements collected during baseflow. Crosses (x) represent instances when no surface

water was detected during the visit. If present, different shapes denote the types of wetland features represented by the locations of interest. Gray vertical lines indicate the start of a water year (Oct 1–Sep 30).

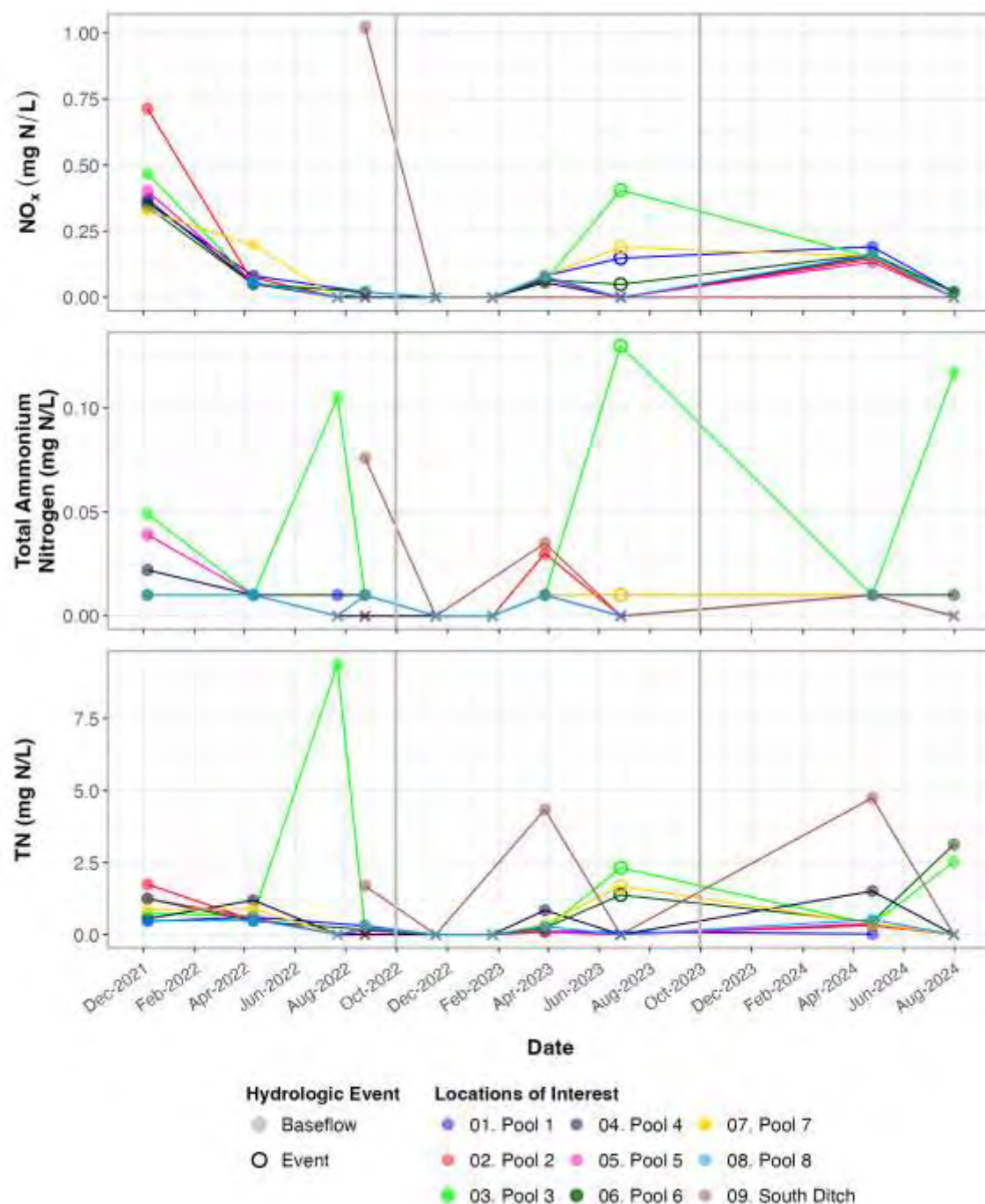


Figure 199. Time series of Nitrite+nitrate (NO_x , top panel) total ammonium nitrogen ($\text{NH}_4\text{-N}$, middle panel), and total nitrogen (TN, bottom panel) concentrations in surface water samples collected at the Van Order Wetland & Forest Restoration Project. Values below the detection limit of the analytical equipment were replaced with half the value of the detection limit. Each point represents one measurement, and colors denote the locations of interest, as indicated in the legend. Open symbols indicate that measurements were collected during a hydrologic event (e.g., storm event) and filled symbols denote measurements collected during baseflow. Crosses (×)

represent instances when no surface water was detected during the visit. If present, different shapes denote the types of wetland features represented by the locations of interest. Gray vertical lines indicate the start of a water year (Oct 1–Sep 30).

Soil Nutrient Status and Processes

Soil phosphate sorption capacity (SPSC) across the Project remained similar at most locations and slightly increased at some locations between Water Years (WYs) 2023 and 2024. All SPSC values for the Project were positive, which suggests a capacity to sorb phosphate and minimal risk of phosphorous release (Figure 200). The highest SPSC values in WY 2024 were recorded at Pool 4 (137 mg phosphorus/kg) and at Pool 6 (124 mg/kg). The remaining pools had relatively moderate SPSC values (50–90 mg/kg). Pool 8 had the lowest minimum SPSC value in WY 2024 (28 mg/kg). The South Ditch, by comparison, had very high SPSC levels (156 mg/kg).

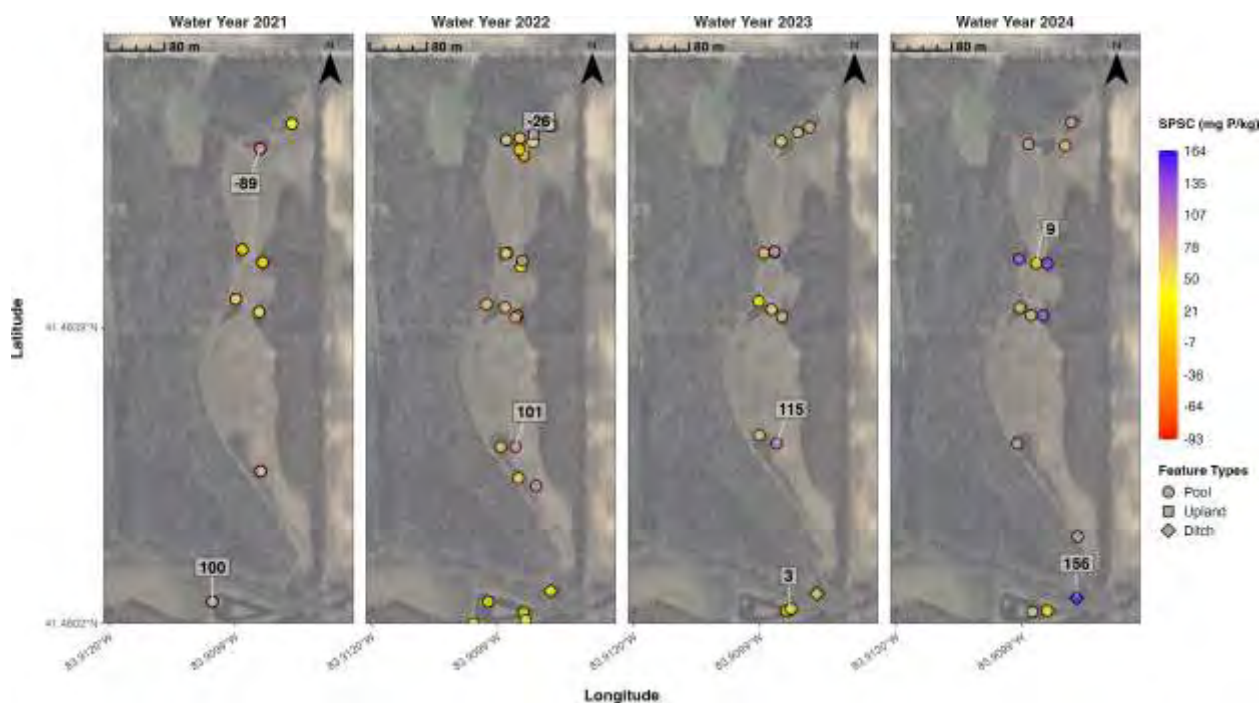


Figure 200. Soil Phosphate Sorption Capacity (SPSC) throughout the Van Order Wetland & Forest Restoration Project. Each point denotes a soil sample (0–5 cm) and different shapes indicate the wetland feature type, as shown in the legend. Colors indicate the SPSC value of each sample relative to the overall range of values observed at the wetland project, as shown in the color bar. Each panel shows the soil samples collected during a respective water year (Oct 1–Sep 30), along with the minimum and maximum SPSC values observed during a given water year. Negative SPSC values indicate the potential for soils to release phosphate, while positive values indicate soils have capacity to sorb phosphate, based on Mehlich-3 extractions of phosphate, iron, and aluminum.

Next Steps to Strengthen Understanding

Annual soil samples will enable continued monitoring of soil phosphate sorption capacity. A small sensor network will collect data about water level, conductivity, and turbidity in select pools, which is important to investigate the connection between Pool 8 and the South Ditch features of this Project. Additional water nutrient samples will be collected only if feasible and if a priority amidst resource constraints. Water nutrient samples will enable researchers to at least get a snapshot of Project nutrient status and surveil for any major changes over time.

Weisgerber-Pohlman Nature Preserve (WEIP)

Project Description

Williams County | Maumee River Watershed

Project size: 75 acres

Partner: Black Swamp Conservancy

The hydrology at this Project is passively managed. The Project has 70 acres of restored wetland, consisting of five isolated depressional pools and one large floodplain wetland on the north side of the site. The floodplain wetland receives water from the Tiffin River during high flow events, while the isolated depressional pools only receive surface water runoff. A hydrologic event at this Project is operationally defined as a storm event in which the Tiffin River floods its bank delivering water to the floodplain wetland.



Figure 201. Aerial image showing surface water flow and sampling locations for the Weisgerber-Pohlman Nature Preserve–Restoration Project. Blue arrows indicate direction of surface water

flow. Dots represent geographic base crew sampling locations, which are grouped by Project features (fill color) where relevant. Text annotations provide additional context about the Project's watershed connection or other important features.

Management Considerations

The Weisgerber-Pohlman Project restores the Tiffin River floodplain by allowing floodwater to enter it via cuts in the streambank. However, flooding via the cuts in the streambank have rarely been observed; this is likely due in part to relatively dry weather conditions in the past three years of monitoring. The vernal pools only have standing water (~15 cm) during a brief period in the spring because of these dry conditions but are performing as intended by retaining water and reducing surface water runoff.



Figure 202. Aerial image of approximate locations of interest for water and soil sampling and discrete manual measurements of water depth and physicochemical parameters at The Weisgerber-Pohlman Nature Preserve Restoration Project during water year 2024 (Oct 1, 2023–Sep 30, 2024). The legend provides the name of each sampling point. Different shapes denote the types of wetland features represented by the locations of interest. If present, different colors

represent locations of interest that belong to a group or complex of features (e.g., a treatment train).

Surface Water Hydrology and Nutrients

The five vernal pools at this Project follow a seasonal flooding regime as expected based on the design of the wetland features; they are wet for brief periods in spring but dry out in the summer. The functionality of the floodplain wetland is unclear due to dry conditions resulting in brief flood periods in Water Years (WY) 2022–2024 (Figure 203). All the vernal pools reach similar depths and dry out with similar timing, with depths of about 1–5 cm by summer. The Seepage Spring is an unplanned feature of the Project, discovered shortly after construction. It is a relatively small depression less than one meter in diameter but up to 45 cm in depth. It is currently being monitored to investigate whether it is a true natural spring, river water from the Tiffin River, or underground tile drainage. During WY 2024 the Seepage Spring had a maximum depth of 45 cm and an average depth of 15 cm.

The Tiffin River had a dissolved reactive phosphorous (DRP) of 0.054 mg P/L and an average Total Phosphorus (TP) of 0.24 mg/L throughout the monitoring sampling trips in WY 2024 (Figure 204). The Vernal and Floodplain pool concentrations were below the minimum detection limit (MDL) of the analytical equipment. Of the wetland pools, Vernal Pool 2 had the highest TP (0.136 mg P/L). Other pools at the Project had similar TP concentrations to one another (averages 0.06–0.09 mg P/L). The Seepage Spring had DRP concentrations below MDL and also had extremely low TP levels near MDL.

The difference in concentration between the Tiffin River and wetland pools at this Project may indicate a lack of connectivity (i.e., the river is not flooding the Project). However, sampling visits often do not occur until late spring or early summer and may miss crucial hydrological events. It is also possible that DRP concentrations are low in the wetland pools because the microbes, plants, and soils therein, which are generally positive for phosphate sorption capacity, have had sufficient time to sorb or uptake DRP.

The Tiffin River had an average nitrogen (TN) concentration of 2.519 ± 2.9 mg N/L throughout the monitoring sampling trips in WY 2024. The Seepage Spring had a higher average TN (0.85 mg N/L) than the vernal pools average TN (0.39 mg N/L) and floodplain wetland average TN (0.63 mg N/L), though there was variability over time (Figure 205).

The water from the Seepage Spring was never seen to have sufficient flow to leave the Project area and enter the Tiffin River, at least under the drought conditions of WY 2023–2024, so it does not appear to be a significant contributor to the nutrient retention function of this wetland. Still, the Seepage Spring is a unique wetland feature at this Project, to surveil over time. Nitrite+nitrate (NO_x) concentrations were greater at the Seepage Spring (~0.91 mg N/L) than in any wetland pool at the Project (~0.16 mg N/L). The difference in NO_x between the Seepage Spring and the wetland pools suggests that the seepage water is subsurface drainage from an agricultural field since the NO_x is typical of such drainage and not characteristic of a typical spring. Groundwater from the Tiffin River may be the source of this spring, however, the

elevation may be too high for this to be possible. The Tiffin River had NO_x concentrations ranging from 0.29 to 3.8 mg N/L. However, the Seepage Spring had total ammonium nitrogen values (~0.01 mg N/L) more similar to the pools (~0.01 mg N/L) than the river (~0.112 mg N/L). The Seepage Spring also tends to have some of the highest electrical conductivity values at the Project and lower turbidity than the vernal pools. The high conductivity values also suggest agricultural drainage as the source. Researchers did not observe flow in the water from the Seepage Spring that was sufficient enough to leave the Project area and enter the Tiffin River so nutrients being delivered by this feature may be filtered or transformed in the wetland pools.

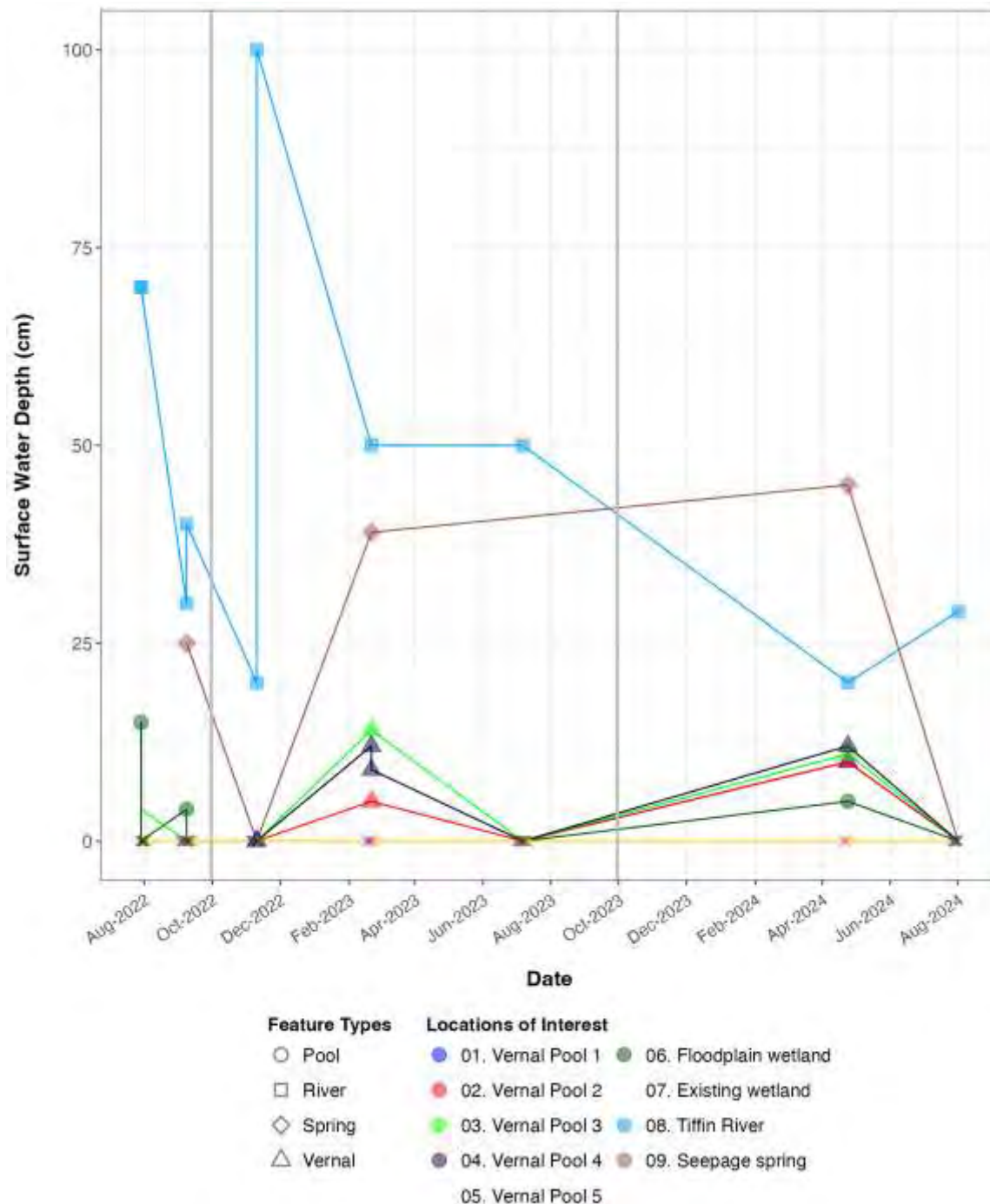


Figure 203. Time series of discrete, manually measured surface water depth at the Weisgerber-Pohlman Nature Preserve Restoration Project. Depths were measured approximately monthly. Each point represents one measurement and colors denote the locations of interest, as indicated in the legend. Open symbols indicate samples that were collected during a hydrologic event (e.g., storm event) and filled symbols denote samples collected during baseflow. Crosses (x) represent instances when no surface water was detected during the visit. If present, different shapes denote

the types of wetland features represented by the locations of interest. Gray vertical lines indicate the start of a water year (Oct 1–Sep 30).

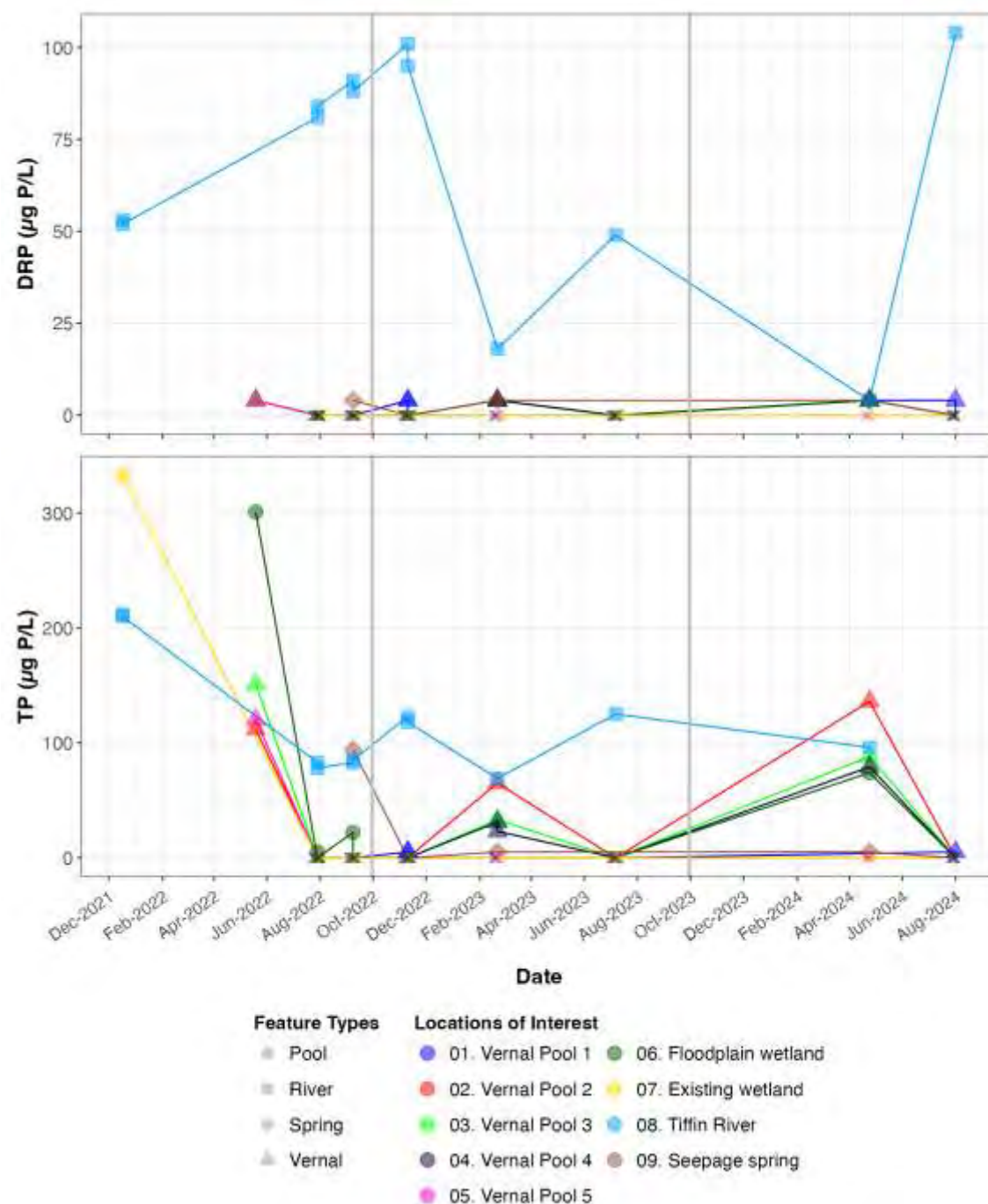


Figure 204. Time series of dissolved reactive phosphorus (DRP, top panel) and total phosphorus (TP, bottom panel) concentrations in surface water samples collected at the Weisgerber-Pohlman Nature Preserve Restoration Project. Values below the detection limit of the analytical equipment were replaced with half the value of the detection limit. Each point represents one measurement, and colors denote the locations of interest, as indicated in the legend. Open symbols indicate that measurements were collected during a hydrologic event (e.g., storm event) and filled symbols denote measurements collected during baseflow. Crosses (×) represent

instances when no surface water was detected during the visit. If present, different shapes denote the types of wetland features represented by the locations of interest. Gray vertical lines indicate the start of a water year (Oct 1–Sep 30).

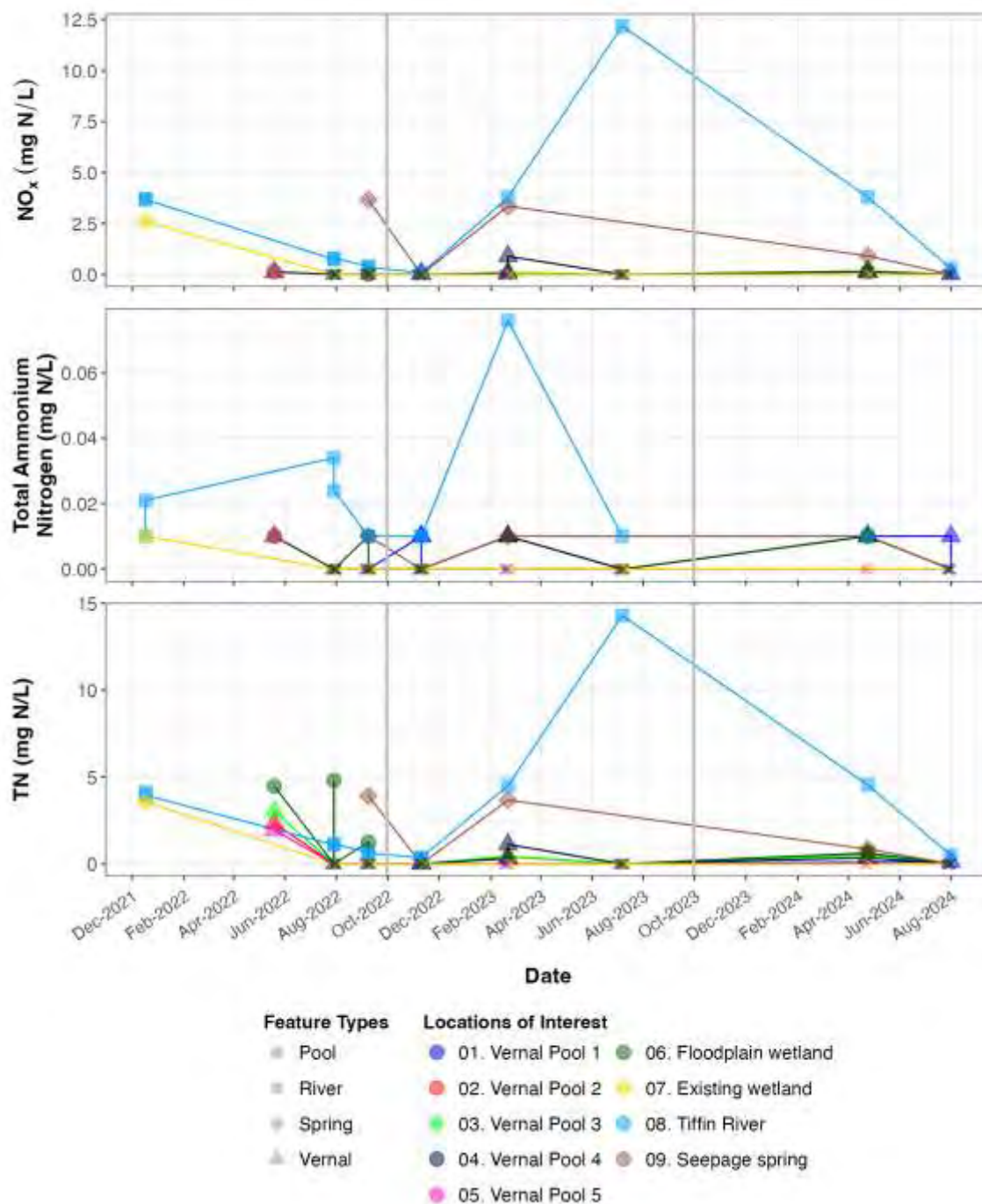


Figure 205. Time series of Nitrite+nitrate (NO_x , top panel) total ammonium nitrogen ($\text{NH}_4\text{-N}$, middle panel), and total nitrogen (TN, bottom panel) concentrations in surface water samples

collected at the Weisgerber-Pohlman Nature Preserve Restoration Project. Values below the detection limit of the analytical equipment were replaced with half the value of the detection limit. Each point represents one measurement, and colors denote the locations of interest, as indicated in the legend. Open symbols indicate that measurements were collected during a hydrologic event (e.g., storm event) and filled symbols denote measurements collected during baseflow. Crosses (×) represent instances when no surface water was detected during the visit. If present, different shapes denote the types of wetland features represented by the locations of interest. Gray vertical lines indicate the start of a water year (Oct 1–Sep 30).

Soil Nutrient Status and Processes

Soil phosphate sorption capacity (SPSC) remained similar at the Project from Water Years (WYs) 2023 to 2024. This trend may be due to lack of connectivity or nutrient delivery in WY 2024. All SPSC values were well above zero, with lowest values associated with the Tiffin River (3 mg phosphorus/kg; Figure 206). Vernal Pool 4 had the highest maximum SPSC value (99 mg/kg) and the highest average SPSC (92 mg/kg). The SPSC values for the remaining vernal pools averaged between 50 and 70 mg/kg, though their range extended above 100 mg/kg. SPSC values in the 50–100 range in the vernal pools are a good indicator that these pools have the capacity to filter nutrients as they are delivered. The Seepage Spring had an average SPSC value (23 mg/kg) of roughly half the vernal pools’.



Figure 206. Soil Phosphate Sorption Capacity (SPSC) throughout the Weisgerber-Pohlman Nature Preserve Restoration Project. Each point denotes a soil sample (0–5 cm) and different shapes indicate the wetland feature type, as shown in the legend. Colors indicate the SPSC value of each sample relative to the overall range of values observed at the wetland project, as shown in the color bar. Each panel shows the soil samples collected during a respective water year (Oct 1–Sep 30), along with the minimum and maximum SPSC values observed during a given water year. Negative SPSC values indicate the potential for soils to release phosphate, while positive values indicate soils have capacity to sorb phosphate, based on Mehlich-3 extractions of phosphate, iron, and aluminum.

Next Steps to Strengthen Understanding

Annual soil samples will enable continued monitoring of soil phosphate sorption capacity. A small sensor network will collect data about water level, conductivity, and turbidity in select pools, which is important to investigate the connection between Seepage Spring features of this Project, as well as the floodplain pool connectivity to the Tiffine River. Additional water nutrient samples will be collected only if feasible and if a priority amidst resource constraints. Water nutrient samples will enable researchers to at least get a snapshot of Project nutrient status and surveil for any major changes over time.

Southwest (Wright State University)

Projects in west central region (Figure 1) are primarily monitored by the geographic base crew centered at the Lake Campus of Wright State University (Stephen J Jacquemin, Principal Investigator)

Williamsburg Wetland Treatment System (EFLA)

Project Description

Clermont County | Grand Lake St. Marys Watershed

Project size: 90 Acres

Partner: Division of Parks & Watercraft and Lake Facilities Authority

Note: The hydrology and surface water chemistry of Williamsburg (East Fork Lake) H2Ohio Project was monitored by the Winston Lab at Ohio State University due to an ODHE HABRI research project. Reported results here include data summary figures for a subset of data.



Figure 1. Aerial image of approximate locations of interest for water and soil sampling and discrete manual measurements of water depth and physicochemical parameters at Williamsburg

Wetland Treatment System Project during water year 2024 (Oct 1, 2023–Sep 30, 2024). The legend provides the name of each sampling point. Different shapes denote the types of wetland features represented by the locations of interest. If present, different colors represent locations of interest that belong to a group or complex of features (e.g., a treatment train).

Nutrient Budget Takeaways

In Water Year 2024, the Williamsburg wetland received 868,000 m³ of water. The Project filtered 1,734 lbs. of total phosphorus, 122 lbs. of dissolved reactive phosphorus, 3,396 lbs. total nitrogen, 651 lbs. nitrite+nitrate, and 127 lbs. of total ammonium nitrogen. The Williamsburg wetland is highly connected to the East Fork of the Lower Maumee River due to a low inflow threshold allowing water to enter the site. The river water the Project receives is high in phosphorus (P) concentration (0.5–1.8 mg P/L) and combined with high volumes (14,000–220,000 m³ per event) leads to high filtration. A portion of P filtration at the Project is due to sediment retained by the wetland which has required managers (Clermont County Soil and Water Conservation District) of the Williamsburg wetland to clear sediment from the inflow to the wetland in both 2023 and 2024 to maintain functionality. No land within the Project was previously used for agriculture, thus the Project does not prevent any additional phosphorus runoff. There is no soil data for this Project.

Indian Creek-Hoffman Wetland and Stream Restoration (INDC)

Project Description

Butler County | Ohio River Watershed

Project size: 22 acres

Partners: Three Valley Conservation Trust

The hydrology at this Project is passively managed. The Project has 13 acres of restored wetland, consisting of three designed flow paths. Water is intended to enter via Indian Creek overflows (forest flow path, riverside flow path), as well as by adjacent field tile inflow. Water exits by surface and/or subsurface connection to Indian Creek. A hydrologic event at this Project is operationally defined as Indian Creek reaching a stage of 1 m.

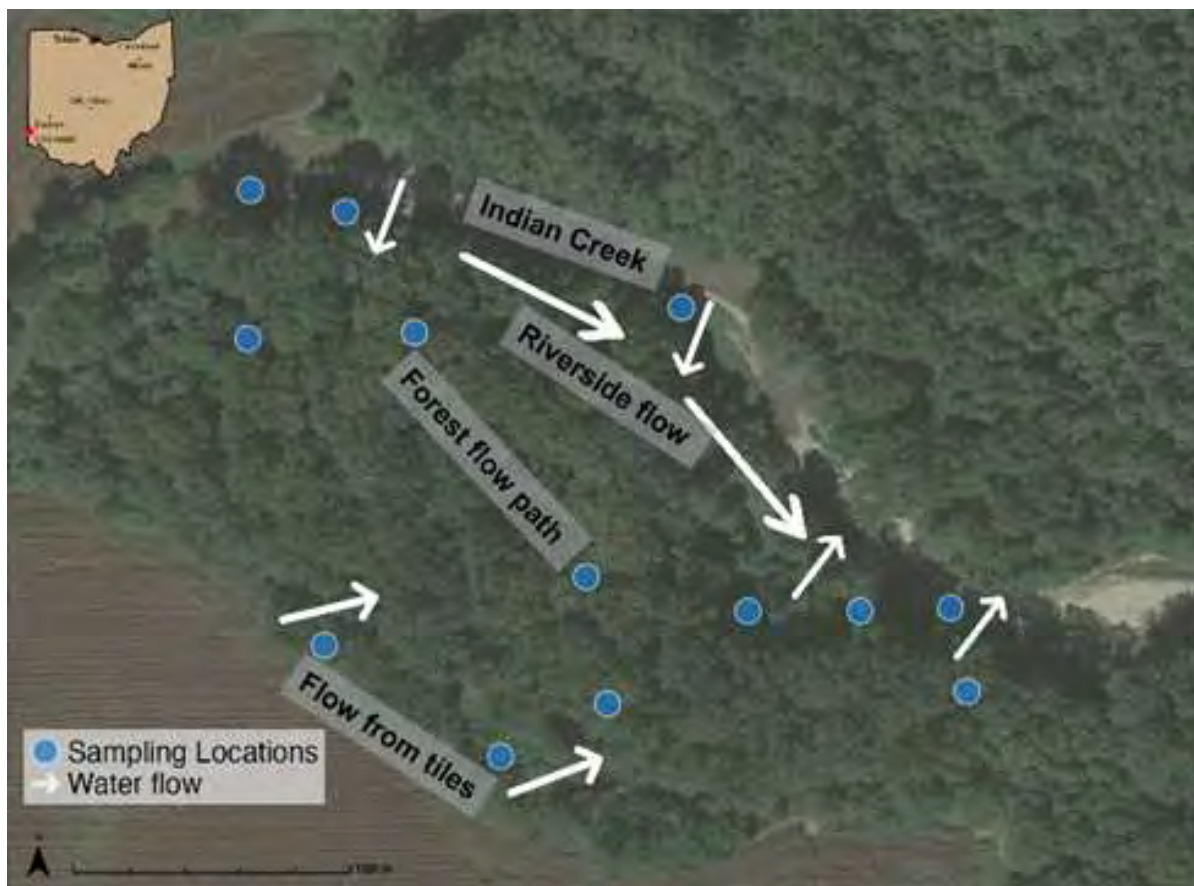


Figure 207. Aerial image showing surface water flow and sampling locations for the Indian Creek-Hoffman Wetland and Stream Restoration Project. Blue arrows indicate direction of surface water flow. Dots represent geographic base crew sampling locations, which are grouped by Project features (fill color) where relevant. Text annotations provide additional context about the Project's watershed connection or other important features.

Management Considerations

As one of the few true forested wetlands in the H2Ohio Wetland Monitoring Program, the Indian Creek Project could have provided unique insight around nutrient retention if it were more connected to water and nutrient sources. The design of the Project focused primarily on the stream restoration, with the wetland-specific modifications limited to the construction of a few flow paths through the forested wetland to facilitate water inputs from Indian Creek and the adjacent field. However, data from Water Year (WY) 2024 indicates that input from the creek did not happen at all during the monitoring period (beginning April 2024) and only a small fraction of field tile water was captured. This lack of connectivity is inherent in the design, as the elevation of the wetland is too far above high flow marks for creek waters to reasonably flow into the Project and the primary field tile that would contribute significant flow was not actually directed into the wetland.

Considering data from years preceding monitoring at the Indian Creek Project, researchers can say that the dry conditions of WY 2024 are not primarily responsible for the lack of connectivity and that, even in wetter years, this Project would likely receive little water and nutrients. Over the past five years, only two high flow events from the creek would have moved water fully into and across the Project and, while some flows were processed along the riparian floodplain shelf, this area would have only been inundated 24 times over that period. Additionally, the floodplain shelf area consists of small pools lined with sand, resulting in low residence times and soils that are less likely to sorb phosphate (i.e., even the portion of the Project most connected to inputs remains limited in its capacity to hold and treat water). Implementing slight redesigns may increase water inputs. The elevation being too high for creek flows is a limitation which could be assessed in site-selection and design of future Projects using existing datasets (elevation and USGS stream flow). Additionally, since the creek flow is limited, subsurface and surface agricultural nonpoint runoff could be guided through the whole Project by capturing the main field tile sooner and directing flow through constructed flow paths.

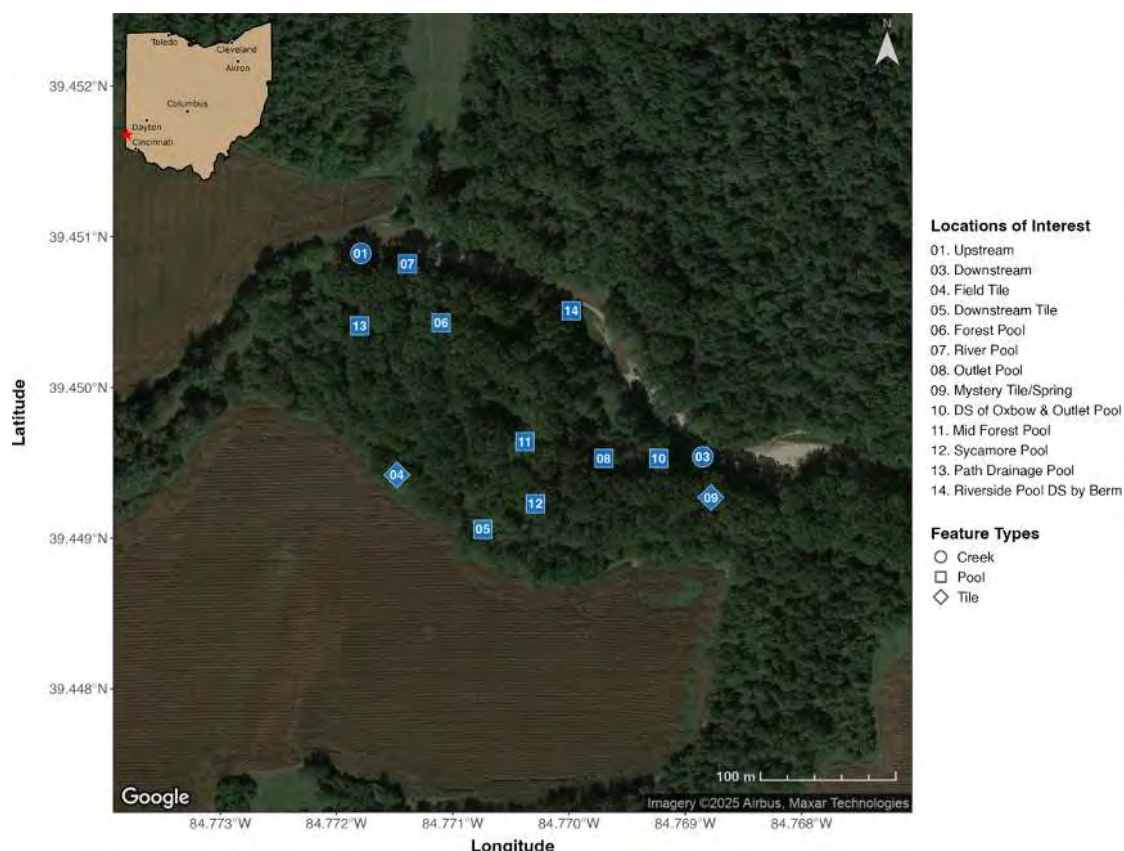


Figure 208. Aerial image of approximate locations of interest for water and soil sampling and discrete manual measurements of water depth and physicochemical parameters at Indian Creek-Hoffmann Wetland and Stream Restoration Project during water year 2024 (Oct 1, 2023–Sep 30, 2024). The legend provides the name of each sampling point. Different shapes denote the types of wetland features represented by the locations of interest. If present, different colors represent locations of interest that belong to a group or complex of features (e.g., a treatment train).

Nutrient Budget Takeaways

There is currently not enough data to calculate filtration values for the Indian Creek-Hoffmann Project. Soils throughout the Project are vulnerable to releasing phosphate, as suggested by soil phosphate sorption capacity values.

Surface Water Hydrology and Nutrients

Overall, the Indian Creek Project received little water from its two inflow sources: two field tiles and Indian Creek (Figure 210). There are multiple possible flow paths, and three of these flow paths (forest, river side, and field tile) were monitored beginning in April of Water Year (WY) 2024 (Figure 207). Total phosphorus (TP) and dissolve reactive phosphorus (DRP) were generally similar at Upstream and Downstream Creek locations, except for an increase between Upstream and Downstream in early/mid-April 2024, corresponding with a hydrologic event (Figure 211, Figure 212). Total nitrogen (TN), nitrite+nitrate (NO_x), and total ammonium

nitrogen (NH₄-N) Upstream were generally similar or slightly lower than Downstream Creek locations. (Figure 213, Figure 214, Supplemental Information). The slight decrease is likely due to dilution from a small tributary confluence between Indian Creek Upstream and Downstream.

Based on base crew Project visit observations and water level logger data, the forest flow path floods when the nearby USGS gage (Sevenmile Creek at Camden OH – 03272700¹³) reaches a stage of 2.3 m. The gage never exceeded an average daily depth of 2.3 m (7.5 ft) in WY 2024 (Figure 209). A water level logger (HOBO Onset) placed in the Forest Pool indicate water levels were consistently approximately 0 cm from April 2024 through September 2024, so Indian Creek never reached a stage high enough for inflow to occur in the forest flow path (Figure 210). Minimal water was observed in Mid Forest Pool and Sycamore Pool (both pools are part of the forest flow path) once which was likely surface water runoff.

The riverside flow path receives water from Indian Creek and consists of two to three depressional, sand lined pools (River Pool and Riverside Pool DS by Berm) that can hold minimal water and flow into the Outlet Pool. Based on water level data in the Outlet Pool, the river side flow path and outlet pool receive water when USGS gage Sevenmile Creek at Camden OH - 03272700 reaches a stage of 1.6 m (5.2 ft). In WY 2024, water flowed through the river flow path ten times (Figure 209). Along this flow path, water was observed in Riverside Pool DS by Berm in July 2024 and had greater TP (0.3 mg P/L) and TN (5 mg N/L) concentrations similar to the Upstream Creek location.

Downstream Tile carries flows from a 15 cm-field tile draining the adjacent farmland. From April 2024 to September 2024, water levels were ~ 0.1 m, except for three peaks reaching up to 0.15 m or 0.2 m in mid-April 2024, early August 2024, and late September 2024 (Figure 210). For the water to flow out of the Downstream Tile pool to the next pool, water depth would have to reach 0.6 m, and water depths never exceed 0.2 m, so water never flowed out of the Downstream Tile pool. On average, TP, DRP, NO_x, NH₄-N, and TN concentrations decreased between Field Tile and Downstream Tile sampling locations (Supplemental Information).

In addition to the three primary flow paths identified during characterization phase, another flow path was discovered when routine monitoring sampling began in February 2024. Researchers suspect the water source is a broken main field tile from the adjacent field that produces a constant stream of water that short circuits the entire wetland. The broken-field tile (Mystery Tile sampling location) results in a short flow path of 28 m that drains straight into Indian Creek (no wetland pools along flow path).

13

“Sevenmile Creek at Camden OH – 03272700.” [waterdata.usgs.gov](https://waterdata.usgs.gov/monitoring-location/03272700). U.S. Department of Interior.
<https://waterdata.usgs.gov/monitoring-location/03272700>

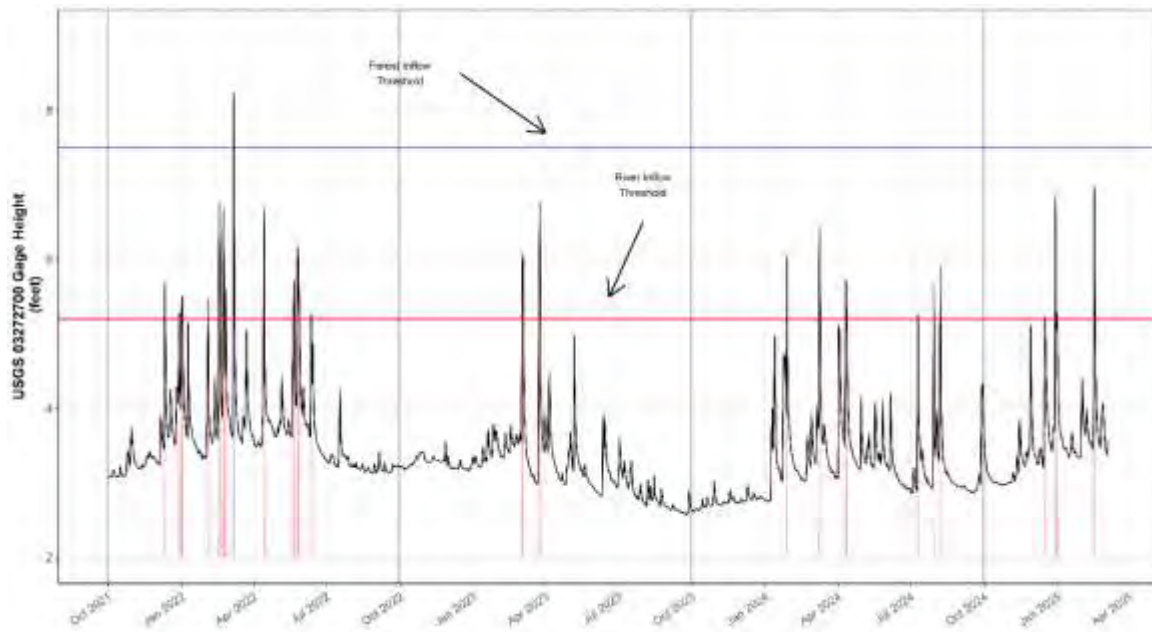


Figure 209. Sevenmile Creek stream gauge height from USGS gage Sevenmile Creek at Camden OH - 03272700. The red line indicates 5.2 ft, above which storm flow water will enter the riverside flow path at Indian Creek-Hoffman Wetland and Stream Restoration Project. The blue line indicates 7.5 ft, above which storm flow water will enter the forest flow path at Indian Creek-Hoffman Wetland and Stream Restoration Project. The black line indicates Sevenmile Creek water height, and the red and blue bars denote when the discharge thresholds in the river were surpassed, which is when researchers estimate that the respective features (red = riverside flow path, blue = forested flow path) were flooded.

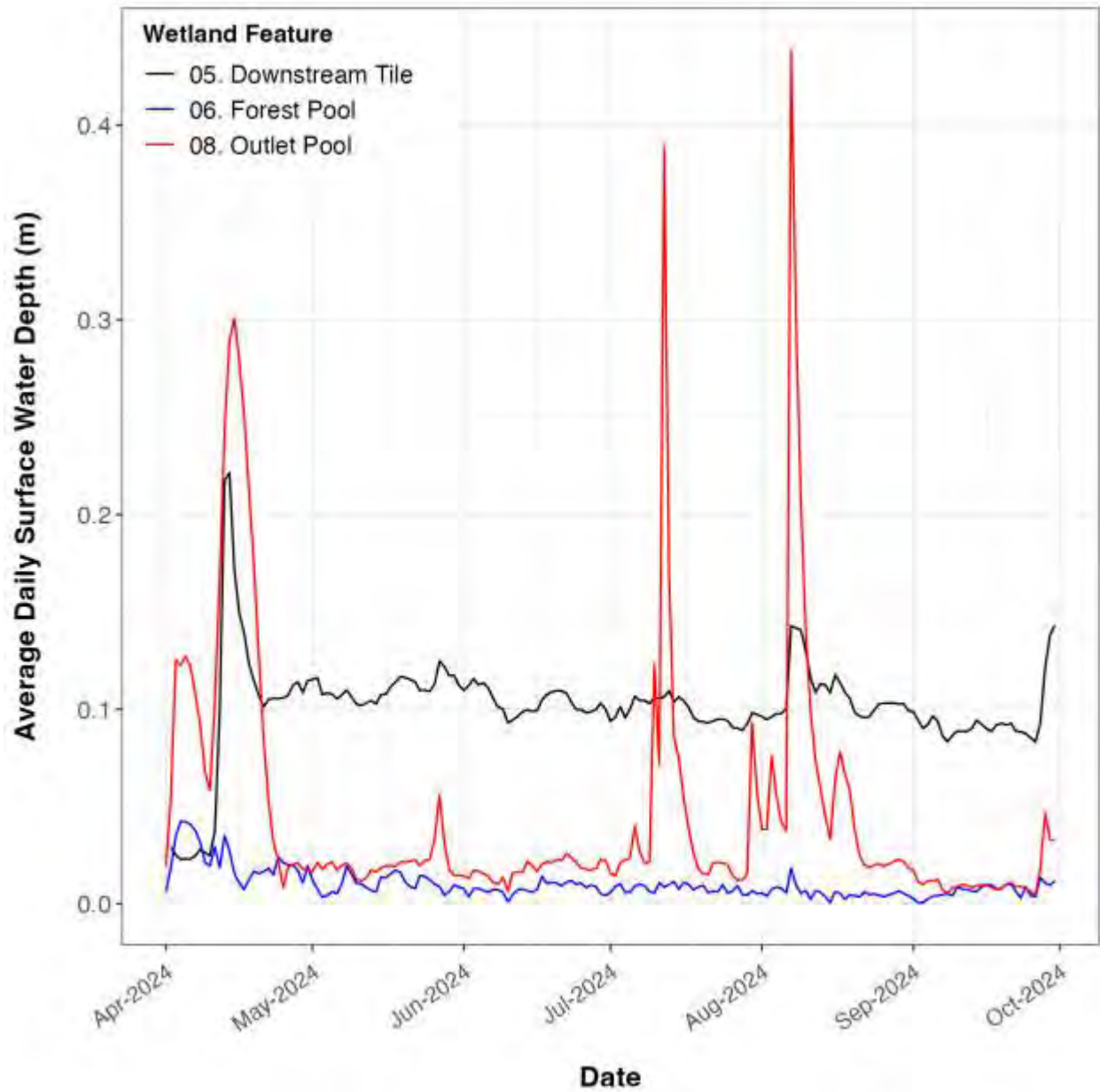


Figure 210. Average daily surface water depth based on continuously logging water level sensors (HOBO Onset) at three wetland features at Indian Creek-Hoffman Wetland and Stream Restoration Project.

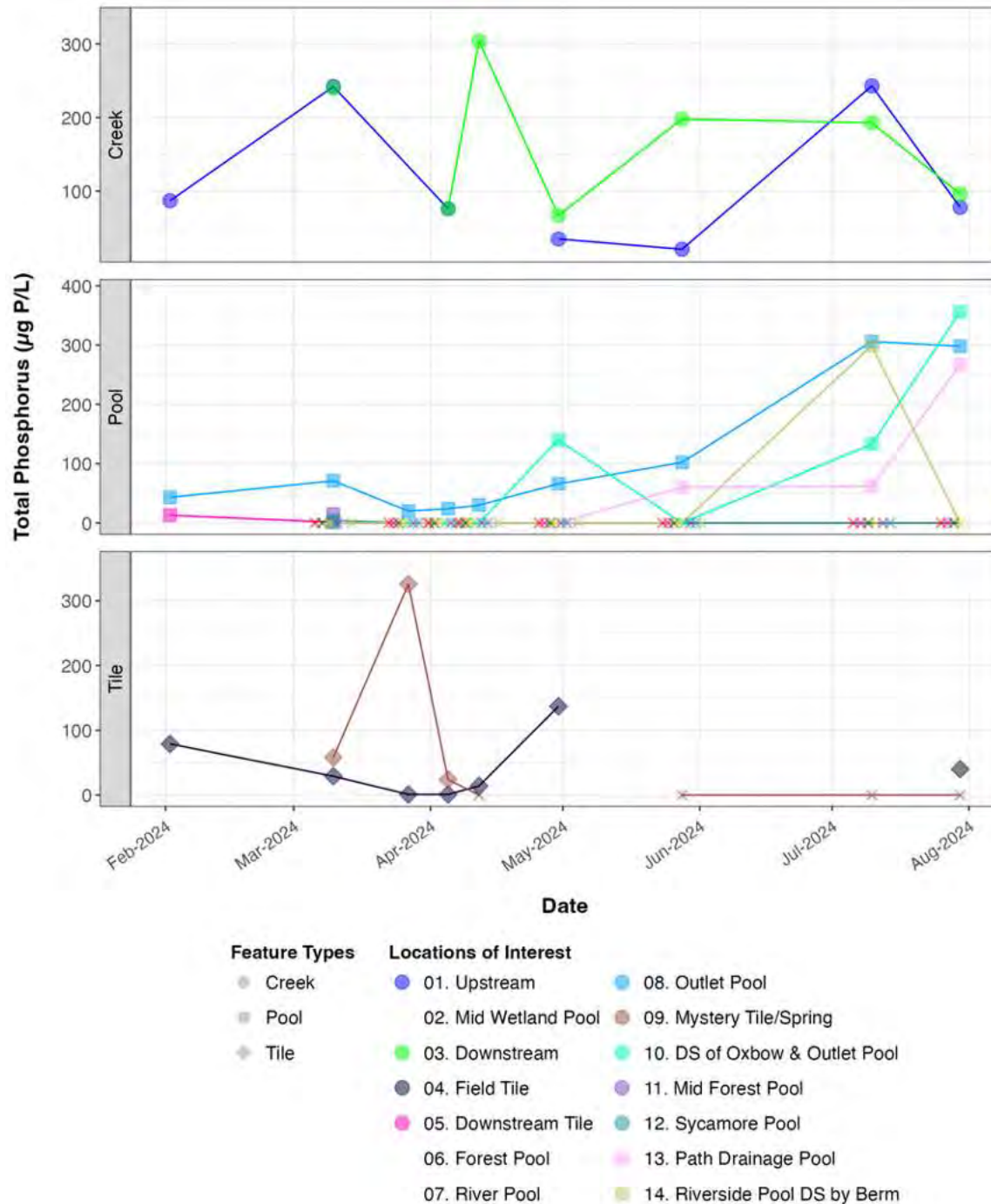


Figure 211. Time series of total phosphorus (TP) concentrations in surface water samples collected at the Indian Creek-Hoffmann Wetland and Stream Restoration Project. Values below the detection limit of the analytical equipment were replaced with half the value of the detection limit. Each point represents one measurement, and colors denote the locations of interest, as indicated in the legend. Open symbols indicate that measurements were collected during a hydrologic event (e.g., storm event) and filled symbols denote measurements collected during

baseflow. Crosses (×) represent instances when no surface water was detected during the visit. If present, different shapes denote the types of wetland features represented by the locations of interest. Gray vertical lines indicate the start of a water year (Oct 1–Sep 30).

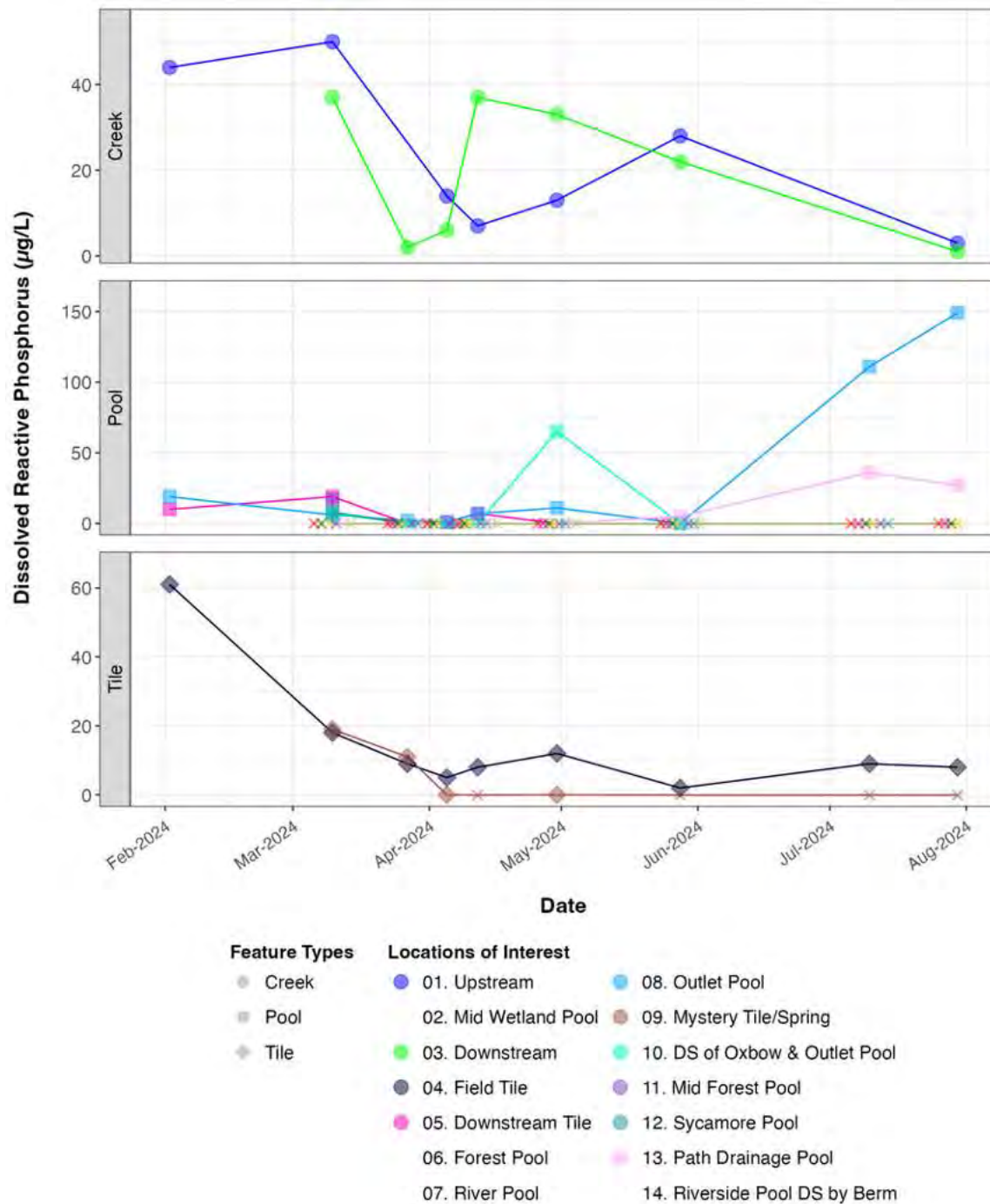


Figure 212. Time series of dissolved reactive phosphorus (DRP) concentrations in surface water samples collected at the Indian Creek-Hoffmann Wetland and Stream Restoration Project. Values below the detection limit of the analytical equipment were replaced with half the value of the detection limit. Each point represents one measurement, and colors denote the locations of interest, as indicated in the legend. Open symbols indicate that measurements were collected during a hydrologic event (e.g., storm event) and filled symbols denote measurements collected during baseflow. Crosses (×) represent instances when no surface water was detected during the visit. If present, different shapes denote the types of wetland features represented by the locations of interest. Gray vertical lines indicate the start of a water year (Oct 1–Sep 30).

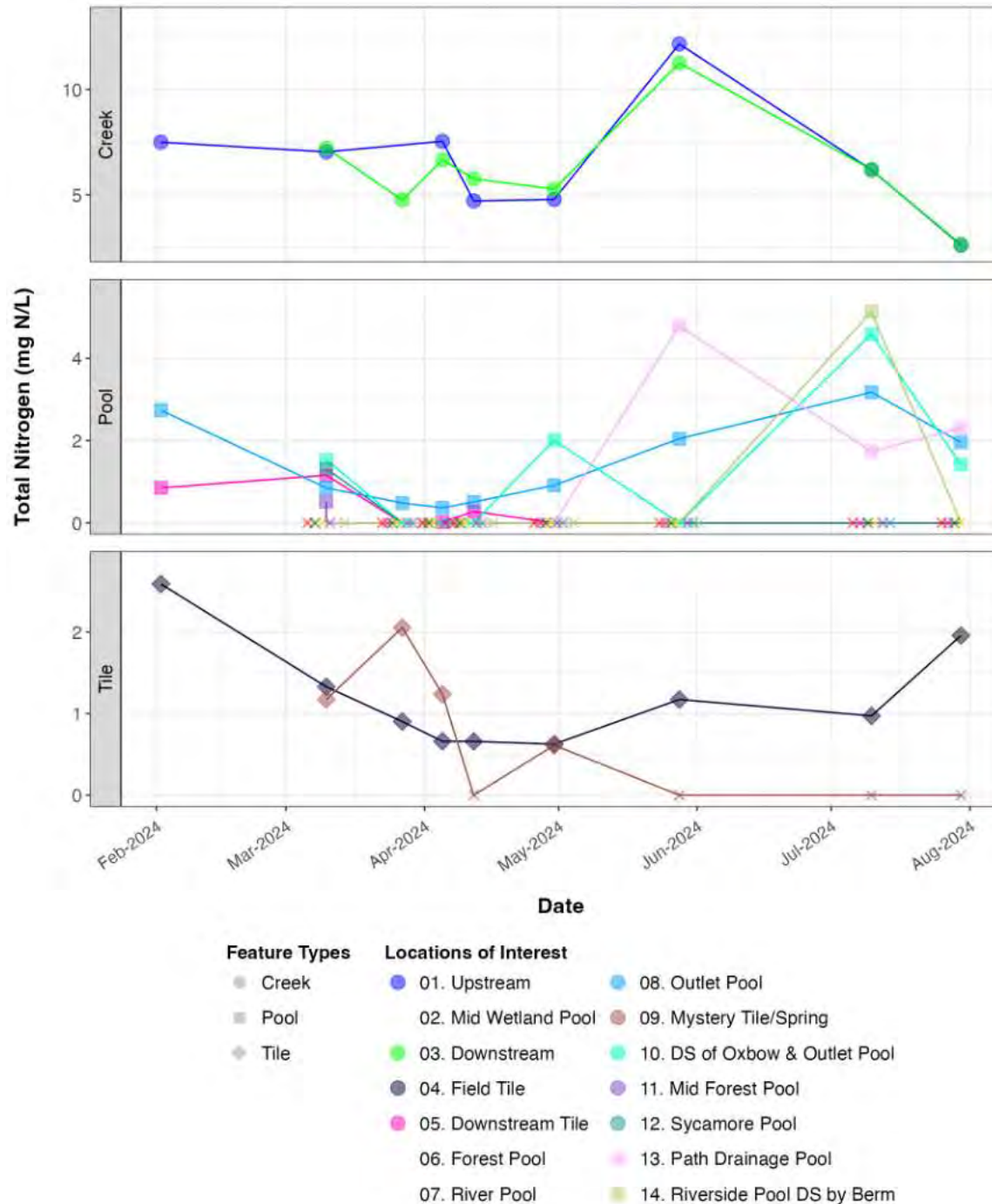


Figure 213. Time series of total nitrogen (TN) concentrations in surface water samples collected at the Indian Creek-Hoffmann Wetland and Stream Restoration Project. Values below the detection limit of the analytical equipment were replaced with half the value of the detection limit. Each point represents one measurement, and colors denote the locations of interest, as indicated in the legend. Open symbols indicate that measurements were collected during a hydrologic event (e.g., storm event) and filled symbols denote measurements collected during

baseflow. Crosses (×) represent instances when no surface water was detected during the visit. If present, different shapes denote the types of wetland features represented by the locations of interest. Gray vertical lines indicate the start of a water year (Oct 1–Sep 30).

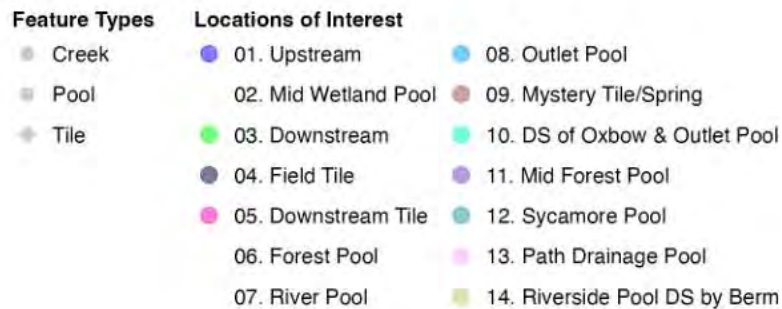
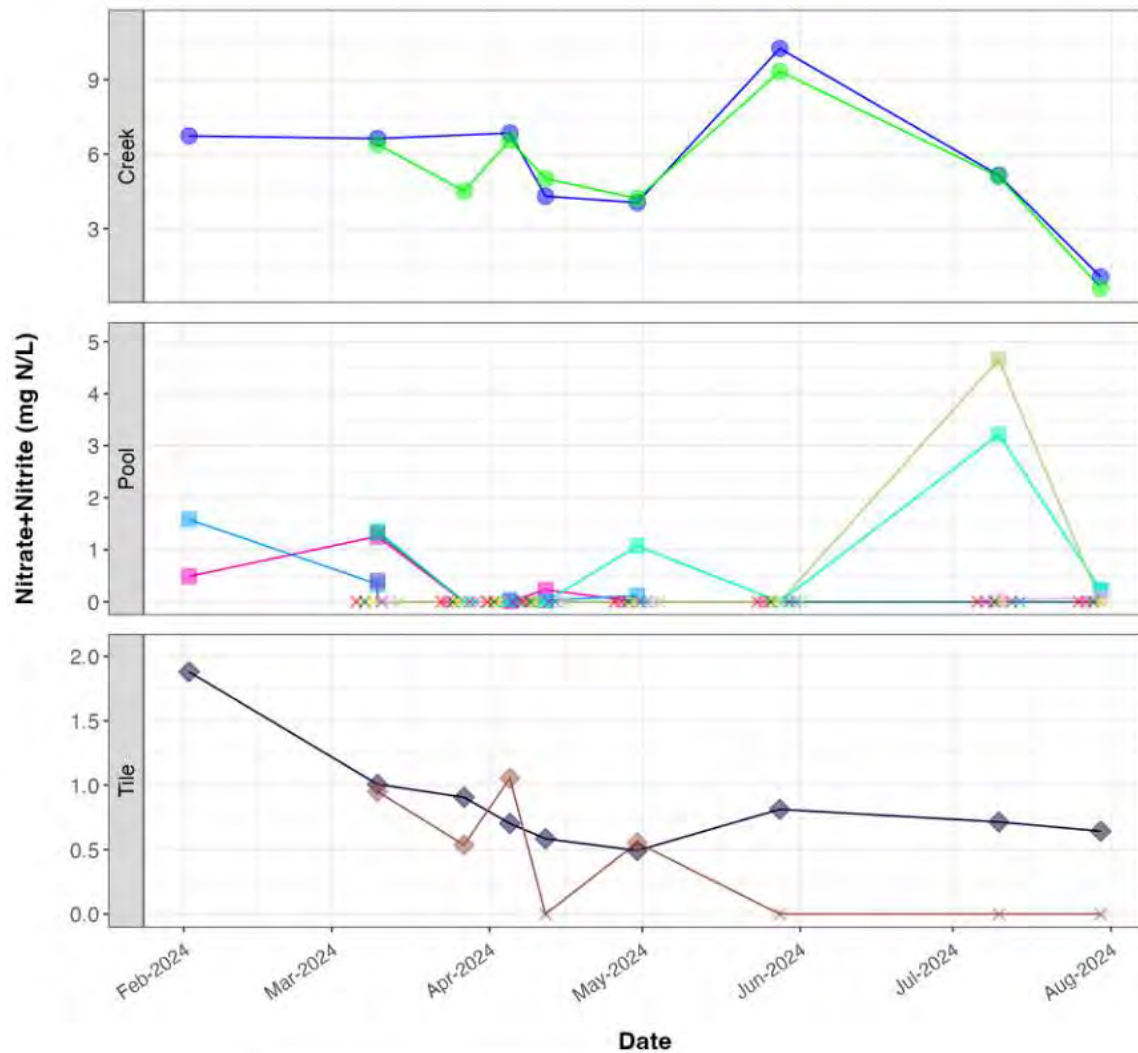


Figure 214. Time series of Nitrite+nitrate (NO_x) concentrations in surface water samples collected at the Indian Creek-Hoffmann Wetland and Stream Restoration Project. Values below the detection limit of the analytical equipment were replaced with half the value of the detection limit. Each point represents one measurement, and colors denote the locations of interest, as indicated in the legend. Open symbols indicate that measurements were collected during a hydrologic event (e.g., storm event) and filled symbols denote measurements collected during baseflow. Crosses (×) represent instances when no surface water was detected during the visit. If present, different shapes denote the types of wetland features represented by the locations of interest. Gray vertical lines indicate the start of a water year (Oct 1–Sep 30).

Soil Nutrient Status and Processes

Soil phosphate sorption capacity (SPSC) values across the Project in Water Year 2024 were close to zero, either slightly positives or slightly negative (Figure 215). This suggests that the sediment across the Project has very little capacity or no capacity to sorb phosphate. The two pools that do receive and hold water (Outlet Pool and Riverside Pool DS by Berm) have negative SPSC values and high water-extractable orthophosphate and nitrite+nitrate concentrations, which could lead to release of nutrients in anoxic conditions.



Figure 215. Soil Phosphate Sorption Capacity (SPSC) throughout the Indian Creek-Hoffmann Wetland and Stream Restoration Project. Each point denotes a soil sample (0–5 cm) and different shapes indicate the wetland feature type, as shown in the legend. Colors indicate the SPSC value of each sample relative to the overall range of values observed at the wetland project, as shown in the color bar. Each panel shows the soil samples collected during a respective water year (Oct 1–Sep 30), along with the minimum and maximum SPSC values observed during a given water year. Negative SPSC values indicate the potential for soils to release phosphate, while positive values indicate soils have capacity to sorb phosphate, based on Mehlich-3 extractions of phosphate, iron, and aluminum.

Next Steps to Strengthen Understanding

The H2Ohio Wetland Monitoring Program does not plan to collect surface water or hydrology data at the Indian Creek Project in Water Year (WY) 2025. During monitoring in WY24, no water from Indian Creek ever entered the forested wetland, and a minimal amount of water flowed through the field tiles. Design modifications would have to be made for the forested wetland to capture flows from Indian Creek or capture the suspected broken field tile. Annual soil sample collection will continue to assess phosphate patterns in sediment across the Project.

Mercer Wetland Complex Restoration (MERW)

Project Description

Mercer County | Grand Lake St. Marys Watershed | Inland Western Ohio

Project size: 60 acres

Partner: Lake Facilities Authority

The hydrology of this Project is actively managed by ODNR staff. The Project has 29.7 acres of restored wetland, featuring two treatment trains (one per phase) with a pump and multiple water level control structures (WLCS). In Phase 1, water is pumped in from Grand Lake St. Marys through a series of tiles under a corn field and into one of two shallow wetland pools, directed by WLCS. In Phase 2, water is pumped in from Grand Lake St. Marys into a pool. In both phases, water level in all pools and flow between pools is controlled using WLCS. Both phases are managed in a “raise and rest” type of style, in which the wetland pools are pumped full in early spring each year and refilled when water levels begin to drop, resulting in wetland pools that are permanently flooded year-round through the combined inputs from pumping and surface runoff events associated with heavy rains. The pump does not run during the winter. A hydrologic event at this Project is operationally defined as any time the pump is turned on or the Project receives 1.3 cm or more of rain.



Figure 216. Aerial image showing surface water flow and sampling locations for the Mercer Wetland Complex Restoration Project. Blue arrows indicate direction of surface water flow. Dots represent geographic base crew sampling locations, which are grouped by Project features (fill color) where relevant. Text annotations provide additional context about the Project's watershed connection or other important features.

Management Considerations

Nutrient concentrations throughout the Project suggest nutrient retention is occurring within Phase 1 and 2 of the Mercer Wetland Project overall. However, particulate matter enters Phase 2 seasonally from the forested wetland pool, rendering that portion of the Project a source of total phosphorus on an annual scale. To increase nutrient load reductions across the Project, the inflow pump for both phases should run more often, to increase the hydraulic loading rate (volume of wetland inflow per wetland acres, HLR). An increase in HLR is often correlated with higher nutrient reduction rates, depending on the functionality of other aspects of the wetland (e.g., soil sorption, vegetation uptake). Due to the active management style of the Project and its inflow pump, drought conditions in Water Year 2024 did not play a role in nutrient reductions associated with the Project. Another way to increase nutrient reductions across both phases would be to seed/reseed Pool 2 in Phase 1 and all pools in Phase 2. Despite the Project operating for 1.5 years, no wetland plants have started to grow in these locations. It is possible the water in Pool 2 of Phase 1 is too deep for wetland plants to establish. If that is the case, the inflow pump would have to be turned off for an appropriate amount of time for vegetation to grow. While this would reduce the HLR in the short term while plants become established, it could increase the Project's potential nutrient retention in the long-term.



Figure 217. Aerial image of approximate locations of interest for water and soil sampling and discrete manual measurements of water depth and physicochemical parameters at Mercer Wetland Complex Restoration Project during water year 2024 (Oct 1, 2023–Sep 30, 2024). The legend provides the name of each sampling point. Different shapes denote the types of wetland features represented by the locations of interest. If present, different colors represent locations of interest that belong to a group or complex of features (e.g., a treatment train). **Note:** Lake inflow Phase 1 and Lake Inflow Phase 2 are the same location.

Nutrient Budget Takeaways

There is currently not enough data to calculate filtration values for the Project. Soils throughout the Project have moderate capacity to sorb phosphate, as suggested by soil phosphate sorption capacity values.

Surface Water Hydrology and Nutrients

In the Phase 1 areas of the Project, nutrient concentrations were typically lower at the outflow (Pool 3 Outflow) than the inflow (Lake Inflow Phase 1; Figure 219, Figure 220, Figure 220, Figure 221, Figure 222). Water Year 2024 annual average concentrations were lower at the outflow than the inflow by 91% for dissolved reactive phosphorus (DRP), 42% for total

phosphorus (TP), 94% for nitrite+nitrate (NO_x), 88% for total ammonium nitrogen (NH₄-N), and 43% for total nitrogen (TN), indicating nutrient filtration by the wetland pools (Supplemental Information). Surface water concentrations of total phosphorus as well as soil water-extractable orthophosphate increased along the flow path (from Pool 1 Outflow Phase 2 to Pool 3 (forest) Outflow Phase 2, Supplemental Information), possibly indicating that phosphate stored in the soil is being released into the water column (Figure 219, Figure 220, Figure 221, Supplemental Information).

In the Phase 2 areas of the Project, nutrient concentrations were typically lower at the outflow (Pool 3 Forest Outflow) than the inflow (Lake Inflow Phase 2), with the exception of a large TP increase in October 2023 and slight TP increase in late March 2024 (Figure 219, Figure 220, Figure 221, Figure 222). Annual average concentrations were lower at the outflow than the inflow for DRP (34% lower), NO_x (79% lower), NH₄-N (18% lower), and TN (39% lower). For TP, outflow TP concentrations were 52% lower than the inflow in the summer, and 23% lower than the inflow in the spring (April – June 2024; Figure 219). In other seasons, the surrounding woodland likely contributes large amounts of particulate matter, especially during fall (July – September 2024) when the outflow TP concentration was 190% greater than the inflow concentration (Figure 219). These seasonal differences in TP concentrations highlight the need for continued monitoring across seasons and years.

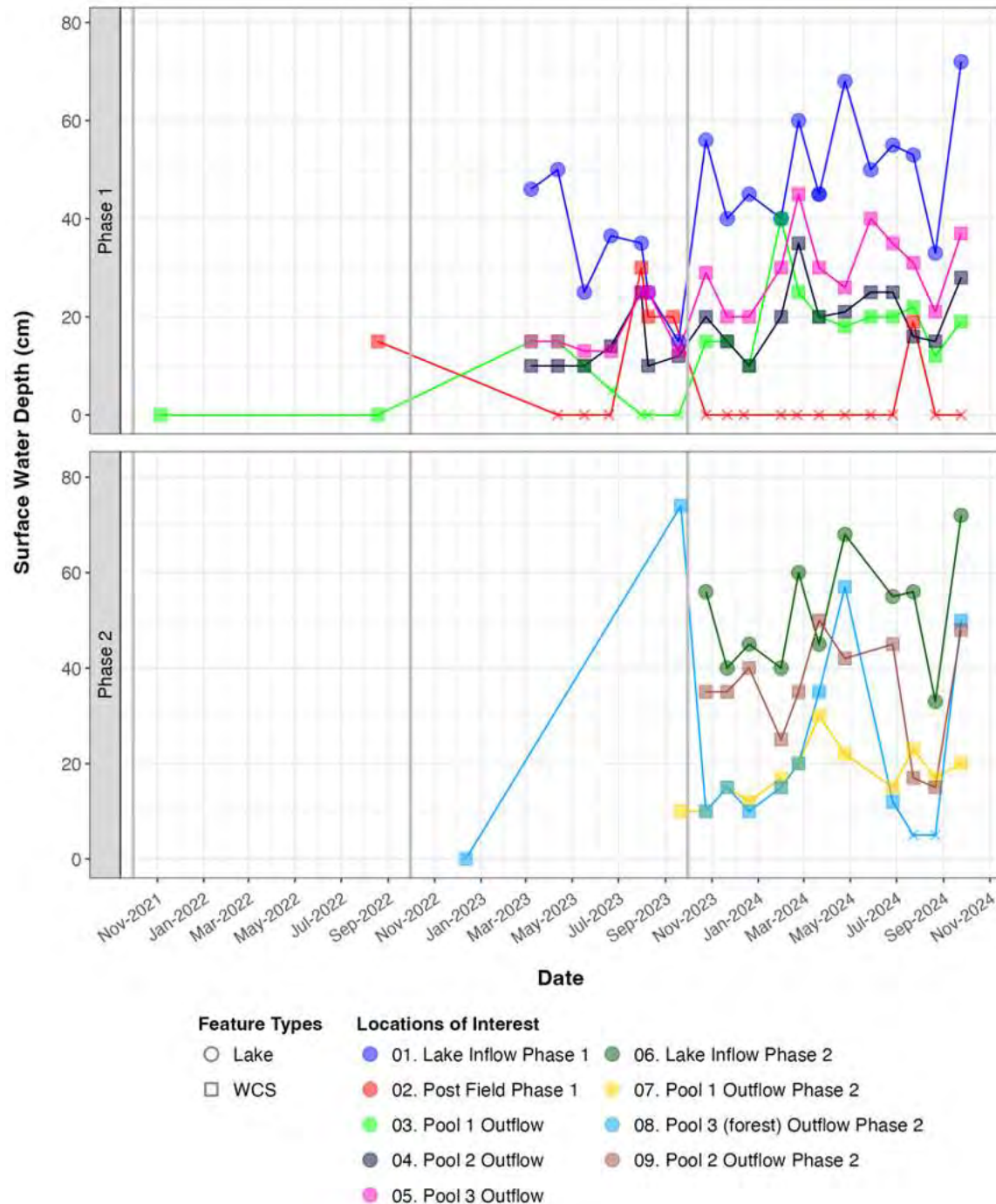


Figure 218. Time series of discrete, manually measured surface water depth at the Mercer Wetland Complex Restoration Project. Depths were measured approximately monthly. Each point represents one measurement and colors denote the locations of interest, as indicated in the legend. Open symbols indicate samples that were collected during a hydrologic event (e.g., storm

event) and filled symbols denote samples collected during baseflow. Crosses (×) represent instances when no surface water was detected during the visit. If present, different shapes denote the types of wetland features represented by the locations of interest. Gray vertical lines indicate the start of a water year (Oct 1–Sep 30).

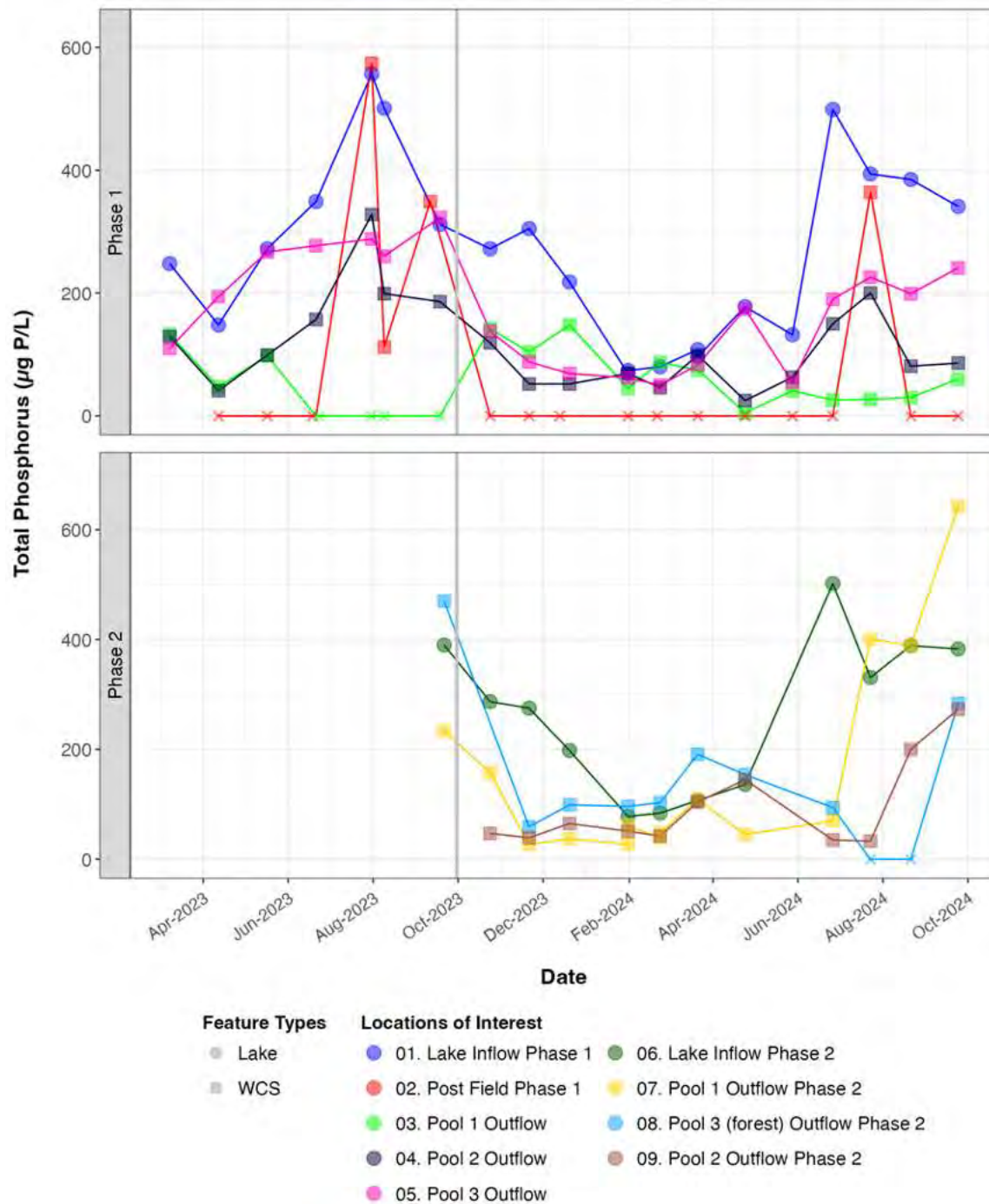


Figure 219. Time series of total phosphorus (TP) concentrations in surface water samples collected at the Mercer Wetland Complex Restoration Project. Values below the detection limit of the analytical equipment were replaced with half the value of the detection limit. Each point represents one measurement, and colors denote the locations of interest, as indicated in the legend. Open symbols indicate that measurements were collected during a hydrologic event (e.g., storm event) and filled symbols denote measurements collected during baseflow. Crosses (×) represent instances when no surface water was detected during the visit. If present, different shapes denote the types of wetland features represented by the locations of interest. Gray vertical lines indicate the start of a water year (Oct 1–Sep 30).

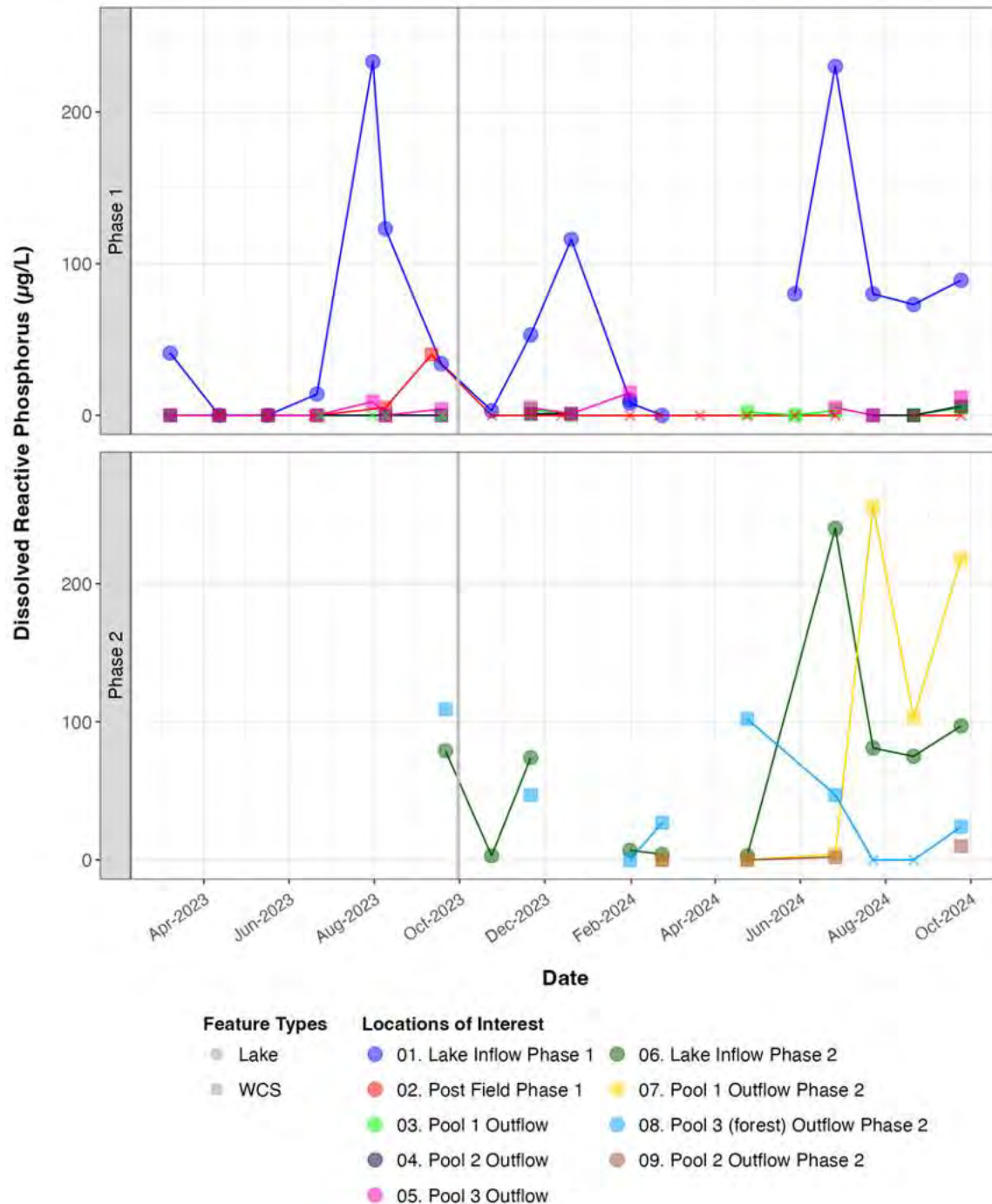


Figure 220. Time series of dissolved reactive phosphorus (DRP) concentrations in surface water samples collected at the Mercer Wetland Complex Restoration Project. Values below the detection limit of the analytical equipment were replaced with half the value of the detection limit. Each point represents one measurement, and colors denote the locations of interest, as indicated in the legend. Open symbols indicate that measurements were collected during a hydrologic event (e.g., storm event) and filled symbols denote measurements collected during

baseflow. Crosses (×) represent instances when no surface water was detected during the visit. If present, different shapes denote the types of wetland features represented by the locations of interest. Gray vertical lines indicate the start of a water year (Oct 1–Sep 30).

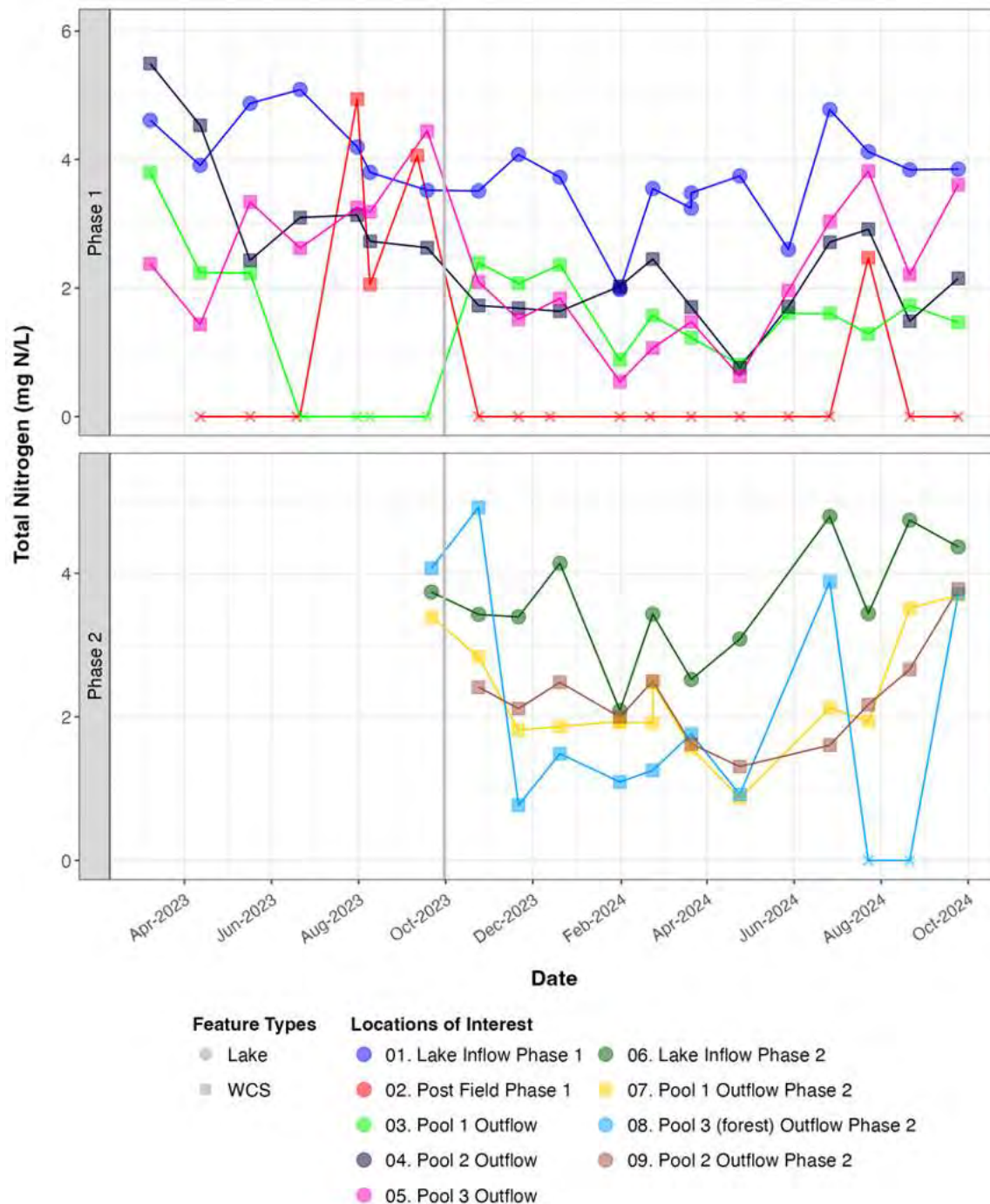


Figure 221. Time series of total nitrogen (TN) concentrations in surface water samples collected at the Mercer Wetland Complex Restoration Project. Values below the detection limit of the

analytical equipment were replaced with half the value of the detection limit. Each point represents one measurement, and colors denote the locations of interest, as indicated in the legend. Open symbols indicate that measurements were collected during a hydrologic event (e.g., storm event) and filled symbols denote measurements collected during baseflow. Crosses (×) represent instances when no surface water was detected during the visit. If present, different shapes denote the types of wetland features represented by the locations of interest. Gray vertical lines indicate the start of a water year (Oct 1–Sep 30).

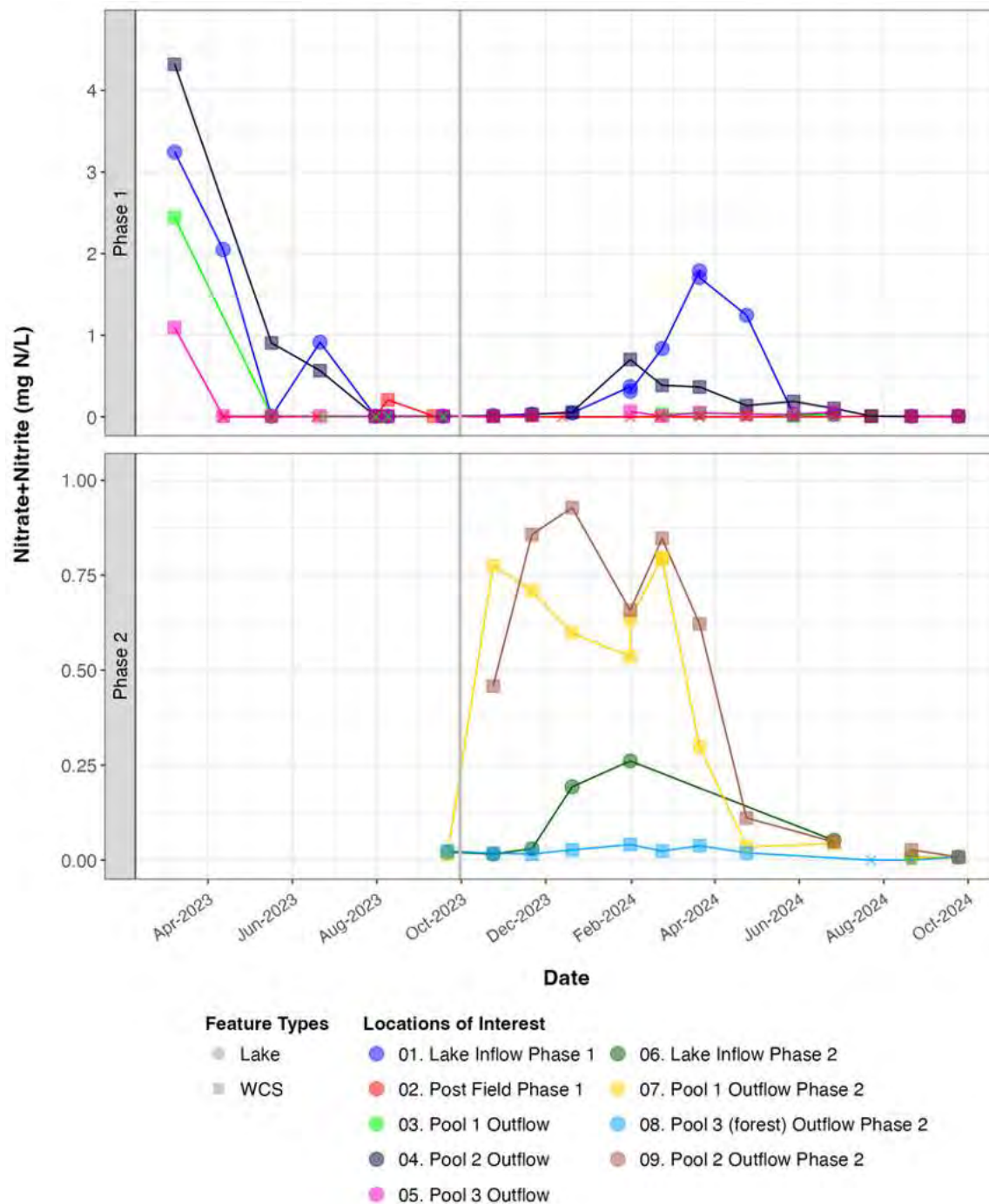


Figure 222. Time series of Nitrite+nitrate (NO_x) concentrations in surface water samples collected at the Mercer Wetland Complex Restoration Project. Values below the detection limit of the analytical equipment were replaced with half the value of the detection limit. Each point represents one measurement, and colors denote the locations of interest, as indicated in the legend. Open symbols indicate that measurements were collected during a hydrologic event (e.g., storm event) and filled symbols denote measurements collected during baseflow. Crosses (×)

represent instances when no surface water was detected during the visit. If present, different shapes denote the types of wetland features represented by the locations of interest. Gray vertical lines indicate the start of a water year (Oct 1–Sep 30).

Soil Nutrient Status and Processes

Overall, soil phosphate sorption capacity (SPSC) values were positive across Phase 1 across years, indicating the sediment's potential to sorb phosphate (Figure 223).

There was little spatial variation among the three wetland pools in Phase 1 (eastern portion of the Project), although the last pool (Pool 3 Outflow Phase 1) had the greatest capacity to sorb phosphate (158 mg P/kg). Soil water extractable nitrate, water extractable ammonium, nitrate+nitrite, and total nitrogen all increased along the flow path (from Pool 1 Outflow to Pool 2 Outflow to Pool 3 Outflow; Supplemental Information).

Phase 2 (western portion of the Project) also had positive SPSC values across the wetland pools. Surface water concentrations of total phosphorus as well as soil water-extractable orthophosphate increased along the flow path (from Pool 1 Outflow Phase 2 to Pool 3 (forest) Outflow Phase 2, Supplemental Information), possibly indicating that phosphate stored in the soil is being released into the water column.



Figure 223. Soil Phosphate Sorption Capacity (SPSC) throughout the Mercer Wetland Complex Restoration Project. Each point denotes a soil sample (0–5 cm) and different shapes indicate the wetland feature type, as shown in the legend. Colors indicate the SPSC value of each sample relative to the overall range of values observed at the wetland project, as shown in the color bar. Each panel shows the soil samples collected during a respective water year (Oct 1–Sep 30), along with the minimum and maximum SPSC values observed during a given water year. Negative SPSC values indicate the potential for soils to release phosphate, while positive values indicate soils have capacity to sorb phosphate, based on Mehlich-3 extractions of phosphate, iron, and aluminum.

Next Steps to Strengthen Understanding

Monthly surface water sample collection and annual soil sample collection will continue in Water Year (WY) 2025 to assess nutrient status at the Projects. Researchers will begin monitoring Phases 3 and 4 of the Project in the spring of WY 2025. Hydrology data will be collected at Phases 3 and 4, in order to complete nutrient load calculations for the first two phase sections of the Project.

Springcreek Confluence Off-Channel Wetlands (SPRC)

Project Description

Miami County | Ohio River Watershed

Project size: 40 acres

Partners: Miami County Park District

The hydrology at this Project is passively managed. The Project (25 acres of restored wetland) is an off-channel wetland consisting of two wetland pools that are connected to one another by a channel. The North Pool exchanges water with Spring Creek, while the South Pool exchanges water with the Great Miami River. A hydrologic event at this Project is operationally defined as an event in which the Great Miami River and Spring Creek flood the wetland pools, possible at discharges of at least 5,229 cubic feet per second (cfs) and 203 cfs, respectively.



Figure 224. Aerial image showing surface water flow and sampling locations for the Springcreek Confluence Off-Channel Wetlands Project. Blue arrows indicate direction of surface water flow. Dots represent geographic base crew sampling locations, which are grouped by Project features

(fill color) where relevant. Text annotations provide additional context about the Project's watershed connection or other important features.

Management Considerations

The drought conditions in Water Year (WY) 2024 played a significant role in the limited water the Springcreek Project received from the Great Miami River and Spring Creek. The floodplain wetland is able to receive water from both the Great Miami River (at 5,229 cubic feet per second, cfs) and Spring Creek (at 203 cfs). In WY 2024, the Great Miami River and Spring Creek offloaded into the wetland pools two times, just as in WY 2023. However, WY 2023 was a similarly dry year according to the annual stream flows, suggesting flows captured by the Great Miami River has been sub-optimal for the past two years of data collection. In WY 2023, 199 lbs. of total phosphorus (TP) and 2,511 lbs. of total nitrogen (TN) were filtered. Only 41 lbs. TP and 1,052 lbs. TN were filtered in WY 2024. For a comparison to wetter years, WY 2022 had 11 offloading events from the Great Miami River and four offloading events from Spring Creek. Less connectivity with adjacent sources of water typically results in lower nutrient load reductions due to lower hydraulic loading rates (volume of water entering the wetland per wetland area). Lowering the Great Miami River inflow notch would allow for more connectivity but less storage capacity during very high flow events, such that a balance would need to be found between capturing high and low flow events while also retaining water long enough for nutrient reductions to occur.

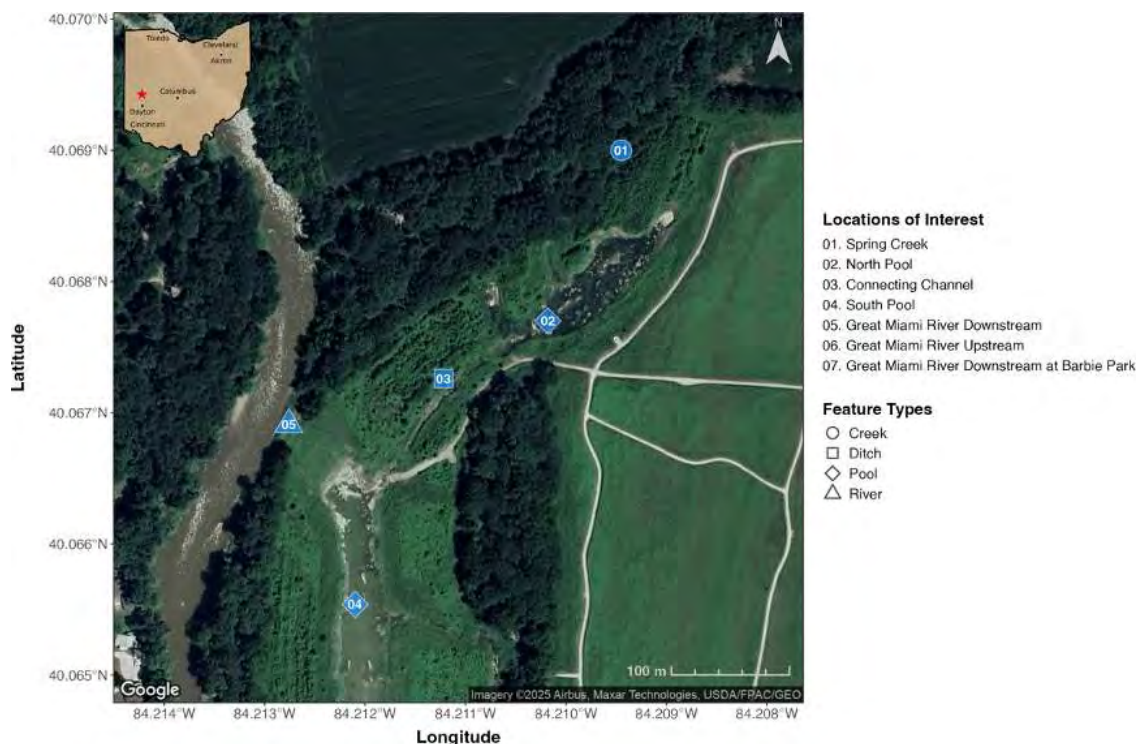


Figure 225. Aerial image of approximate locations of interest for water and soil sampling and discrete manual measurements of water depth and physicochemical parameters at Springcreek Confluence Off-Channel Wetlands Project during water year 2024 (Oct 1, 2023–Sep 30, 2024). The legend provides the name of each sampling point. Different shapes denote the types of wetland features represented by the locations of interest. If present, different colors represent locations of interest that belong to a group or complex of features (e.g., a treatment train).

Nutrient Budget Takeaways

In Water Year (WY) 2024, the Springcreek Project received approximately 242,000 m³ of water. The Project filtered 41 lbs. of total phosphorus (TP), 1,052 lbs. of total nitrogen (TN), 33 lbs. of dissolved reactive phosphorus (DRP), 1,066 lbs. of nitrite+nitrate (NO_x), and 15 lbs. of total ammonium nitrogen (NH₄-N). The wetland pool (South Pool) connected to the Great Miami River is where a majority of the nutrient load is reduced, however, the pool (North Pool) connected to Spring Creek is able to reduce a portion of the nutrient load. Greater load reductions associated with the South Pool are due to much greater inflow volumes. For example, in WY 2024 the Great Miami River pool received 204 million L while the Springcreek pool received only 35 million L.

In WY 2023, the Springcreek Project reduced nutrient loads of TP by 119 lbs., TN by 2,511 lbs., DRP by 54 lbs., NO_x by 2,323 lbs., and NH₄-N by 19 lbs. Compared to WY 2023, all loads reduced in WY 2024 were 20% to 187% lower, meaning some nutrients were reduced by less than half of the load reduced in WY 2023. This is in part due to stream volume captured by the wetland. In WY 2024, the total inflow volume from both the Great Miami River and Spring Creek was 208 million L, 37% lower than volume captured in WY 2023.

The conversion from agricultural land to wetland prevents 35 ± 24 lbs. phosphorus runoff annually. Soils throughout the Project have moderate capacity to sorb phosphate, as suggested by soil phosphate sorption capacity values.

Surface Water Hydrology and Nutrients

Springcreek Confluence Off-Channel Wetlands consists of permanently flooded floodplains experiencing seasonal flooding events. The North Pool receives flows from Spring Creek when stream flow reaches 203 cubic feet per second (cfs) and the South Pool receives flows from the Great Miami River when stream flow reaches 5,229 cfs. Nutrient concentrations were typically lower in the wetland than the Great Miami River and Spring Creek, indicative of nutrient filtration. There are times of the year where concentrations inside the Springcreek Pool are higher than concentrations in Spring Creek, but these instances only occur during low flow when there is little to no connectivity between the creek and pool.

Overall, there is little to no concentration difference for all nutrients between Great Miami River Upstream and Downstream (Figure 228, Figure 229, Figure 230, Figure 231). This may in part be due to the small proportion of total river flow that the Project captures. In Water Year 2024, a total of 613 billion L of water flowed through the Great Miami River, and 17 billion L flowed

through Spring Creek at the wetland inflow notches. Of these total flows, the wetland pools were able to capture 204 million L from the Great Miami River (0.03%) and 35 million L from Spring Creek (0.21%).

During flow events in which the river or creek flooded into the wetland, the pool volumes also spike (Figure 226, Figure 227). There are also times of the year when the creek flows and pool volumes rise, but there is no offloading event. This rising relationship between the river, creek, and pools may suggest subsurface flow, either from the river or creek or groundwater from a high-water table. Groundwater wells would be needed at the Project to determine if the water input is from subsurface flow from the Great Miami River or groundwater.

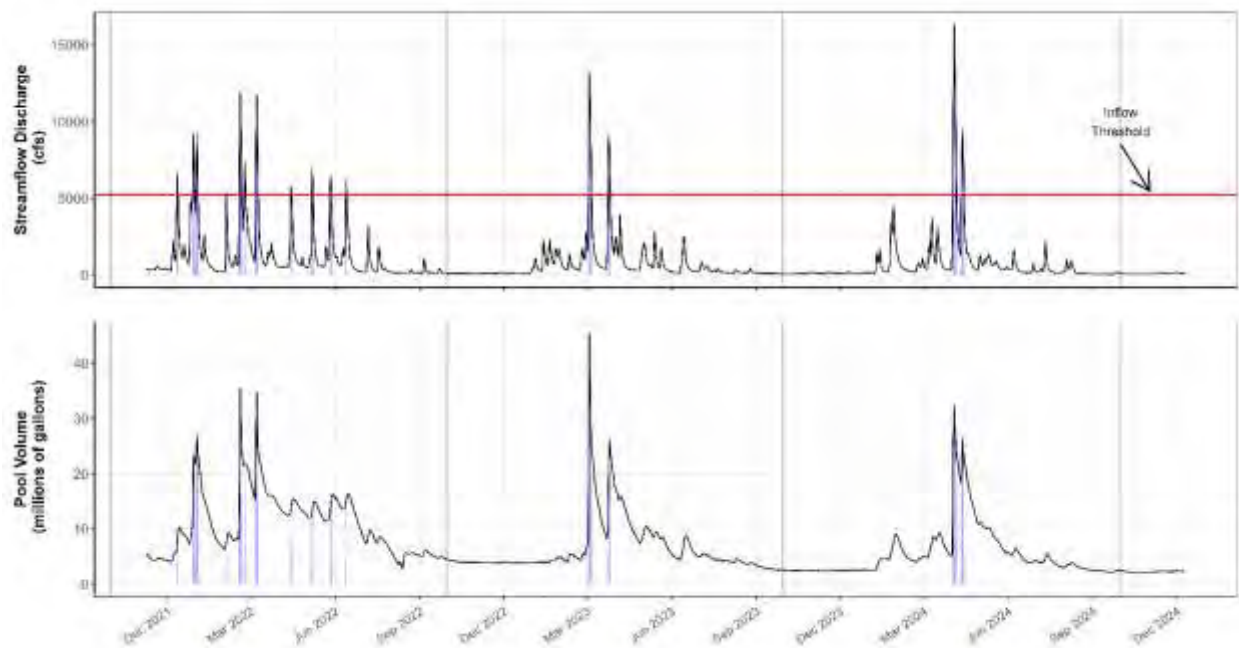


Figure 226. Streamflow from November 18, 2021 to September 30, 2024 USGS gage Great Miami River at Troy Ohio–03262700, watershed weighted to get discharge at the wetland where (a) is the Great Miami River and (b) is Spring Creek. Blue indicates stream flow, and grey indicates pool volume. The dashed lines are 148,068 L/s (a) 5,776 L/s (b), above which storm flow will enter Springcreek Confluence Off-Channel Wetlands.

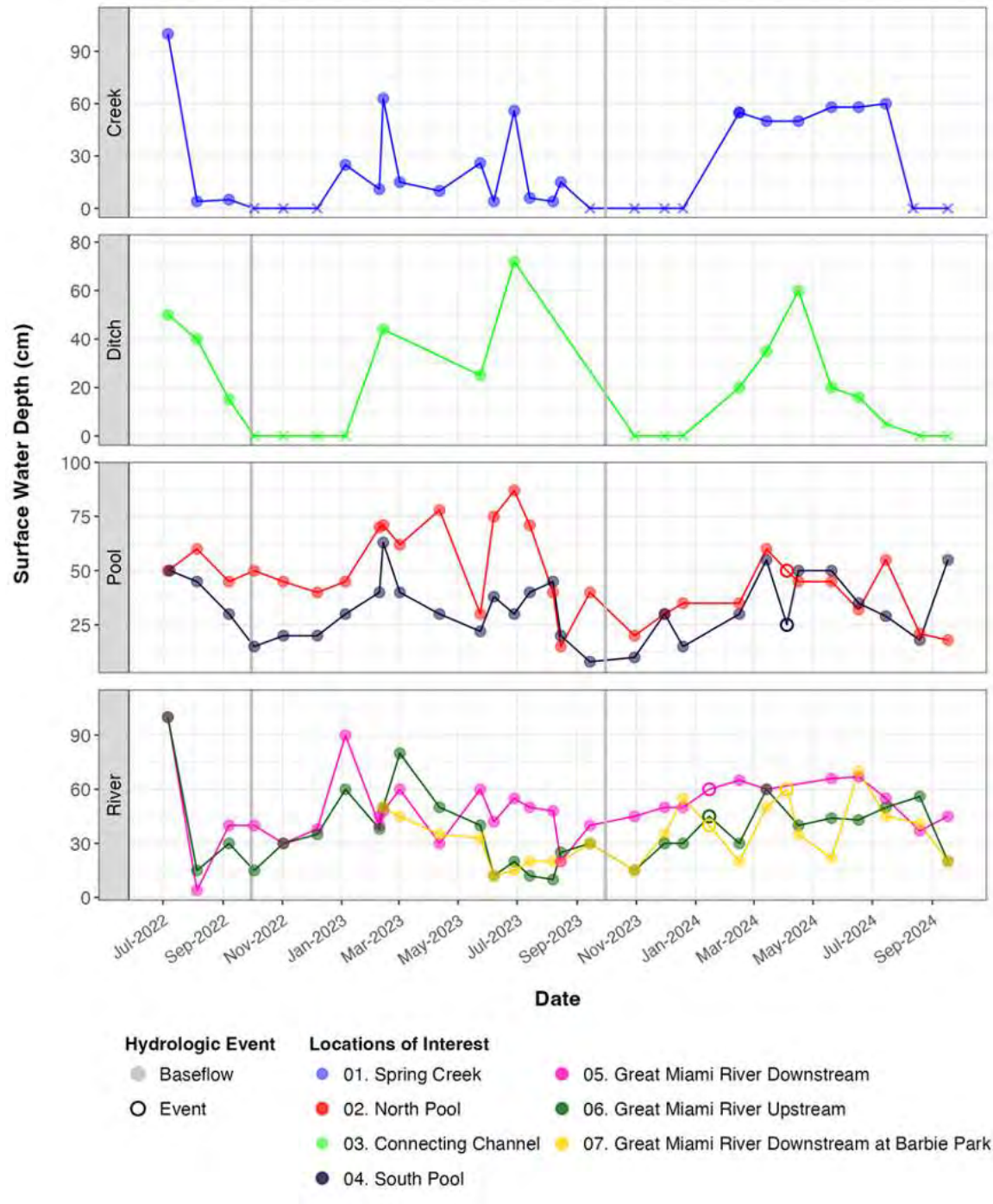


Figure 227. Time series of discrete, manually measured surface water depth at the Springcreek Confluence Off-Channel Wetlands Project. Depths were measured approximately monthly. Each point represents one measurement and colors denote the locations of interest, as indicated in the

legend. Open symbols indicate samples that were collected during a hydrologic event (e.g., storm event) and filled symbols denote samples collected during baseflow. Crosses (×) represent instances when no surface water was detected during the visit. If present, different shapes denote the types of wetland features represented by the locations of interest. Gray vertical lines indicate the start of a water year (Oct 1–Sep 30).

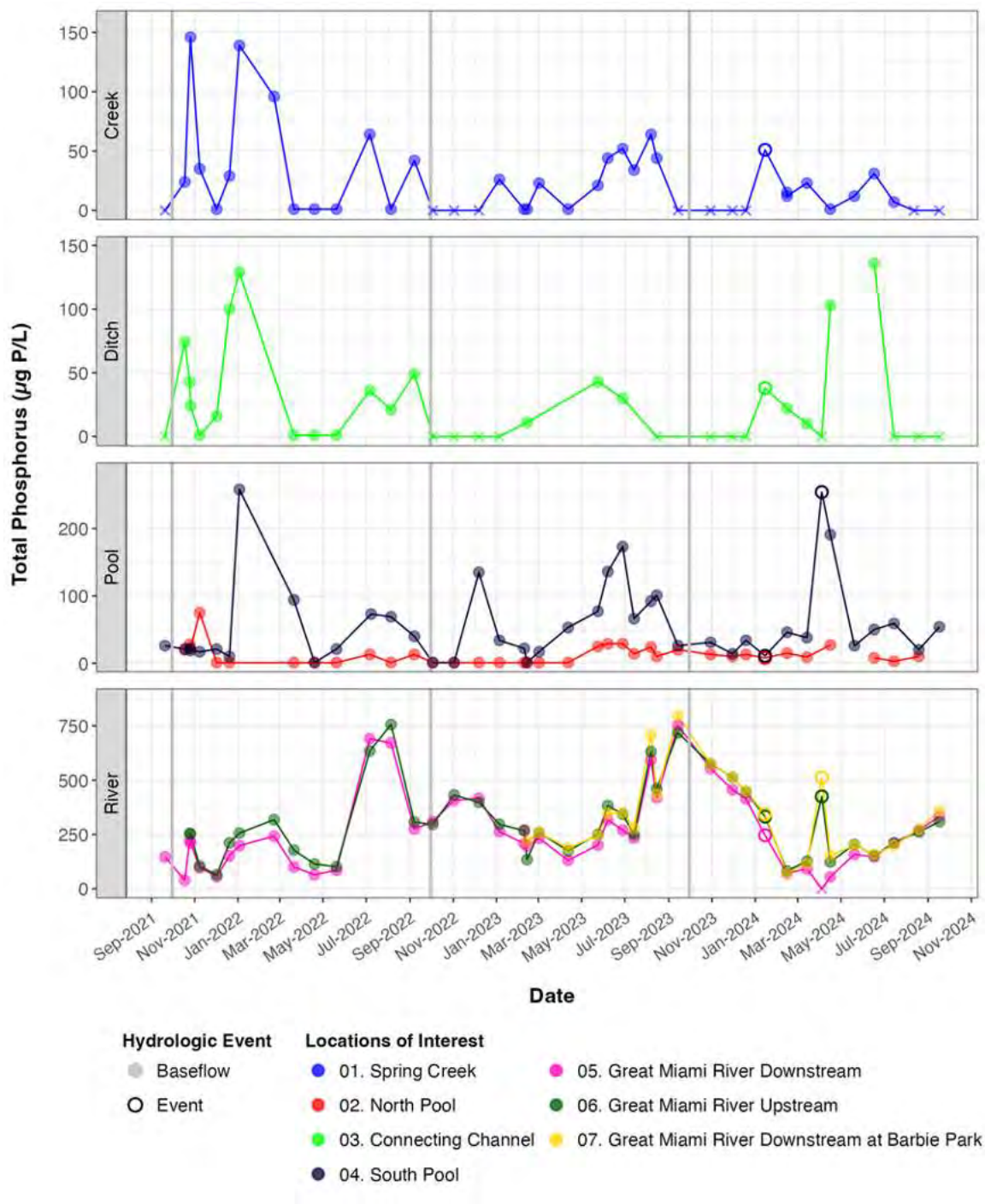


Figure 228. Time series of total phosphorus (TP) concentrations in surface water samples collected at the Springcreek Confluence Off-Channel Wetlands Project. Values below the detection limit of the analytical equipment were replaced with half the value of the detection limit. Each point represents one measurement, and colors denote the locations of interest, as indicated in the legend. Open symbols indicate that measurements were collected during a hydrologic event (e.g., storm event) and filled symbols denote measurements collected during baseflow. Crosses (×) represent instances when no surface water was detected during the visit. If present, different shapes denote the types of wetland features represented by the locations of interest. Gray vertical lines indicate the start of a water year (Oct 1–Sep 30).

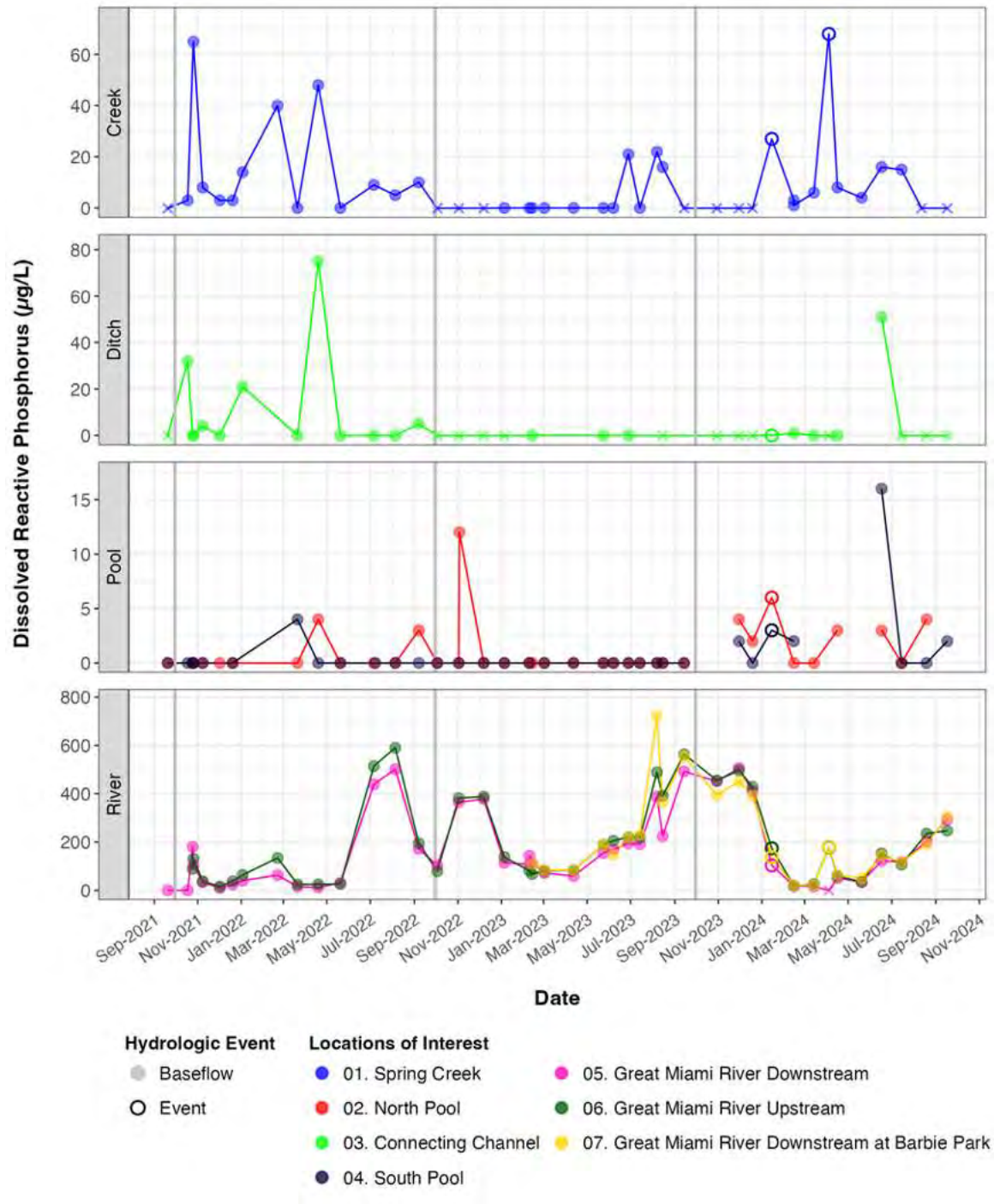


Figure 229. Time series of dissolved reactive phosphorus (DRP) concentrations in surface water samples collected at the Springcreek Confluence Off-Channel Wetlands Project. Values below the detection limit of the analytical equipment were replaced with half the value of the detection limit. Each point represents one measurement, and colors denote the locations of interest, as indicated in the legend. Open symbols indicate that measurements were collected during a hydrologic event (e.g., storm event) and filled symbols denote measurements collected during

baseflow. Crosses (×) represent instances when no surface water was detected during the visit. If present, different shapes denote the types of wetland features represented by the locations of interest. Gray vertical lines indicate the start of a water year (Oct 1–Sep 30).

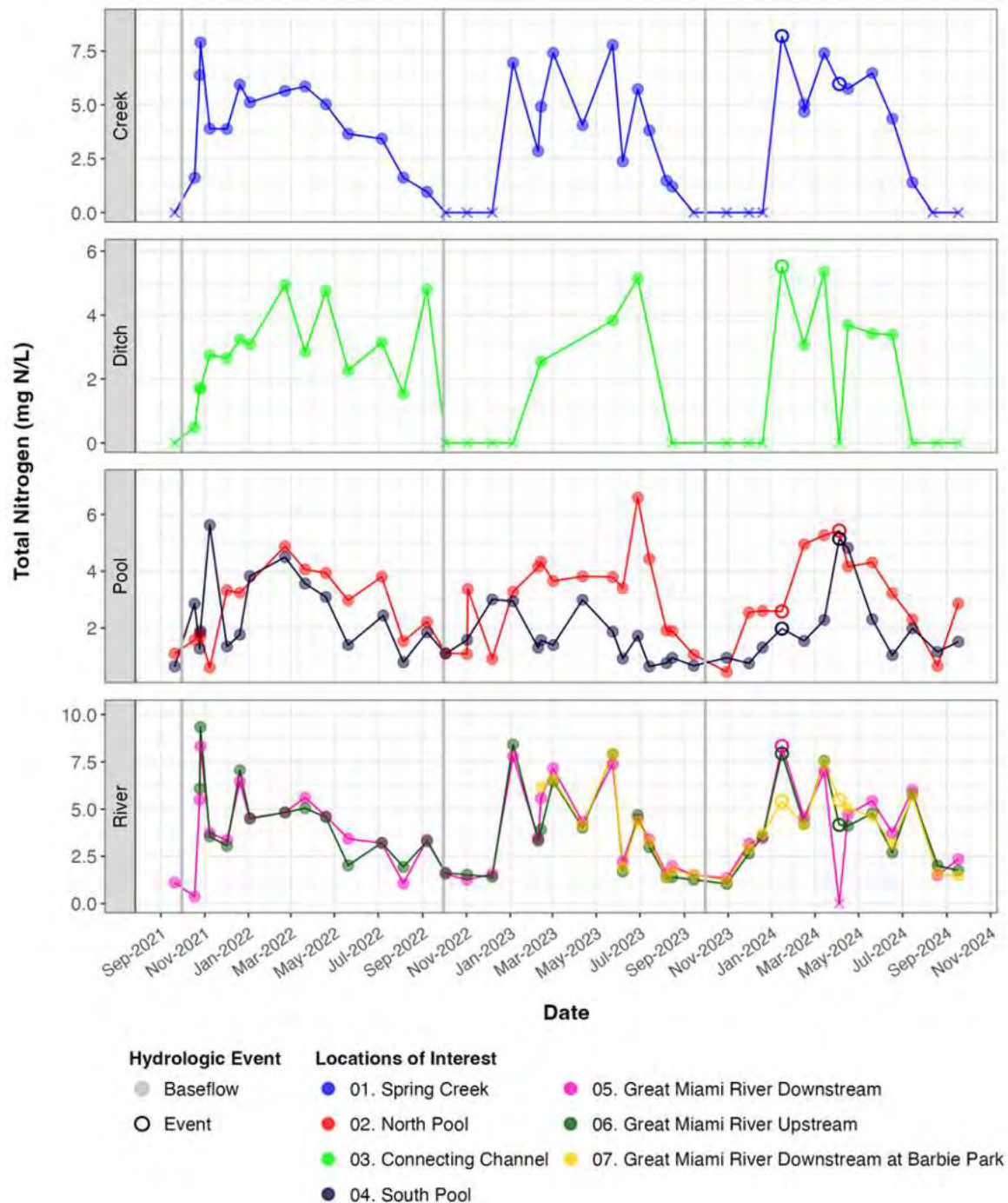


Figure 230. Time series of total nitrogen (TN) concentrations in surface water samples collected at the Springcreek Confluence Off-Channel Wetlands Project. Values below the detection limit of the analytical equipment were replaced with half the value of the detection limit. Each point represents one measurement, and colors denote the locations of interest, as indicated in the legend. Open symbols indicate that measurements were collected during a hydrologic event (e.g., storm event) and filled symbols denote measurements collected during baseflow. Crosses (×) represent instances when no surface water was detected during the visit. If present, different shapes denote the types of wetland features represented by the locations of interest. Gray vertical lines indicate the start of a water year (Oct 1–Sep 30).

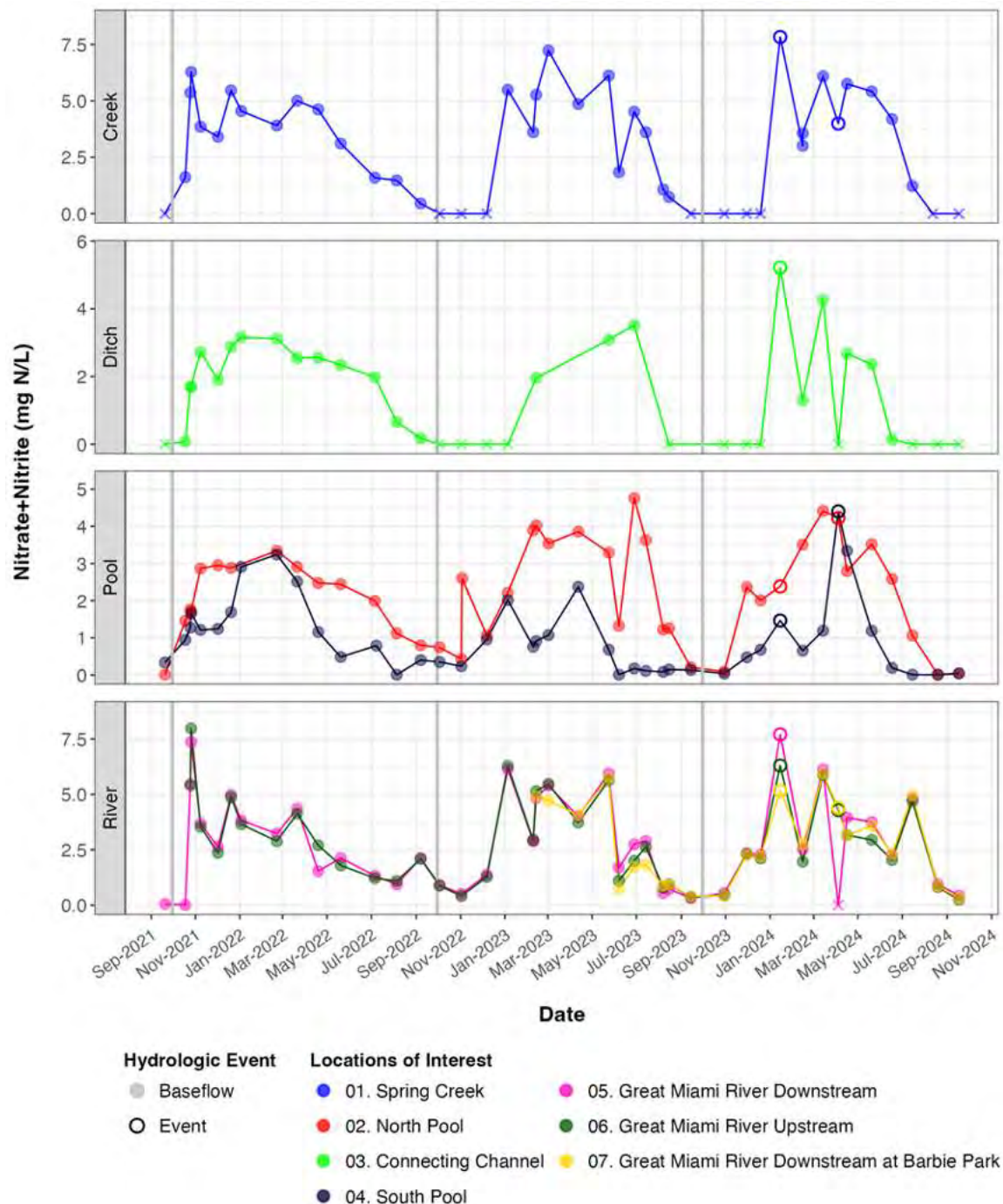


Figure 231. Time series of Nitrite+nitrate (NO_x) concentrations in surface water samples collected at the Springcreek Confluence Off-Channel Wetlands Project. Values below the detection limit of the analytical equipment were replaced with half the value of the detection limit. Each point represents one measurement, and colors denote the locations of interest, as indicated in the legend. Open symbols indicate that measurements were collected during a hydrologic event (e.g., storm event) and filled symbols denote measurements collected during

baseflow. Crosses (×) represent instances when no surface water was detected during the visit. If present, different shapes denote the types of wetland features represented by the locations of interest. Gray vertical lines indicate the start of a water year (Oct 1–Sep 30).

Soil Nutrient Status and Processes

Positive soil phosphate sorption capacity (SPSC) values across the Project are indicative of the sediment’s capacity to sorb phosphate. However, the values are not highly positive (average 35 mg/kg, excluding one sample with outlier Mehlich-3-extracted (M-3) aluminum concentration of 1096 ppm). Soils could be phosphate-saturated quickly, possibly due to the sandy/gravel composition of the sediment in the wetland pools (Figure 232). There was a slight increase in SPSC from Water Year (WY) 2023 to WY 2024, likely due to an increase in extractable M3 iron concentrations. Additionally, there is no spatial difference observed for SPSC between the North Pool and South Pool, meaning the pools have similar capacity to store phosphate.



Figure 232. Soil Phosphate Sorption Capacity (SPSC) throughout the Springcreek Confluence Off-Channel Wetlands Project. Each point denotes a soil sample (0–5 cm) and different shapes indicate the wetland feature type, as shown in the legend. Colors indicate the SPSC value of each sample relative to the overall range of values observed at the wetland project, as shown in the color bar. Each panel shows the soil samples collected during a respective water year (Oct 1–Sep 30), along with the minimum and maximum SPSC values observed during a given water year. Negative SPSC values indicate the potential for soils to release phosphate, while positive values indicate soils have capacity to sorb phosphate, based on Mehlich-3 extractions of phosphate, iron, and aluminum.

Next Steps to Strengthen Understanding

Surface water samples, annual soil samples, and hydrology data will continue to be collected in Water Year 2025 to determine nutrient reductions associated with the Project. To better understand nutrient concentration and load reductions associated with inflow events, more surface water samples need to be collected for the rising limb, peak, and falling limb, equivalent to an increase in flow, highest flow, and decrease in flow. However, this may not be feasible

given travel time and monitoring of multiple Projects. Collecting more nutrient and hydrology data across time would help improve accuracy of nutrient load calculations.

Tipp City Off-Channel Wetlands (TIPC)

Project Description

Miami County | Great Miami River Watershed

Project size: 18.3 acres

Partners: City of Tipp City

The hydrology at this Project is passively managed. The Project (10 acres restored wetland) is an off-channel wetland, consisting of a large, permanently flooded pool. Water enters from the Great Miami River via inflow notch and inundates the pool basin. There is no dedicated outflow, but water exits via backflow and likely also subsurface exchange with the river or groundwater. A hydrologic event at this Project is operationally defined as a flow event when the river discharge rate at the inflow notch reaches approximately 2,627 cubic feet per second, causing river water to flood the wetland pool.



Figure 233. Aerial image showing surface water flow and sampling locations for the Tipp City Off-Channel Wetland Project. Blue arrows indicate direction of surface water flow. Dots represent geographic base crew sampling locations, which are grouped by Project features (fill color) where relevant. Text annotations provide additional context about the Project's watershed connection or other important features.

Management Considerations

Some nutrient results (e.g., lbs. of total phosphorus (TP) removed) suggest potential influence of dryer weather, however, drought conditions in Water Year (WY) 2024 did not have a significant impact on the volume received by the Tipp City Project from the Great Miami River compared to WY 2023. WY 2024 nutrient reductions were lower than reductions in WY 2023 for dissolved reactive phosphorus, TP, nitrite+nitrate, and total ammonium nitrogen despite there being greater inflow volumes in WY 2024. The river floods into the wetland pools when river discharge rate at the inflow notch reaches approximately 2,627 cubic feet per second, which resulted in eight inflow events in WY 2023 and five inflow events in WY 2024. All inflow events in WYs 2023 and 2024 occurred in winter and spring. The distribution of events between the years was also similar; active inflow occurred for 18 days in WY 2023 and 20 days in WY 2024. Although there were three fewer events in WY 2024, there was a greater total inflow volume of approximately 256 million L versus approximately 248 million L in WY 2023. To increase the number of flooding events, the inflow notch could be lowered to capture flows more frequently from the Great Miami River, however, a balance would have to be met between filtering nutrient loads and not inundating the entire Project

Since the completion of construction in December 2022, there has not been a large amount of vegetation establishment throughout the wetland. It may be beneficial to plant vegetation in the shallower areas of the wetland pool (i.e., elevated flats and around the edge of the pool) as another way to potentially increase nutrient reductions. However, vegetation may not be able to survive drastic changes in water level (i.e., extreme flooding in winter and spring, and drought conditions in summer and fall).



Figure 234. Aerial image of approximate locations of interest for water and soil sampling and discrete manual measurements of water depth and physicochemical parameters at Tipp City Off-Channel Wetland Project during water year 2024 (Oct 1, 2023–Sep 30, 2024). The legend provides the name of each sampling point. Different shapes denote the types of wetland features represented by the locations of interest. If present, different colors represent locations of interest that belong to a group or complex of features (e.g., a treatment train).

Nutrient Budget Takeaways

In Water Year (WY) 2024, the Tipp City Project received approximately 257,000 m³ of water. The Project filtered 37 lbs. of total phosphorus (TP), 23 lbs. of dissolved reactive phosphorus (DRP), 1,162 lbs. of nitrite+nitrate (NO_x), 1,121 lbs. of total nitrogen (TN), and 64 lbs. of total ammonium nitrogen (NH₄-N). Although the wetland received more inflows in WY 2024 than WY 2023, less nutrients were filtered (not including NH₄-N) in WY 2024. This could likely be due to the large volume of water and timing of the April 2024 events. Flows for the April 2, 2024 event were so large that the floodplain wetland became part of the river and was unable to hold water for nutrient reduction. The wetland was already at maximum volume capacity when, just three days after the end of the prior event, another large storm event occurred. Such large events in a short period of time result in decreased water storage capacity and shorter residence times, leading to lower nutrient reductions.

DRP, TP, and NH₄-N loads filtered in summer and fall were similar in WYs 2023 and 2024. However, NO_x and TN loads filtered in summer and fall WY 2024 were greater than loads filtered in WY 2023. This is likely a result of greater inflow volumes and higher concentrations in WY 2024 versus in WY 2023. In winter of WY 2023 and WY 2024, loads filtered were greatest for all nutrients measured across all seasons, with an exception for lowest load filtered for DRP. Fall WY 2024 resulted in the greatest DRP load filtered across seasons. Variability in nutrient loads filtered across years and seasons highlights the importance of sample frequency across season and years.

The conversion from agricultural land to wetland prevents 13 ± 9 lbs. phosphorus runoff annually. Soils throughout the Project have low capacity to sorb phosphate, as suggested by soil phosphate sorption capacity values. Some locations within the Project have soils that are vulnerable to releasing phosphate.

Surface Water Hydrology and Nutrients

The Tipp City Project consists of a large, permanently flooded pool that experiences seasonal flooding events. Overall, the average Wetland (Wetland Inflow and Mid Wetland Near HOB0) nutrient concentrations were lower than Great Miami River Upstream nutrient concentrations (Figure 237, Figure 238). Across all seasons in Water Year (WY) 2024, nutrient concentrations were reduced between Great Miami River and wetland pool. These nutrient reductions were greatest in the fall for dissolved reactive phosphorus, total phosphorus, nitrite+nitrate (NO_x), and total nitrogen (TN). Total ammonium nitrogen (NH₄-N) reductions between the Great Miami River and the wetland pools were greatest in the winter. The inflow concentration for NH₄-N was much greater in winter, allowing for a greater percentage reduction between Great Miami River Upstream and the wetland pool.

Upstream and Downstream Great Miami River exhibit similar trends in nutrient concentrations across WY 2023 and 2024 (Figure 237, Figure 238). Great Miami River Downstream typically has lower nutrient concentrations. There are periods of time, albeit very rarely, in which Great Miami River Downstream NO_x, NH₄-N, and TN concentrations are slightly greater or equal to the Great Miami River Upstream concentrations. Lower Great Miami River Downstream nutrient concentrations are likely due to a combination of treatment from the wetland and dilution from Honey Creek, a tributary that flows into the Great Miami River downstream of the wetland and upstream of the sampling location.

Inflow events in which the Great Miami River breached the inflow notch correspond to large increases then decreases in pool volume (Figure 235). There are also changes in pool volume when the Great Miami River does not breach the inflow notch. These increases and decreases in pool volume without the Great Miami River breaching the notch are evidence of subsurface interaction between the wetland and the river and/or groundwater. The influence of groundwater is likely due to being situated over the Great Miami Buried Valley Aquifer.

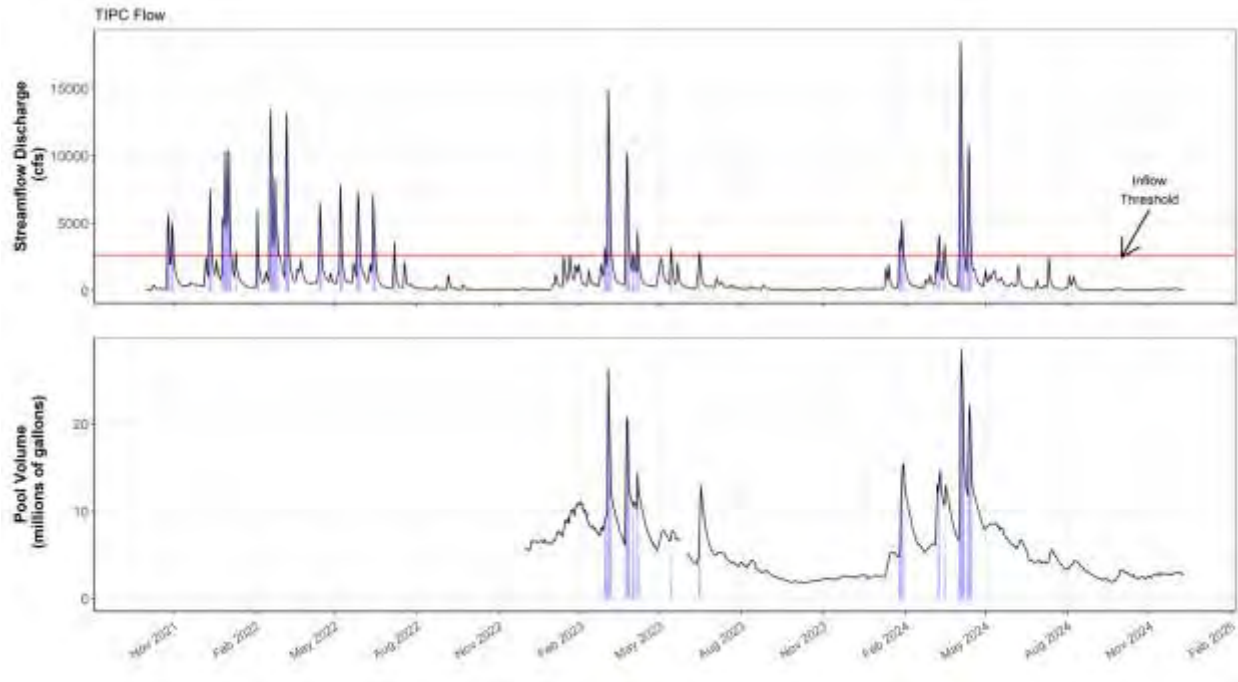


Figure 235. (Top) Great Miami River streamflow from USGS gage Great Miami at Troy, OH - 3262700 was watershed weighted to get river stream flow at the wetland. The red line is 2,627 cubic feet per second, above which storm flow water will enter Tipp City Off-Channel Wetland. The black line indicates Miami River flow, and the purple bars denote when the discharge threshold in the river was surpassed, which is when researchers estimate that the pools were flooded. (Bottom) The black line indicates pool volume at the Project's main wetland pool, as estimated from data from water level logger (HOBO[®], Onset and Solinst Levellogger 5, Solinst Canada Ltd.) placed in the wetland pool.

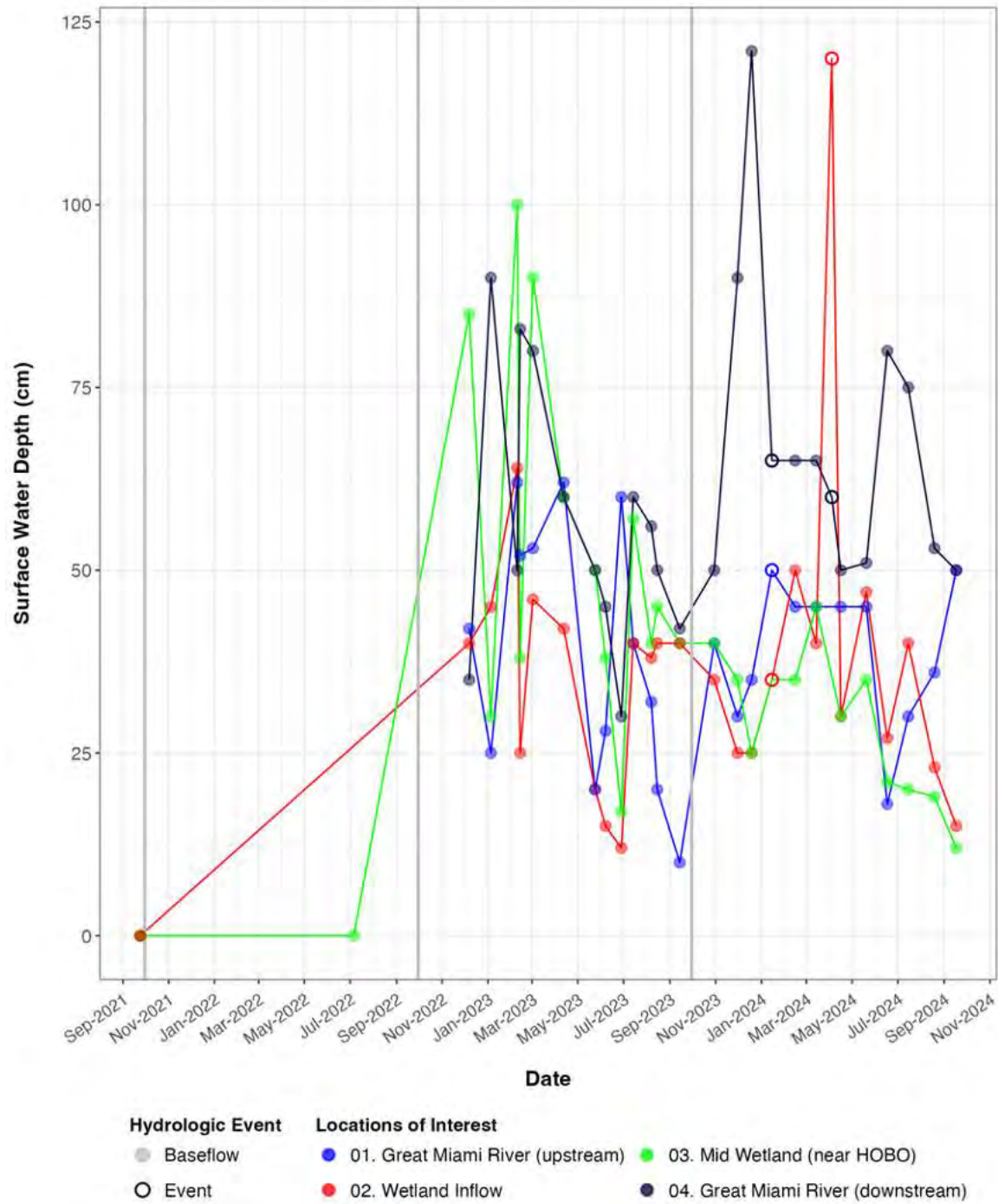


Figure 236. Time series of discrete, manually measured surface water depth at the Tipp City Off-Channel Wetland Project. Depths were measured approximately monthly. Each point represents one measurement and colors denote the locations of interest, as indicated in the legend. Open symbols indicate samples that were collected during a hydrologic event (e.g., storm event) and

filled symbols denote samples collected during baseflow. Crosses (×) represent instances when no surface water was detected during the visit. If present, different shapes denote the types of wetland features represented by the locations of interest. Gray vertical lines indicate the start of a water year (Oct 1–Sep 30).

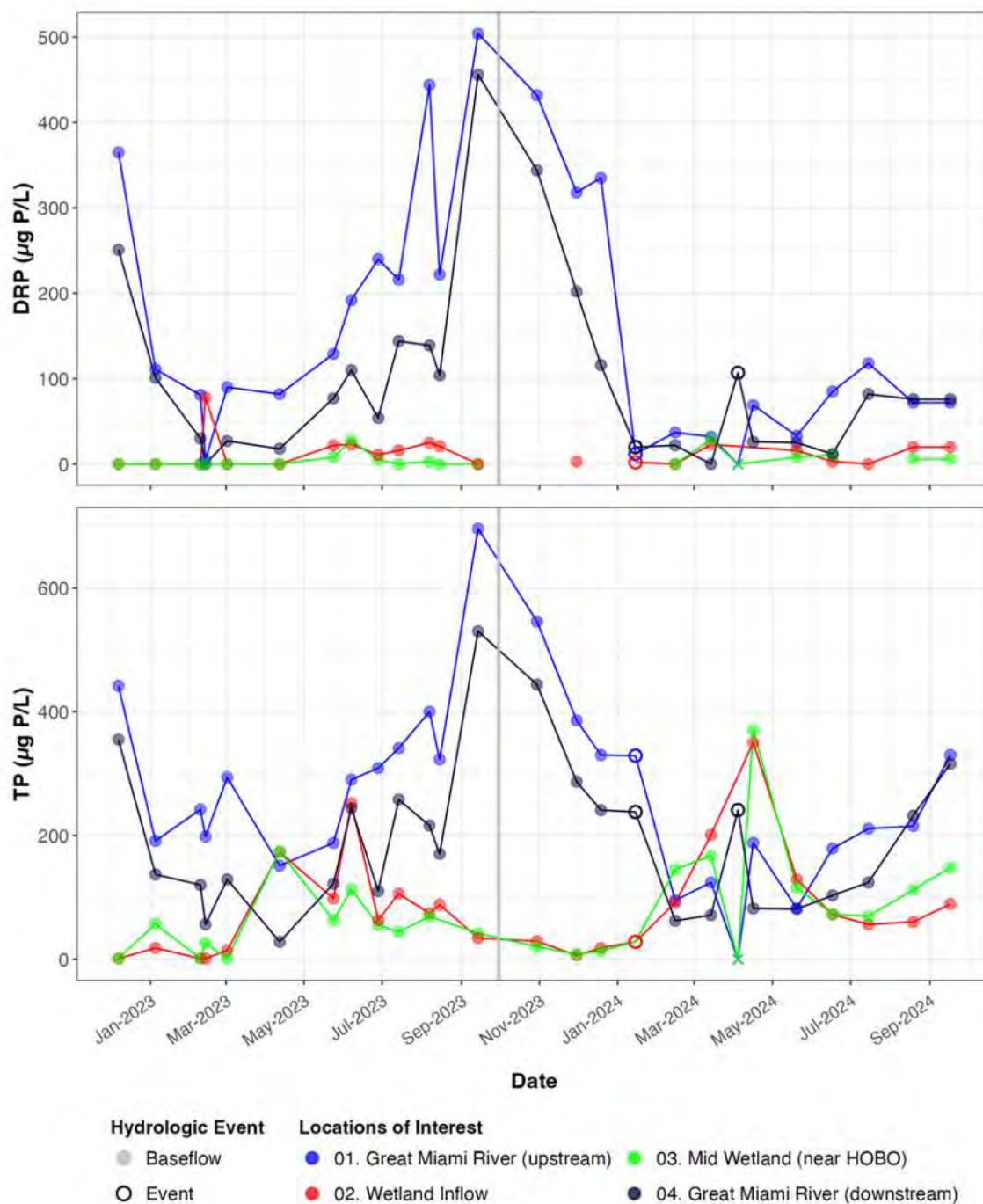


Figure 237. Time series of dissolved reactive phosphorus (DRP, top panel) and total phosphorus (TP, bottom panel) concentrations in surface water samples collected at the Tipp City Off-Channel Wetland Project. Values below the detection limit of the analytical equipment were replaced with half the value of the detection limit. Each point represents one measurement, and colors denote the locations of interest, as indicated in the legend. Open symbols indicate that measurements were collected during a hydrologic event (e.g., storm event) and filled symbols

denote measurements collected during baseflow. Crosses (×) represent instances when no surface water was detected during the visit. If present, different shapes denote the types of wetland features represented by the locations of interest. Gray vertical lines indicate the start of a water year (Oct 1–Sep 30).

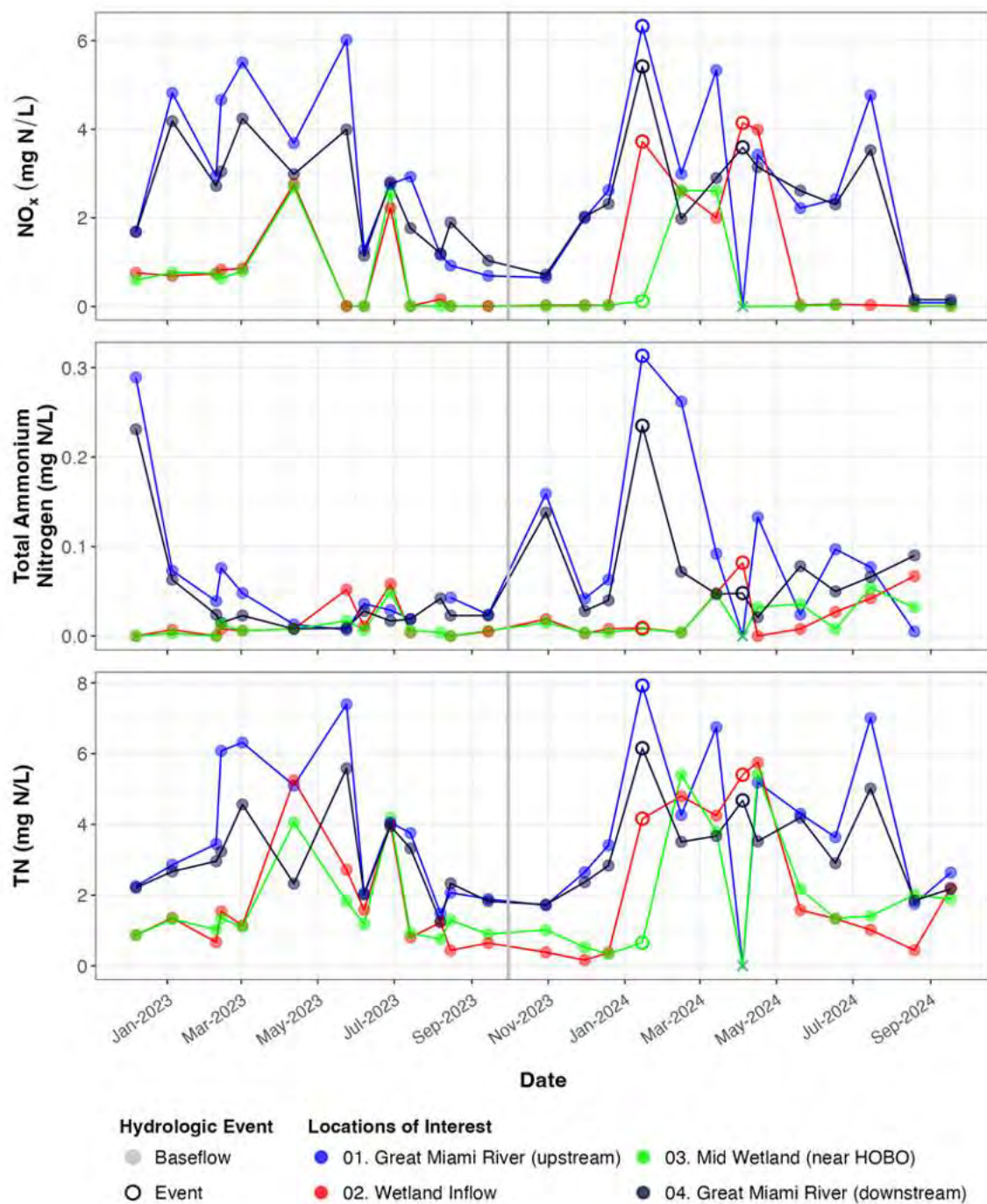


Figure 238. Time series of Nitrite+nitrate (NO_x , top panel) total ammonium nitrogen ($\text{NH}_4\text{-N}$, middle panel), and total nitrogen (TN, bottom panel) concentrations in surface water samples collected at the Tipp City Off-Channel Wetland Project. Values below the detection limit of the analytical equipment were replaced with half the value of the detection limit. Each point represents one measurement, and colors denote the locations of interest, as indicated in the legend. Open symbols indicate that measurements were collected during a hydrologic event (e.g., storm event) and filled symbols denote measurements collected during baseflow. Crosses (×) represent instances when no surface water was detected during the visit. If present, different shapes denote the types of wetland features represented by the locations of interest. Gray vertical lines indicate the start of a water year (Oct 1–Sep 30).

Soil Nutrient Status and Processes

Overall, soil phosphate sorption capacity (SPSC) varies across the wetland, indicating a capacity to sorb phosphate in some places and vulnerability to release phosphate in others (Figure 239). However, the SPSC values are not highly positive (average 28 mg phosphorus (P)/kg), meaning they could become saturated more quickly than clay soils, which is expected due to the sandy/gravel sediment bottom of the wetland. There is little to no spatial variability across the wetland pool; all three sampling locations exhibited soil total phosphorus concentrations of 380 mg P/kg. SPSC values increased from Water Year (WY) 2023 (average 6.6 mg/kg) to WY 2024 due to an increase in Mehlich-3-extractable iron and aluminum.



Figure 239. Soil Phosphate Sorption Capacity (SPSC) throughout the Tipp City Off-Channel Wetland Project. Each point denotes a soil sample (0–5 cm) and different shapes indicate the wetland feature type, as shown in the legend. Colors indicate the SPSC value of each sample relative to the overall range of values observed at the wetland project, as shown in the color bar. Each panel shows the soil samples collected during a respective water year (Oct 1–Sep 30), along with the minimum and maximum SPSC values observed during a given water year. Negative SPSC values indicate the potential for soils to release phosphate, while positive values indicate soils have capacity to sorb phosphate, based on Mehlich-3 extractions of phosphate, iron, and aluminum.

Next Steps to Strengthen Understanding

Surface water samples, annual soil samples, and hydrology data will continue to be collected in Water Year 2025. To understand nutrient concentration and load reductions for flow events, the goal of continued monitoring is to collect surface water samples during the rising limb, peak, and falling limb of the events. However, this might not be feasible due to logistics (e.g., scope of work, number of trips, number of total Projects to be monitored). Additionally, the dilution factor of the tributary Honey Creek should be investigated to determine if lower nutrient reductions downstream in the Great Miami River are associated with the wetland, dilution from Honey Creek, or a combination of both.

Walnut Creek Treatment Wetland Restoration (WALC)

Project Description

Franklin County | Walnut Creek Watershed | Inland Central Ohio

Project size: 17 Acres

Partner: Columbus and Franklin County Metro Parks

The hydrology at this Project is passively managed. The Project (17.4 acres restored wetland) is an off-channel wetland consisting of a permanently flooded deep settling pool at the inflow and at the outflow, with seasonally flooded hummocks and hollows connecting the settling pools. Water enters the Project from Walnut Creek via the inflow notch at the north of the Project and exits back to Walnut Creek via the water level control structure (WLCS) at the south. A hydrologic event at this Project is operationally defined as an event in which Walnut Creek floods the wetland, possible at a discharge of at least 1,064 cubic feet per second.



Figure 240. Aerial image showing surface water flow and sampling locations for the Walnut Creek Treatment Wetland Restoration Project. Blue arrows indicate direction of surface water flow. Dots represent geographic base crew sampling locations, which are grouped by Project features (fill color) where relevant. Text annotations provide additional context about the Project's watershed connection or other important features.

Management Considerations

Compared to precipitation during Water Year (WY) 2023, the drought of WY 2024 did not have a huge impact on the water input received by Walnut Creek Treatment Wetland Restoration. Flooding events occur when Walnut Creek stream flow is equal to or exceeds 1,064 cubic feet per second. The Project was able to treat 1.1% (1.6 billion L) of the annual WY 2024 Walnut Creek flows compared to only 0.5% (768 million L) of the annual WY 2023 Walnut Creek flows. There were five offloading events in both WY 2023 and WY 2024, however, the volume of events in WY 2024 was much greater in a short period of time, allowing more water to be treated due to the high-water elevation of Walnut Creek. For a comparison to a wetter year, if construction of the wetland were complete in WY 2022, there would have been an estimated 10 flooding events. Lowering the inflow notch would allow for more flows to be treated by the Project, potentially supporting greater nutrient reduction. However, this may cause concern with volume capacity of the Project where the whole Project would become inundated. A balance would have to be found between capturing more events while not inundating the entire Project and still obtaining nutrient reductions.

Additionally, the stop logs in the water level control structures (WLCS) could be adjusted to retain more water inside the wetland during flow events. During WY 2023 and 2024 the stop logs were set to a height of 165 cm throughout the year, but the WLCS can hold up to 165 cm of logs, depending on the design of the Project and how much water the wetland can accommodate at that level. Increasing the stop log height by just one 18-cm stop log would result in greater residence times and water volume inside the wetland.

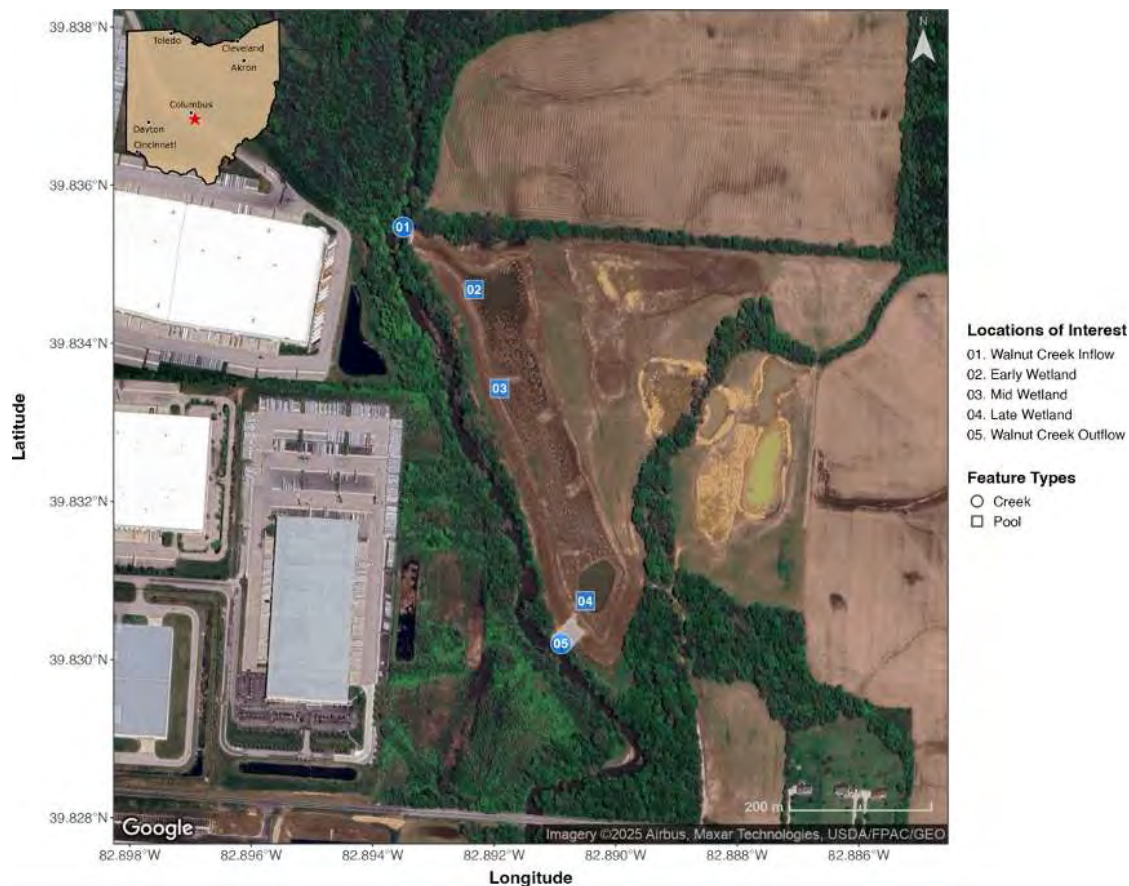


Figure 241. Aerial image of approximate locations of interest for water and soil sampling and discrete manual measurements of water depth and physicochemical parameters at Walnut Creek Treatment Wetland Restoration Project during water year 2024 (Oct 1, 2023–Sep 30, 2024). The legend provides the name of each sampling point. Different shapes denote the types of wetland features represented by the locations of interest. If present, different colors represent locations of interest that belong to a group or complex of features (e.g., a treatment train).

Nutrient Budget Takeaways

In Water Year (WY) 2024, the Walnut Creek Project received approximately 1.7 million m³ of water. The Project filtered 488 lbs. of total phosphorus (TP), 4,701 lbs. of total nitrogen (TN), 289 lbs. of dissolved reactive phosphorus (DRP), and 6,786 lbs. of nitrite+nitrate (NO_x), compared to load reductions of 165 lbs. (TP), -553 lbs. (TN), 116 lbs. (DRP), and 376 lbs. (NO_x) in WY 2023. The Project was a source of total ammonium nitrogen and released 27 lbs. in WY 2023 and 13 lbs. in WY 2024. Overall, load reductions increased from WY 2023 to WY 2024 for all nutrients. This could be due to the amount of water from Walnut Creek that was treated. The volume of inflow in WY 2024 from Walnut Creek increased by 53%, increasing the hydraulic loading rate (volume of wetland inflow per wetland area, HLR).

It should be noted that nutrient load estimates for WY 2023 have higher uncertainty than estimates at other Projects, as only a few months out of the year were sampled, including high

flow ($\geq 1,064$ cubic feet per second, cfs) months meaning that an underestimate is likely. A majority of the nutrient load reduced for floodplain wetlands occurs during high flow events. No high flow events (river flows $\geq 1,064$ cfs) were sampled in WY 2023 spring and winter, possibly leading to inaccurate nutrient concentrations (outflow concentrations higher than inflow), indicating a net export of nutrients during storm events.

The conversion from agricultural land to wetland prevents 46 ± 31 lbs. phosphorus runoff annually. Soils throughout the Project have low capacity to sorb phosphate, as suggested by soil phosphate sorption capacity values.

Surface Water Hydrology and Nutrients

Walnut Creek Treatment Wetland Restoration is a floodplain wetland that acts as a treatment train during flood events. The flooding regime of the Project consists of permanently flooded deep (4.6 m) settling pools at the Project's inflow and outflow, with seasonally flooded hummocks and hollows connecting the settling pools.

Overall, there was little to no concentration difference between Walnut Creek Upstream and Walnut Creek Downstream for all monitored nutrients (total phosphorus, dissolved reactive phosphorus, nitrite+nitrate (NO_x), total ammonium nitrogen ($\text{NH}_4\text{-N}$), and total nitrogen (TN, Figure 244, Figure 245). The volume of water in Walnut Creek is much higher than the volume of the wetland pools, and it is likely that not enough water was intercepted by the wetland to cause a decrease in downstream concentration. In Water Years (WYs) 2023 and 2024, only 0.5% and 1.1% of the annual stream flows were captured by the wetland (Figure 242). Concentrations of all monitored nutrients at Walnut Creek Upstream were generally high in the summer, but flow volume in Walnut Creek during the summer may not have been high enough for offloading events (flooding from Walnut Creek to Early Wetland) to occur and filter these nutrients. WY 2023 and WY had fewer summer flooding events compared to WY 2022, based on streamflow data used to estimate flooding events (Figure 242).

On average, nutrient concentrations were slightly lower at the second settling pool (Late Wetland) than the first settling pool (Early Wetland), and differences were often minimal (Figure 244, Figure 245). However, differences between the first and second settling Pools were notably greater in September 2023 – February 2024 ($\text{NH}_4\text{-N}$, TN) and during a February 2024 hydrologic event (NO_x , TN). Additionally, the first settling pool (Early Wetland) had elevated total ammonium ($\text{NH}_4\text{-N}$) compared to the creek and other wetland locations in January 2024 and May 2024 (Figure 245).

Over the 1.5-year sampling period, researchers observed and sampled in the hummocks and hollows during only two of the 18 sampling trips; this is further evidence that even after flow events, this portion of the Project holds water for a short time. When the hummocks and hollows (Mid Wetland) flooded during hydrologic events in late January and mid-April 2024, most nutrient concentrations increased to similar levels as the Creek (Figure 244, Figure 245).

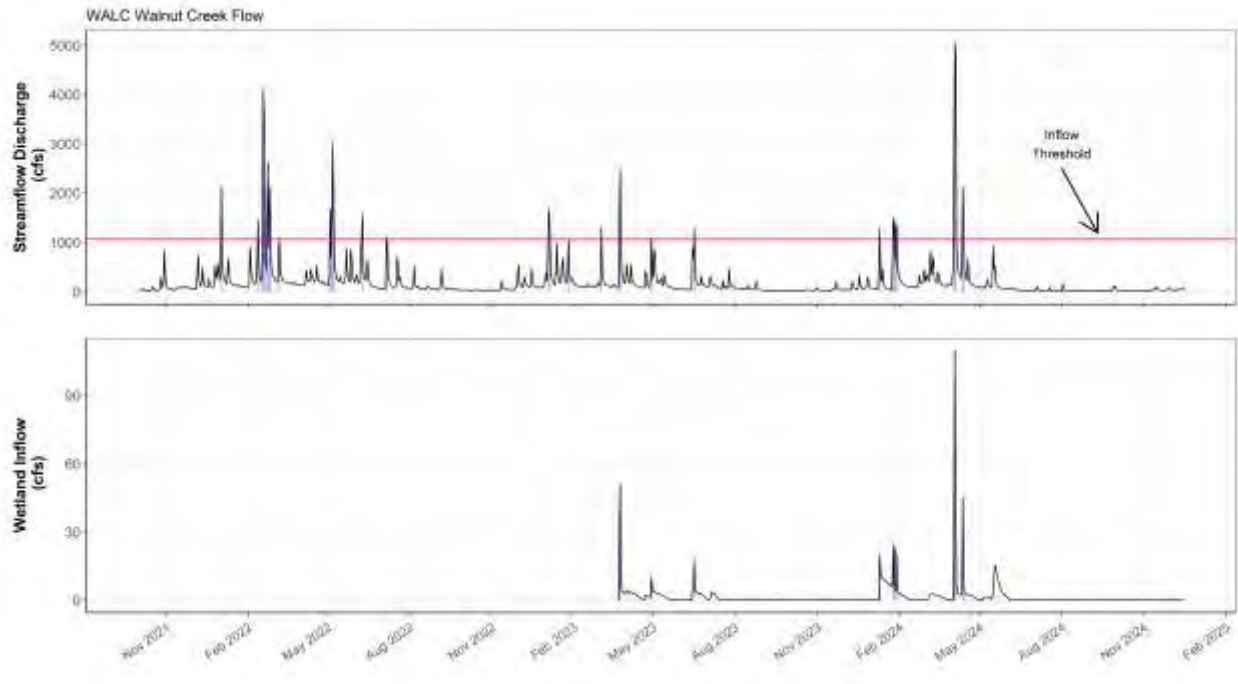


Figure 242. (Top) Walnut Creek streamflow from USGS gage Walnut Creek at Ashville OH - 03229796 was watershed weighted to get river stream flow at the wetland. The red line is 1,064 c, above which storm flow water will enter Walnut Creek Wetland Treatment Restoration. The black line indicates Walnut Creek flow, and the purple bars denote when the discharge threshold in the river was surpassed, which is when researchers estimate that the pools were flooded. (Bottom) The black line indicates pool volume at the Project's main wetland pool, as estimated using a flat weir equation from data from water level logger (HOB0[®], Onset) placed in the wetland pool.

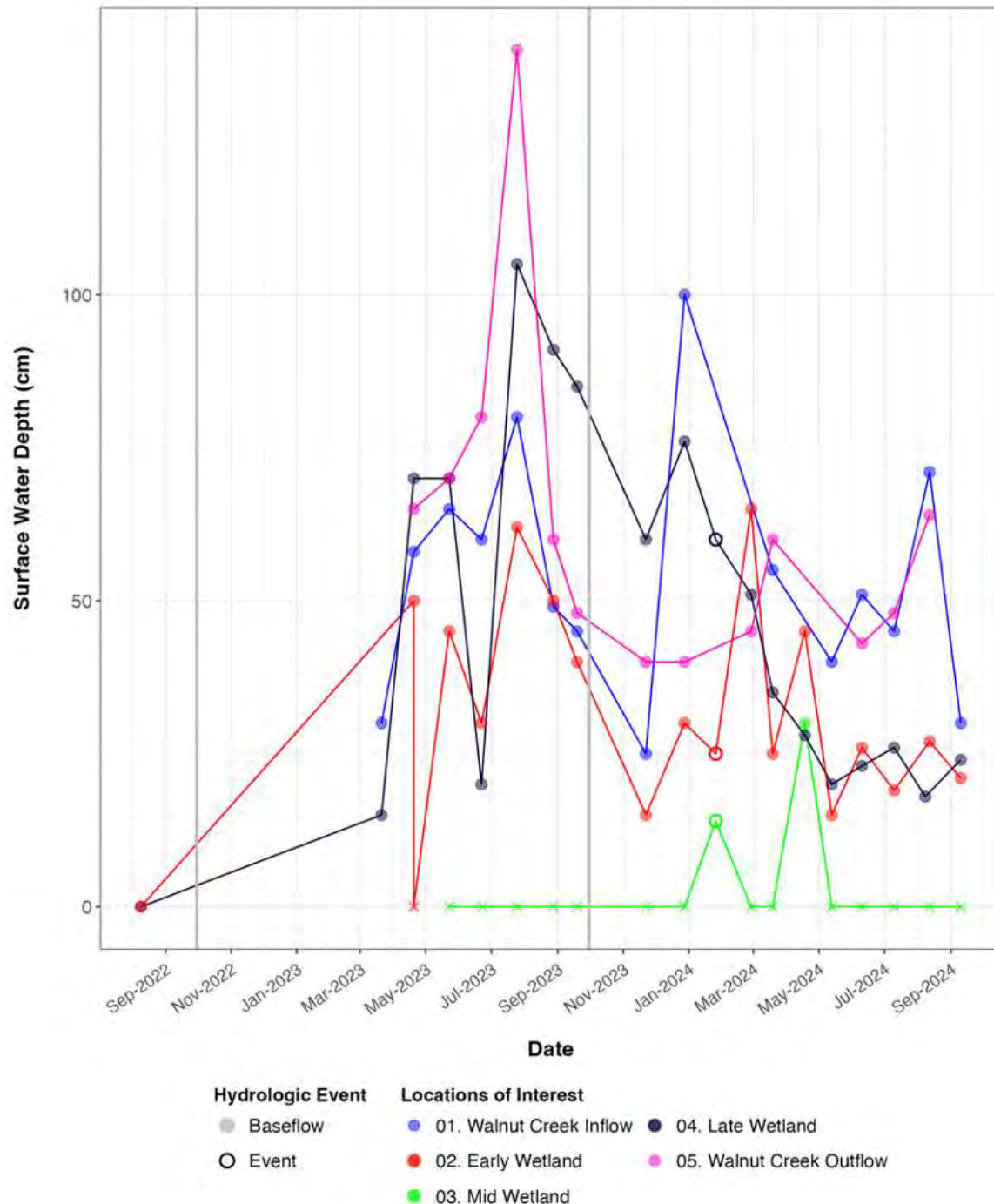


Figure 243. Time series of discrete, manually measured surface water depth at the Walnut Creek Treatment Wetland Restoration Project. Depths were measured approximately monthly. Each point represents one measurement and colors denote the locations of interest, as indicated in the legend. Open symbols indicate samples that were collected during a hydrologic event (e.g., storm event) and filled symbols denote samples collected during baseflow. Crosses (×) represent instances when no surface water was detected during the visit. If present, different shapes denote

the types of wetland features represented by the locations of interest. Gray vertical lines indicate the start of a water year (Oct 1–Sep 30).

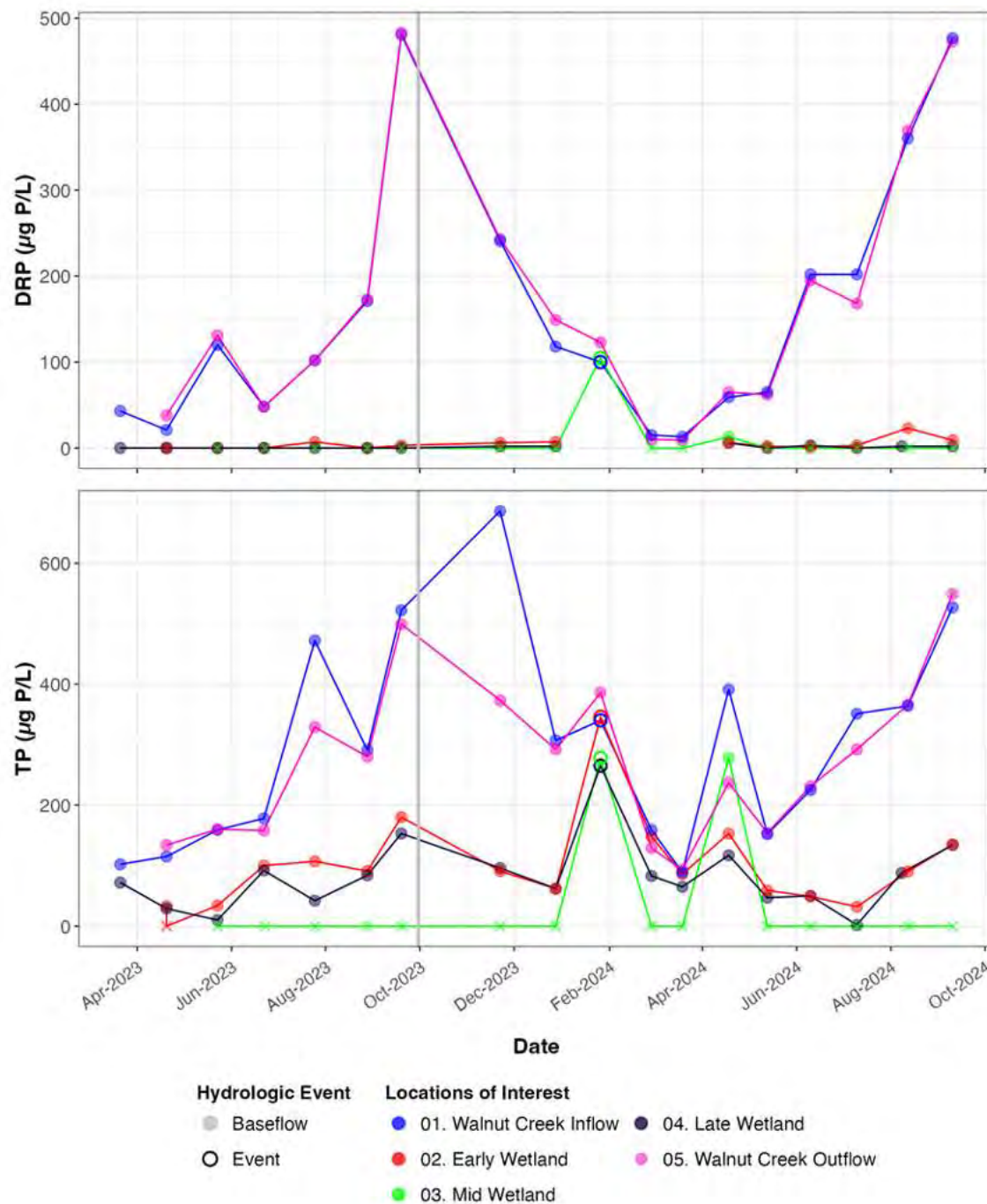


Figure 244. Time series of dissolved reactive phosphorus (DRP, top panel) and total phosphorus (TP, bottom panel) concentrations in surface water samples collected at the Walnut Creek Treatment Wetland Restoration Project. Values below the detection limit of the analytical

equipment were replaced with half the value of the detection limit. Each point represents one measurement, and colors denote the locations of interest, as indicated in the legend. Open symbols indicate that measurements were collected during a hydrologic event (e.g., storm event) and filled symbols denote measurements collected during baseflow. Crosses (×) represent instances when no surface water was detected during the visit. If present, different shapes denote the types of wetland features represented by the locations of interest. Gray vertical lines indicate the start of a water year (Oct 1–Sep 30).

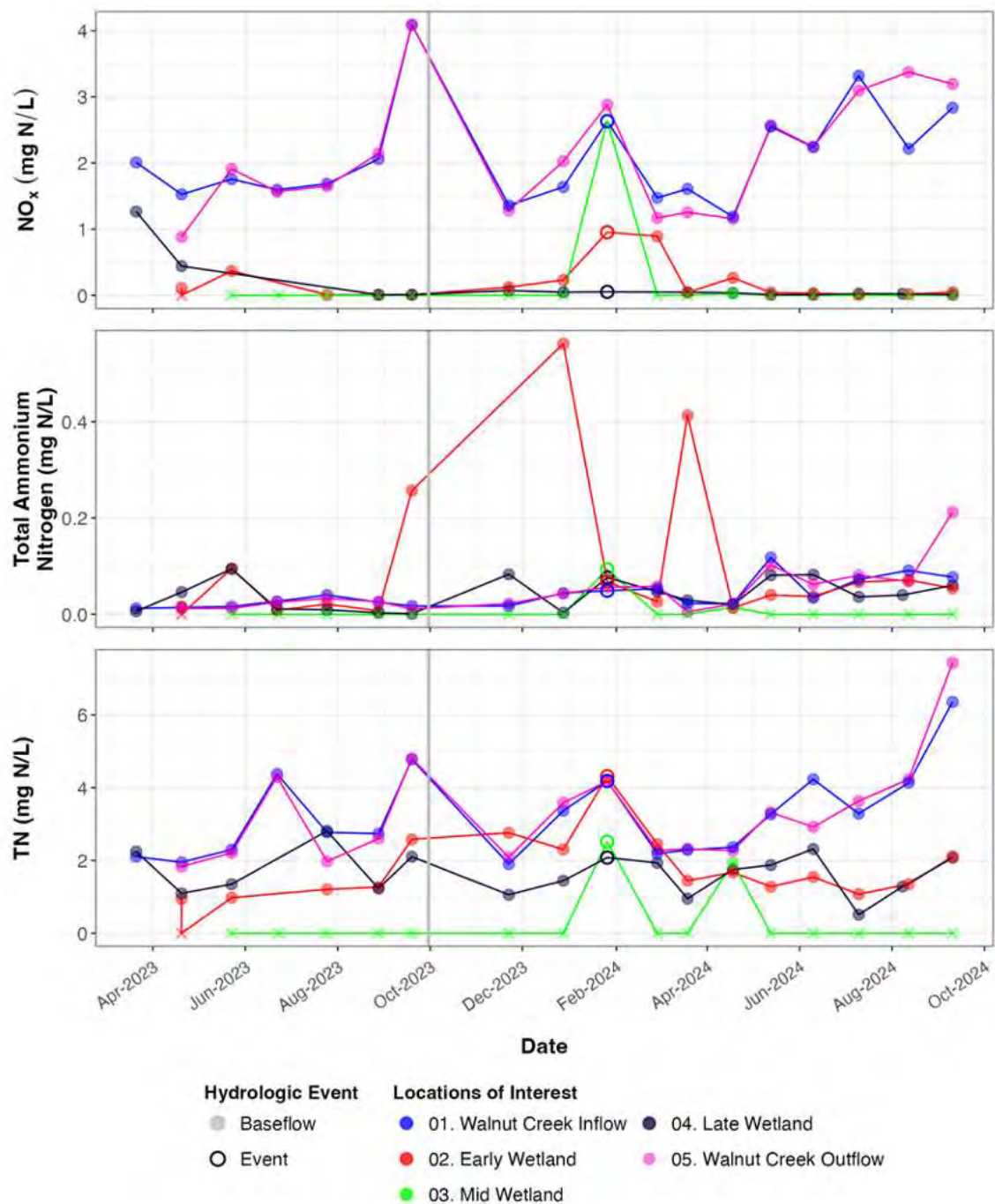


Figure 245. Time series of Nitrite+nitrate (NO_x , top panel) total ammonium nitrogen ($\text{NH}_4\text{-N}$, middle panel), and total nitrogen (TN, bottom panel) concentrations in surface water samples collected at the Walnut Creek Treatment Wetland Restoration Project. Values below the detection limit of the analytical equipment were replaced with half the value of the detection limit. Each point represents one measurement, and colors denote the locations of interest, as indicated in the legend. Open symbols indicate that measurements were collected during a

hydrologic event (e.g., storm event) and filled symbols denote measurements collected during baseflow. Crosses (×) represent instances when no surface water was detected during the visit. If present, different shapes denote the types of wetland features represented by the locations of interest. Gray vertical lines indicate the start of a water year (Oct 1–Sep 30).

Soil Nutrient Status and Processes

Overall, the soil phosphate sorption capacity (SPSC) values across the Project are positive, indicative of the sediment's potential to sorb phosphate (Figure 246). In Water Year (WY), SPSC ranged from 66 to 94 mg P/kg, and were similar to WY 2023 values (Supplemental Information). There is some spatial variation in soil nutrients across the Project; annual average soil total phosphorus concentrations decreased along the flow path from the first settling pool (Early Wetland; 870 mg P/kg), hummocks and hollows (Mid Wetland; 578 mg P/kg), and second settling pool (Late Wetland; 573 mg P/kg; Supplemental Information).

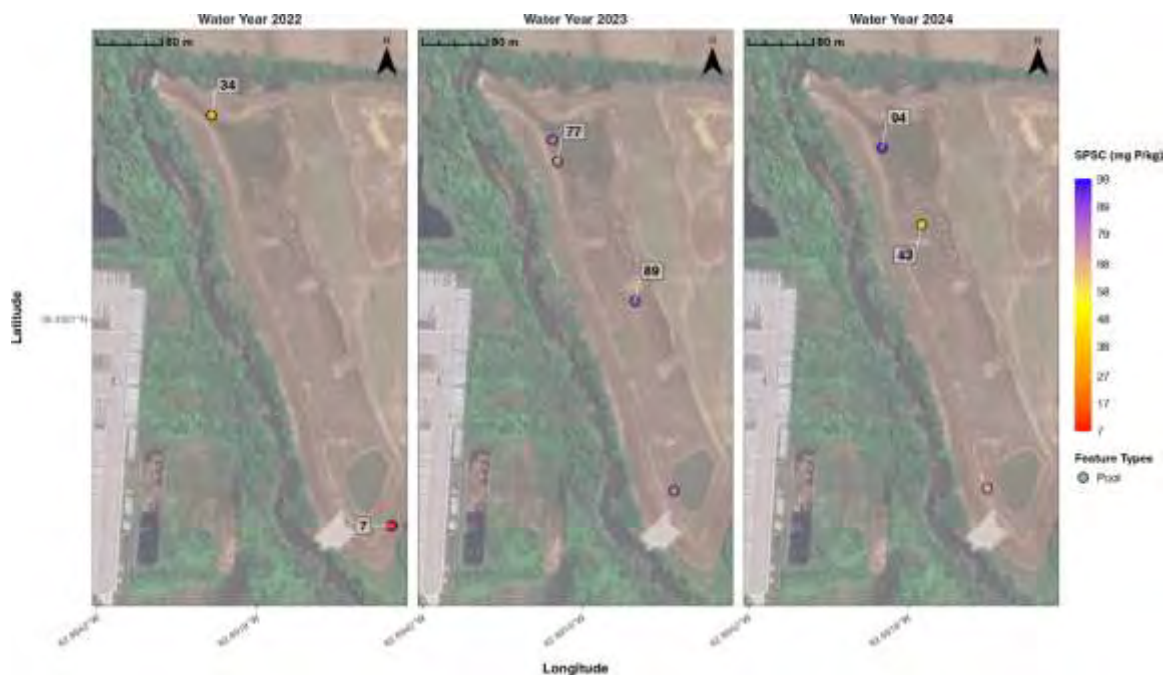


Figure 246. Soil Phosphate Sorption Capacity (SPSC) throughout the Walnut Creek Treatment Wetland Restoration Project. Each point denotes a soil sample (0–5 cm) and different shapes indicate the wetland feature type, as shown in the legend. Colors indicate the SPSC value of each sample relative to the overall range of values observed at the wetland project, as shown in the color bar. Each panel shows the soil samples collected during a respective water year (Oct 1–Sep 30), along with the minimum and maximum SPSC values observed during a given water year. Negative SPSC values indicate the potential for soils to release phosphate, while positive values indicate soils have capacity to sorb phosphate, based on Mehlich-3 extractions of phosphate, iron, and aluminum.

Next Steps to Strengthen Understanding

The H2Ohio Wetland Monitoring Program does not plan to collect surface water samples after April 2025 at Walnut Creek Treatment Wetland Restoration in Water Year (WY) 2025. Hydrology and annual soil samples will continue to be collected in WY 2025 and analysis of existing data will continue to determine volume of water captured from Walnut Creek and accumulation of phosphorus in sediment.

West Central (Heidelberg University)

Projects in west central region (Figure 1) are primarily monitored by the geographic base crew centered at the National Center for Water Quality Research at Heidelberg University (Nathan Manning, Principal Investigator).

Andreoff Wetland Restoration (ANDW)

Project Description

Wyandot | Blanchard River Watershed

Project size: 278 Acres

Partners: Ducks Unlimited

The hydrology at this Project is passively managed. The Project has 278 acres of restored wetland and consists of a single 1.5-acre wetland pool without designed inflows or outflows. The pool receives surface runoff from the surrounding landscape and largely functions as an isolated wetland. A hydrologic event at this Project is operationally defined as an event where the Project receives runoff.



Figure 247. Aerial image showing surface water flow and sampling locations for the Andreoff Wetland Restoration Project. Blue arrows indicate direction of surface water flow. Dots represent geographic base crew sampling locations, which are grouped by Project features (fill color) where relevant. Text annotations provide additional context about the Project's watershed connection or other important features.

Management Considerations

Andreoff Wetland Restoration (hereafter Andreoff Wetland Project) is a depressional isolated wetland without any designed inflows or outflows, similar to Fruth Wetland. During most of the year, the Main Pool retains water even under prolonged drought conditions. At its deepest point, the Main Pool is estimated to be about one meter. In Water Year 2025, this Project will transition from a Non-Focal 1 designation (seasonal sampling) to Non-Focal 2 (annual sampling). While this is an isolated wetland, periods of increased rainfall can cause surface runoff from the surrounding fields to drain into the pool, and once the pool reaches maximum capacity it drains into the adjacent ditch. Base crews qualitatively observed this phenomenon during April 2024 rain events, but the installation of a flume or water level control structure allowing water to exit the Main Pool at a set location would be needed for researchers to have a set point to sample from and be able to determine the nutrient concentration at this intermittent outflow. This data, combined with drainage area calculations, would allow researchers to calculate a load reduction that would otherwise drain directly into stormwater ditches if the Main Pool did not exist.



Figure 248. Aerial image of approximate locations of interest for water and soil sampling and discrete manual measurements of water depth and physicochemical parameters at Andreoff Wetland Restoration Project during water year 2024 (Oct 1, 2023–Sep 30, 2024). The legend provides the name of each sampling point. Different shapes denote the types of wetland features represented by the locations of interest. If present, different colors represent locations of interest that belong to a group or complex of features (e.g., a treatment train).

Nutrient Budget Takeaways

There is currently not enough data to calculate filtration values for the Andreoff Wetland Project. No land within the Project was previously used for agriculture, thus the Project does not prevent any phosphorus runoff. Soils throughout the Project have high capacity to sorb phosphate, as suggested by soil phosphate sorption capacity values.

Surface Water Hydrology and Nutrients

In Water Year (WY) 2024 there was one storm sampling event and one ambient sampling event. During the storm sampling event in April 2024 there was observed flow into the wetland and out of the wetland into the connecting roadside ditch (Figure 249). This is the only time that this was observed and was following a period of heavy rainfall. During this sampling event, dissolved oxygen readings spiked as a result of increased hydrologic activity in the pool. In prior years dissolved oxygen was 8.2 ± 0 mg/L (2022), 9.4 ± 1 mg/L (2023) and then spiked to 36.1 ± 46 mg/L in 2024. Time series data shows that turbidity was lowest in WY 2024 despite the storm event. In WY 2023 turbidity exceeded 300 FNU, while in WY 2024 it was approximately 100 FNU, even with the increased runoff from the April storm event. As expected, the dissolved reactive phosphorus (DRP) concentrations spiked in the main pool in April and total phosphorus decreased, indicating a higher concentration of DRP suspended in the water from precipitation runoff (Figure 250). The pool nutrient concentration returned to the more typical nutrient concentration of 0.038 mg phosphorus (P)/L dissolved reactive phosphorus and 0.309 mg P/L total phosphorus after the event.

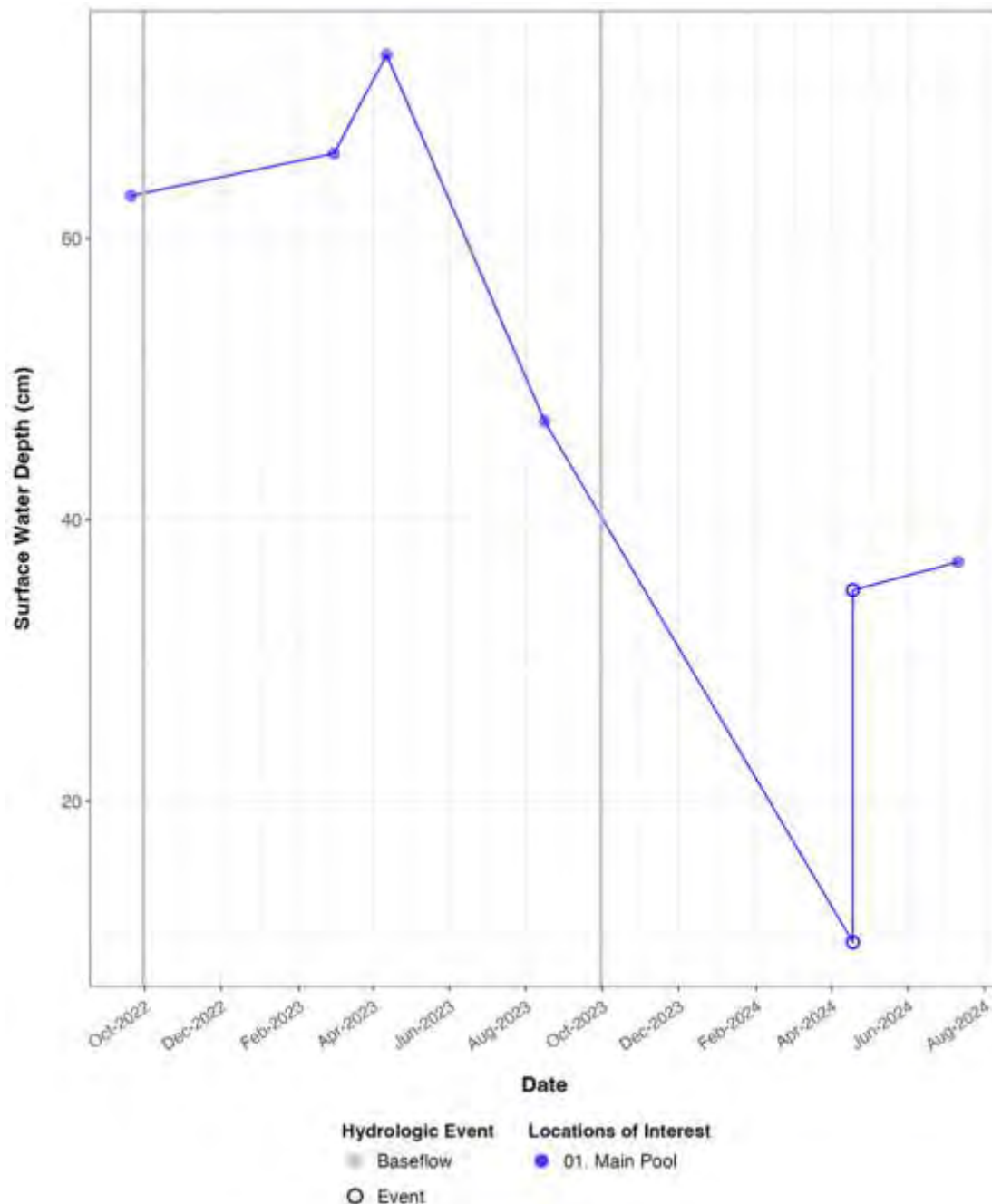


Figure 249. Time series of discrete, manually measured surface water depth at the Andreoff Wetland Restoration Project. Depths were measured approximately monthly. Each point represents one measurement and colors denote the locations of interest, as indicated in the legend. Open symbols indicate samples that were collected during a hydrologic event (e.g., storm event) and filled symbols denote samples collected during baseflow. Crosses (×) represent instances when no surface water was detected during the visit. If present, different shapes denote

the types of wetland features represented by the locations of interest. Gray vertical lines indicate the start of a water year (Oct 1–Sep 30).

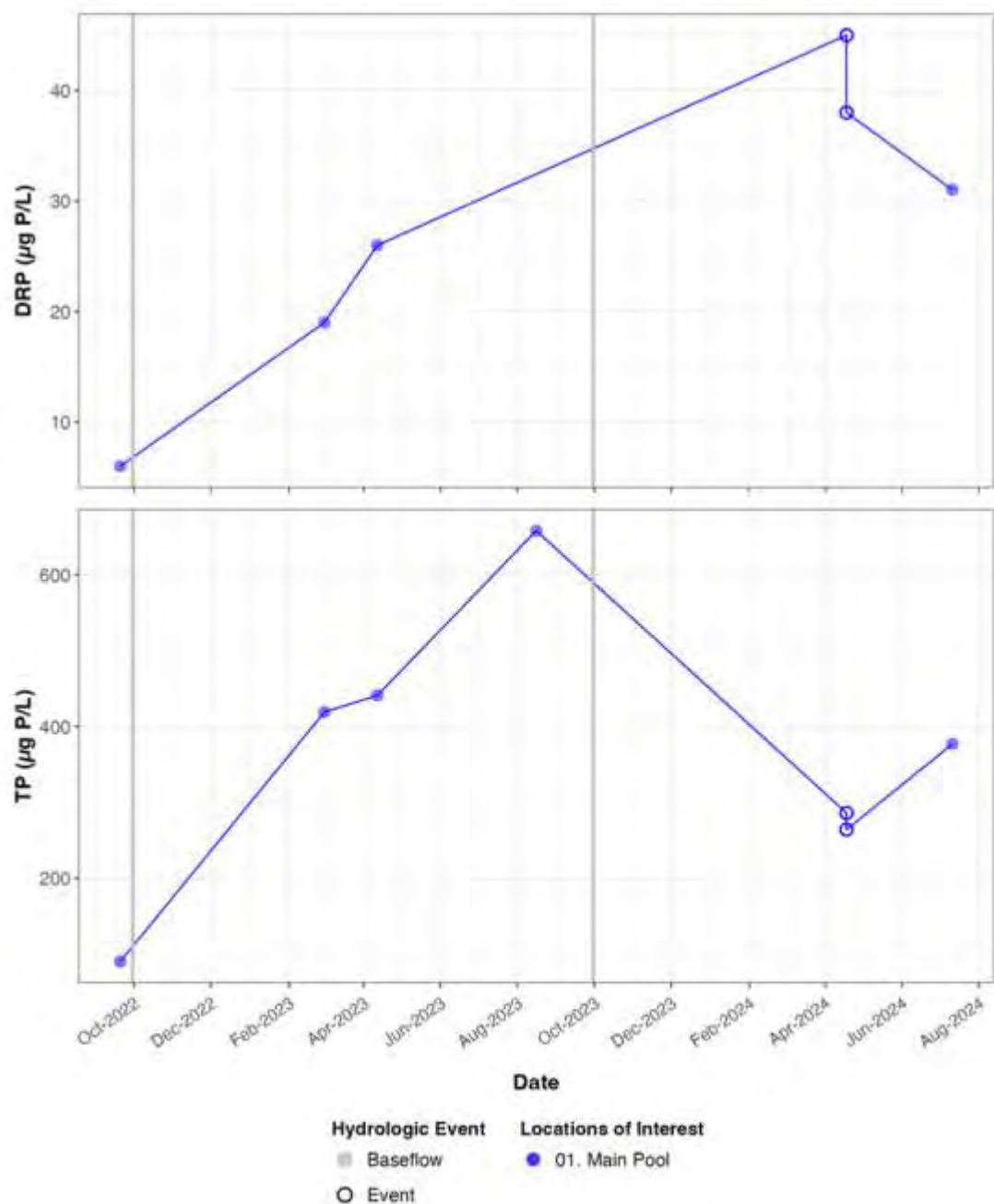


Figure 250. Time series of dissolved reactive phosphorus (DRP, top panel) and total phosphorus (TP, bottom panel) concentrations in surface water samples collected at the Andreoff Wetland

Restoration Project. Values below the detection limit of the analytical equipment were replaced with half the value of the detection limit. Each point represents one measurement, and colors denote the locations of interest, as indicated in the legend. Open symbols indicate that measurements were collected during a hydrologic event (e.g., storm event) and filled symbols denote measurements collected during baseflow. Crosses (×) represent instances when no surface water was detected during the visit. If present, different shapes denote the types of wetland features represented by the locations of interest. Gray vertical lines indicate the start of a water year (Oct 1–Sep 30).

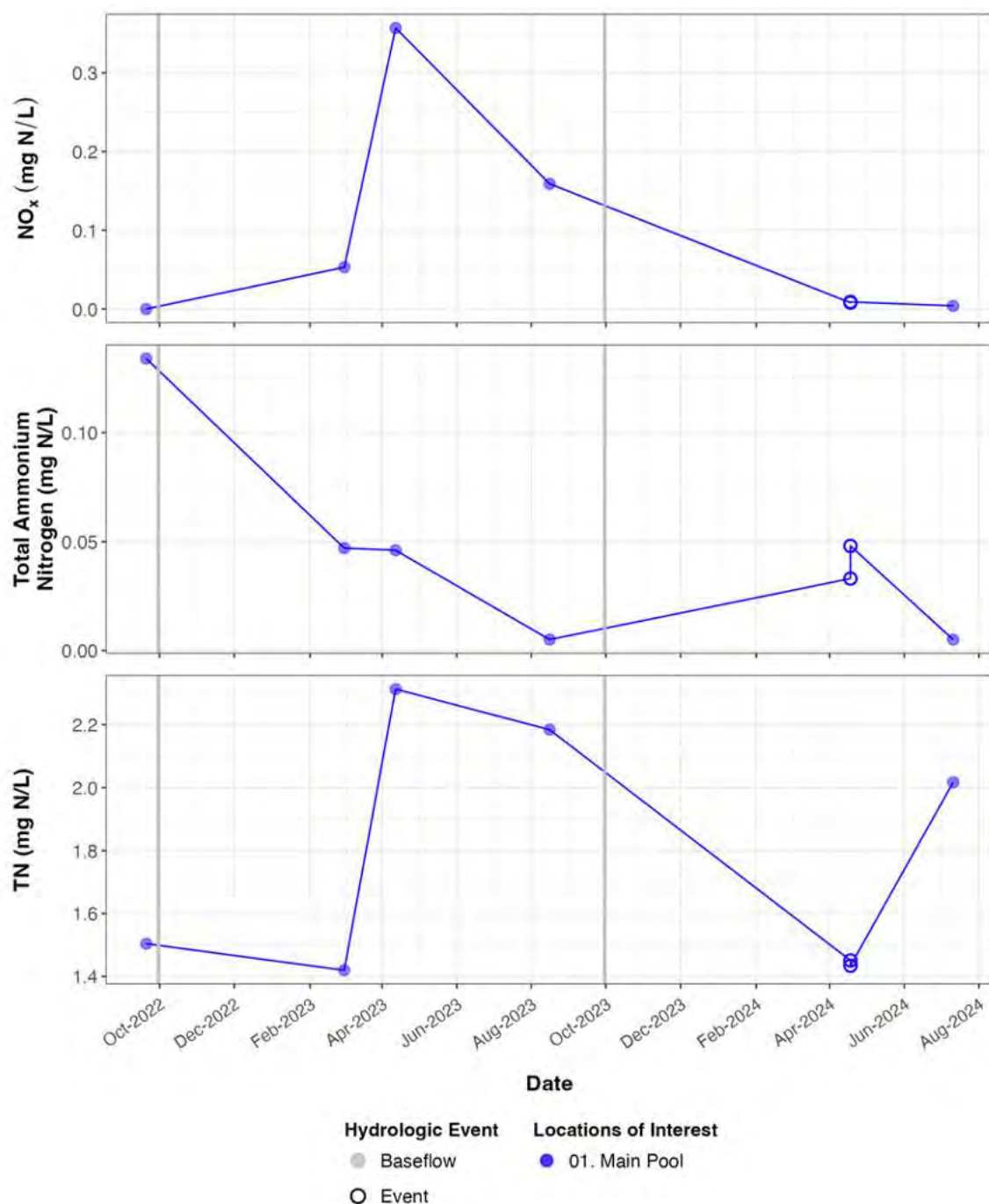


Figure 251. Time series of Nitrite+nitrate (NO_x, top panel) total ammonium nitrogen (NH₄-N, middle panel), and total nitrogen (TN, bottom panel) concentrations in surface water samples collected at the Andreoff Wetland Restoration Project. Values below the detection limit of the analytical equipment were replaced with half the value of the detection limit. Each point represents one measurement, and colors denote the locations of interest, as indicated in the legend. Open symbols indicate that measurements were collected during a hydrologic event (e.g.,

storm event) and filled symbols denote measurements collected during baseflow. Crosses (×) represent instances when no surface water was detected during the visit. If present, different shapes denote the types of wetland features represented by the locations of interest. Gray vertical lines indicate the start of a water year (Oct 1–Sep 30).

Soil Nutrient Status and Processes

Water Year 2024 was the first year of soil sampling at Andreoff Wetland Restoration. Six samples split between two transects were collected at the Project; one from the upland spoil mound and the other across the main pool from east to west. With an average soil phosphate sorption capacity value of 152 mg phosphorus/kg, results indicate that Andreoff Wetland has a high capacity to sorb phosphate (Figure 252). Additional years of soil sampling will be needed to determine if the Project will continue to be a sink or if it will approach its capacity for nutrient retention given its minimal inflow events and even lower outflow events.



Figure 252. Soil Phosphate Sorption Capacity (SPSC) throughout the Andreoff Wetland Restoration Project. Each point denotes a soil sample (0–5 cm) and different shapes indicate the wetland feature type, as shown in the legend. Colors indicate the SPSC value of each sample relative to the overall range of values observed at the wetland project, as shown in the color bar. Each panel shows the soil samples collected during a respective water year (Oct 1–Sep 30), along with the minimum and maximum SPSC values observed during a given water year. Negative SPSC values indicate the potential for soils to release phosphate, while positive values indicate soils have capacity to sorb phosphate, based on Mehlich-3 extractions of phosphate, iron, and aluminum.

Next Steps to Strengthen Understanding

In Water Year 2025, this Project will transition from a Non-Focal 1 designation (seasonal sampling) to Non-Focal 2 (annual sampling). Unless the main pool floods on a regular basis with inflows and outflows sufficient to justify returning the Project to Non-Focal 1, annual sampling will be performed following heavy precipitation events like the one last observed in April 2024 to determine if there is a nutrient load captured from the draining of the adjacent fields before the main pool outflows to the roadside ditch. Otherwise, Andreoff Wetland will remain at the Non-Focal 2 designation with annual water and soil sample collection.

Blanchard River Floodplain Restoration (BLAR)

Project Description

Putnam County | Blanchard River Watershed

Project size: 50 Acres

Partners: Maumee Watershed Conservancy District

The hydrology at this Project is passively managed. The Project has 27 acres of restored wetland, consisting of a floodplain channel and a series of isolated vernal pools between the floodplain channel and the river. During storm events the Blanchard River rises to flood its banks into the diversion channel before reconnecting with the Blanchard River downstream. During ambient conditions, the Blanchard River will backflow into the diversion channel from the lower portion of the channel. The isolated vernal pools only receive flood water during record flows and do not hold water for long. A hydrologic event at this Project is operationally defined as a storm event in which the Blanchard River floods its banks into the diversion channel.



Figure 253. Aerial image showing surface water flow and sampling locations for the Blanchard River Floodplain Restoration Project. Blue arrows indicate direction of surface water flow. Dots represent geographic base crew sampling locations, which are grouped by Project features (fill color) where relevant. Text annotations provide additional context about the Project's watershed connection or other important features.

Management Considerations

While the Blanchard River Floodplain Restoration Project (hereafter Blanchard Floodplain Project) successfully created a floodwater diversion channel to the Blanchard River, nutrient capture from Blanchard River inflow could still be improved. The Project was designed to allow the Blanchard River to overflow into the diversion channel once the river reaches a certain level, behaving as a flowthrough wetland. However, as the Project currently functions, the river rarely floods in excess of the approximately 3 m over baseflow that is needed for the river to enter the channel. Instead, most water from the Blanchard River enters through the outflow (River Lower). While these sufficiently high flow events are rare, researchers would not recommend lowering the inlet to capture flooding events at lower flows because the flow rate of flooding events entering the channel prevents settling and nutrient processing. Managing this Project as a floodplain wetland rather than a flowthrough could improve its potential to capture nutrients. Researchers suggest considering improvements to the lower portion of the channel that would facilitate retention and filtering of the backflow entering the outlet from the river year-round (i.e., a means of controlling flow entering/exiting at River Lower). The lower portion of the channel also does not have the same vegetation density as the rest of the channel, decreasing the opportunity for nutrient uptake through vegetation. While the channel depth is too deep to plant vegetation, planting vegetation along the banks would be more beneficial to nutrient uptake than the large rock that currently lines the banks.



Figure 254. Aerial image of approximate locations of interest for water and soil sampling and discrete manual measurements of water depth and physicochemical parameters at Blanchard River Floodplain Restoration Project during water year 2024 (Oct 1, 2023–Sep 30, 2024). The legend provides the name of each sampling point. Different shapes denote the types of wetland features represented by the locations of interest. If present, different colors represent locations of interest that belong to a group or complex of features (e.g., a treatment train).

Nutrient Budget Takeaways

There is currently not enough data to calculate filtration values for the Blanchard River Project. However, the conversion from agricultural land to wetland prevents 32 ± 22 lbs. of phosphorus runoff annually. Soils throughout the Project have moderate to high capacity to sorb phosphate, as suggested by soil phosphate sorption capacity values.

Surface Water Hydrology and Nutrients

The Blanchard River Floodplain Restoration Project (hereafter Blanchard Floodplain Project) was successful in creating a river diversion channel to redirect the Blanchard River during peaks of high flow to reduce flooding and create wetland pools capable of storing floodwater and filtering nutrients that would otherwise continue to flow downstream. The lower elevation of the channel's outlet compared to the inlet allows the Blanchard River to backflow into the channel even at baseflow conditions allowing for year-round storage and filtering. Researchers have found that the River Upper (inlet) and River Middle (mid channel) typically have similar manually measured water depths compared to the River Lower (outlet) location of interest (Figure 255). The River Lower location also has a much greater depth and variability than the other two locations as well. Across all figures for time series data for the Project, the River Upper and River Middle locations follow very similar trends for the three sampling events that were performed in Water Year (WY) 2024, with River Lower having slight differences as expected based on what researchers know of Project hydrology. In WY 2024 there was also a greater average dissolved reactive phosphorus (DRP, 0.057 mg P/L) and total phosphorus (TP, 0.357 mg P/L) concentrations at the River Lower location than the other two locations. Average trends for these nutrients have generally been decreasing over the course of the H2Ohio Wetland Monitoring Program (Figure 256). A higher outflow concentration than inflow concentration might be cause for concern at some flowthrough wetlands. However, due to the design of this Project the higher nutrient concentration at the River Lower location of interest can be attributed to backflow directly from the river that has not had the chance to settle or adsorb to the sediment. If a water sample was collected from the Blanchard River upstream from the project, it would likely have a similar concentration to what is seen in the River Lower location. In contrast to DRP and TP trends in average annual nitrite+nitrate and total ammonium nitrogen have been increasing steadily over the last three years of monitoring (Figure 257). This concentration could be increasing as the wetland develops or it could also be the result of the Ottawa Wastewater

Treatment facility outlet which is located upstream from the River Lower location which, combined with agricultural runoff, could contribute to the increasing nitrogen concentrations found across the Project but more specifically the River Lower location.

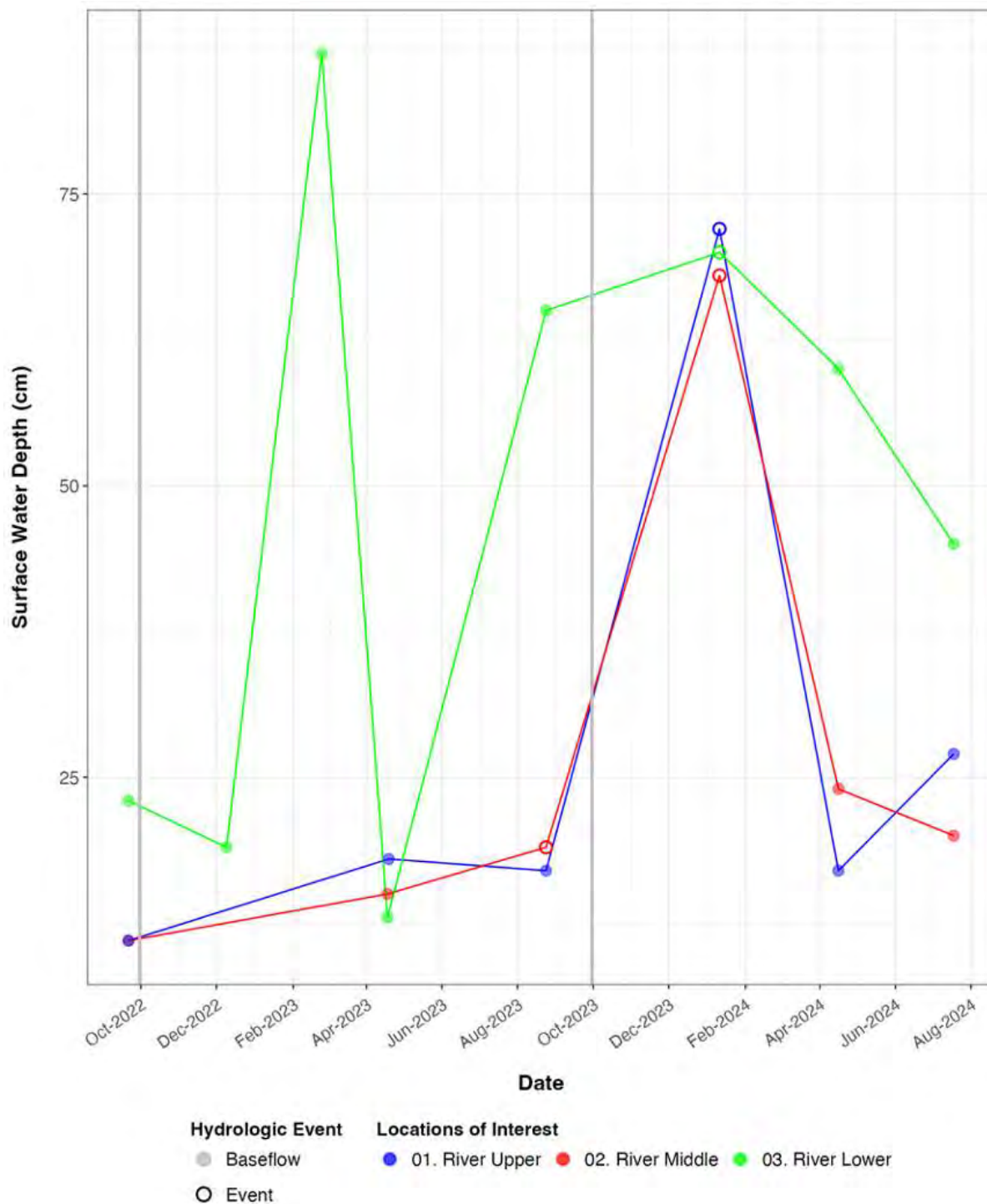


Figure 255. Time series of discrete, manually measured surface water depth at the Blanchard River Floodplain Restoration Project. Depths were measured approximately monthly. Each point represents one measurement and colors denote the locations of interest, as indicated in the legend. Open symbols indicate samples that were collected during a hydrologic event (e.g., storm event) and filled symbols denote samples collected during baseflow. Crosses (×) represent instances when no surface water was detected during the visit. If present, different shapes denote the types of wetland features represented by the locations of interest. Gray vertical lines indicate the start of a water year (Oct 1–Sep 30).

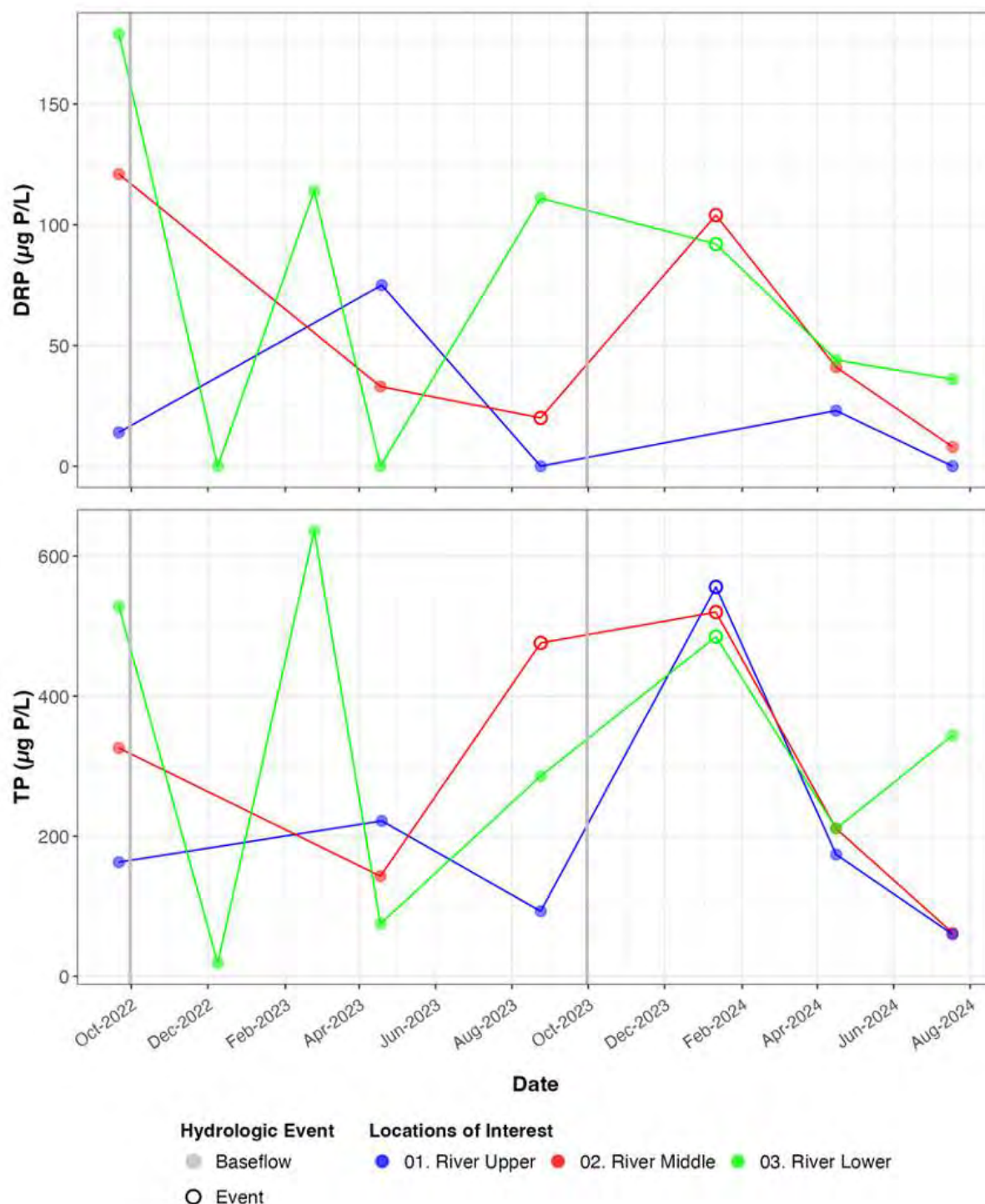


Figure 256. Time series of dissolved reactive phosphorus (DRP, top panel) and total phosphorus (TP, bottom panel) concentrations in surface water samples collected at the Blanchard River Floodplain Restoration Project. Values below the detection limit of the analytical equipment were replaced with half the value of the detection limit. Each point represents one measurement,

and colors denote the locations of interest, as indicated in the legend. Open symbols indicate that measurements were collected during a hydrologic event (e.g., storm event) and filled symbols denote measurements collected during baseflow. Crosses (×) represent instances when no surface water was detected during the visit. If present, different shapes denote the types of wetland features represented by the locations of interest. Gray vertical lines indicate the start of a water year (Oct 1–Sep 30).

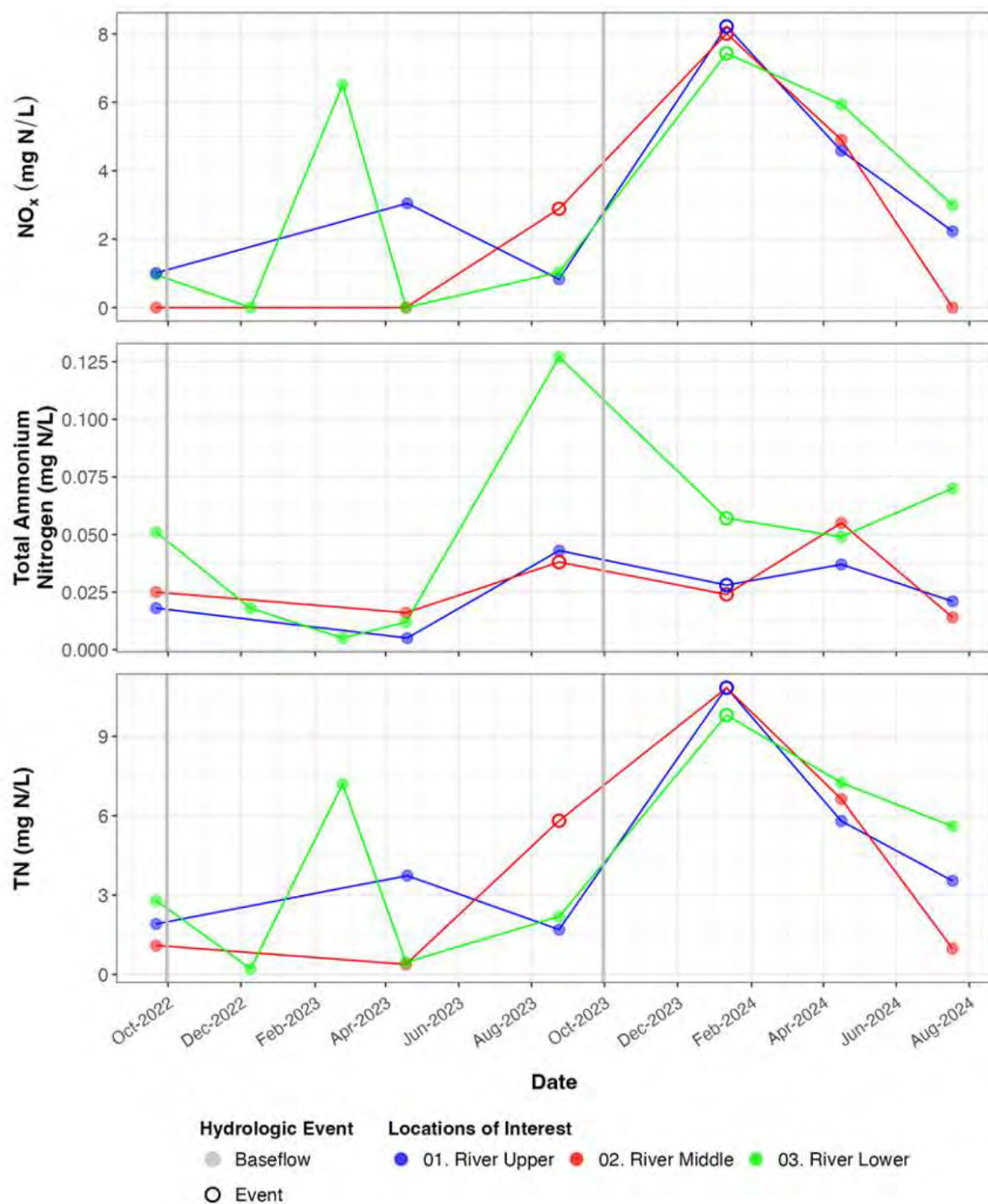


Figure 257. Time series of Nitrite+nitrate (NO_x, top panel) total ammonium nitrogen (NH₄-N, middle panel), and total nitrogen (TN, bottom panel) concentrations in surface water samples collected at the Blanchard River Floodplain Restoration Project. Values below the detection limit of the analytical equipment were replaced with half the value of the detection limit. Each point

represents one measurement, and colors denote the locations of interest, as indicated in the legend. Open symbols indicate that measurements were collected during a hydrologic event (e.g., storm event) and filled symbols denote measurements collected during baseflow. Crosses (×) represent instances when no surface water was detected during the visit. If present, different shapes denote the types of wetland features represented by the locations of interest. Gray vertical lines indicate the start of a water year (Oct 1–Sep 30).

Soil Nutrient Status and Processes

Soil phosphate sorption capacity (SPSC) in Water Year 2024 at Blanchard Floodplain Project ranged from 29.19 to 116.17 mg phosphorus/kg, with the River Middle location of interest having the highest available SPSC value (Figure 258). All locations of interest at the Project are currently positive, meaning that the soil should have the capacity to sorb nutrients. While this is the first year of soil chemistry data at the Blanchard Floodplain Project, the results are as researchers would expect based on what is known of water chemistry at the Project, with higher dissolved reactive phosphorus and total phosphorus values in water found at the River Lower location. Base crews have also noted that the River Middle location has a greater vegetation density than the others, allowing for more nutrients to be taken up by the plants from the soil, yielding higher SPSC. Also, much like what is shown in the water nutrient data, soil data shows high total nitrogen at the River Lower location compared to the other two locations.

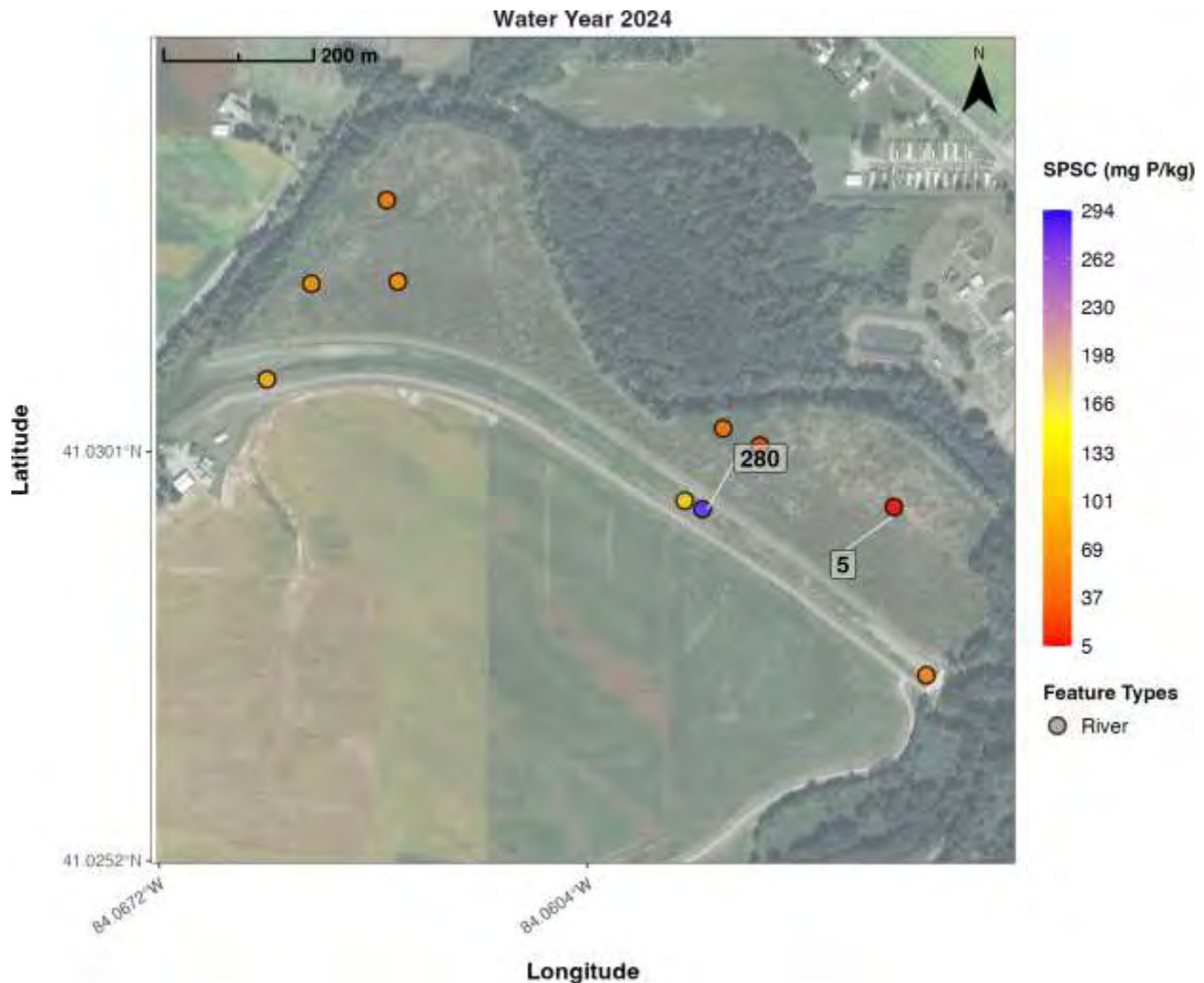


Figure 258. Soil Phosphate Sorption Capacity (SPSC) throughout the Blanchard River Floodplain Restoration Project. Each point denotes a soil sample (0–5 cm) and different shapes indicate the wetland feature type, as shown in the legend. Colors indicate the SPSC value of each sample relative to the overall range of values observed at the wetland project, as shown in the color bar. Each panel shows the soil samples collected during a respective water year (Oct 1–Sep 30), along with the minimum and maximum SPSC values observed during a given water year. Negative SPSC values indicate the potential for soils to release phosphate, while positive values indicate soils have capacity to sorb phosphate, based on Mehlich-3 extractions of phosphate, iron, and aluminum.

Next Steps to Strengthen Understanding

Researchers have found that river backflow into the channel occurs more often than overflow at the concrete inlet. Researchers have also observed that substantial amount of runoff enters the channel from the adjacent field. As a result, researchers will redefine an event from when there is flow at the inlet to also consider when there is inflow from the field tile, as well as backflow

from the river. A water level logger at the River Lower location of interest will help base crews to determine when water levels increase from base flow and use that level to compare to USGS staff gauges to determine when the river is back flowing into the river. River inflow is not the only Project inflow source, there is also a series of approx. 5–8 surface water and tile drainage outlets from the adjacent field that drain into the channel. These tile drains are more likely nutrient input sources than the diversion channel inlet itself considering that the river needs to rise approximately 3 m before it can enter the diversion channel as designed. Thus, more water sampling focus must be placed on these agricultural field inlets. The impact of the Ottawa Wastewater Treatment Facility outlet is located upstream from the River Lower location which, combined with agricultural runoff, could contribute to elevated nutrient levels in the River Lower Location.

Bright Conservation Area Wetland Restoration Initiative (BRIC)

Project Description

Hancock County | Blanchard River Watershed

Project size: 10.5 Acres

Partners: Hancock Park District

The hydrology at this Project is passively managed, with the outflow having two Agri Drain water level control structures that discharge to the Blanchard River from pools 1 and 2. The Project has 8.5 acres of restored wetland, consisting of four wetland pools. Pools 1 and 2 receive tile inflow from up gradient agricultural fields, while pools 3 and 4 receive surface runoff from an agricultural field on the southern border of the Project. Pool 4 overflows into pool 3, which overflows into Pool 2. During high flows of > 1000 cubic feet per second (cfs) the adjacent Blanchard River floods the wetland. A hydrologic event at this Project is operationally defined as a storm event in which the flow of Blanchard River is > 1000 cfs and floods the wetland.

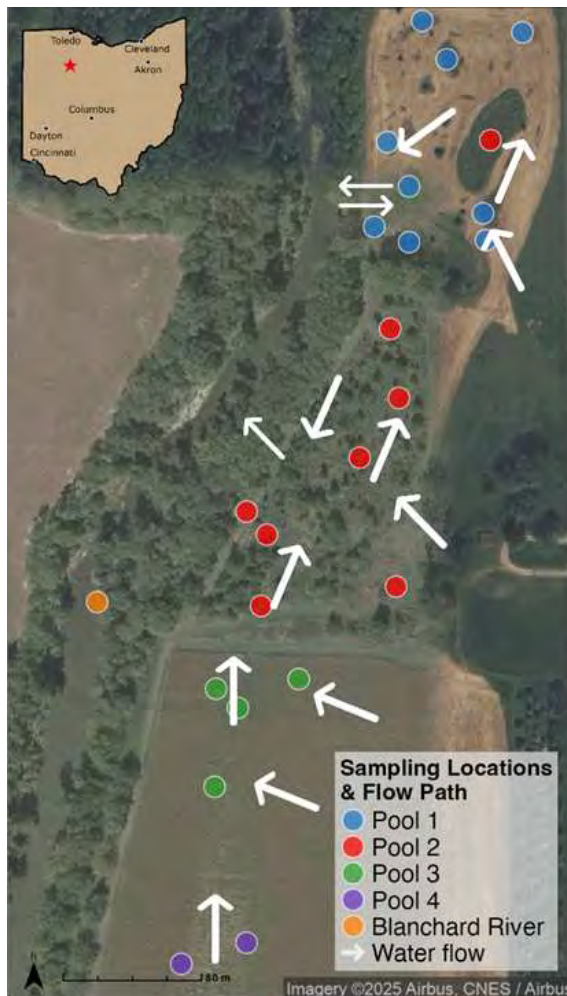


Figure 259. Aerial image showing surface water flow and sampling locations for the Bright Conservation Area Wetland Restoration Initiative Project. Blue arrows indicate direction of surface water flow. Dots represent geographic base crew sampling locations, which are grouped by Project features (fill color) where relevant. Text annotations provide additional context about the Project's watershed connection or other important features.

Management Considerations

The Bright Conservation Area Wetland Restoration Initiative Project (hereafter Bright Wetland Project) was successful in restoring agricultural land into 10.5 acres of semi-connected wetland pools to retain, capture, and store nutrients from runoff before outflowing into the Blanchard River with only minor design setbacks. During a high flow event in April 2024, base crews identified two locations where the outflows were not functioning as designed. The water control feature in Pool 1 (WCF 1) allows backflow from the Blanchard River into the pool during high flow events. Increasing the level of the stoplogs would prevent backflow into Pool 1 while increasing connectivity between Pool 1 and Existing Wetland 1 allowing nutrient filtration opportunity. Raising the stoplogs would also eliminate the possibility of WCF 1 acting as an inflow during high flow events, helping to solidify researchers' understanding of Project hydrology while ensuring the Project captures water as intended. The other design issue noted in Water Year 2024 is that a low section of the walking path berm that surrounds Pool 2 has been allowing surface water to bypass the Pool 2 water control feature (WCF 2) and flow to the Blanchard River. Increasing the height of the low section of Pool 2 berm would allow water to flow through the water control feature as designed, increasing residence time within the pool. ODNR engineers are aware of the low berm issue in Pool 2 and are making alteration plans to increase berm height.

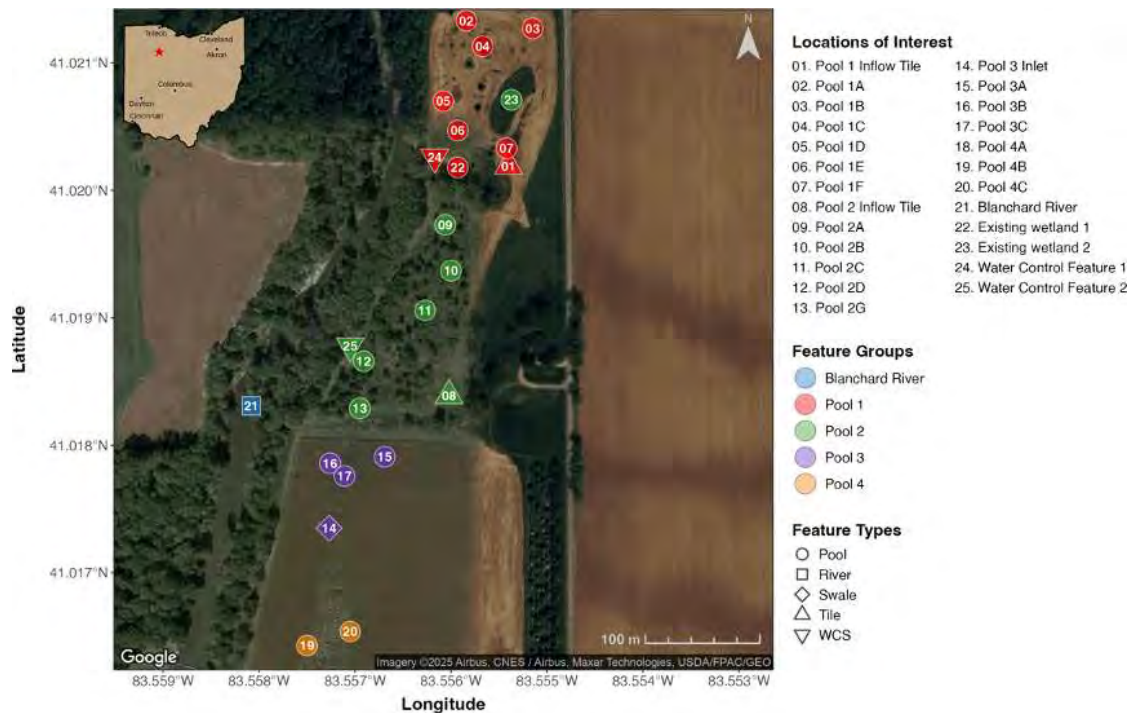


Figure 260. Aerial image of approximate locations of interest for water and soil sampling and discrete manual measurements of water depth and physicochemical parameters at Bright Conservation Area Wetland Restoration Initiative Project during water year 2024 (Oct 1, 2023–Sep 30, 2024). The legend provides the name of each sampling point. Different shapes denote the types of wetland features represented by the locations of interest. If present, different colors represent locations of interest that belong to a group or complex of features (e.g., a treatment train).

Nutrient Budget Takeaways

There is currently not enough data to calculate filtration values for Bright Wetland Project. No land within the Project was previously used for agriculture, thus the Project does not prevent any phosphorus runoff. Soils throughout the Project have moderate to high capacity to sorb phosphate, as suggested by soil phosphate sorption capacity values.

Surface Water Hydrology and Nutrients

Bright Wetland is composed of four main pools: Pools 1 and 2 receive water from subsurface inflow tiles from upland agricultural fields as well as runoff and outflow to the Blanchard River via water level control structures. Both pools are designed in a “horseshoe” shape to direct water from the inflow around an island (Pool 1) or walking path “peninsula” (Pool 2) to the outflow to increase pool settling times. Pool 4 receives agricultural runoff from the southern boarding field which drains into Pool 3 and Pool 2 at high volume flow. Researchers also believe that during extreme high flow events the Blanchard River floods its banks and causes complete connectivity

between all four pools, although the exact flow condition and inflow point are not yet known. Driftwood and debris piles caught in the tree line separating Pool 2 from Existing Wetland 2 indicate the river breaches its banks somewhere in the southern portion of the Project. To better understand how the Project retains water, water level loggers have been installed in summer of 2024 in Pool 1 and 2 inflows and Pool 3. During dry periods, pools tend to dry out in the order of Pool 2, 1, 3, and then 4. As expected, Pool 4A and 4B have the greatest average pool depth of 17 cm (Pool 4A) and 24 cm (Pool 4B).

During Water Year 2024 there was a total of nine water sampling events with one storm sampling event captured on April 2 (Figure 261). Physiochemical measurements and water chemistry at Bright Wetland follow trends as expected. At all locations of interest physiochemical measurements follow similar trendlines with specific emphasis on turbidity, indicating the Project's likelihood to be uniformly impacted by drought and storm events. During the June sampling event, Pool 2 Inflow showed higher pH and dissolved oxygen at a larger degree than other samples taken during that monitoring event. The average pH for the Project as a whole was 7.6, with Pool 1D having the greatest average pH of 7.9. Dissolved reactive phosphorus (DRP) and total phosphorus (TP) trends are similar across the Project with spikes following storm events (April 2024, Figure 262). The only exception to this is the larger DRP spike in the Pool 1 Inflow of over 0.2 mg/L. Next to Pool 1 Inflow, the second highest concentration was 0.1 mg/L at Pool 1B. After the April storm event, TP and DRP concentrations began to decrease with one final TP spike in Pool 4 before the pools dried out in late summer. If more pools could have been sampled before drying out, similar spikes might have been observed by researchers. Pool 1 Inflow had the highest average DRP concentration of 0.074 mg/L with the outflow concentration at Water Control Feature 1 being 0.1 mg/L. Since there was only one sampling event in which Pool 1 had outflow, and this coincided with the river backflow into the wetland, it is difficult to determine whether the 0.1 mg/L phosphorus concentration represents phosphorus entering the wetland from the river, leaving the wetland into the river, or a combination of both. Location of interest Pool 1D could give a better indication of nutrient concentrations leaving Pool 1 rather than the outflow itself due to its current set level. As noted in the management considerations section, data from the June sampling event showed increases in select parameters in the time series data comparable to storm events. This data is not the result of a major storm or flooding event but rather increasing pool concentrations as the water in the pools dries out.

Pool 1 Inflow and Pool 2 Inflow are locations of interest that are sampled even when there is no flow. As a result, there are sampling baseflow events in mid-June showing elevated results for pH, conductivity, and total phosphorus that were not the direct result of a storm or flooding event, but rather pool drying from drought conditions. Also of note, the Bowling Green State University base crew performed sampling of Bright Wetland in 2023 before transferring the Project to Heidelberg University base crew in 2024.

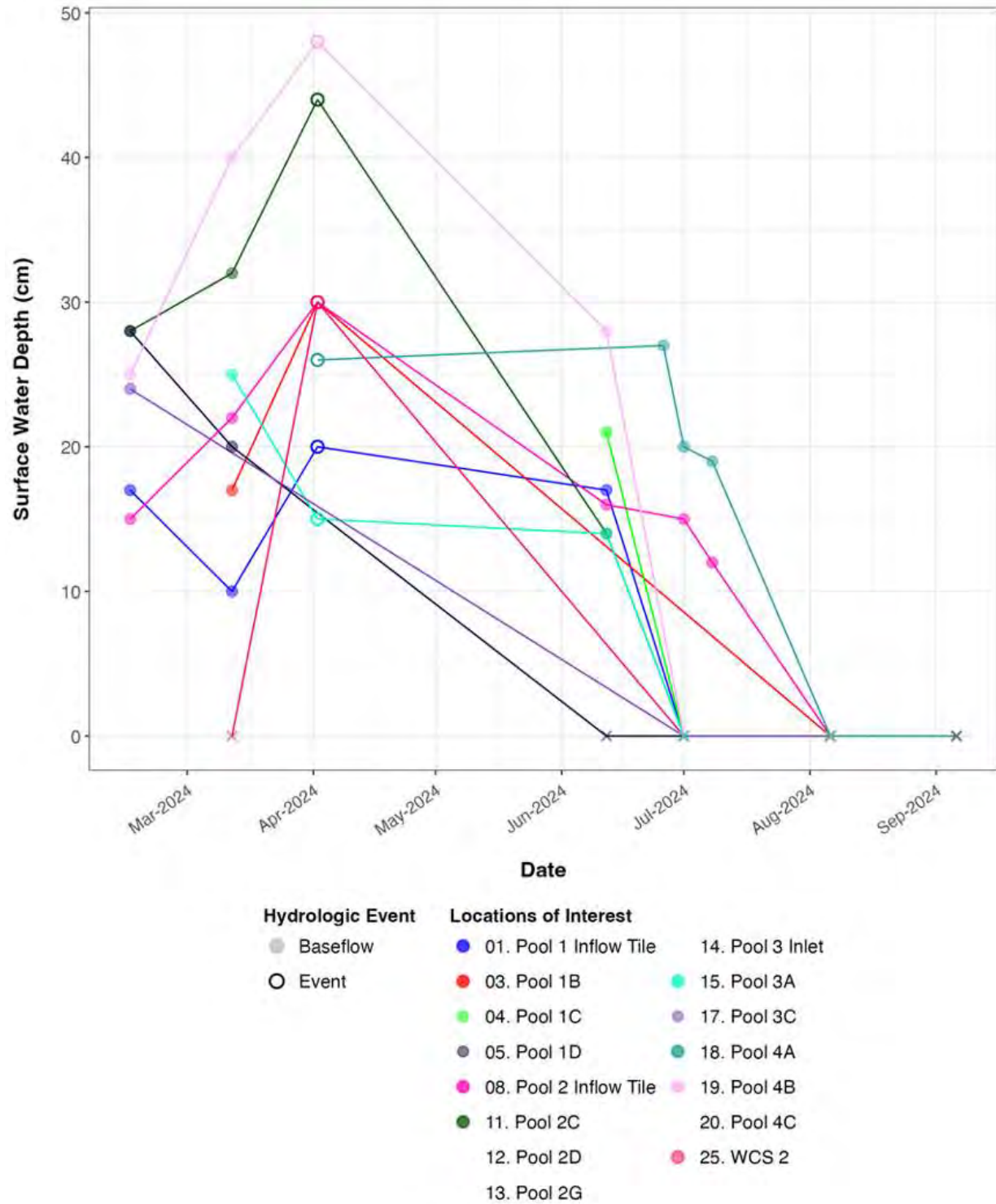


Figure 261. Time series of discrete, manually measured surface water depth at the Bright Conservation Area Wetland Restoration Initiative Project. Depths were measured approximately

monthly. Each point represents one measurement and colors denote the locations of interest, as indicated in the legend. Open symbols indicate samples that were collected during a hydrologic event (e.g., storm event) and filled symbols denote samples collected during baseflow. Crosses (×) represent instances when no surface water was detected during the visit. If present, different shapes denote the types of wetland features represented by the locations of interest. Gray vertical lines indicate the start of a water year (Oct 1–Sep 30).

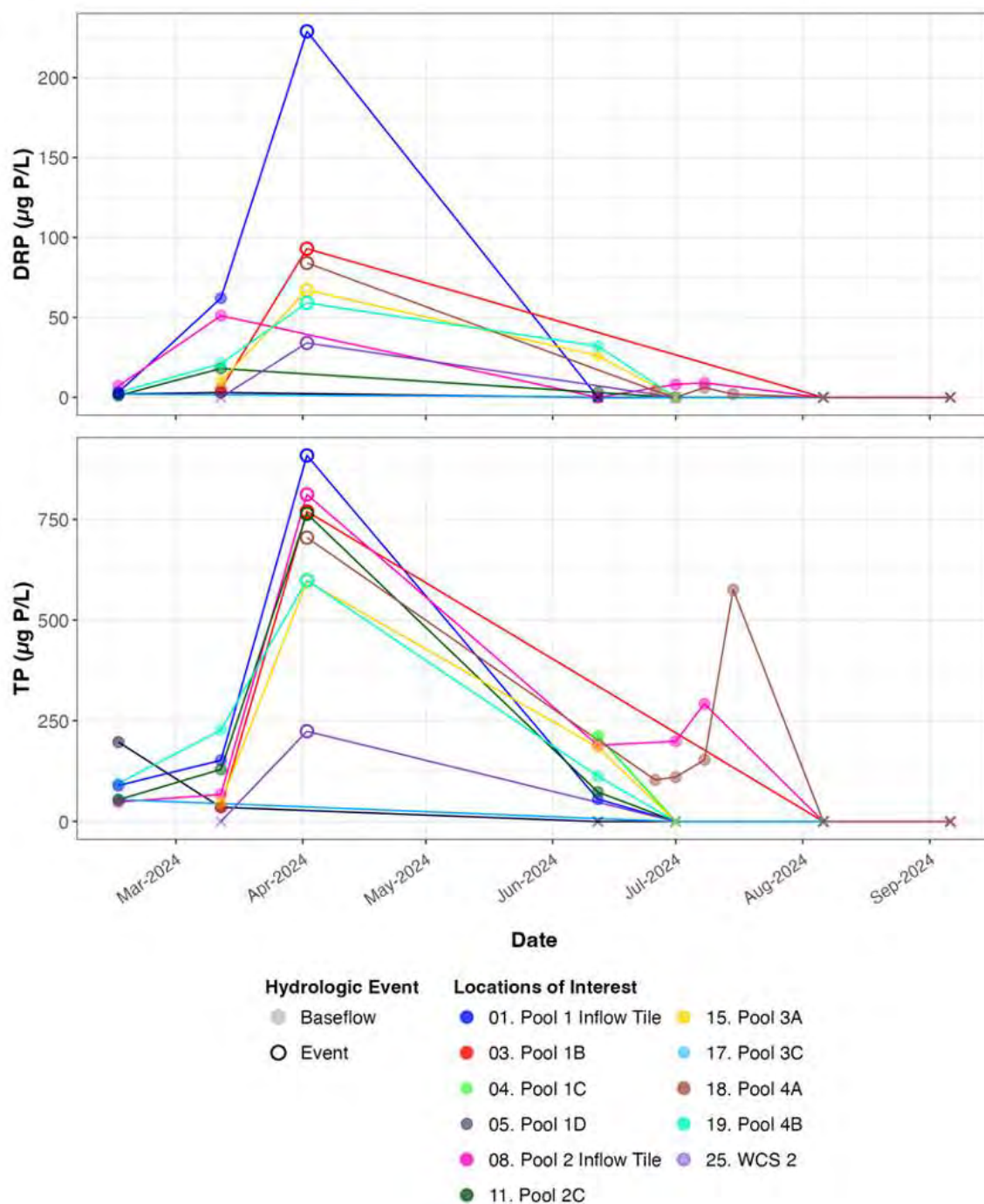


Figure 262. Time series of dissolved reactive phosphorus (DRP, top panel) and total phosphorus (TP, bottom panel) concentrations in surface water samples collected at the Bright Conservation Area Wetland Restoration Initiative Project. Values below the detection limit of the analytical equipment were replaced with half the value of the detection limit. Each point represents one measurement, and colors denote the locations of interest, as indicated in the legend. Open symbols indicate that measurements were collected during a hydrologic event (e.g., storm event) and filled symbols denote measurements collected during baseflow. Crosses (×) represent instances when no surface water was detected during the visit. If present, different shapes denote the types of wetland features represented by the locations of interest. Gray vertical lines indicate the start of a water year (Oct 1–Sep 30).

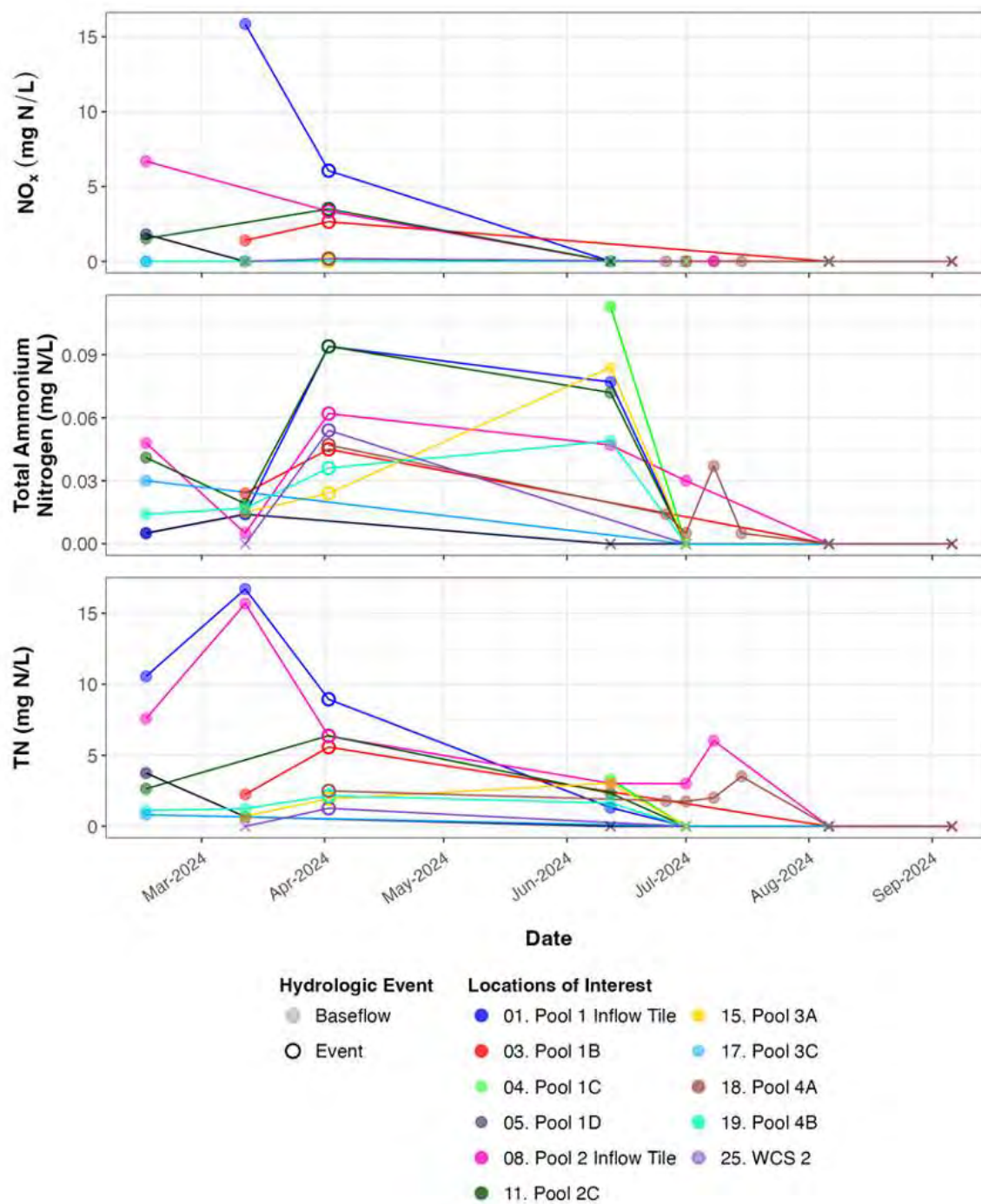


Figure 263. Time series of Nitrite+nitrate (NO_x, top panel) total ammonium nitrogen (NH₄-N, middle panel), and total nitrogen (TN, bottom panel) concentrations in surface water samples collected at the Bright Conservation Area Wetland Restoration Initiative Project. Values below the detection limit of the analytical equipment were replaced with half the value of the detection limit. Each point represents one measurement, and colors denote the locations of interest, as

indicated in the legend. Open symbols indicate that measurements were collected during a hydrologic event (e.g., storm event) and filled symbols denote measurements collected during baseflow. Crosses (×) represent instances when no surface water was detected during the visit. If present, different shapes denote the types of wetland features represented by the locations of interest. Gray vertical lines indicate the start of a water year (Oct 1–Sep 30).

Soil Nutrient Status and Processes

Soil phosphate sorption capacity (SPSC) values in Water Year 2024 at Bright Wetland ranged from 97.3 to 176.9 mg phosphorus/L, with Pool 4 having the highest available SPSC value (Figure 264). All locations of interest at Bright Conservation Wetland are currently positive, meaning that the soil should have the capacity to sorb phosphate. All SPSC values across the Project have increased from 2022, indicating a higher capacity to sorb phosphate as the wetland develops post-construction. Surprisingly, Pool 2 appears to have the greatest SPSC values. In a wetland with established vegetation, this could be indicative of a release. However, in the case of Bright Wetland it is more likely that the lower SPSC values found in 2022 data were the result of underdeveloped vegetation and underperforming soils. Pool sedimentation and vegetation uptake can also be an explanation for the shift in soil capacity.

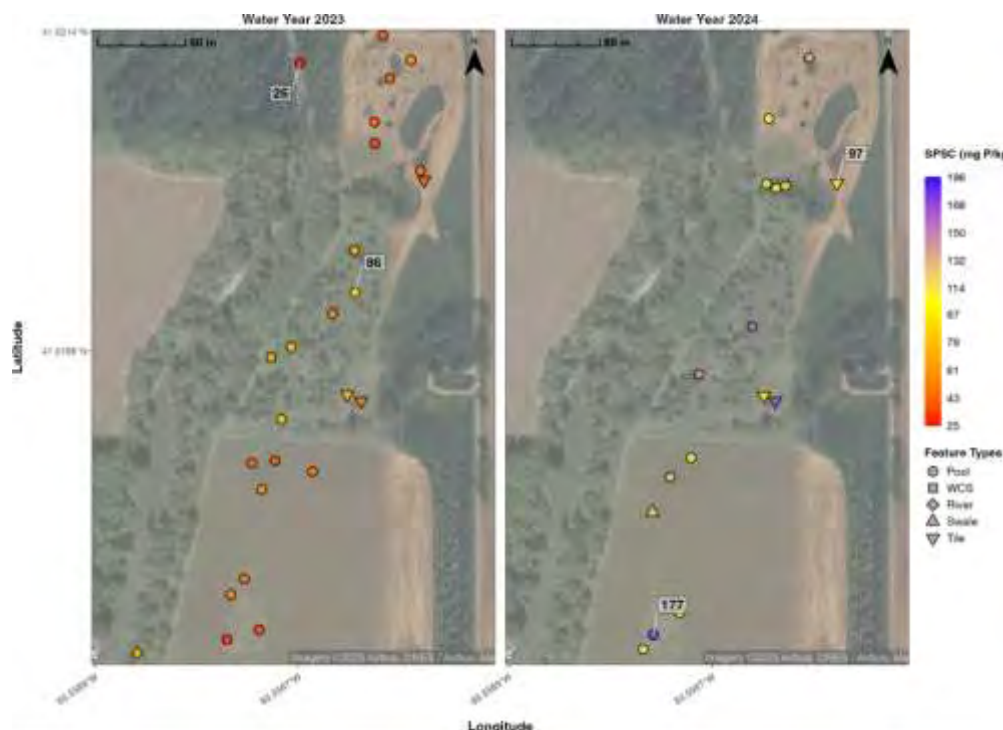


Figure 264. Soil Phosphate Sorption Capacity (SPSC) throughout the Bright Conservation Area Wetland Restoration Initiative Project. Each point denotes a soil sample (0–5 cm) and different shapes indicate the wetland feature type, as shown in the legend. Colors indicate the SPSC value

of each sample relative to the overall range of values observed at the wetland project, as shown in the color bar. Each panel shows the soil samples collected during a respective water year (Oct 1–Sep 30), along with the minimum and maximum SPSC values observed during a given water year. Negative SPSC values indicate the potential for soils to release phosphate, while positive values indicate soils have capacity to sorb phosphate, based on Mehlich-3 extractions of phosphate, iron, and aluminum.

Next Steps to Strengthen Understanding

In Water Year 2025, Bright Wetland will remain a Non-Focal 1 wetland, and monthly sampling will continue to better understand Project hydrology. Special focus will be placed on how water enters the Project, whether that be through inflow tiles or flooding. USGS staff gauges and precipitation gauges will be used to make determinations of what levels cause flow into to the site. Additional storm event monitoring will also be performed. All the prior listed information will help researchers better understand functionality of the Project as well as determine the Project exhibits traits, making it eligible for a Focal Project designation.

Buehler Farms Treatment Wetland (BUEF)

Project Description

Sandusky County | Sandusky River Watershed

Project size: 45 Acres

Partners: Ottawa Soil and Water Conservation District

The hydrology at this Project is actively managed. The Project has 40 acres of restored wetland, consisting of a coastal diked wetland pool that receives water from a ditch adjacent to the pool through a control structure. The ditch appears to be a mix of tile drain runoff from adjacent agricultural fields and is connected to Little Muddy Creek through culverts under the road. There are two water level control structures at this Project, one is near the intake pump and the other connects to Little Muddy Creek. A hydrologic event at this Project is operationally defined as an event when water is let into or out of the Project through a water level control structure.



Figure 265. Aerial image showing surface water flow and sampling locations for the Buehler Farms Treatment Wetland Project. Blue arrows indicate direction of surface water flow. Dots

represent geographic base crew sampling locations, which are grouped by Project features (fill color) where relevant. Text annotations provide additional context about the Project's watershed connection or other important features.

Management Considerations

No management considerations at this time.



Figure 266. Aerial image of approximate locations of interest for water and soil sampling and discrete manual measurements of water depth and physicochemical parameters at Buehler Farms Treatment Wetland Project during water year 2024 (Oct 1, 2023–Sep 30, 2024). The legend provides the name of each sampling point. Different shapes denote the types of wetland features represented by the locations of interest. If present, different colors represent locations of interest that belong to a group or complex of features (e.g., a treatment train).

Nutrient Budget Takeaways

There is currently not enough data to calculate filtration values for Buehler Farms Project. No land within the Project was previously used for agriculture, thus the Project does not prevent any

phosphorus runoff. Soils throughout the Project have high capacity to sorb phosphate, as suggested by soil phosphate sorption capacity values.

Soil Nutrient Status and Processes

Soil phosphate sorption capacity (SPSC) values indicate that the Buehler Farms Treatment Wetland Project has a high capacity to sorb phosphate. All SPSC values within the main area of the wetland (excluding the inflow pump) have values over 100 mg/kg (Figure 267).



Figure 267. Soil Phosphate Sorption Capacity (SPSC) throughout the Buehler Farms Treatment Wetland Project. Each point denotes a soil sample (0–5 cm) and different shapes indicate the wetland feature type, as shown in the legend. Colors indicate the SPSC value of each sample relative to the overall range of values observed at the wetland project, as shown in the color bar. Each panel shows the soil samples collected during a respective water year (Oct 1–Sep 30), along with the minimum and maximum SPSC values observed during a given water year. Negative SPSC values indicate the potential for soils to release phosphate, while positive values indicate soils have capacity to sorb phosphate, based on Mehlich-3 extractions of phosphate, iron, and aluminum.

Next Steps to Strengthen Understanding

The H2Ohio Wetland Monitoring Program does not plan to collect data at Buehler Farms Treatment Wetland Project in Water Year 2025. Despite requesting the property owner to notify the researchers when pumping events are delivering water from the ditch into the wetland, it is unknown if the Project is actively pumped or managed. If the Project is not pumping from the

inflow ditch there is a missed opportunity to capture nutrients before flowing into Muddy Creek and Sandusky Bay.

Clary-Boulee-McDonald (CBMC)

Project Description

Seneca County | Sandusky River Watershed

Project size: 162 Acres

Partners: Black Swamp Conservancy District and Seneca County Park District

The hydrology at this Project is passively managed. The Project has a total of 45 acres restored wetland and is bisected by Wolf Creek, a segment of the Sandusky River. The northern portion of the Project consists of a wetland pool, swale, and wet meadow. During high flow, Wolf Creek floods its banks into the swale and Pool 3. The southern portion of the wetland consists of wet meadows and two wetland pools. During high flow, Wolf Creek also floods its banks and flows into the pools via cut banks. During dry periods, Pool 1 rarely holds water while Pool 2 holds water year-round. All three pools additionally receive surface runoff from the surrounding wet meadows. A hydrologic event at this Project is operationally defined as a storm event in which Wolf Creek floods its banks and delivers water to the wetland pools.

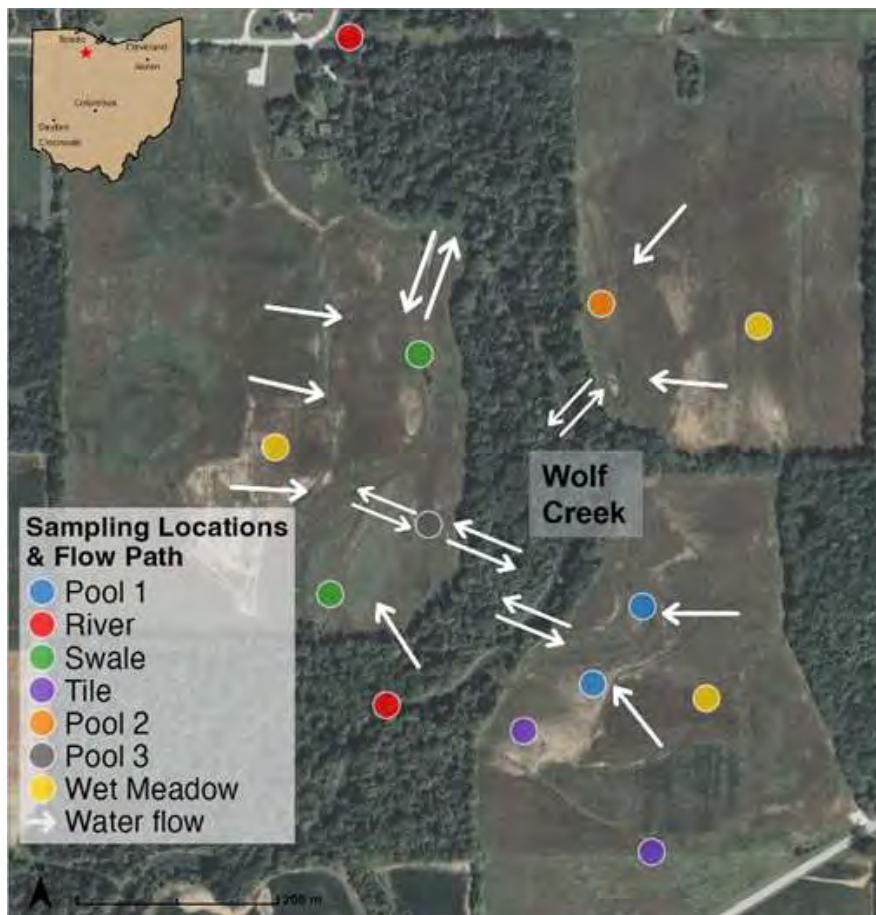


Figure 268. Aerial image showing surface water flow and sampling locations for the Clary-Boulee-McDonald Nature Preserve Project. Blue arrows indicate direction of surface water flow. Dots represent geographic base crew sampling locations, which are grouped by Project features (fill color) where relevant. Text annotations provide additional context about the Project's watershed connection or other important features.

Management Considerations

In Water Year (WY) 2024, there were limited times when water from Wolf Creek entered Clary-Boulee-McDonald (hereafter Wolf Creek Wetland), due to drought conditions. Only one storm sampling event occurred for this Project and three baseflow sampling events in WY 2024. During one of the baseflow samplings all of the pools were completely dry. Evidence of flood water from Wolf Creek has been observed entering the Swale, Pool 3 and Pool 2 but real time flooding has never been observed by Base Crews. Pool 1 is designed to capture larger storm events from Wolf Creek but primarily receives surface water from the surrounding wet meadow. Lowering the berms between Wolf Creek and Pool 1 could increase the water connectivity between these two features during smaller storm events throughout the year. Increasing connectivity between Wolf Creek and Pool 1 could help to increase the nutrient filtration potential of Pool 1.

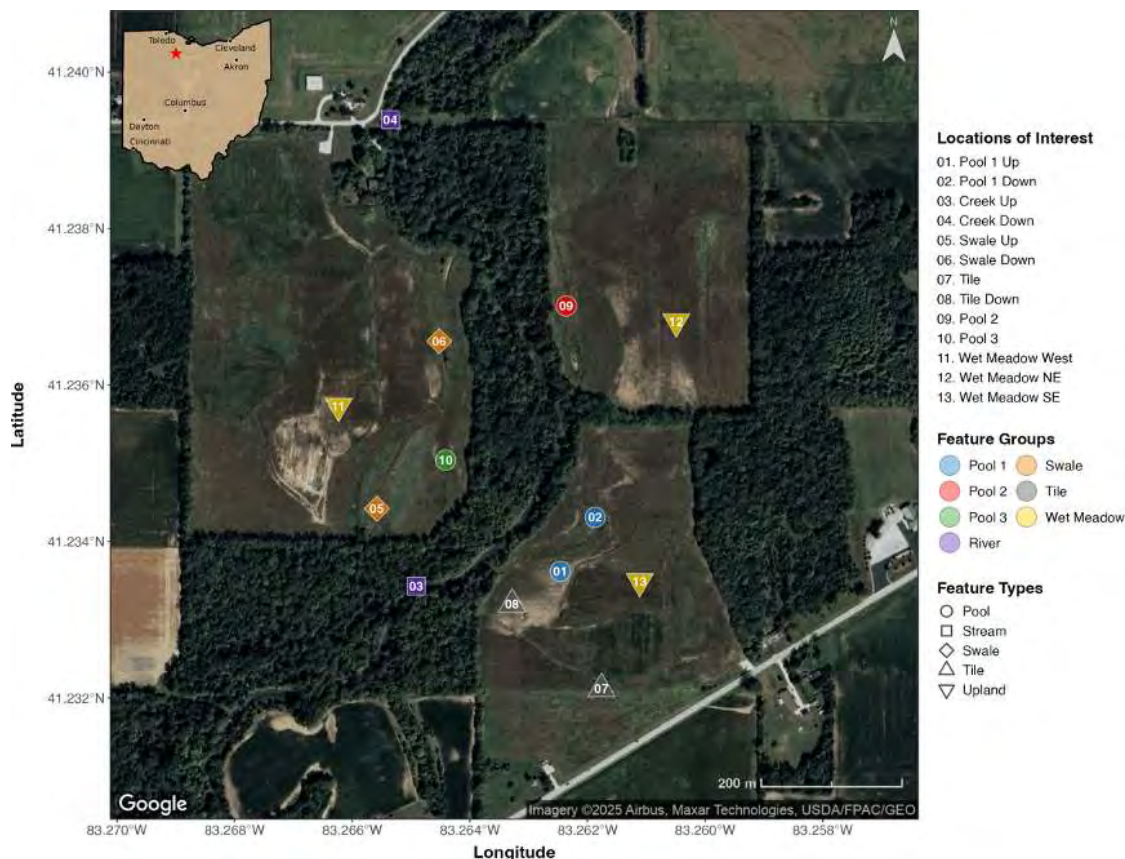


Figure 269. Aerial image of approximate locations of interest for water and soil sampling and discrete manual measurements of water depth and physicochemical parameters at Clary-Boulee-McDonald Nature Preserve Project during water year 2024 (Oct 1, 2023–Sep 30, 2024). The legend provides the name of each sampling point. Different shapes denote the types of wetland features represented by the locations of interest. If present, different colors represent locations of interest that belong to a group or complex of features (e.g., a treatment train).

Nutrient Budget Takeaways

There is currently not enough data to calculate filtration values for the Clary-Boulee-McDonald Project. However, the conversion from agricultural land to wetland prevents 103 ± 70 lbs. of phosphorus runoff annually. Soils throughout the Project have moderate to high capacity to sorb phosphate, as suggested by soil phosphate sorption capacity values.

Surface Water Hydrology and Nutrients

Due to drought conditions in Water Year (WY) 2024 there was a limited number of samples collected for the Project (Figure 270). The highest concentrations of dissolved reactive phosphorus (DRP), total phosphorus, total nitrogen, total ammonium nitrogen, and nitrate+nitrite occurred at the Tile Down location during a storm event in January (Figure 271, Figure 272). This tile collects water from farmland to the south and then takes this water directly to Wolf Creek. Due to this, these higher concentrations of nutrients are not likely to get processed by the Project wetlands until entering Pool 2 further downstream, if not bypassing the Project altogether. There appears to be some temporal relationships between and within pools, but with the low water conditions and limited sampling in WY 2024 it is difficult to predict trends in the water quality data. In general, DRP values were low throughout the Project area during ambient conditions and elevated during the one storm sampling in January of 2024. Increased sampling frequency in 2025 will improve the H2Ohio Wetland Monitoring Program's ability to assess trends in water quality for the Project.

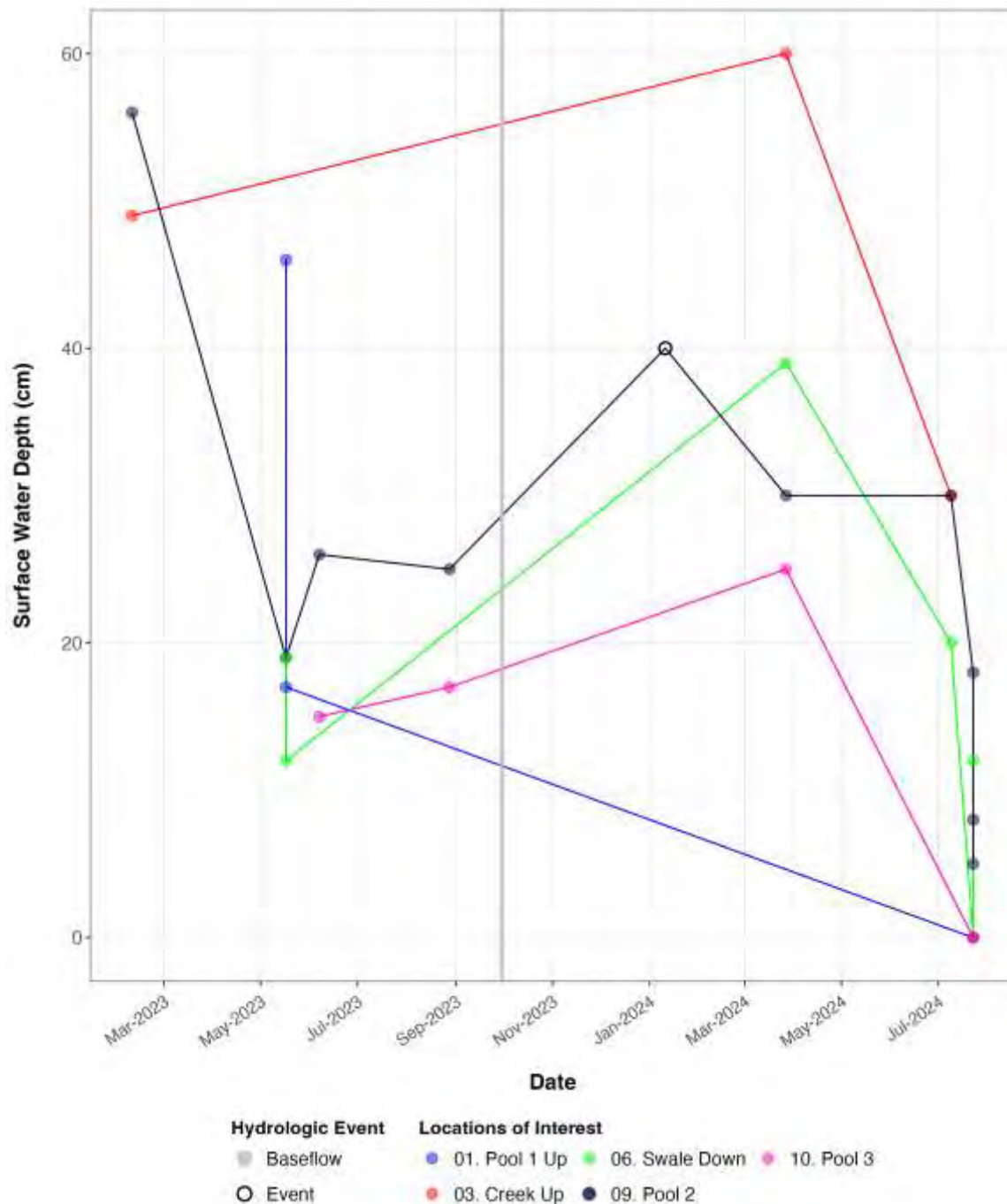


Figure 270. Time series of discrete, manually-measured surface water depth at the Clary-Boulee-McDonald Nature Preserve Project. Depths were measured approximately monthly. Each point represents one measurement and colors denote the locations of interest, as indicated in the legend. Open symbols indicate samples that were collected during a hydrologic event (e.g., storm event) and filled symbols denote samples collected during baseflow. Crosses (×) represent instances when no surface water was detected during the visit. If present, different shapes denote

the types of wetland features represented by the locations of interest. Gray vertical lines indicate the start of a water year (Oct 1–Sep 30).

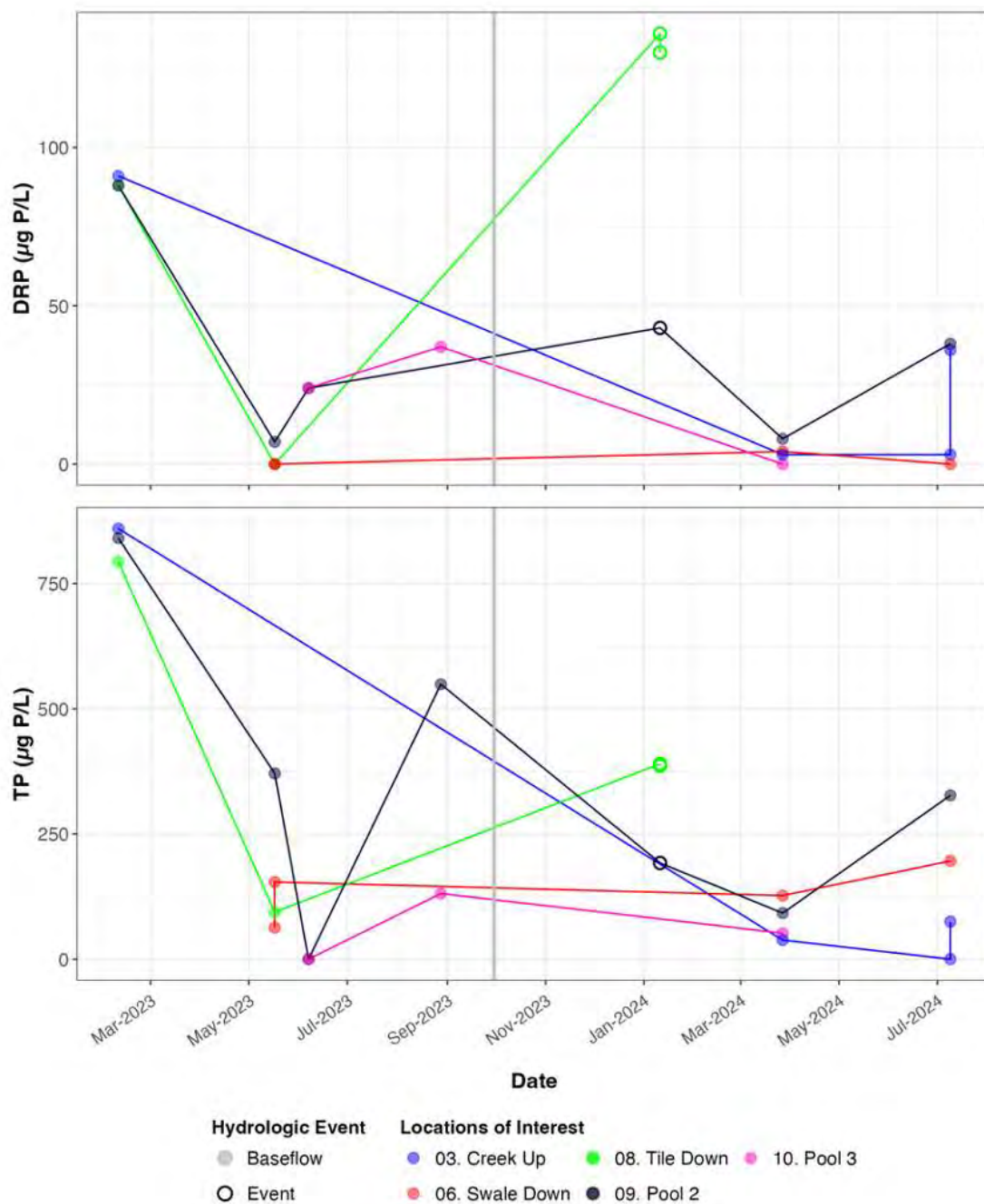


Figure 271. Time series of dissolved reactive phosphorus (DRP, top panel) and total phosphorus (TP, bottom panel) concentrations in surface water samples collected at the Clary-Boulee-McDonald Nature Preserve Project. Values below the detection limit of the analytical equipment were replaced with half the value of the detection limit. Each point represents one measurement,

and colors denote the locations of interest, as indicated in the legend. Open symbols indicate that measurements were collected during a hydrologic event (e.g., storm event) and filled symbols denote measurements collected during baseflow. Crosses (×) represent instances when no surface water was detected during the visit. If present, different shapes denote the types of wetland features represented by the locations of interest. Gray vertical lines indicate the start of a water year (Oct 1–Sep 30).

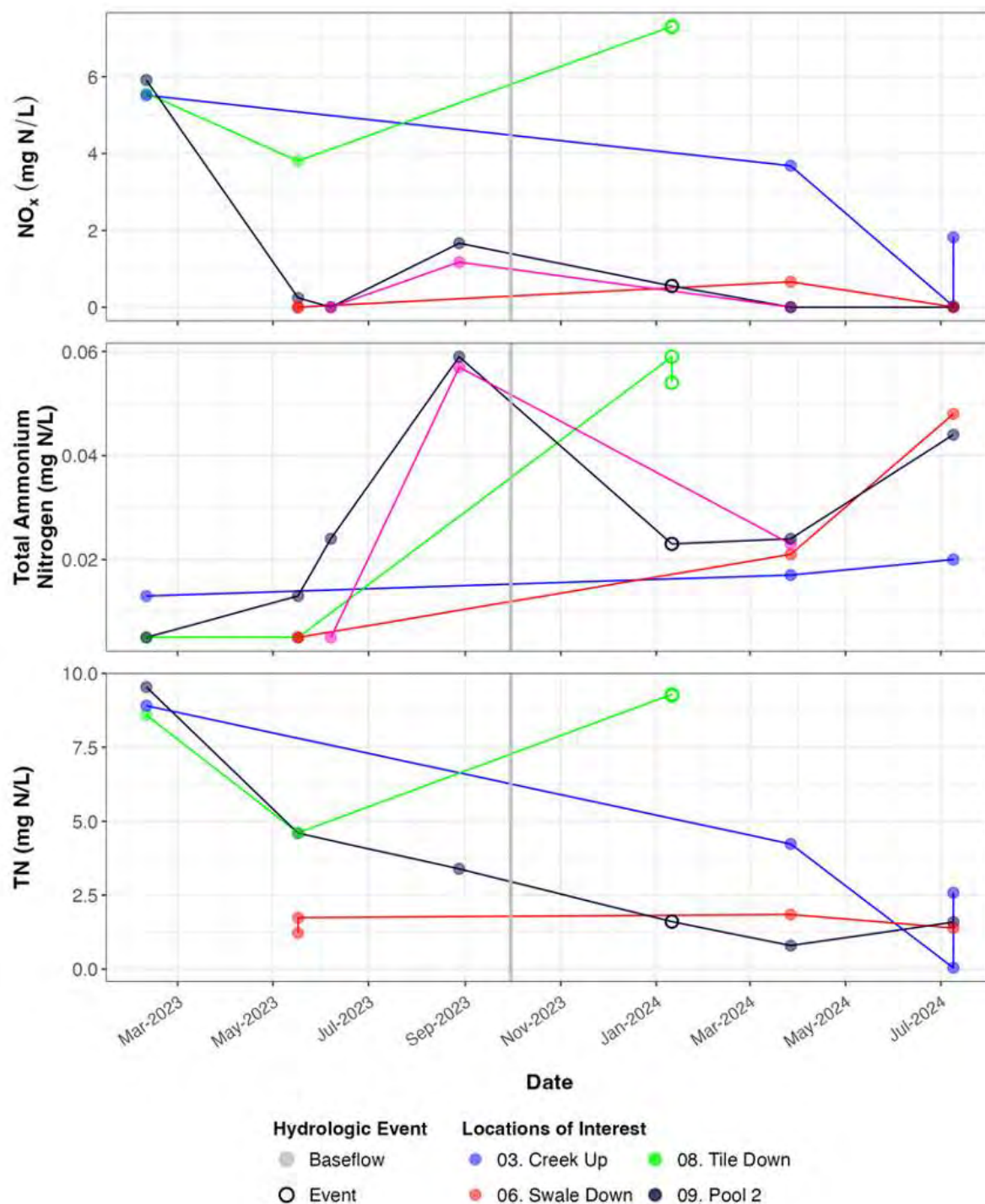


Figure 272. Time series of Nitrite+nitrate (NO_x, top panel) total ammonium nitrogen (NH₄-N, middle panel), and total nitrogen (TN, bottom panel) concentrations in surface water samples collected at the Clary-Boulee-McDonald Nature Preserve Project. Values below the detection limit of the analytical equipment were replaced with half the value of the detection limit. Each

point represents one measurement, and colors denote the locations of interest, as indicated in the legend. Open symbols indicate that measurements were collected during a hydrologic event (e.g., storm event) and filled symbols denote measurements collected during baseflow. Crosses (×) represent instances when no surface water was detected during the visit. If present, different shapes denote the types of wetland features represented by the locations of interest. Gray vertical lines indicate the start of a water year (Oct 1–Sep 30).

Soil Nutrient Status and Processes

Soil phosphate sorption capacity (SPSC) data for the Clary-Boulee-McDonald Project suggests that the soils have the capacity to sorb phosphate (Figure 273). The Swale and Pool 2 have the highest capacity to sorb phosphate, followed by Pools 1 and 3. The Swale and Pool 2 currently interact with Wolf Creek flood waters more than Pools 1 and 3, indicating that during flood conditions dissolved reactive phosphorus is more likely to be absorbed in the Swale and Pool 2. This is the first year for SPSC data collection at this Project, so continued collection of SPSC data will be important to track how this Project is processing phosphate in the soils throughout the Project area.



Figure 273. Soil Phosphate Sorption Capacity (SPSC) throughout the Clary-Boulee-McDonald Nature Preserve Project. Each point denotes a soil sample (0–5 cm) and different shapes indicate the wetland feature type, as shown in the legend. Colors indicate the SPSC value of each sample relative to the overall range of values observed at the wetland project, as shown in the color bar. Each panel shows the soil samples collected during a respective water year (Oct 1–Sep 30), along with the minimum and maximum SPSC values observed during a given water year. Negative SPSC values indicate the potential for soils to release phosphate, while positive values

indicate soils have capacity to sorb phosphate, based on Mehlich-3 extractions of phosphate, iron, and aluminum.

Next Steps to Strengthen Understanding

To strengthen understanding of nutrient movement throughout this Project area, more frequent water quality monitoring, both during ambient and storm event conditions, needs to be performed in Water Year (WY) 2025. Better water flow and level data needs to be collected for the swale area, because it is the primary source of connection with Wolf Creek. Water level sensors were placed in the Swale, Pool 2, and Pool 3 late in WY 2024 that will help to bridge this gap in data. With more water quality data in combination with better water flow and level data throughout the Project area, a nutrient budget can be calculated for this Project in WY 2025.

Fruth Wetland Nature Preserve (FRUW)

Project Description

Seneca County | Sandusky River Watershed

Project size: 18 Acres

Partners: Seneca County Park District

The hydrology of this Project is passively managed. The Project has 10 acres of restored wetland and consists of four wetland pools that connect to Wolf Creek in the southeast via shallow groundwater. A hydrologic event at this Project is operationally defined as a storm event in which the depressional pools receive runoff.



Figure 274. Aerial image showing surface water flow and sampling locations for the Fruth Wetland Nature Preserve Project. Blue arrows indicate direction of surface water flow. Dots represent geographic base crew sampling locations, which are grouped by Project features (fill color) where relevant. Text annotations provide additional context about the Project's watershed connection or other important features.

Management Considerations

The Fruth Wetland Nature Preserve (hereafter Fruth Wetland) restoration successfully transformed a recreation field prone to precipitation-driven flooding (even following tile drain installation) into a wetland, greatly improving the area's water storage capacity and reducing peak streamflow downstream. However, the Fruth Wetland Project is an isolated wetland without any inflow or outflow connections. Due to the lack of direct inputs that would characterize

floodplains and flow-through wetlands, precipitation events and seasonal groundwater table fluctuations are the primary hydrologic drivers at this Project. This lack of direct system inputs and outputs, coupled with Base Crews' limited ability to assess groundwater influences due to sedimented monitoring wells, limited the nutrient calculation mechanisms primarily to phosphorus. Expanding the amount of stormwater runoff the Project receives by increasing either connection to upland drainage or connection to subsurface tile drainage on the southern border of the Project could improve its nutrient retention potential. Little is known about the impact of storm events on Pool 1 Complex nutrient concentrations, as it remains dry for the majority of the year. When there is runoff in the pool after a precipitation event, it is rarely enough to properly sample and dries out soon after. If there are extended periods in which the Pool 1 Complex retains water these events are missed by base crews, whose focus must be sampling Focal projects. Consider improvements such as allowing direct tile inflow from the southern bordering field or digging the pools deeper to increase groundwater connectivity. These alterations would allow more input to Pool 1 following storm events and for Pool 1 to retain water for a greater portion of the year, allowing researchers to collect more water samples from this location.

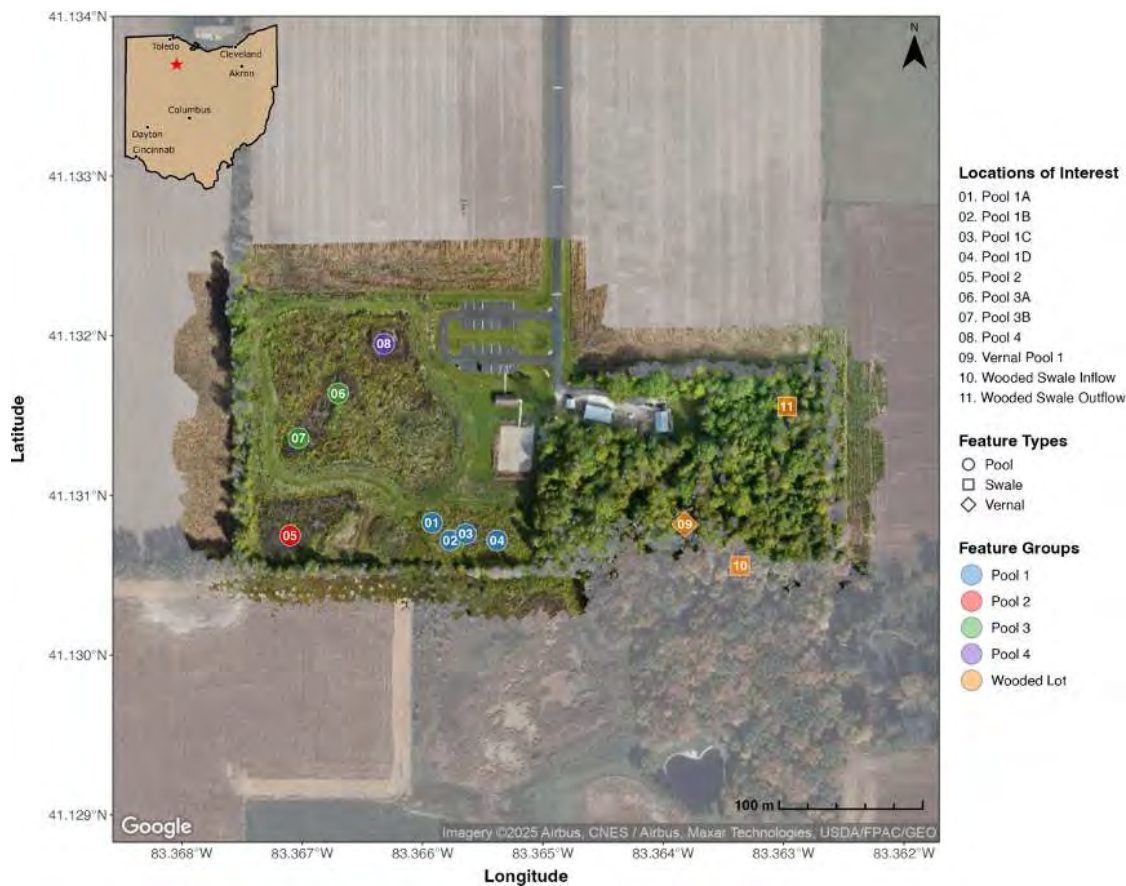


Figure 275. Aerial image of approximate locations of interest for water and soil sampling and discrete manual measurements of water depth and physicochemical parameters at Fruth Wetland Nature Preserve Project during water year 2024 (Oct 1, 2023–Sep 30, 2024). The legend

provides the name of each sampling point. Different shapes denote the types of wetland features represented by the locations of interest. If present, different colors represent locations of interest that belong to a group or complex of features (e.g., a treatment train).

Nutrient Budget Takeaways

There is currently not enough data to calculate filtration values for the Fruth Project. However, the conversion from agricultural land to wetland prevents 12 ± 8 lbs. of phosphorus runoff annually. Soils throughout the Project have a wide range in capacity to sorb phosphate, as suggested by soil phosphate sorption capacity values, although all values were positive in WY 2024.

Surface Water Hydrology and Nutrients

Since Fruth Wetland Nature Preserve is an isolated wetland with no direct inflows or upland drainage, precipitation and groundwater influence are crucial in the Project's potential to capture nutrients. Without any upland drainage or pool connectivity, much of Fruth Wetlands hydrologic connectivity exists in subsurface groundwater interactions. During the Water Year (WY) 2024 there were a total of nine water sampling events, with only one storm sampling event on July 7 (Figure 276). Pool 3 had both the deepest and shallowest average pool depth for pools most regularly sampled in WY 2024, with the exception of Pool 1. Pool 3A had an average pool depth of 46 ± 18 cm and Pool 3B had an average depth of 24 ± 27 cm. This variance of depth is likely the result of Pool 3A's more central location in the basin and of its presumably lower elevation, compared to Pool 3B. Pool 3B also had microtopography changes due to muskrat or other wildlife activity which resulted in buildup of sediment and debris at Pool 3B's location of interest. Pool 1 is largely excluded from water depth considerations because it does not retain water on a consistent basis. There was only one instance when Pool 1C was observed to have 26 cm of water. However, all the other subpools within the Pool 1 complex had less than 10 cm of water or were dry for all other sampling events. In WY 2024 the vernal pools and swales in the woodland area did not hold any water. Following heavy precipitation events the pools would be muddy but have less than 1 cm of standing water.

Over the course of monitoring, Fruth Wetland dissolved reactive phosphorous (DRP) and total phosphorus (TP) concentrations were on average higher in WY 2024 than previous years (Figure 277, Figure 278). In WY 2024, Pool 4 had two DRP peaks near 0.004 mg/L in February and July (Figure 278). A peak of that concentration was last seen in July 2021. Except for those three events, DRP concentrations in Pool 4 have not risen above 0.001 mg/L. Pool 3 was the most variable in water levels and often recorded the greatest water depth at this site. In addition, pool 3 also recorded the highest DRP (0.026 mg P/L) and TP (0.485 mg P/L) concentrations at Fruth. Similarly, there were also increases in total nitrogen concentrations (TN) across all pools as water levels decreased due to drought conditions throughout the second half of 2024 (Figure 279). The increasing TN value coinciding with low water conditions indicates a concentration effect of TN in the water not caused by additional inputs of N into the pool but rather the low water level.

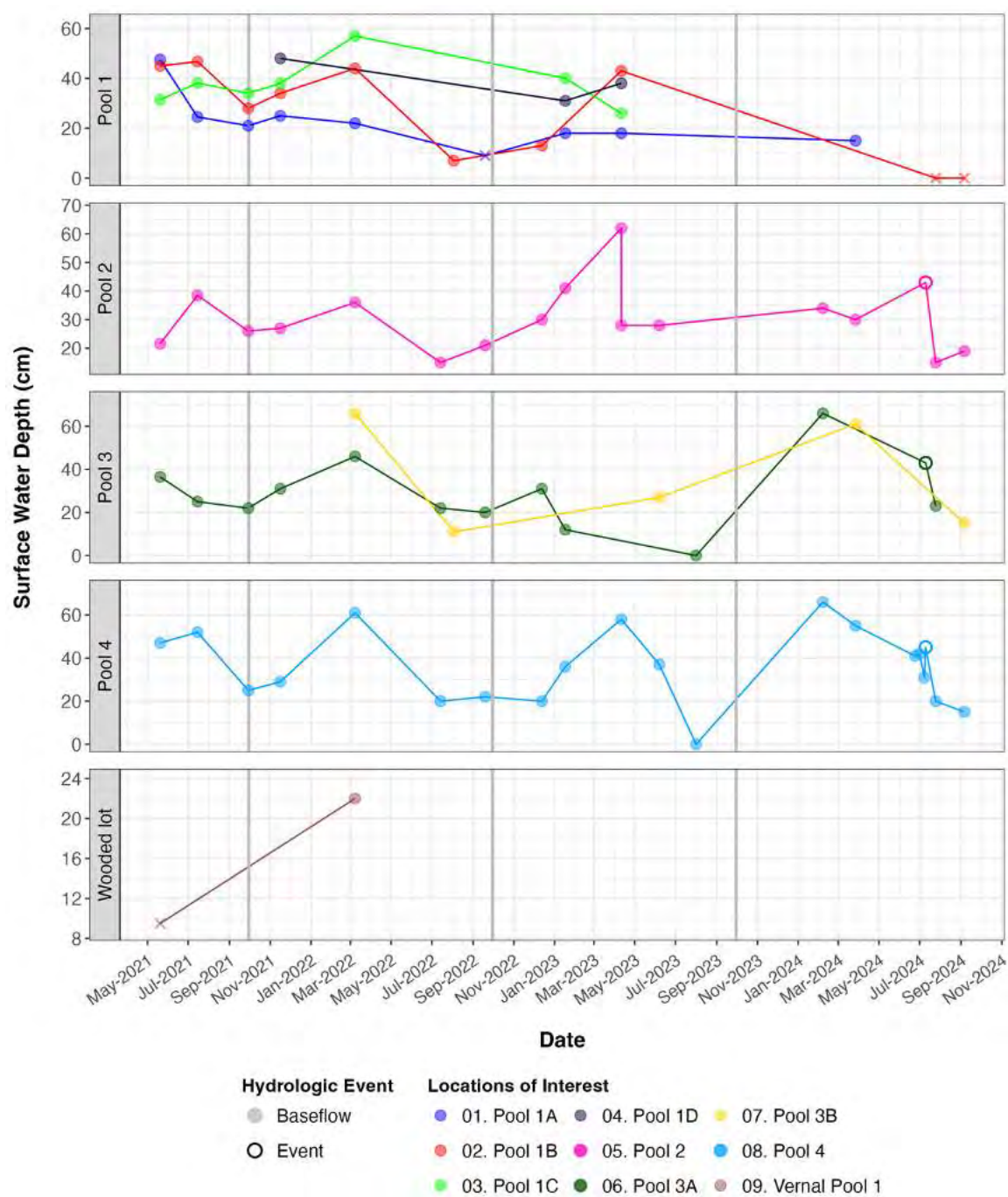


Figure 276. Time series of discrete, manually measured surface water depth at the Fruth Wetland Nature Preserve Project. Depths were measured approximately monthly. Each point represents one measurement and colors denote the locations of interest, as indicated in the legend. Open symbols indicate samples that were collected during a hydrologic event (e.g., storm event) and

filled symbols denote samples collected during baseflow. Crosses (×) represent instances when no surface water was detected during the visit. If present, different shapes denote the types of wetland features represented by the locations of interest. Gray vertical lines indicate the start of a water year (Oct 1–Sep 30).

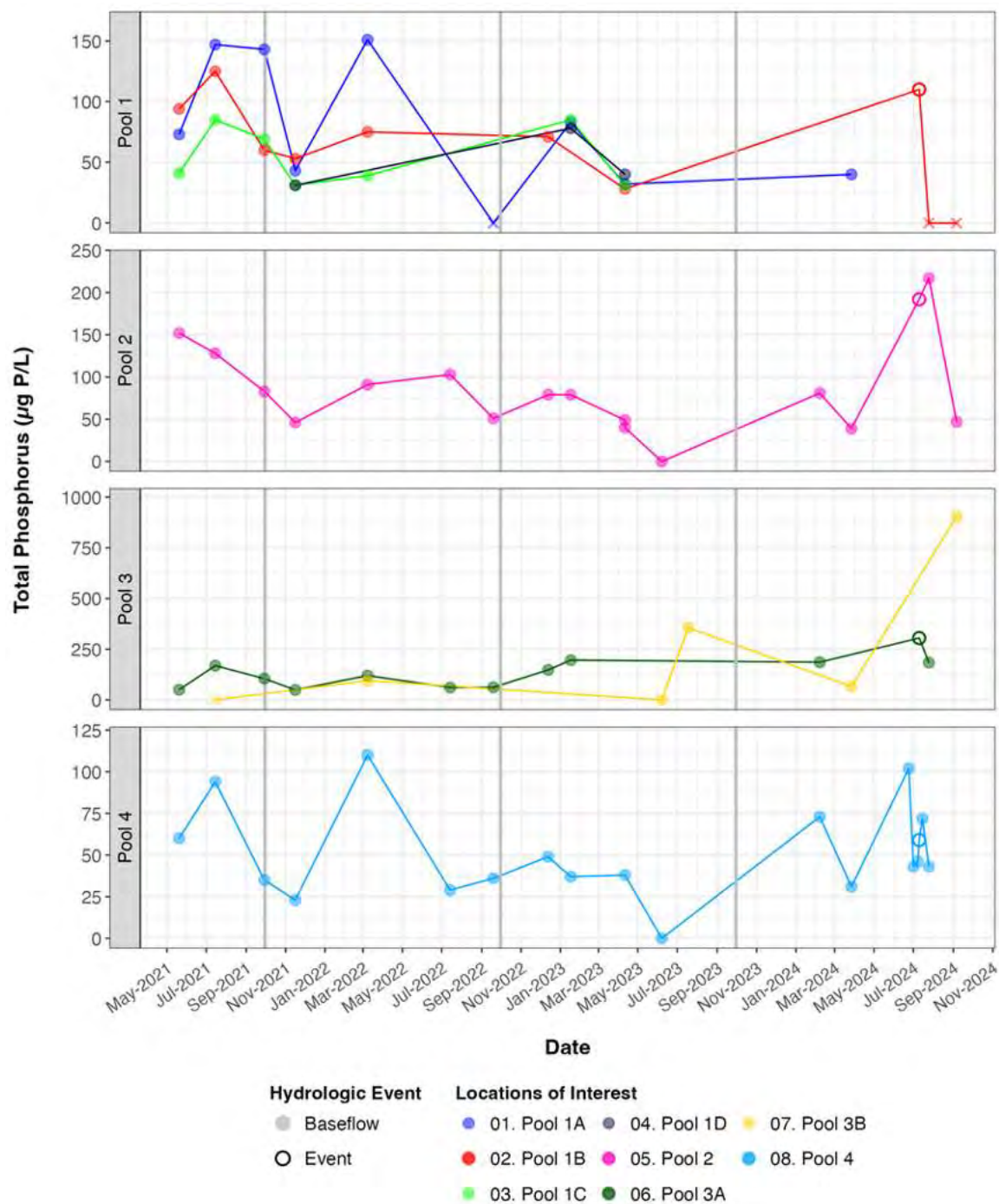


Figure 277. Time series of total phosphorus (TP) concentrations in surface water samples collected at the Fruth Wetland Nature Preserve Project. Values below the detection limit of the analytical equipment were replaced with half the value of the detection limit. Each point represents one measurement, and colors denote the locations of interest, as indicated in the legend. Open symbols indicate that measurements were collected during a hydrologic event (e.g., storm event) and filled symbols denote measurements collected during baseflow. Crosses (×) represent instances when no surface water was detected during the visit. If present, different shapes denote the types of wetland features represented by the locations of interest. Gray vertical lines indicate the start of a water year (Oct 1–Sep 30).

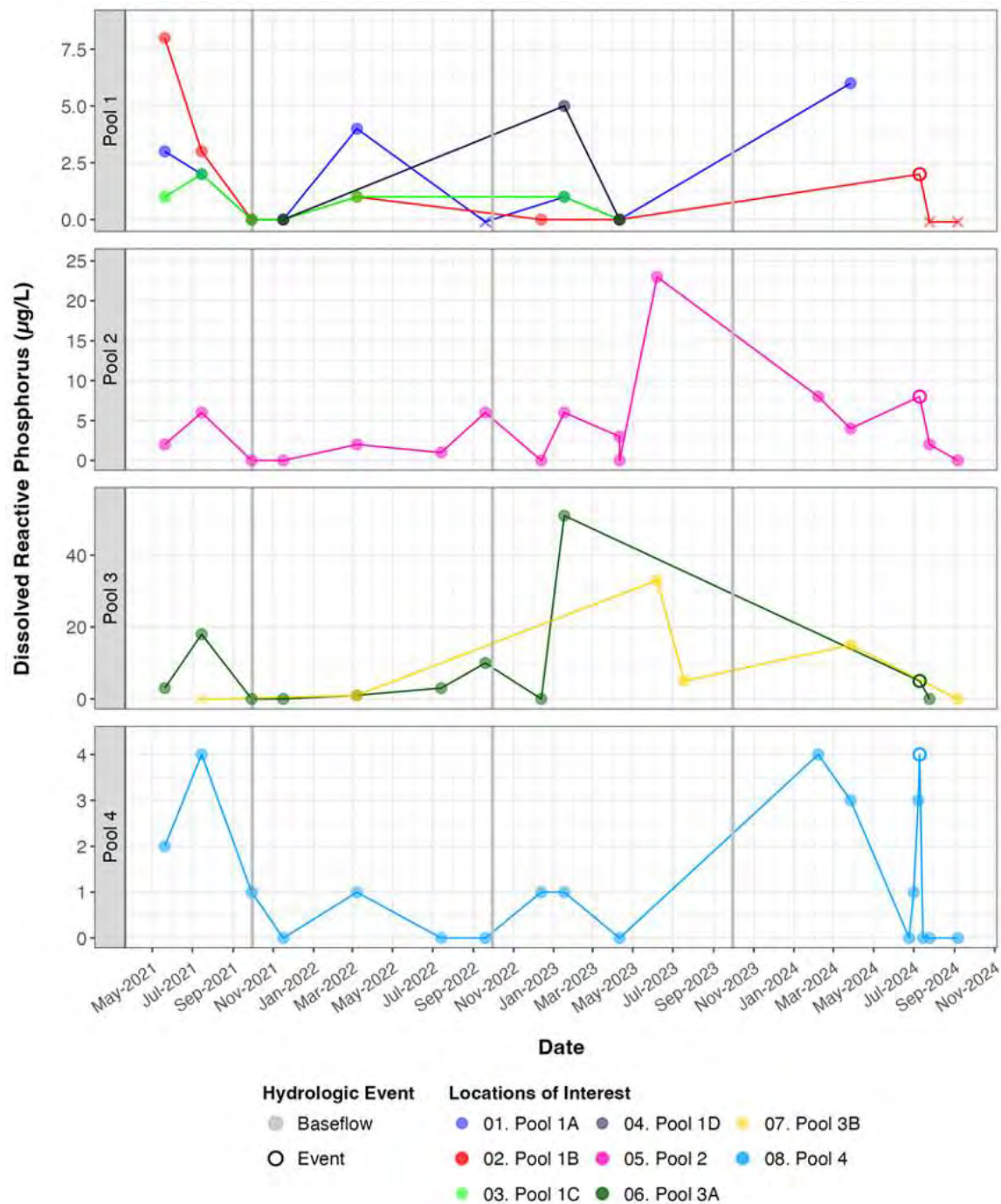


Figure 278. Time series of dissolved reactive phosphorus (DRP) concentrations in surface water samples collected at the Fruth Wetland Nature Preserve Project. Values below the detection limit of the analytical equipment were replaced with half the value of the detection limit. Each point represents one measurement, and colors denote the locations of interest, as indicated in the legend. Open symbols indicate that measurements were collected during a hydrologic event (e.g., storm event) and filled symbols denote measurements collected during baseflow. Crosses (×)

represent instances when no surface water was detected during the visit. If present, different shapes denote the types of wetland features represented by the locations of interest. Gray vertical lines indicate the start of a water year (Oct 1–Sep 30).

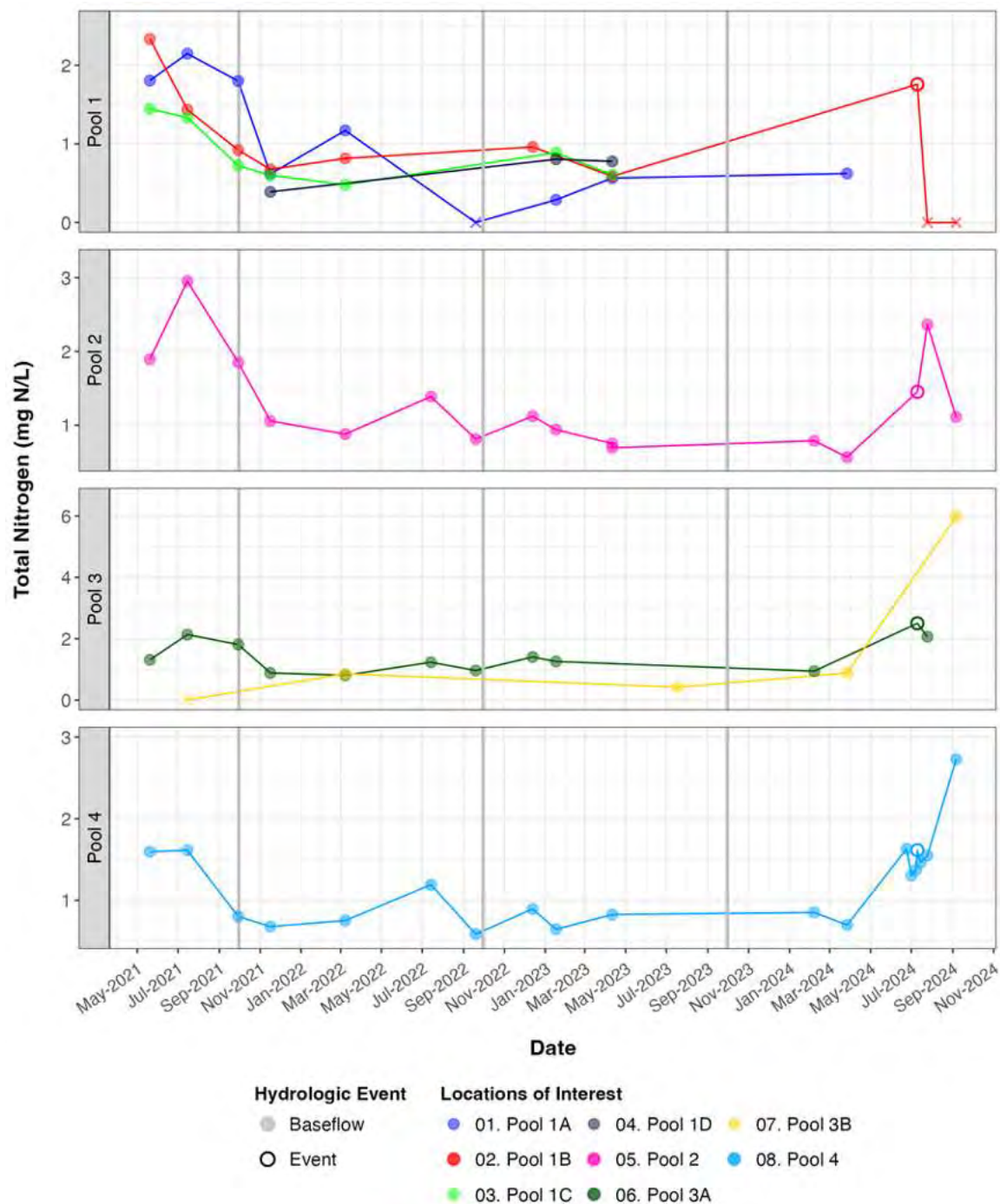


Figure 279. Time series of total nitrogen (TN) concentrations in surface water samples collected at the Fruth Wetland Nature Preserve Project. Values below the detection limit of the analytical

equipment were replaced with half the value of the detection limit. Each point represents one measurement, and colors denote the locations of interest, as indicated in the legend. Open symbols indicate that measurements were collected during a hydrologic event (e.g., storm event) and filled symbols denote measurements collected during baseflow. Crosses (×) represent instances when no surface water was detected during the visit. If present, different shapes denote the types of wetland features represented by the locations of interest. Gray vertical lines indicate the start of a water year (Oct 1–Sep 30).

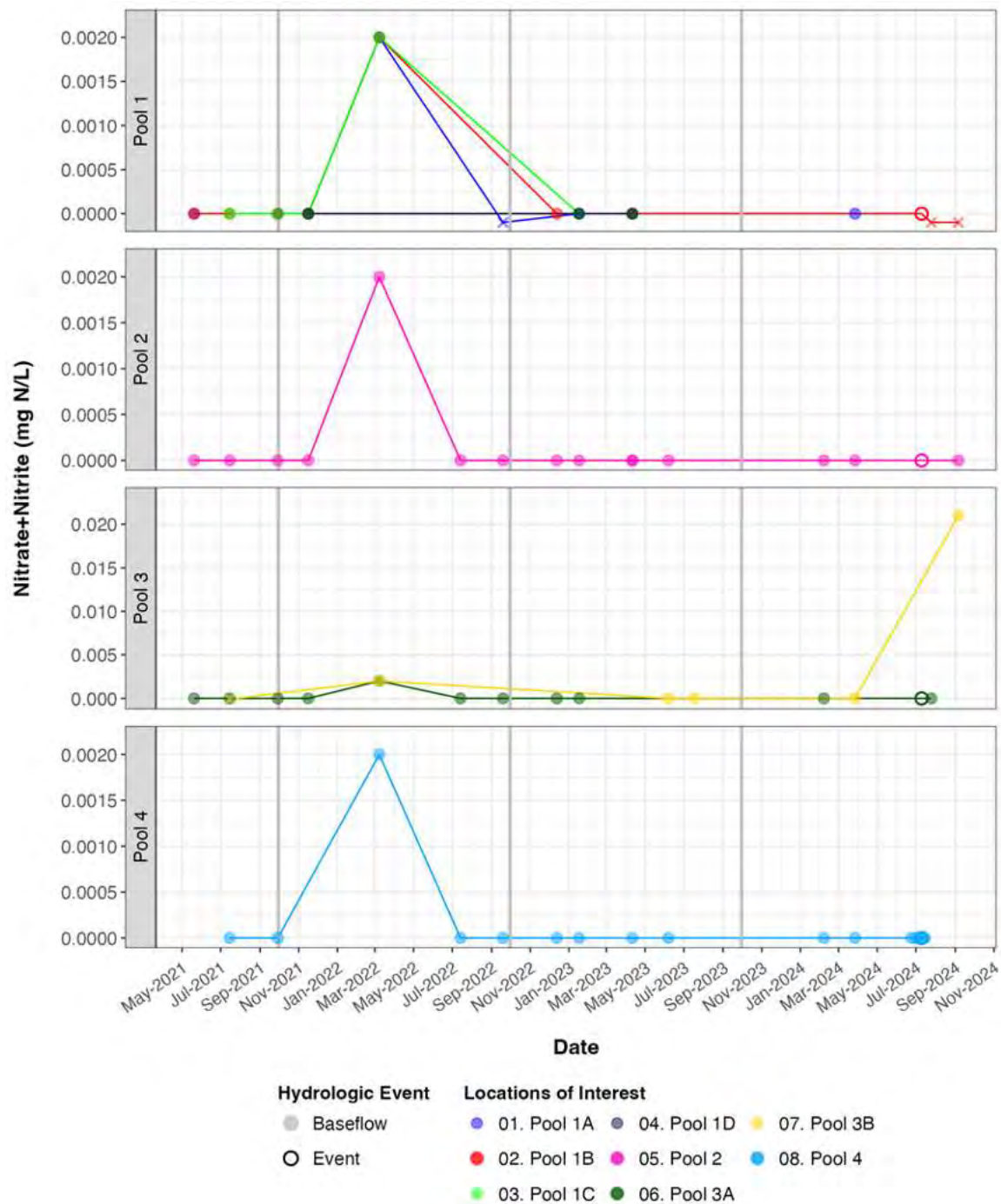


Figure 280. Time series of Nitrite+nitrate (NO_x) concentrations in surface water samples collected at the Fruth Wetland Nature Preserve Project. Values below the detection limit of the analytical equipment were replaced with half the value of the detection limit. Each point represents one measurement, and colors denote the locations of interest, as indicated in the legend. Open symbols indicate that measurements were collected during a hydrologic event (e.g., storm event) and filled symbols denote measurements collected during baseflow. Crosses (x)

represent instances when no surface water was detected during the visit. If present, different shapes denote the types of wetland features represented by the locations of interest. Gray vertical lines indicate the start of a water year (Oct 1–Sep 30).

Soil Nutrient Status and Processes

Compared to previous years, soil conductivity was higher across all locations of interest at this Project, with the lowest soil conductivity values within the bermed area. Like Water Year 2023, Pool 1 had the highest conductivity (1864 $\mu\text{S}/\text{cm}$ in Pool 1B). While these conductivity measurements are lower than in other projects, they were most like the measurements in the Oakwoods Wetland Project, which is also an isolated wetland complex. Across the Project, soil pH averaged 6.8, with all locations acidic except for Pools 1A, 1B, and 1C, which were basic. Soil samples collected from Vernal Pool 1 and the Wooded Swale have a similar pH of 6.8. Mehlich-3-extractable phosphorus (M3-P) was low across the main sampling locations Pools 1–4 (0.54–13.42 mg phosphorus (P)/kg) indicating relatively low soil P concentrations. The Wooded Swale Outflow had the highest concentration (67.66 mg/kg) across the entire project. Fruth Wetland Nature Preserve soils have positive soil phosphate sorption capacity (SPSC) values for all soil locations of interest, suggesting a capacity to sorb phosphate. Compared to the previous years' data, SPSC values in Pool 1 remained low, but values in Pools 2 and 3 increased, falling mostly in the range of 150–200 mg/kg (Figure 281). This shift in SPSC could be attributed to an increase in vegetation density. Pool 1 had minimal vegetation development since the beginning of monitoring, whereas Pools 2 and 3 saw rapid takeover of *Typha spp.* even after management action in Pool 2. Since there are no active outflows at the Project, this increase in SPSC can be likely attributed to vegetation uptake or another mechanism, rather than a release.

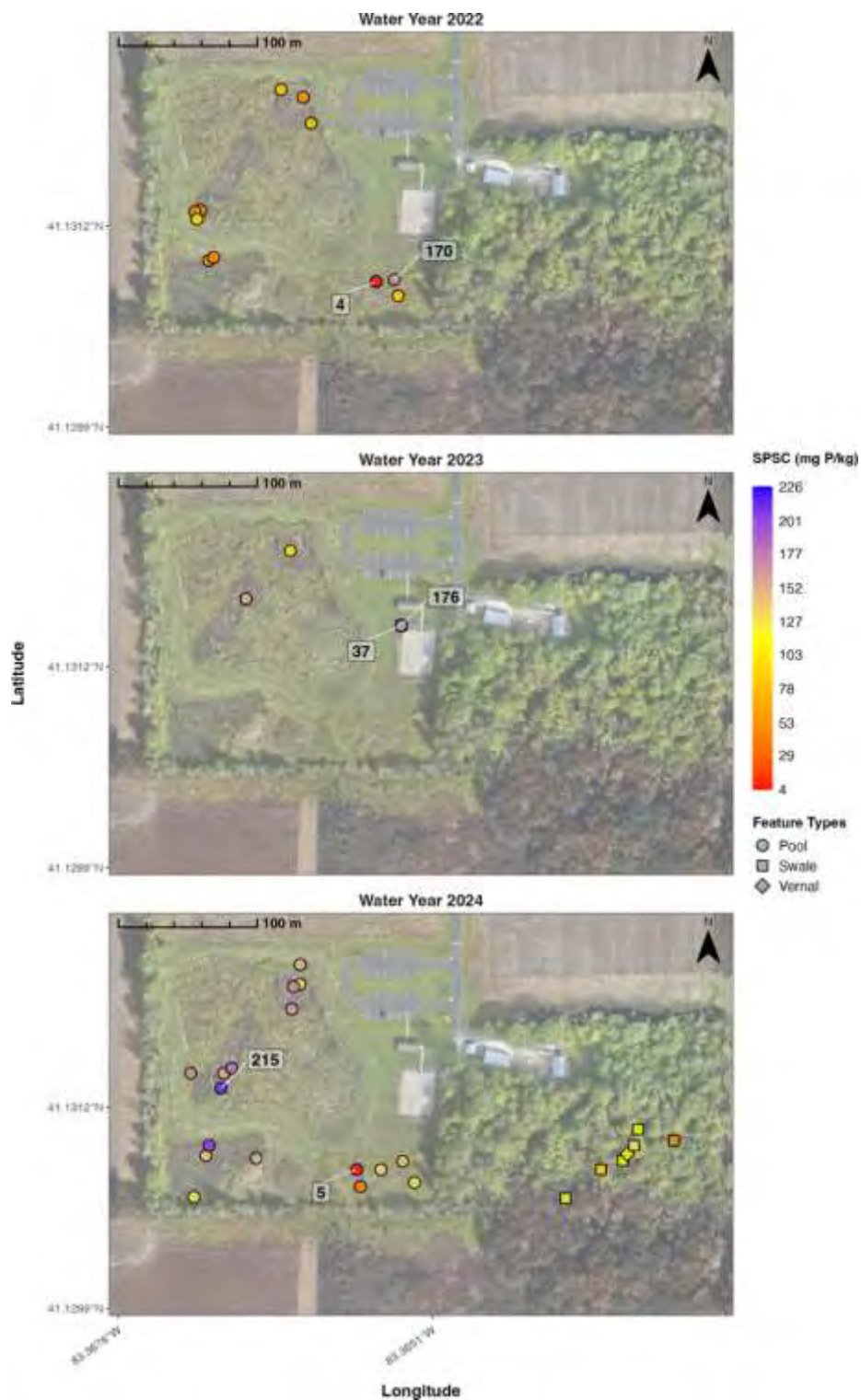


Figure 281. Soil Phosphate Sorption Capacity (SPSC) throughout the Fruth Wetland Nature Preserve Project. Each point denotes a soil sample (0–5 cm) and different shapes indicate the

wetland feature type, as shown in the legend. Colors indicate the SPSC value of each sample relative to the overall range of values observed at the wetland project, as shown in the color bar. Each panel shows the soil samples collected during a respective water year (Oct 1–Sep 30), along with the minimum and maximum SPSC values observed during a given water year. Negative SPSC values indicate the potential for soils to release phosphate, while positive values indicate soils have capacity to sorb phosphate, based on Mehlich-3 extractions of phosphate, iron, and aluminum.

Next Steps to Strengthen Understanding

In the coming year, base crews plan to consistently monitor groundwater in four wells installed on the Fruth Wetland Project. This will help researchers better delineate contributions of surface water versus groundwater in nutrient load calculations. Additional focus on vegetation abundance and density within pools will help researchers understand the role of vegetation in nutrient load reduction in surface water. Researchers need to better understand differences in the vegetated versus unvegetated portions within Pool 2, as well as differences in Pool 3A and 3B. Base crews also tend to miss sampling opportunities following storm events at Pool 1 due to the short holding times and prioritization of other Projects. Partner sampling at Fruth Wetland Nature Preserve would allow Nature Center employees to collect samples from Pool 1 following precipitation events or notify base crews so that more water samples can be collected from and a better understanding of Pool 1's role in nutrient reduction at the site.

Sandusky River Headwaters Preserve Wetland and Habitat Restoration (SRHE)

Project Description

Crawford County | Sandusky River Watershed

Project size: 7 Acres

Partners: Crawford Park District

The hydrology at this Project is passively managed. The Project has 7 acres of restored wetland, consisting of two main wetland pools (East and West) and a series of small vernal pools. Flow from the primary inflow stream originates from an agricultural field and flows to the Project area through forested hillside before it splits between the east and west wetlands. After flowing through the East and West Wetlands, water flows into the Sandusky River. The East Wetland additionally contains a wet meadow, as well as six vernal pools that only receive surface runoff. A hydrologic event at this Project is operationally defined as a storm event in which flow is delivered from the inflow stream to the East and West Wetlands.



Figure 282. Aerial image showing surface water flow and sampling locations for the Sandusky River Headwaters Preserve Wetland and Habitat Restoration Project. Blue arrows indicate direction of surface water flow. Dots represent geographic base crew sampling locations, which are grouped by Project features (fill color) where relevant. Text annotations provide additional context about the Project's watershed connection or other important features.

Management Considerations

The Sandusky River Headwaters Preserve Wetland and Habitat Restoration (hereafter Sandusky River Headwaters Project) appears to be functioning as designed: as a flow-through wetland that increases both nutrient storage and nutrient uptake opportunity of water that, prior to construction, would have flowed directly into the Sandusky River from upland agricultural land. This Project diverted the stream which drained the upland agricultural field into two wetland pools, creating a buffer to slow the flow of water into the river and allow nutrients to be stored or removed. Researchers anecdotally noticed that the East Wetland, including wet meadow and vernal pools, is more densely vegetated and has a larger diversity of vegetation than the West Wetland, likely resulting from more persistent inundation in the East compared to West wetland. However, in Water Year (WY) 2024 vegetation development was observed in the West Wetland. Base crews also noticed that more flow was directed into the East Wetland than the West Wetland due to naturally occurring damming at the diversion point. These flow imbalances may limit optimal opportunity for nutrient filtration by vegetation and soils in the West Wetland. Regular clearance of debris at the East and West Wetland diversion point by either managers or base crews could increase flow to ensure both wetlands are functioning as efficiently as possible.

In part due to atypically dry conditions, there was only one storm flow event for WY 2024, observed in April, which resulted in outflow from both wetlands. Apart from such major flow events, much of the Project's surface water remains in the wetlands except for loss from evaporation and transpiration mechanisms. The West Wetland has a larger storage capacity per area than the East Wetland due to its depressional "bathtub" shape; for waters in the West Wetland to reach the outflow there must be a substantial inflow at an amount that is rarely achieved. The East Wetland is slightly smaller in area than the West Wetland and, due to its microtopography, it breaches its banks to the outflow more often. However, in contrast to the West Wetland, water from the East Wetland must make its way overland through the wet meadow and over a walking path before it enters the river. Although both wetlands have different design characteristics, their unique features contribute to similar water retention overall. The vernal pools in the wet meadow portion of the East Wetland rarely hold water from upland drainage due to surface water redirection from the placement of spoils upgradient from the pools. If the mounds were moved to the other side of the vernal pools, more water would be captured by the pools and held rather than draining around the pools, therefore improving the Projects overall nutrient reduction capacity.

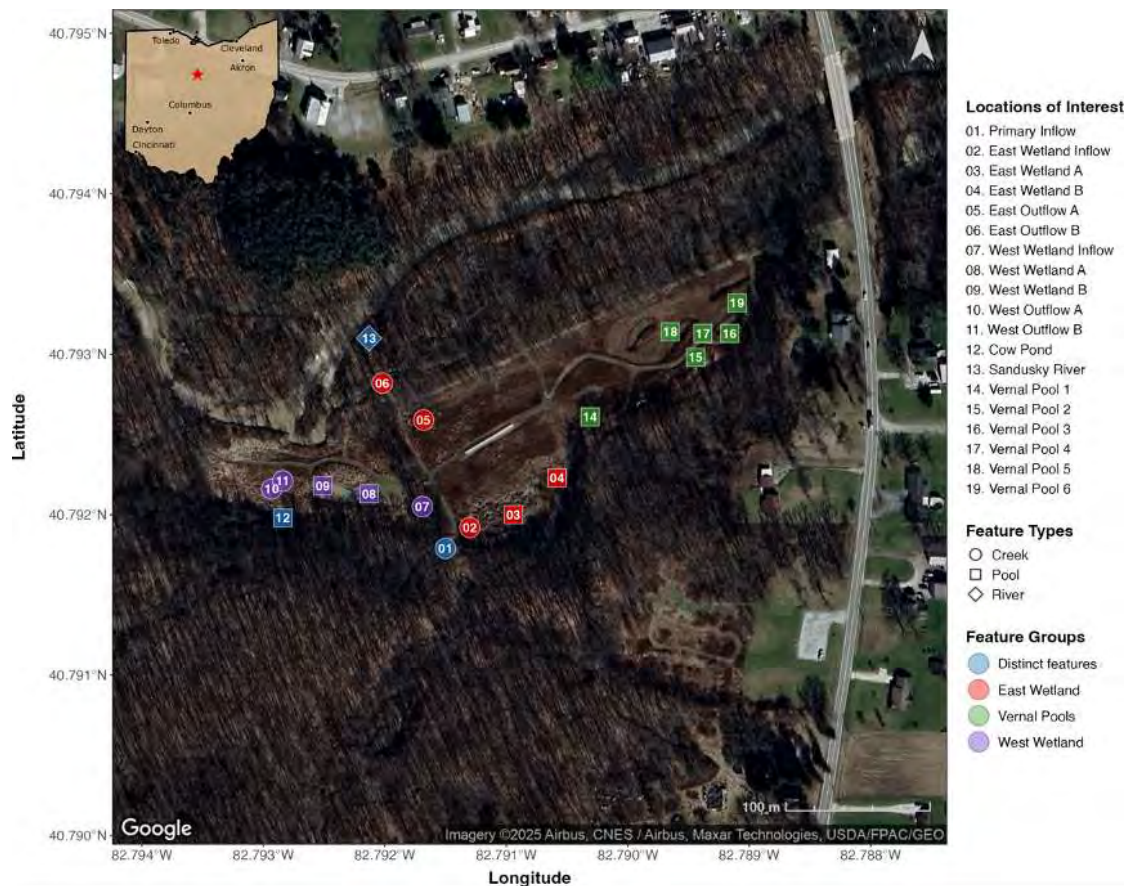


Figure 283. Aerial image of approximate locations of interest for water and soil sampling and discrete manual measurements of water depth and physicochemical parameters at Sandusky River Headwaters Preserve Wetland & Habitat Restoration Project during water year 2024 (Oct 1, 2023–Sep 30, 2024). The legend provides the name of each sampling point. Different shapes denote the types of wetland features represented by the locations of interest. If present, different colors represent locations of interest that belong to a group or complex of features (e.g., a treatment train).

Nutrient Budget Takeaways

There is currently not enough data to calculate filtration values for the Sandusky River Headwaters Project. However, the conversion from agricultural land to wetland prevents 24 ± 16 lbs. of phosphorus runoff annually. Soils throughout the Project have moderate capacity to sorb phosphate, as suggested by soil phosphate sorption capacity values.

Surface Water Hydrology and Nutrients

In Water Year 2024 there was a total of six water sampling events. One storm sampling event had flow from the East and West Outflow, one event only had flow from the West Wetland, and

the remainder were ambient sampling events with no outflow. The initial sampling event with outflow was on April 3, 2024 and the following was April 25, 2024. Apart from those two events, there was rarely inflow or outflow at the Project, even with standing water at the Primary Inflow year-round (Figure 284).

The total phosphorus (TP) concentration at the outflow of the East Wetland (East Outflow A) was measured at 0.31 mg P/L following the flow event on April 3, 2024 (Figure 285). During the following sampling event on April 25, there was no longer flow from the East Outflow A. On April 3 the West Wetland Outflow had a total phosphorus concentration (TP) measured at 0.35 mg P/L, which dropped to ~0.1 mg P/L after the following April 25th sampling event (Figure 285). Dissolved reactive phosphorus (DRP) concentrations during the April 3rd sampling event were lower at the outflow than at the inflow for both the East Wetland (0.057 mg P/L at the inflow, 0.043 mg P/L at the outflow) and the West Wetland (0.048 mg P/L at the inflow, 0.027 mg P/L at the outflow, Figure 286). DRP concentrations then decreased to 0 mg/L across all sampled locations at the following sampling event on April 25. Except for the two observed flow events, there was often no outflow from either wetland, indicating that all inflow phosphorus was filtered.

The Sandusky River had the highest nitrite+nitrate concentration of (2.61 mg N/L, which was more than double that of the east (1.15 mg N/L) and west wetland inflows (1.13 mg N/L). The Sandusky River Headwaters Project was also impacted by drought conditions, demonstrated mostly by spikes in TP, DRP, total nitrogen, and total ammonium nitrogen in the East Wetland before the pools dried out in September (Figure 285, Figure 286, Figure 287, Figure 288). Dissolved oxygen in the East Wetland dropped below 60% saturation during this time as well. During this time base crews observed deceased wildlife such as frogs and fish, indicating hypoxic conditions.

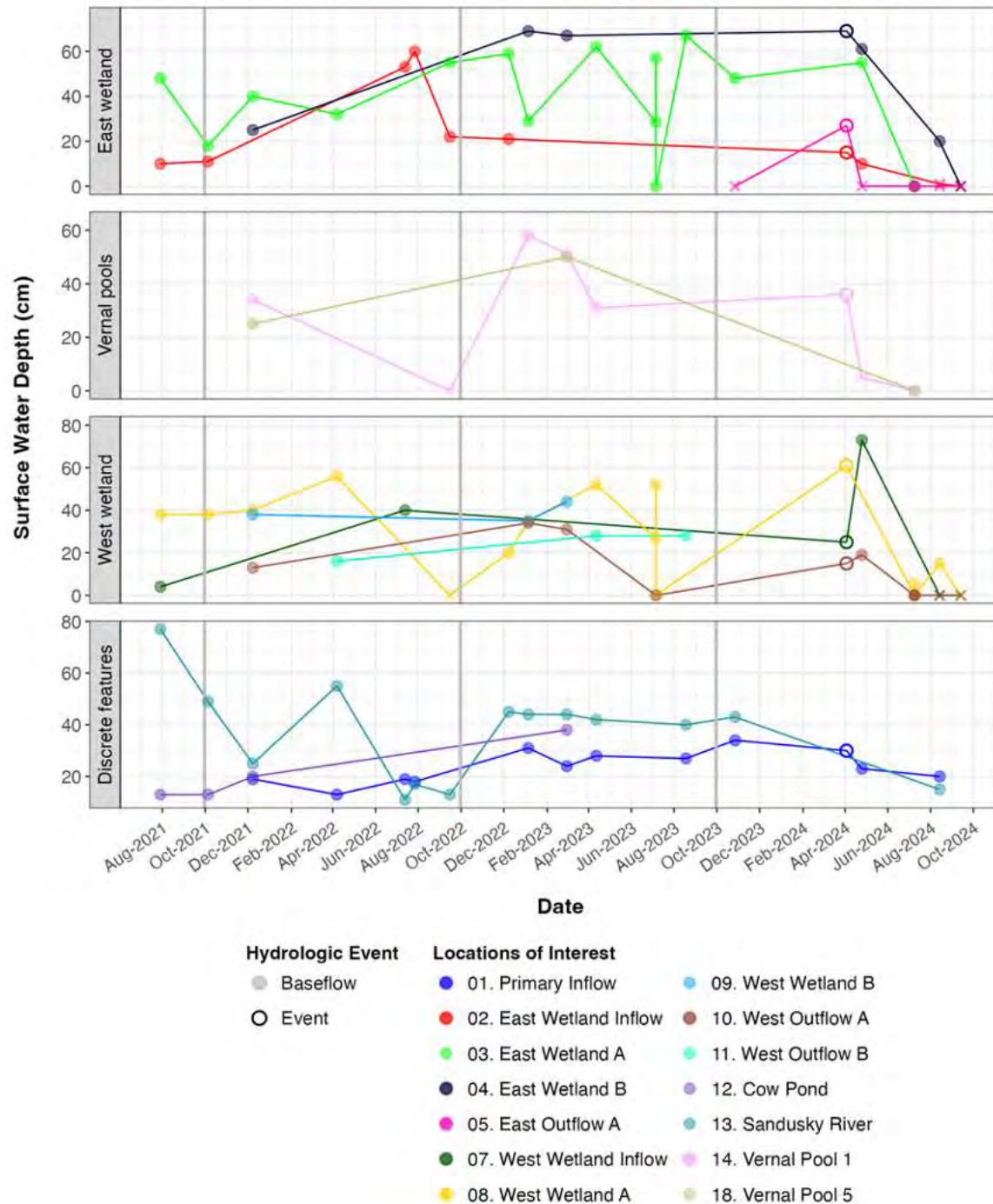


Figure 284. Time series of discrete, manually measured surface water depth at the Sandusky River Headwaters Preserve Wetland & Habitat Restoration Project. Depths were measured approximately monthly. Each point represents one measurement and colors denote the locations of interest, as indicated in the legend. Open symbols indicate samples that were collected during

a hydrologic event (e.g., storm event) and filled symbols denote samples collected during baseflow. Crosses (×) represent instances when no surface water was detected during the visit. If present, different shapes denote the types of wetland features represented by the locations of interest. Gray vertical lines indicate the start of a water year (Oct 1–Sep 30).

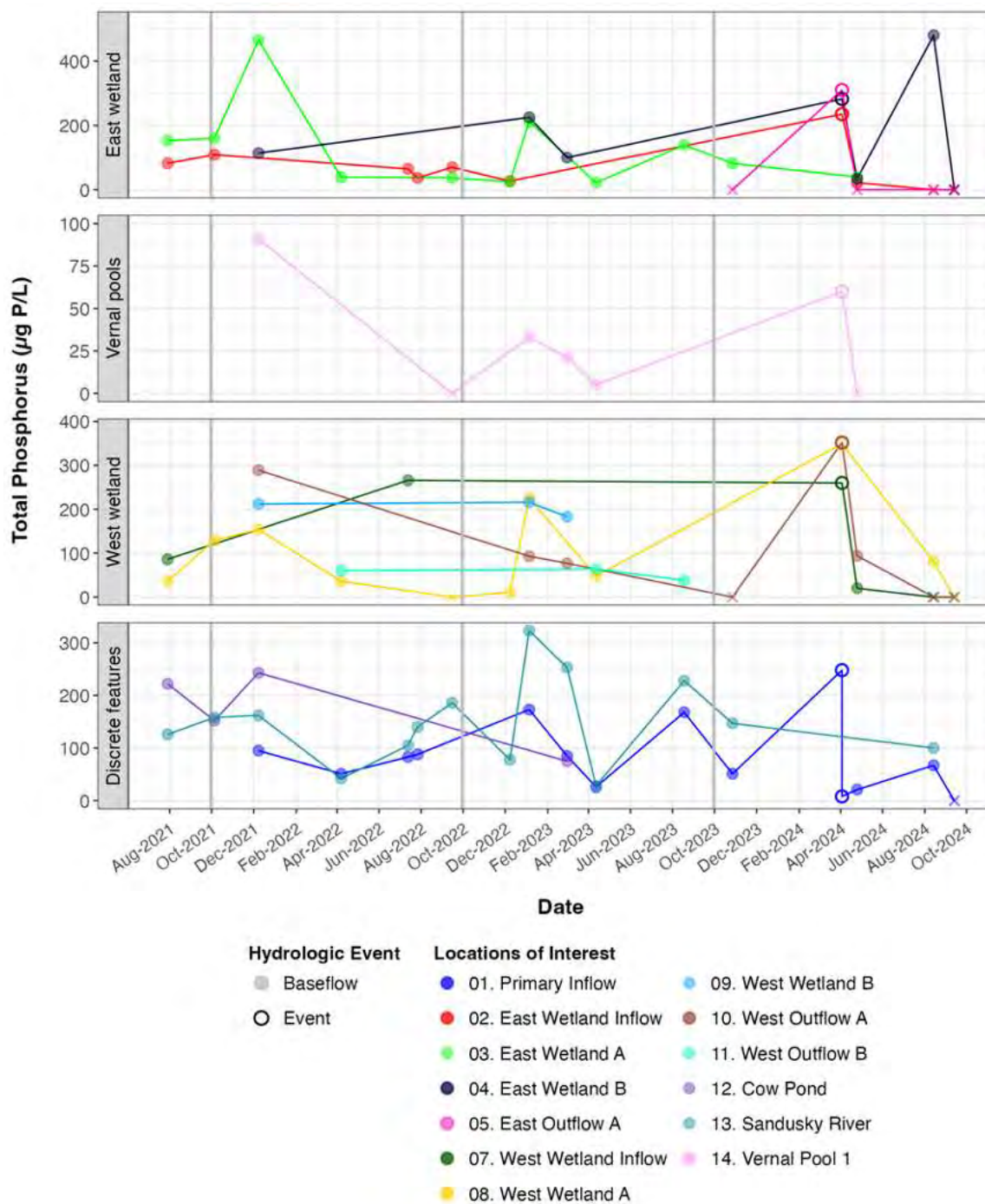


Figure 285. Time series of total phosphorus (TP) concentrations in surface water samples collected at the Sandusky River Headwaters Preserve Wetland & Habitat Restoration Project. Values below the detection limit of the analytical equipment were replaced with half the value of the detection limit. Each point represents one measurement, and colors denote the locations of interest, as indicated in the legend. Open symbols indicate that measurements were collected during a hydrologic event (e.g., storm event) and filled symbols denote measurements collected during baseflow. Crosses (×) represent instances when no surface water was detected during the visit. If present, different shapes denote the types of wetland features represented by the locations of interest. Gray vertical lines indicate the start of a water year (Oct 1–Sep 30).

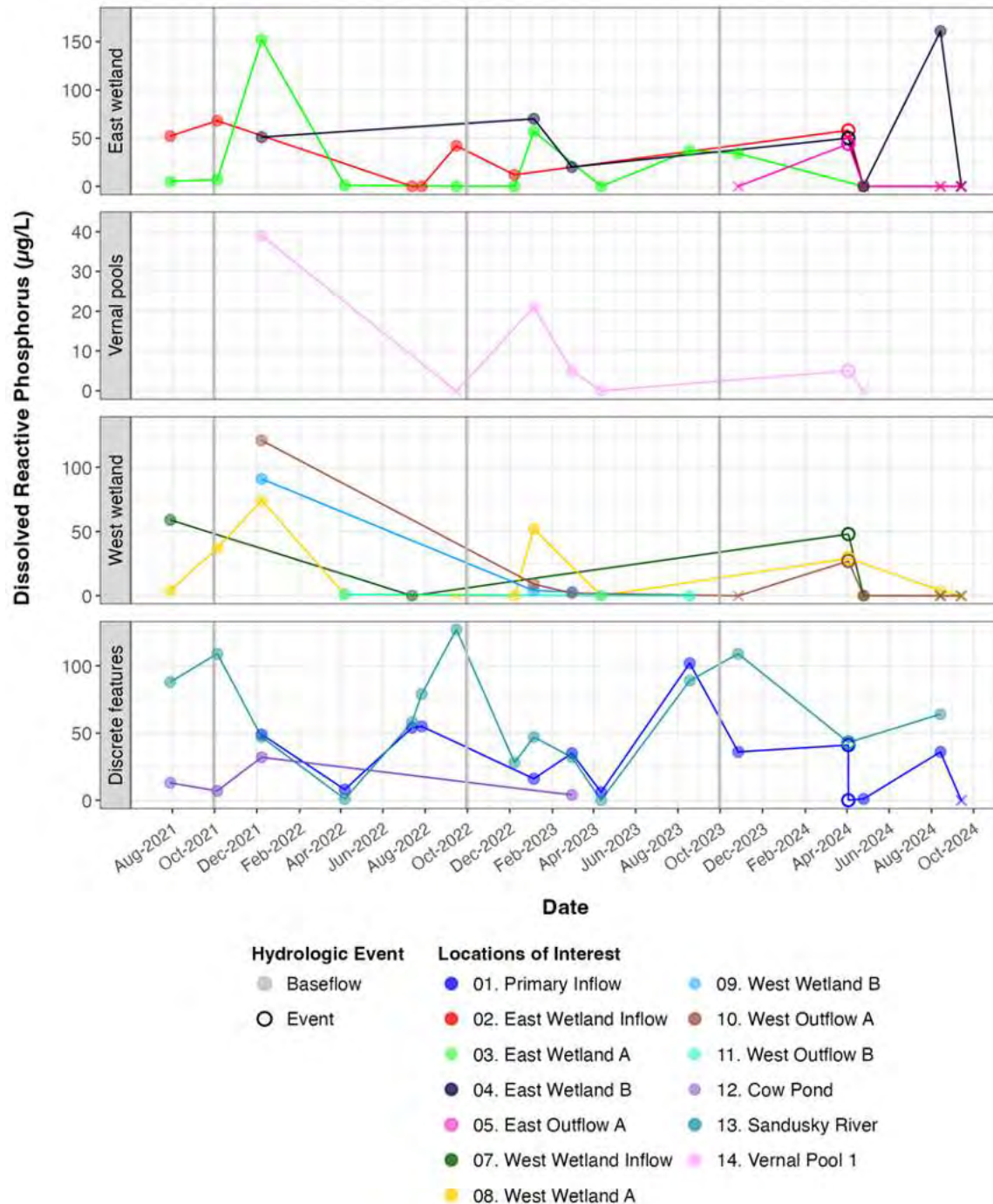


Figure 286. Time series of dissolved reactive phosphorus (DRP) concentrations in surface water samples collected at the Sandusky River Headwaters Preserve Wetland & Habitat Restoration Project. Values below the detection limit of the analytical equipment were replaced with half the value of the detection limit. Each point represents one measurement, and colors denote the locations of interest, as indicated in the legend. Open symbols indicate that measurements were collected during a hydrologic event (e.g., storm event) and filled symbols denote measurements

collected during baseflow. Crosses (×) represent instances when no surface water was detected during the visit. If present, different shapes denote the types of wetland features represented by the locations of interest. Gray vertical lines indicate the start of a water year (Oct 1–Sep 30).

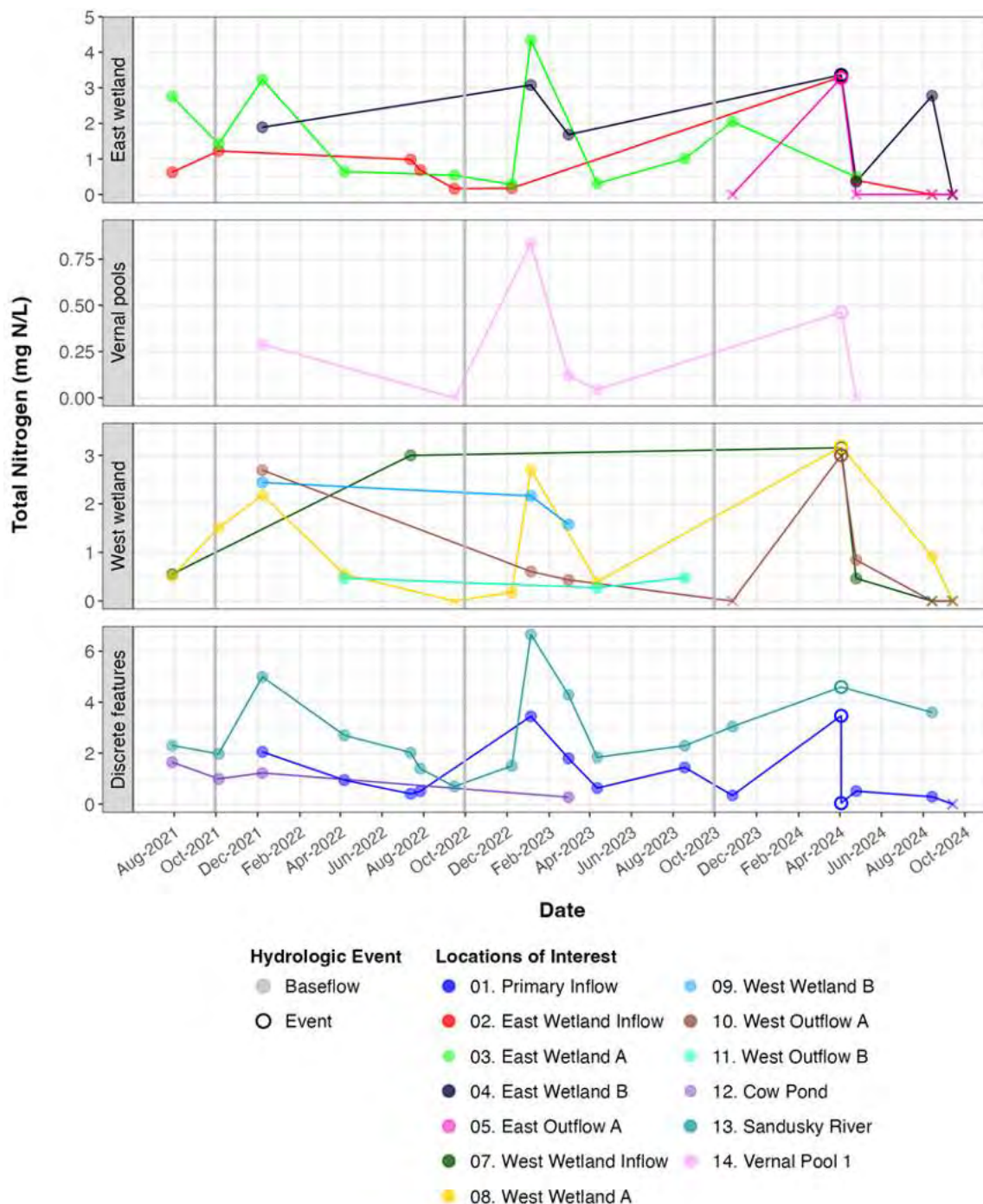


Figure 287. Time series of total nitrogen (TN) concentrations in surface water samples collected at the Sandusky River Headwaters Preserve Wetland & Habitat Restoration Project. Values

below the detection limit of the analytical equipment were replaced with half the value of the detection limit. Each point represents one measurement, and colors denote the locations of interest, as indicated in the legend. Open symbols indicate that measurements were collected during a hydrologic event (e.g., storm event) and filled symbols denote measurements collected during baseflow. Crosses (×) represent instances when no surface water was detected during the visit. If present, different shapes denote the types of wetland features represented by the locations of interest. Gray vertical lines indicate the start of a water year (Oct 1–Sep 30).

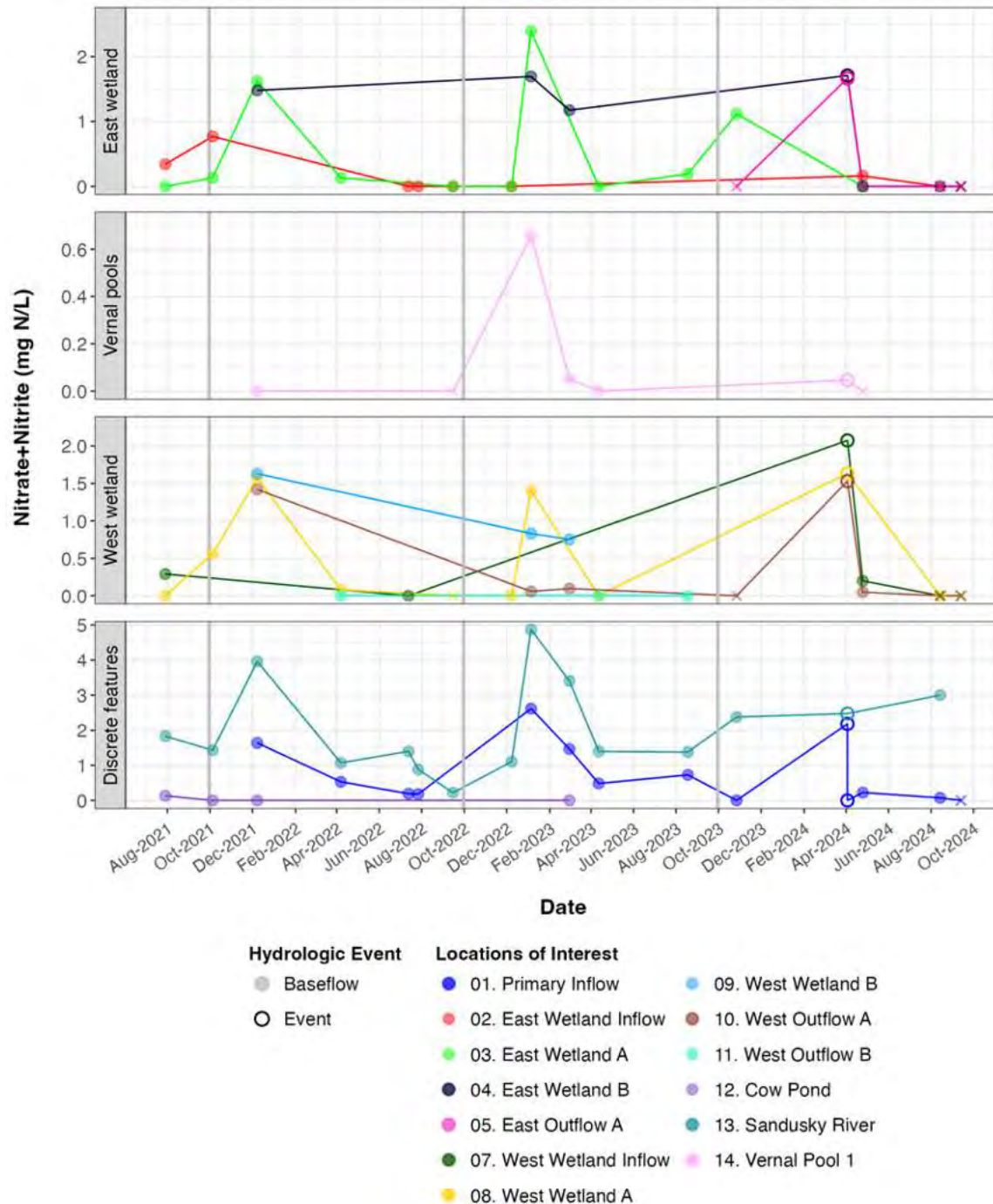


Figure 288. Time series of Nitrite+nitrate (NO_x) concentrations in surface water samples collected at the Sandusky River Headwaters Preserve Wetland & Habitat Restoration Project. Values below the detection limit of the analytical equipment were replaced with half the value of the detection limit. Each point represents one measurement, and colors denote the locations of interest, as indicated in the legend. Open symbols indicate that measurements were collected during a hydrologic event (e.g., storm event) and filled symbols denote measurements collected

during baseflow. Crosses (×) represent instances when no surface water was detected during the visit. If present, different shapes denote the types of wetland features represented by the locations of interest. Gray vertical lines indicate the start of a water year (Oct 1–Sep 30).

Soil Nutrient Status and Processes

Soil pH levels were within a neutral range (6.068–7.785) for all sampling locations, and the overall Project pH was 6.9. Soil conductivity was highly variable, ranging from 255 to 5044.66 $\mu\text{S}/\text{cm}$. Soil phosphate sorption capacity (SPSC) values were positive across the Project, suggesting an overall capacity to sorb phosphate. The Project's lowest SPSC values occurred near the inflows and outflow, indicating these soils are important to the site's overall capacity to sorb phosphate. More phosphate sorption may be occurring near the inflows and outflows of the Project. However, many of the soil samples collected from the main wetland pools have higher SPSC values, which suggest that the Sandusky River Headwaters Project can sorb phosphate (Figure 289). East Wetland Outflow A had the lowest SPSC value (21.5 mg phosphorus (P)/kg), however, it is still positive, suggesting a moderate capacity to sorb phosphate. Compared to previous years of soil sampling, SPSC has drastically decreased in some locations, such as the shift from 236.5 mg/kg to 21.5 mg/kg in the East Wetland Outflow. Vegetation density, sampling location variability, vegetation growth and dieback, and phosphorus sorption are all possible explanations of this shift. Water Year (WY) 2023 also lacked the quantity of samples and sampling locations that WY 2022 and WY 2024 had, making it difficult to determine whether the shift has been occurring gradually over the last several years or if there was a more drastic change between WY 2023 and 2024. Mehlich-3-extractable aluminum (M3-Al) and iron (M3-Fe) varied greatly across sampling locations and did not correlate to one another or to Mehlich-3-extractable P levels. West Wetland A had the greatest total nitrogen (2901 mg nitrogen/kg) and East Wetland Outflow A had the greatest total phosphorus (TP, 726 mg P/kg) soil concentration. Overall, water-extractable nitrate and total ammonium nitrogen were both higher than water-extractable phosphate. While this Project has the capacity to sorb phosphate, the lowest SPSC values are found near the outflows, indicating these locations might be the first to release P once the Project reaches total P capacity (Figure 289).

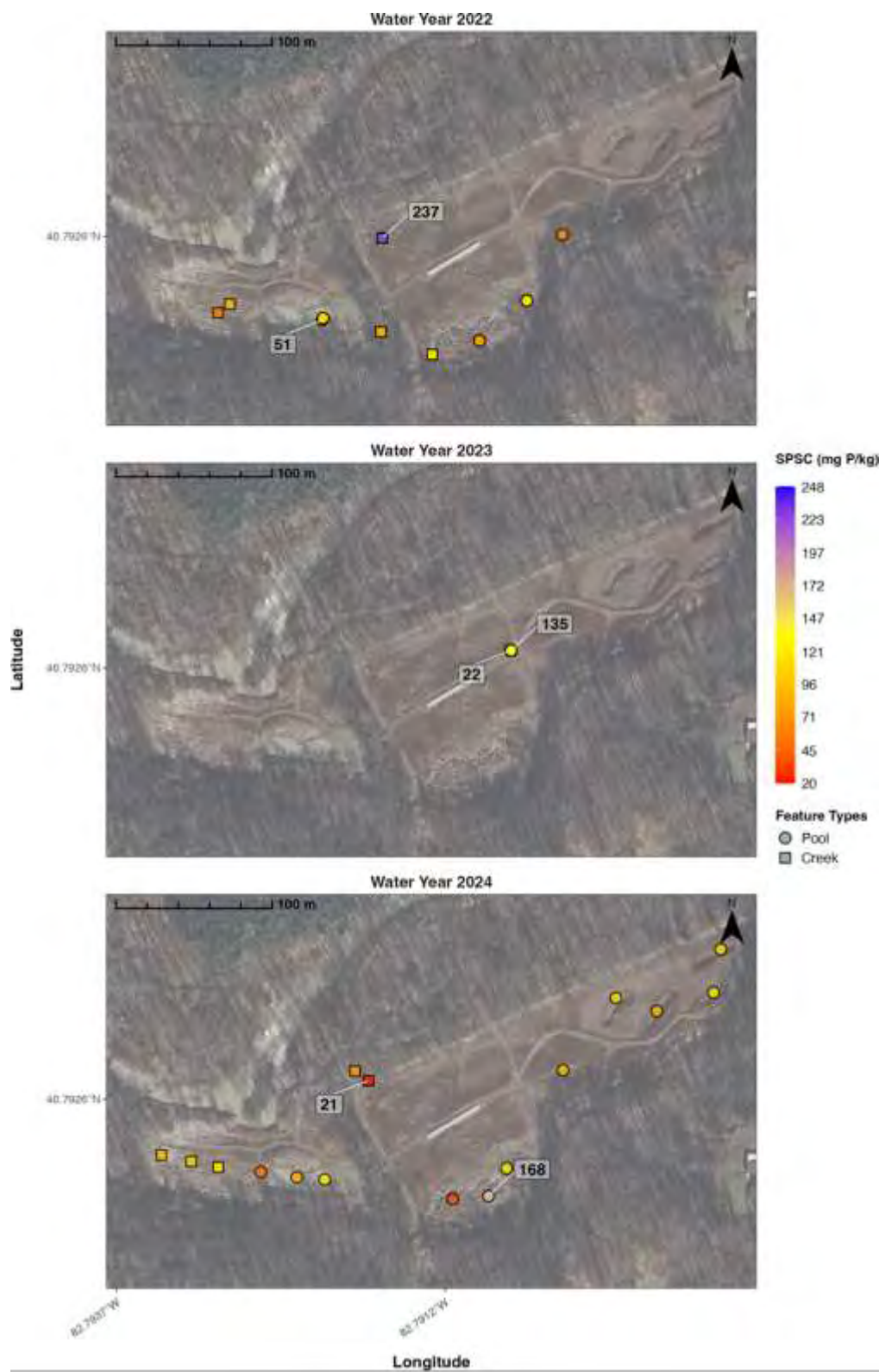


Figure 289. Soil Phosphate Sorption Capacity (SPSC) throughout the Sandusky River Headwaters Preserve Wetland & Habitat Restoration Project. Each point denotes a soil sample (0–5 cm) and different shapes indicate the wetland feature type, as shown in the legend. Colors indicate the SPSC value of each sample relative to the overall range of values observed at the wetland project, as shown in the color bar. Each panel shows the soil samples collected during a respective water year (Oct 1–Sep 30), along with the minimum and maximum SPSC values observed during a given water year. Negative SPSC values indicate the potential for soils to release phosphate, while positive values indicate soils have capacity to sorb phosphate, based on Mehlich-3 extractions of phosphate, iron, and aluminum.

Next Steps to Strengthen Understanding

Over the coming monitoring year, researchers will continue to assess water level measurements and pool volumes, along with flow from the primary inflow, to calculate the water and nutrient storage capacity at this Project. Volume calculations will also support nutrient load reduction estimates associated with this wetland restoration project. Continued development of soil sampling at set locations of interests will assist researchers to build a database of soil phosphate sorption capacity (SPSC) values that have been lacking in prior years of monitoring and will provide insight into the site's potential for phosphorus sorption as the Project matures. More SPSC data will be critical to understand which soil locations within the Project are becoming saturated with phosphate and could help to drive future management considerations at the Project.

Sugarcamp 7 Blanchard Habitat (SUGB)

Project Description

Putnam County | Blanchard River Watershed

Project size: 6 Acres

Partner: Private Landowner

The hydrology of this Project is passively managed. The Project has 9 acres of restored wetland, consisting of a flow-through wetland system as well as around 50 hummock and hollow pools within a floodplain wetland. The main pool has four inflows that flow into the pool before discharging into a ditch flowing into the Blanchard River. Two of the inflows are surface water runoff; one directs water from the hummock and hollow portion of the wetland and the other drains from an agricultural field to the east. The other two inflows are tile drainage from surrounding areas. A hydrologic event at this Project is operationally defined as a storm event in which the Blanchard River floods its banks filling the hummock and hollow pool.



Figure 290. Aerial image showing surface water flow and sampling locations for the Sugarcamp 7 Blanchard Habitat Project. Blue arrows indicate direction of surface water flow. Dots represent geographic base crew sampling locations, which are grouped by Project features (fill color) where relevant. Text annotations provide additional context about the Project's watershed connection or other important features.

Management Considerations

The Sugarcamp 7 Blanchard Habitat Project (hereafter Sugarcamp 7) is a unique H2Ohio wetland in that it treats both point source (septic tank) and nonpoint source (tile drain) inflows. This helps maintain a consistent water level and nutrient source in the main pool even under drought conditions. Throughout Water Year 2024, the main pool outflow often had no flow, indicating much of the nutrient input was stored and not exported. Continued data collection should help researchers better assess the duration of that storage. The vernal pool and the hummock and hollow pools are variable in their water storage and resulting potential to filter nutrients. Some hummock and hollow pools (HH pools) have never contained water, which researchers believe is due to their elevation relative to the other HH pools and the river. Some have water seasonally and some will only retain water following flooding event with the river. Researchers have yet to collect water samples from HH pools only impacted by flooding events.

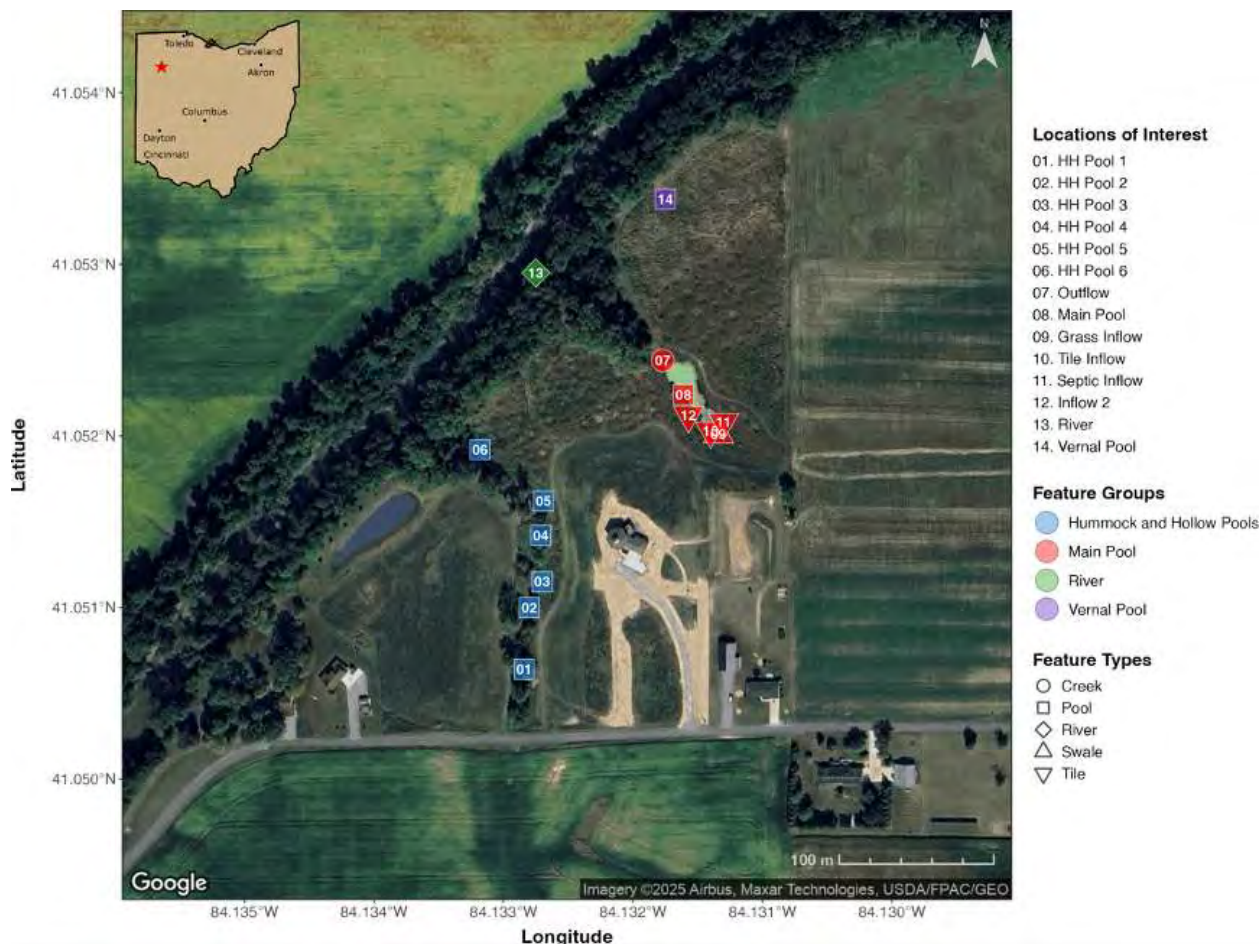


Figure 291. Aerial image of approximate locations of interest for water and soil sampling and discrete manual measurements of water depth and physicochemical parameters at Sugarcamp 7 Blanchard Habitat Project during water year 2024 (Oct 1, 2023–Sep 30, 2024). The legend provides the name of each sampling point. Different shapes denote the types of wetland features represented by the locations of interest. If present, different colors represent locations of interest that belong to a group or complex of features (e.g., a treatment train).

Nutrient Budget Takeaways

There is currently not enough data to calculate filtration values for the Sugarcamp 7 Project. However, the conversion from agricultural land to wetland prevents 13 ± 9 lbs. of phosphorus runoff annually. Soils throughout the Project have high capacity to sorb phosphate, as suggested by soil phosphate sorption capacity values.

Surface Water Hydrology and Nutrients

Pool depths across all sampling locations at Sugarcamp 7 ranged from 0 cm to 36 cm (Figure 292). The deepest locations were the Main Pool, Main Pool Outflow and hummock and hollow (HH) Pool 1. Many of the hummock and hollow pools were dry through much of the year and averaged far lower depths. Researchers only observed a measurable depth in the outflow during two storm event conditions. The septic and tile inflows were often submerged, so the depth measured at those locations often reflected the main pool depth at the edge rather than depth of water in the tile or septic pipes. There is evidence of the Blanchard River flooding the entire Project during high flow events resulting in complete connectivity of pools. Depth notably increased during storm events in the HH pools and Main Pool. Following storm events, there is increased flow at the inflow tiles and water in each of the HH pools along the chosen sampling transect. In addition to the two inflow tiles in the main pool, the pool also receives surface water runoff from the HH pools and from a grassed inflow “swale”.

Total phosphorus (TP) and dissolved reactive phosphorus (DRP) concentrations overall increased after storm conditions compared to ambient conditions (Figure 293, Figure 294). Ambient TP concentrations were still elevated (> 0.15 mg/L), but with lower DRP concentrations; much of that phosphorus (P) was likely particulate bound or in organic form. Inflow concentrations during a storm event had lower TP and DRP concentrations compared to the main pool and the outflow. However, this may reflect that the researchers missed the storm event inflow and captured that event as it was exiting the main pool. Generally nutrient concentrations in surface water have decreased since the beginning of monitoring in Water Year (WY) 2022 except for the septic inflow which has nearly doubled in concentration since 2022 (0.048 mg P/L to 0.097 mg P/L DRP and 0.321 mg P/L to 0.707 mg P/L TP). The septic inflow is known to be fed by household sewage treatment systems. However, the exact location of these systems or the number of systems tied into this outflow is not known. In addition to TP and DRP, nitrite+nitrate and total ammonium concentrations have also been increasing in the septic inflow over the last several years (Figure 293, Figure 294, Figure 296). If these trends continue, Sugarcamp 7 could become a nutrient source, as it currently stands the average DRP

concentration of the outflow (0.074 mg P/L) is nearing the average river concentration (0.077 mg P/L). Researchers have not had the opportunity to capture an event where the Blanchard River floods into Sugarcamp 7, however base crews will watch USGS staff gauges to see if higher flows flood Sugarcamp 7 in future years. Note that Hummock and Hollow pool sampling locations have changed location from WY 2023.

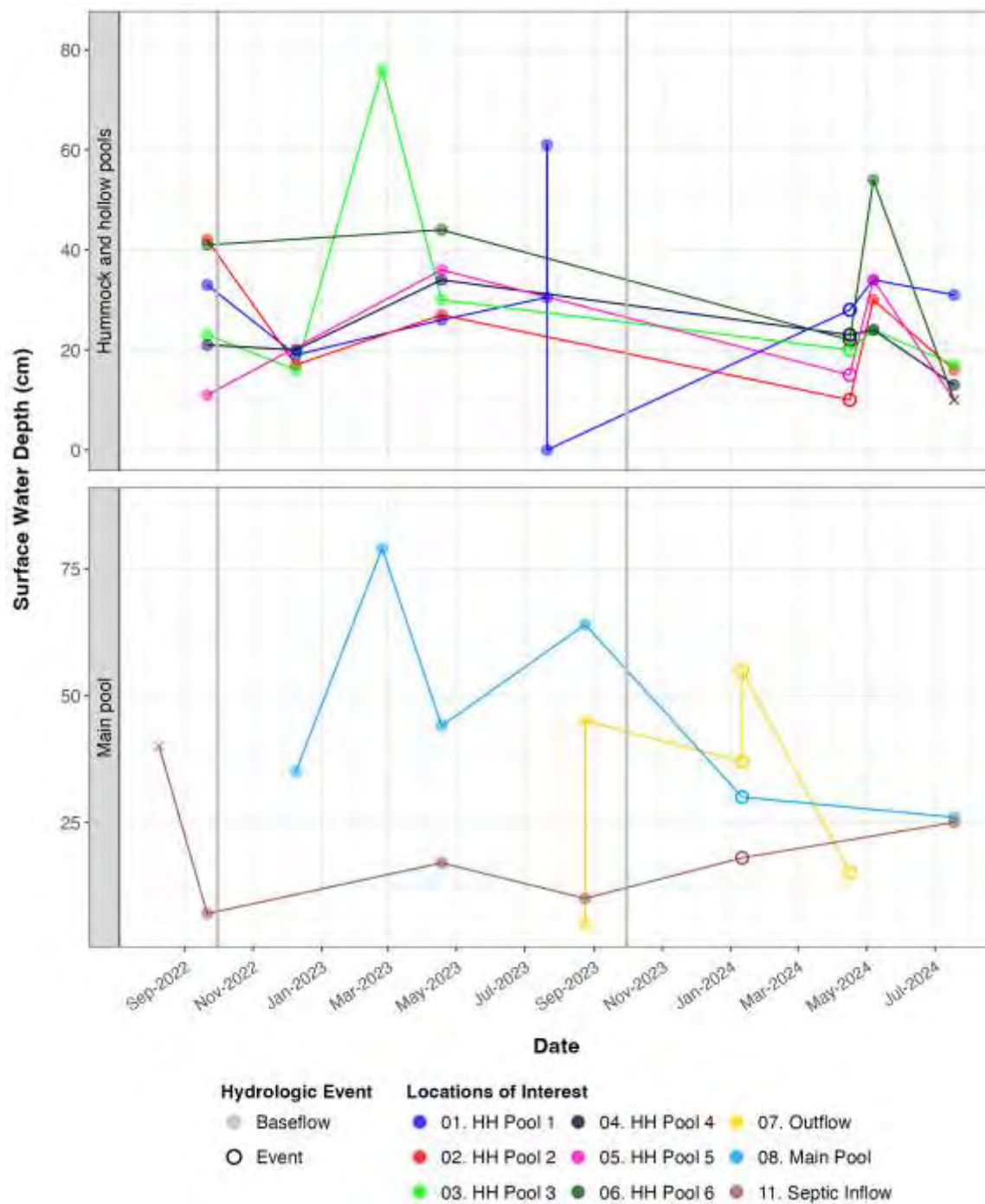


Figure 292. Time series of discrete, manually measured surface water depth at the Sugarcamp 7 Blanchard Habitat Project. Depths were measured approximately monthly. Each point represents one measurement and colors denote the locations of interest, as indicated in the legend. Open symbols indicate samples that were collected during a hydrologic event (e.g., storm event) and filled symbols denote samples collected during baseflow. Crosses (×) represent instances when no surface water was detected during the visit. If present, different shapes denote the types of wetland features represented by the locations of interest. Gray vertical lines indicate the start of a water year (Oct 1–Sep 30).

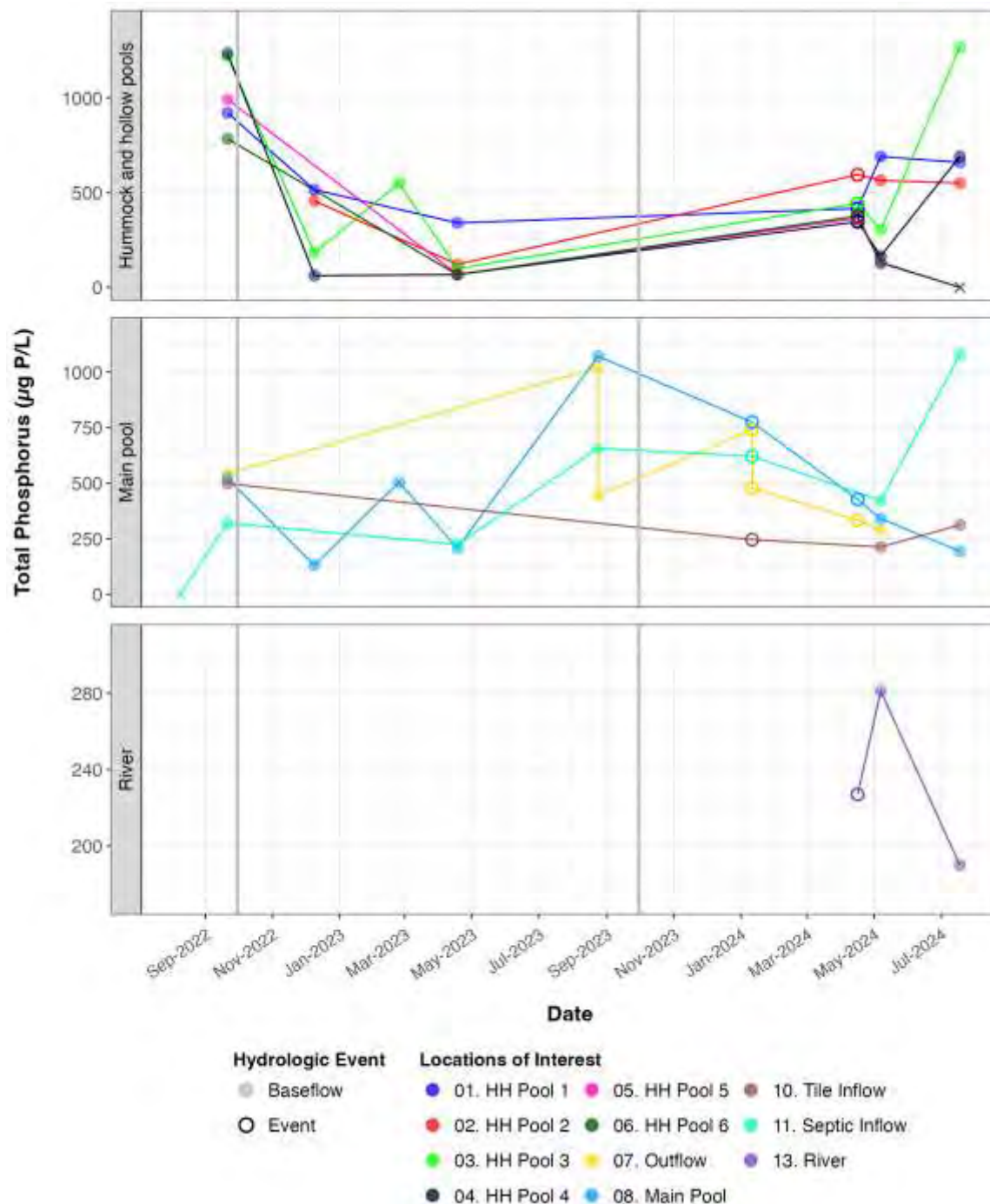


Figure 293. Time series of total phosphorus (TP) concentrations in surface water samples collected at the Sugarcamp 7 Blanchard Habitat Project. Values below the detection limit of the analytical equipment were replaced with half the value of the detection limit. Each point represents one measurement, and colors denote the locations of interest, as indicated in the legend. Open symbols indicate that measurements were collected during a hydrologic event (e.g., storm event) and filled symbols denote measurements collected during baseflow. Crosses (×) represent instances when no surface water was detected during the visit. If present, different

shapes denote the types of wetland features represented by the locations of interest. Gray vertical lines indicate the start of a water year (Oct 1–Sep 30).

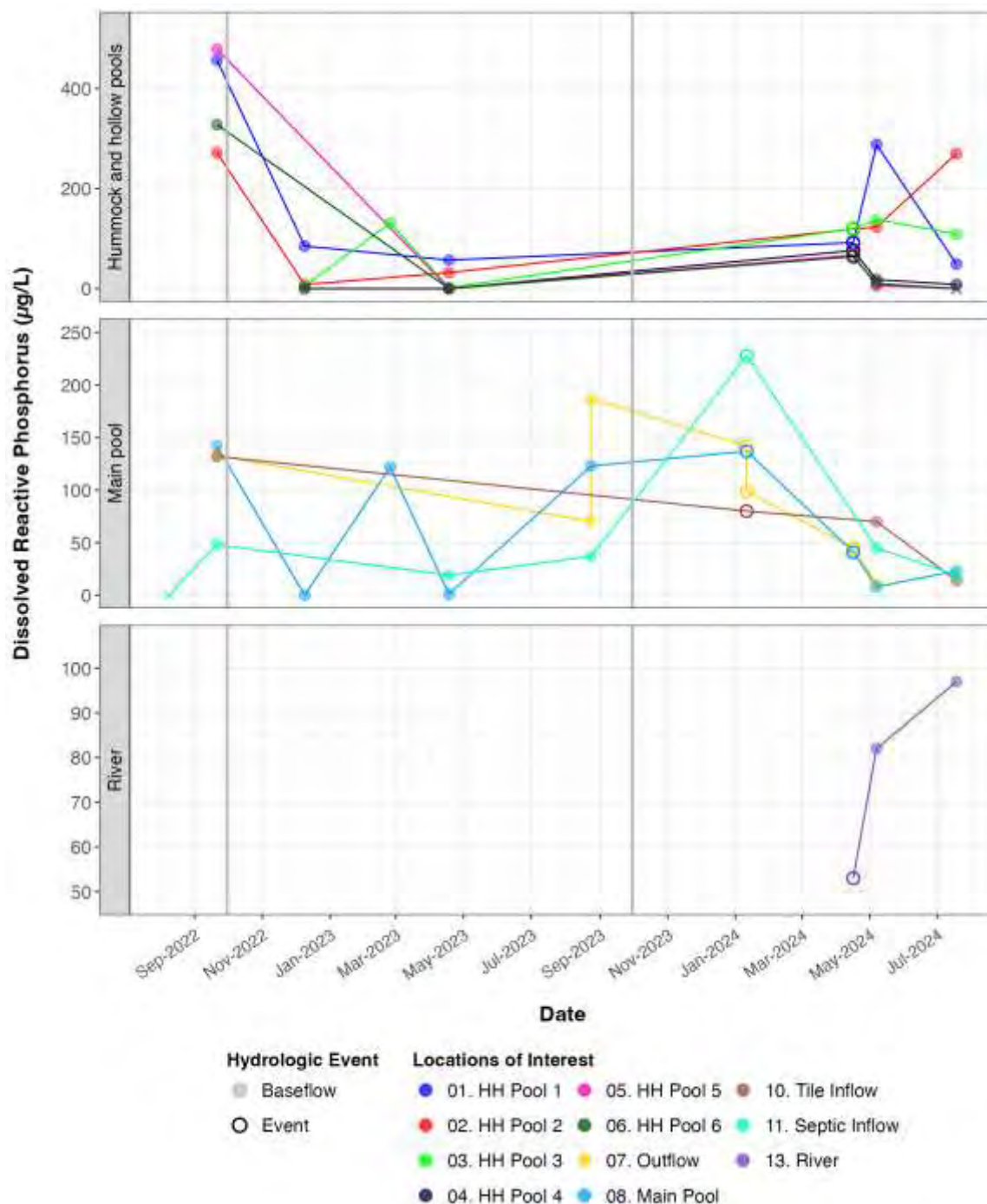


Figure 294. Time series of dissolved reactive phosphorus (DRP) concentrations in surface water samples collected at the Sugarcamp 7 Blanchard Habitat Project. Values below the detection limit of the analytical equipment were replaced with half the value of the detection limit. Each

point represents one measurement, and colors denote the locations of interest, as indicated in the legend. Open symbols indicate that measurements were collected during a hydrologic event (e.g., storm event) and filled symbols denote measurements collected during baseflow. Crosses (×) represent instances when no surface water was detected during the visit. If present, different shapes denote the types of wetland features represented by the locations of interest. Gray vertical lines indicate the start of a water year (Oct 1–Sep 30).

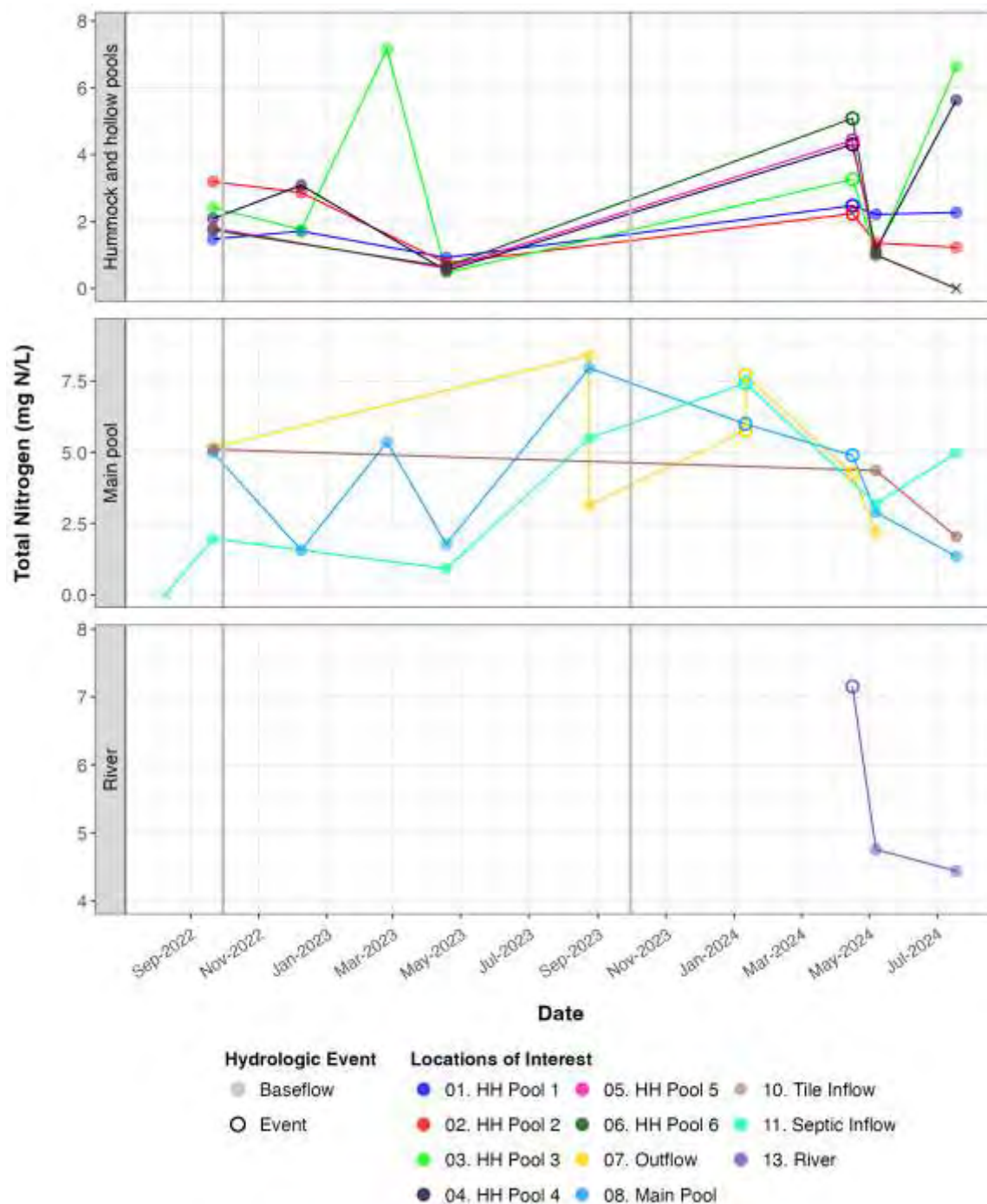


Figure 295. Time series of total nitrogen (TN) concentrations in surface water samples collected at the Sugarcamp 7 Blanchard Habitat Project. Values below the detection limit of the analytical equipment were replaced with half the value of the detection limit. Each point represents one measurement, and colors denote the locations of interest, as indicated in the legend. Open symbols indicate that measurements were collected during a hydrologic event (e.g., storm event) and filled symbols denote measurements collected during baseflow. Crosses (×) represent instances when no surface water was detected during the visit. If present, different shapes denote the types of wetland features represented by the locations of interest. Gray vertical lines indicate the start of a water year (Oct 1–Sep 30).

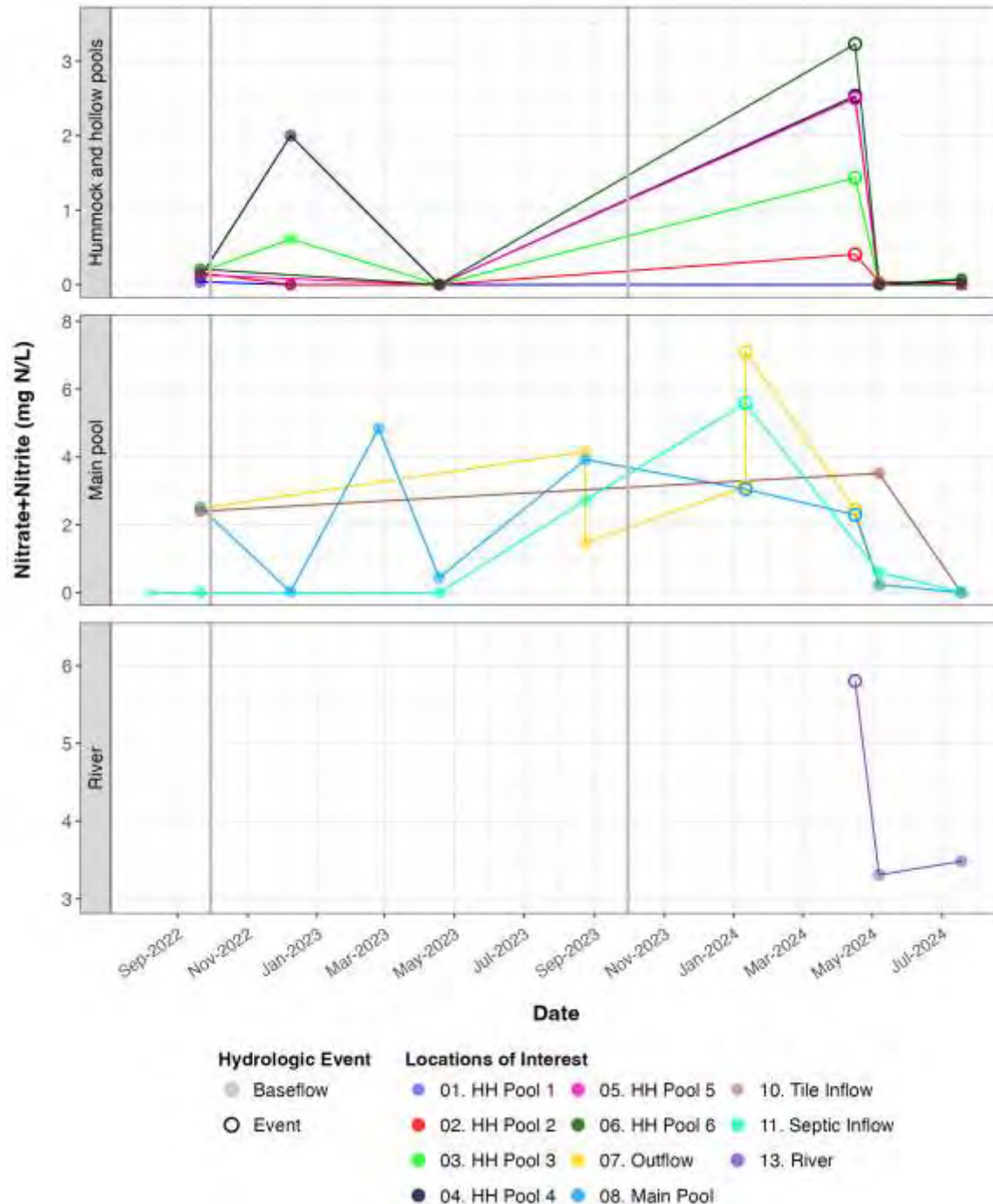


Figure 296. Time series of Nitrite+nitrate (NO_x) concentrations in surface water samples collected at the Sugarcamp 7 Blanchard Habitat Project. Values below the detection limit of the analytical equipment were replaced with half the value of the detection limit. Each point represents one measurement, and colors denote the locations of interest, as indicated in the legend. Open symbols indicate that measurements were collected during a hydrologic event (e.g., storm event) and filled symbols denote measurements collected during baseflow. Crosses (×) represent instances when no surface water was detected during the visit. If present, different

shapes denote the types of wetland features represented by the locations of interest. Gray vertical lines indicate the start of a water year (Oct 1–Sep 30).

Soil Nutrient Status and Processes

With the exception of one soil sample collected in Water Year (WY) 2023, WY 2024 was the first year of complete soil sample collection at Sugarcamp 7. Soil samples were collected from the Main Pool, Vernal Pool and from each of the Hummock and Hollow (HH) pools. Samples were collected along the edge and the deepest locations of the Main Pool. Soil pH ranged from 5.4 to 7.5 in WY 2024, whereas pH values in WY 2023 were all slightly above neutral. Soil conductivity was comparable to other H2Ohio wetland soils, except for within the Main Pool, which had the highest soil conductivity of 3,819 $\mu\text{S}/\text{cm}$. This could be due to this pool being fed directly by a tile from home septic systems that could have elevated conductivity. All other soil conductivities were 898 $\mu\text{S}/\text{cm}$ (HH Pool 3) or below. There was no observable difference between Mehlich-3-extractable P (M3-P), iron (M3-Fe), or aluminum (M3-Al) between the HH pools and the Main Pool. The soil phosphate sorption capacity values were all positive, ranging from 61.44 to 209.56 mg phosphorus/kg, suggesting the soils have a high capacity to sorb additional phosphorus (Figure 297).



Figure 297. Soil Phosphate Sorption Capacity (SPSC) throughout the Sugarcamp 7 Blanchard Habitat Project. Each point denotes a soil sample (0–5 cm) and different shapes indicate the wetland feature type, as shown in the legend. Colors indicate the SPSC value of each sample relative to the overall range of values observed at the wetland project, as shown in the color bar. Each panel shows the soil samples collected during a respective water year (Oct 1–Sep 30), along with the minimum and maximum SPSC values observed during a given water year. Negative SPSC values indicate the potential for soils to release phosphate, while positive values indicate soils have capacity to sorb phosphate, based on Mehlich-3 extractions of phosphate, iron, and aluminum.

Next Steps to Strengthen Understanding

Monitoring at this Project can be challenging, as inflows are frequently submerged below the main pool surface and the hummock and hollow pools cannot all be monitored due to their large abundance. Researchers have installed continuous water level loggers at the main pool and outflow and are looking forward to translating that information into water storage and possible load reduction estimates over the coming year. Researchers also need to understand how the Project behaves during flood conditions and need to more effectively sample Sugarcamp 7 during these events to better understand nutrient concentrations. With the installation of the sensor network in the main pool and live access to water level researchers will be able to actively monitor storm events as they are occurring. More storm event sampling of water volume and water concentration is needed to fully understand the capacity of the main wetland pool to filter inputs to the river. Additionally, more SPSC samples will need to be collected in Water Year 2025 to determine if there are any increases or decreases in the Projects overall capacity to sorb phosphate.

Upper Blanchard River Watershed Project (UPPB)

Project Description

Wyandot County | Blanchard River Watershed

Project size: 30 Acres

Partners: Wyandot Soil and Water Conservation District

This Project's inflow is passively managed, while the outflow is controlled by a water level control structure located at the west of the property. The Project has 30 acres of restored wetland, consisting of two wetland pools with the main pool being fed by an upstream agricultural ditch. During high flow events, this ditch receives both surface runoff and tile drainage from the surrounding fields. Surface water enters the Project via a wide ditch into the main pool. This Project also has a large branching pool that does not connect to the rest of the wetland pools during ambient flow. A hydrologic event at this Project is operationally defined as a storm event in which flow is expected through the upstream agricultural ditch.



Figure 298. Aerial image showing surface water flow and sampling locations for the Upper Blanchard River Watershed Project. Blue arrows indicate direction of surface water flow. Dots represent geographic base crew sampling locations, which are grouped by Project features (fill

color) where relevant. Text annotations provide additional context about the Project's watershed connection or other important features.

Management Considerations

There is a noticeable difference seen in aerial imagery and chemistry data for nutrient parameters and turbidity between the Main Pool and the Branching Pool at Upper Blanchard River Watershed Project, largely attributed to the lack of vegetation in the Main Pool. Increasing the amount of vegetation in the main pool would not only lower turbidity in the pool but would also aid in the reduction of nutrient concentrations before leaving the Project.

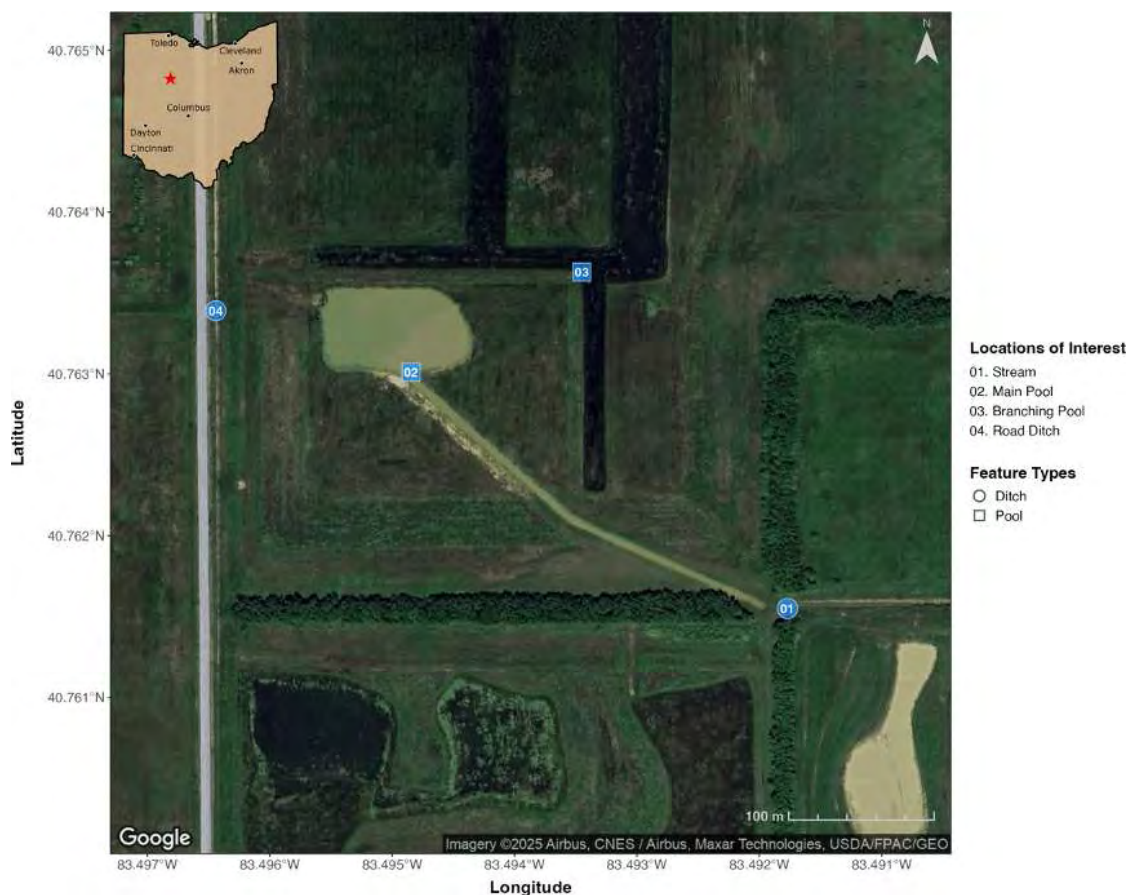


Figure 299. Aerial image of approximate locations of interest for water and soil sampling and discrete manual measurements of water depth and physicochemical parameters at Upper Blanchard River Watershed Project during water year 2024 (Oct 1, 2023–Sep 30, 2024). The legend provides the name of each sampling point. Different shapes denote the types of wetland features represented by the locations of interest. If present, different colors represent locations of interest that belong to a group or complex of features (e.g., a treatment train).

Nutrient Budget Takeaways

There is currently not enough data to calculate filtration values for the Upper Blanchard Project. However, the conversion from agricultural land to wetland prevents 20 ± 13 lbs. of phosphorus runoff annually. Soils throughout the Project have high capacity to sorb phosphate, as suggested by soil phosphate sorption capacity values.

Surface Water Hydrology and Nutrients

Upper Blanchard Project has successfully worked to reroute an agricultural drainage ditch through an existing wetland pool to facilitate nutrient reduction before draining offsite. Water exits the Project via a water level control structure rather than bypassing existing wetland capacity. Water enters the Project through the main inflow channel (“stream” location of interest) which drains upland agriculture fields. From there the water enters the main pool where it has the opportunity to settle. Except for algal growth there is little vegetation established within the main pool, so the majority of sorption must occur through sediments. Once the pool water level reaches its threshold, water exits the Project through a water level control structure into an adjacent roadside ditch.

Water depth was slightly lower in Water Year (WY) 2024 than in WY 2023, likely the result of drought conditions (Figure 300). As the Project currently functions, runoff drains into the main inflow stream from upland fields, enters the main pool and remains there until it reaches its capacity, and then flows through the water level control structure into the roadside ditch. Even during high flow events where the inflow is greater than the outflow, there is no connectivity between the main pools and the branching pool. When water levels were low, base crews observed remnants of tile connecting the branching pool to the stream, however, there has never been evidence of pool connection.

In WY 2024 there was a total of ten sampling events at Upper Blanchard Project, four of which were storm sampling events. The average pH measured at the Project was slightly basic, except for the Branching Pool which had an average pH of 8.2. Both the inflow and outflow had a pH of 7.2, and the main pool had a pH of 7.8. Turbidity in the main pool also decreased from an average peak of 357 FNU in WY 2023 to 186 FNU in WY 2024. Base crews noted the consistently high turbidity in the stream and main pool even during ambient sampling events. The cause of the turbidity may be the clay and silt that was suspended following construction and for unknown reasons has remained suspended. One storm sampling event in February 2024 resulted in similar total phosphorus across all locations of interest, even at the branching pool with no direct connection to the rest of the wetland. The main pool has the greatest average total phosphorus concentration of 0.302 ± 0.1 mg P/L of all locations of interest. The Road Ditch has an average total phosphorus concentration of 0.265 ± 0.1 mg P/L, which is comparable to the inflow of the Project (0.291 ± 0.1 mg P/L). The lack of difference would be a concern for the overall functionality of the Project, however, the samples taken from Road Ditch were taken during periods of high flow and could contain water that was not filtered through the Project. The similar concentrations could also be the result of water not having the opportunity to settle in the main pool before discharging, because of the increased flow across the Project.

In conclusion, the Upper Blanchard Project, while successfully rerouting agricultural drainage through a wetland pool, demonstrates mixed results regarding nutrient reduction. While turbidity decreased in WY 2024, likely due to settling, the Project exhibited limited effectiveness in reducing total phosphorus, particularly during high-flow events. The comparable total phosphorus concentrations between the inflow and outflow, coupled with the consistently high turbidity in the main pool, suggest potential limitations in the wetland's capacity to effectively process nutrients. Further investigation is needed to determine the source of the persistent turbidity and to optimize the project's function, especially during storm events, to achieve significant nutrient reduction and improve water quality.

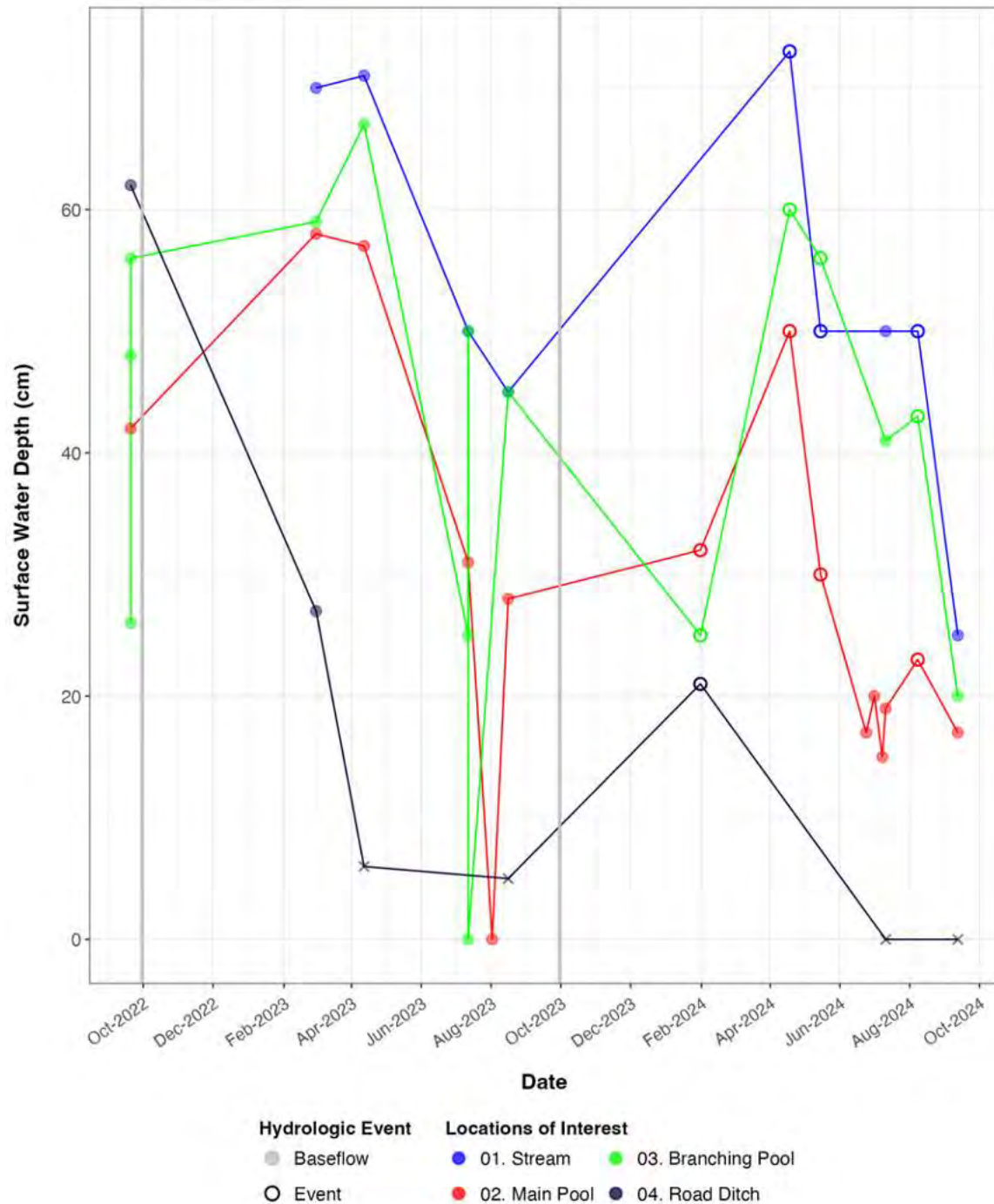


Figure 300. Time series of discrete, manually measured surface water depth at the Upper Blanchard River Watershed Project. Depths were measured approximately monthly. Each point represents one measurement and colors denote the locations of interest, as indicated in the legend. Open symbols indicate samples that were collected during a hydrologic event (e.g., storm

event) and filled symbols denote samples collected during baseflow. Crosses (×) represent instances when no surface water was detected during the visit. If present, different shapes denote the types of wetland features represented by the locations of interest. Gray vertical lines indicate the start of a water year (Oct 1–Sep 30).

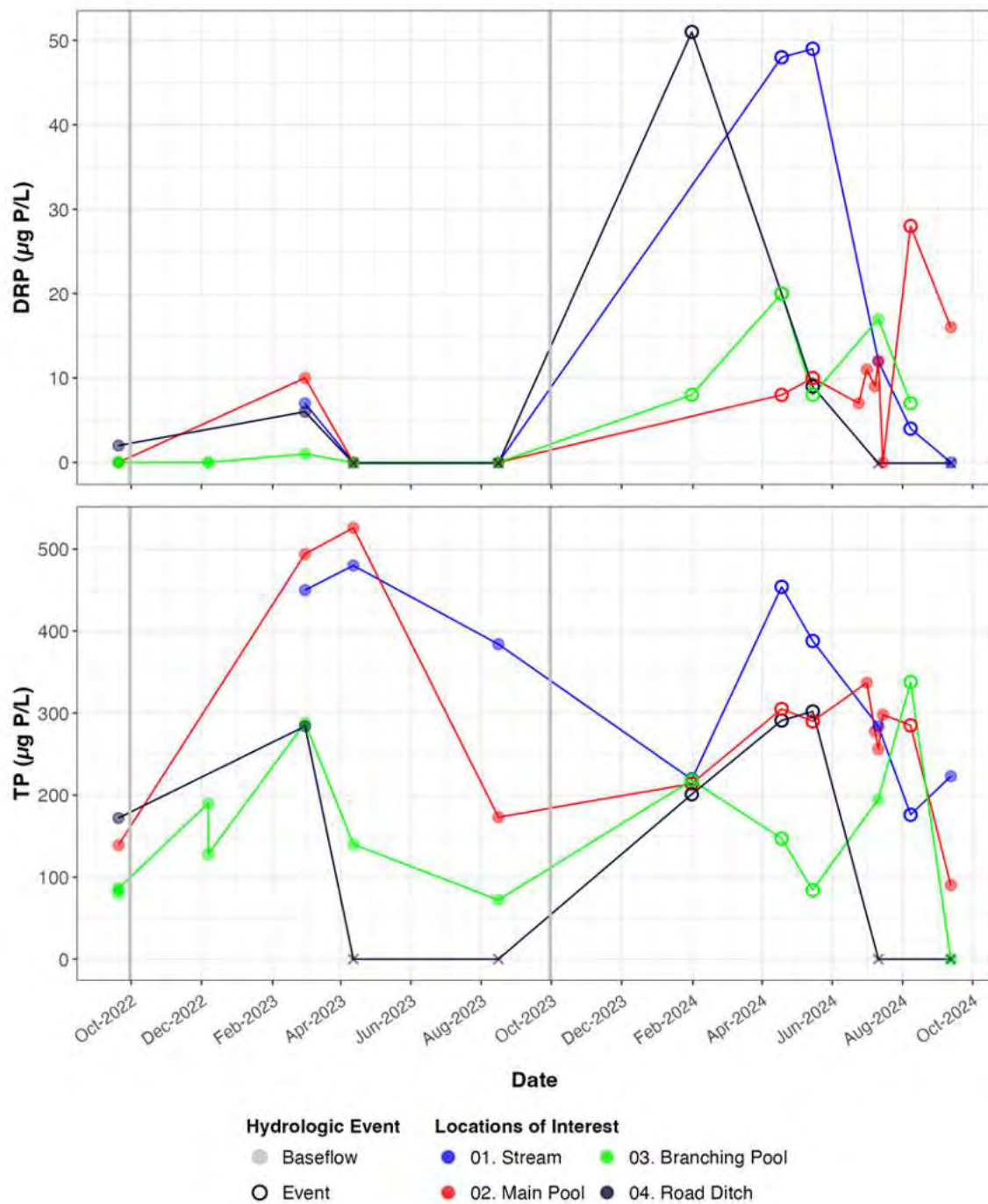


Figure 301. Time series of dissolved reactive phosphorus (DRP, top panel) and total phosphorus (TP, bottom panel) concentrations in surface water samples collected at the Upper Blanchard River Watershed Project. Values below the detection limit of the analytical equipment were replaced with half the value of the detection limit. Each point represents one measurement, and colors denote the locations of interest, as indicated in the legend. Open symbols indicate that measurements were collected during a hydrologic event (e.g., storm event) and filled symbols denote measurements collected during baseflow. Crosses (×) represent instances when no surface water was detected during the visit. If present, different shapes denote the types of wetland features represented by the locations of interest. Gray vertical lines indicate the start of a water year (Oct 1–Sep 30).

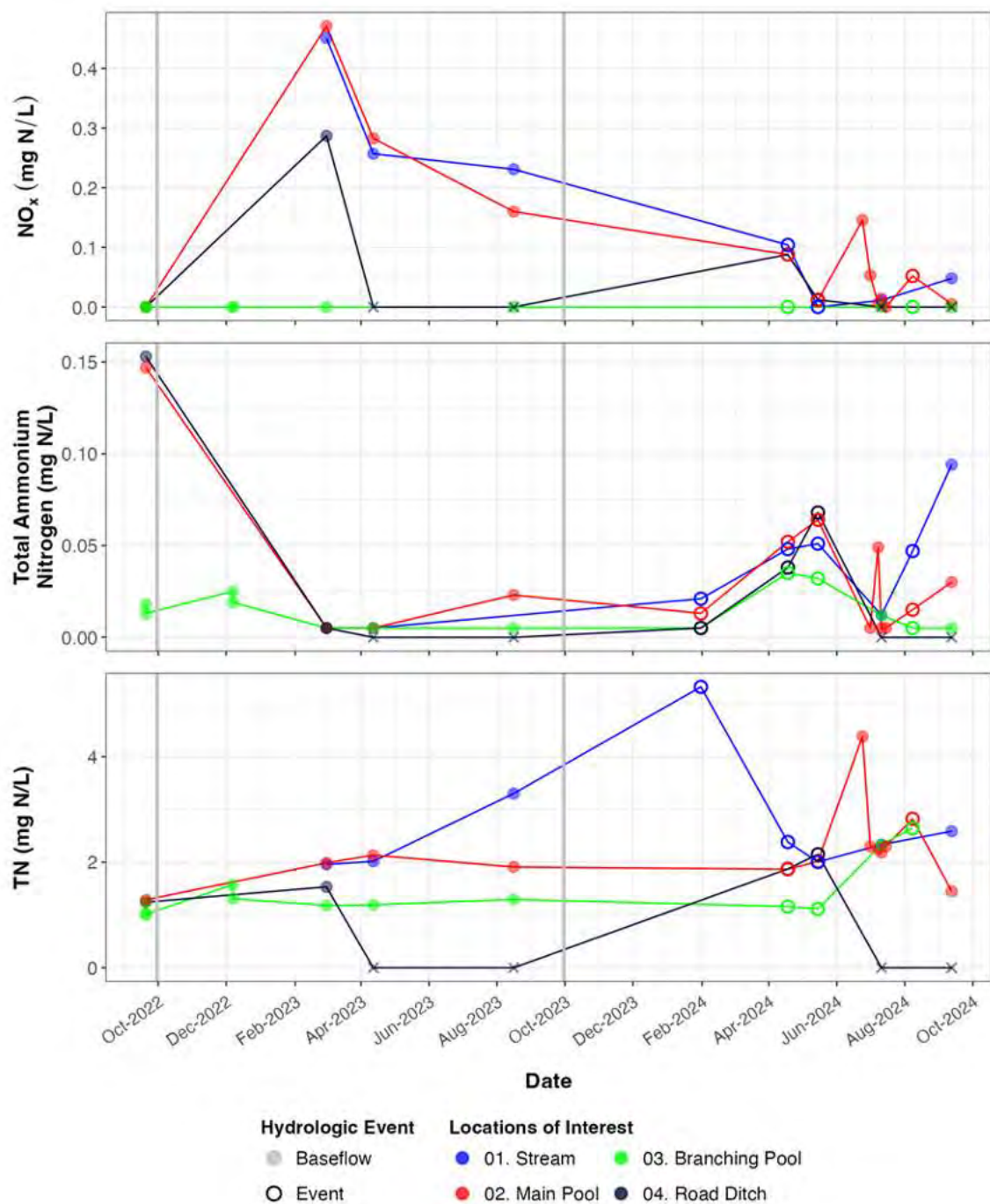


Figure 302. Time series of Nitrite+nitrate (NO_x, top panel) total ammonium nitrogen (NH₄-N, middle panel), and total nitrogen (TN, bottom panel) concentrations in surface water samples collected at the Upper Blanchard River Watershed Project. Values below the detection limit of the analytical equipment were replaced with half the value of the detection limit. Each point represents one measurement, and colors denote the locations of interest, as indicated in the legend. Open symbols indicate that measurements were collected during a hydrologic event (e.g.,

storm event) and filled symbols denote measurements collected during baseflow. Crosses (×) represent instances when no surface water was detected during the visit. If present, different shapes denote the types of wetland features represented by the locations of interest. Gray vertical lines indicate the start of a water year (Oct 1–Sep 30).

Soil Nutrient Status and Processes

Soil phosphate sorption capacity (SPSC) in Water Year 2024 at Upper Blanchard Project ranged from 81.8 to 192.4 mg phosphorus/kg. The Stream location of interest had the highest available SPSC value (163.774 mg/kg; Figure 303). All locations of interest at the Project currently have positive SPSC values, meaning that the soil should have the capacity to sorb phosphate. In comparison to SPSC values from Water Year (WY) 2023, values across all locations of interest increased in WY 2024, indicating an even greater capacity to sorb.



Figure 303. Soil Phosphate Sorption Capacity (SPSC) throughout the Upper Blanchard River Watershed Project. Each point denotes a soil sample (0–5 cm) and different shapes indicate the wetland feature type, as shown in the legend. Colors indicate the SPSC value of each sample relative to the overall range of values observed at the wetland project, as shown in the color bar. Each panel shows the soil samples collected during a respective water year (Oct 1–Sep 30), along with the minimum and maximum SPSC values observed during a given water year. Negative SPSC values indicate the potential for soils to release phosphate, while positive values indicate soils have capacity to sorb phosphate, based on Mehlich-3 extractions of phosphate, iron, and aluminum.

Next Steps to Strengthen Understanding

Researchers will need to determine flow calculations for the Project to determine conditions for which there is active inflow and outflow at the Project without residence time to allow nutrient

settling and sorption. Researchers will also need to determine if there are any remaining connections between the Branching Pool and the Main Pool. If any connection still exists, this may be allowing water from the inflow to also enter the Branching Pool, facilitating more storage and filtering than otherwise intended.

Appendix I: Additional Figures and Narratives

Focal Projects

Brooks Park

Hydrogeophysics

Bulk apparent conductivity (ECa) was generally lower in the upland berms of this Project and higher near the pool boundaries, ranging from 1 to 112 mS/m (Figure 304). Measurements in the middle portion of the site near locations of interest 2, 7, 8, and 9 were collected about two weeks after measurements on the southern and northern areas. Changing Project conditions between sampling events likely confounded the shift in ECa range observed in the middle portion of the site, as measurements in the middle portion of the Project near locations of interest 2, 7, 8, and 9 (Settling Pool, Pool 3, Pool 4, Flat Between Pools 5 and 6) were collected about two weeks after data on the southern and northern areas (Locations of interest 10, 11, 12, 5, 13; Pool 7, Pool 10,

Pool 13, Outflow, Coldwater Creek at Outflow). While ECa were collected over the entire Project, equipment errors during collection required data near locations of interest 3 and 6 (Overland Drainage, Overland Pool A) be removed from the dataset to ensure accuracy of reported values.

Despite changing Project conditions and missing data, relative differences between ECa values can still be useful in determining how sediment properties are related to ECa. By relating ECa and measured pore water conductivity (ECw, Figure 305), geophysical data can be used to map sediment property distribution. Electrical signal primarily travels through electrolytic pore fluid within soils, which is captured by ECw. However, additional analysis indicates that other factors besides pore fluid are moderately contributing to ECa at this Project (See Appendix I).

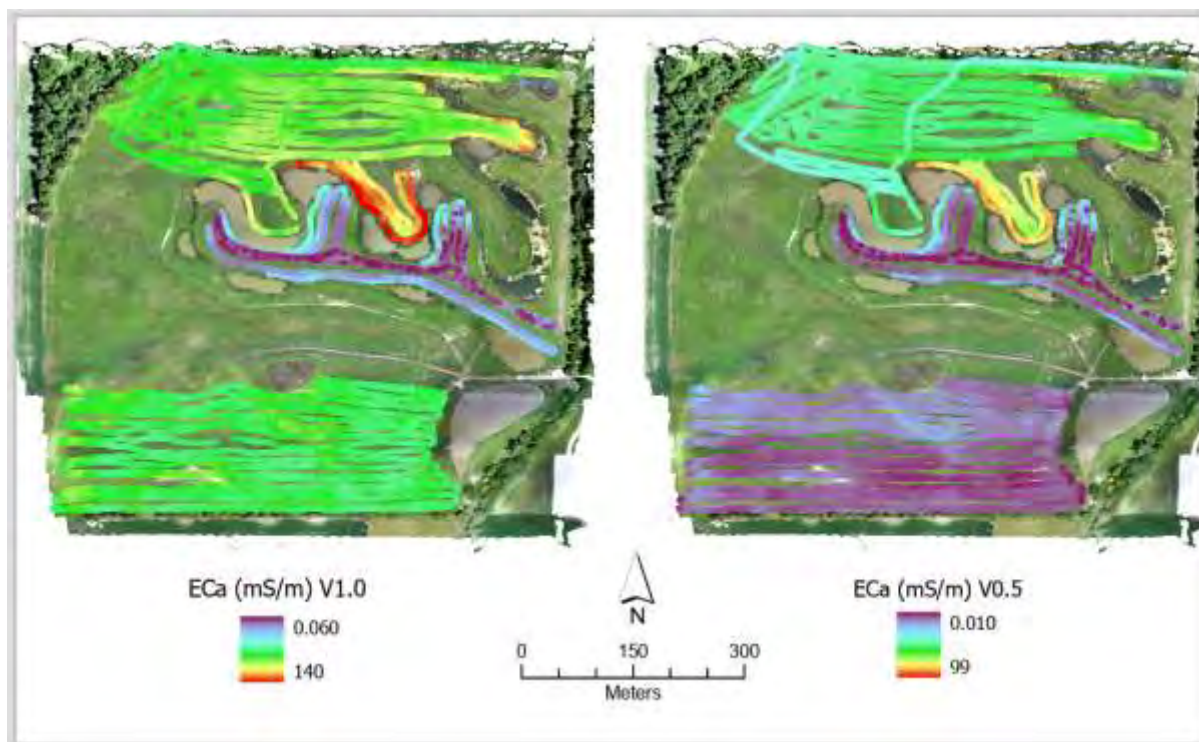


Figure 304. Apparent bulk soil electrical conductivity (ECa) at Burntwood-Langenkamp Wetland Conservation area in August – September 2023 for (left) 1.5-m depth (1.0-m coil spacing) and (right) 0.75-m depth (0.5-m coil spacing) of investigation.

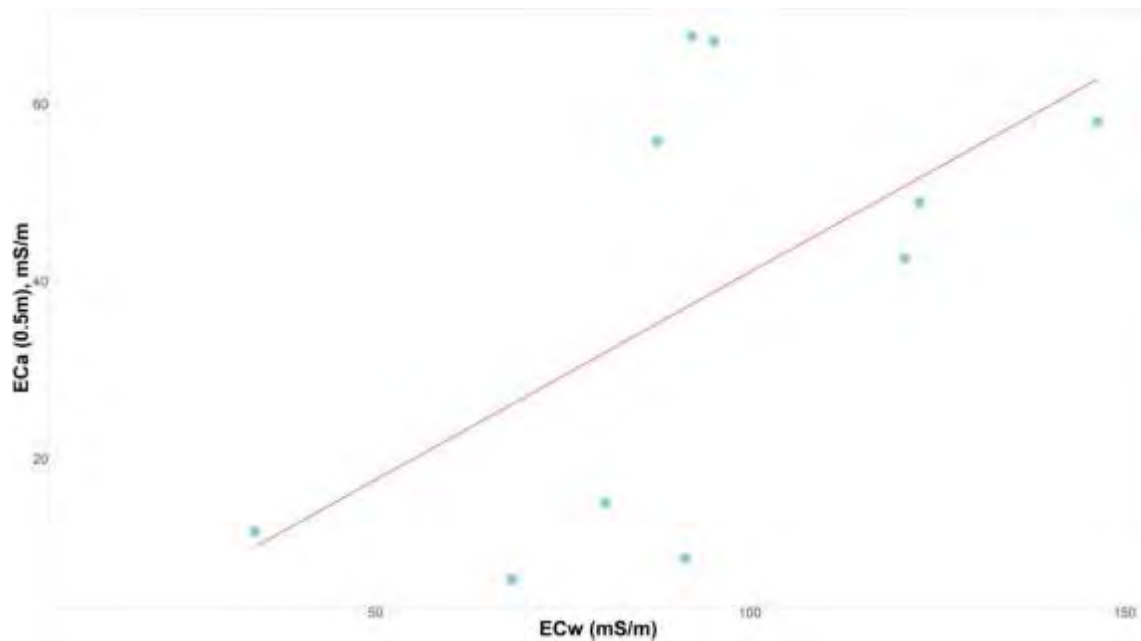


Figure 305. A linear regression of Burntwood-Langenkamp Wetland Conservation Area of the Bulk soil electrical conductivity (ECa) at the 0.75-m depth of investigation in relation to pore water conductivity (ECw) collected at 30 cm. ($R^2 = 0.41$).

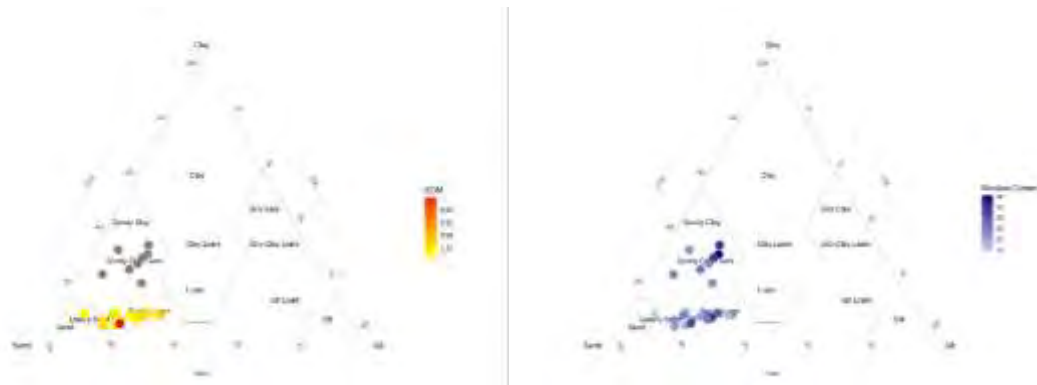


Figure 306. Soil texture triangle, in the USDA configuration, highlighting the classification of the soil samples taken at the Brooks Park Wetland Creation & Water Quality Initiative through soil and hydrometer analysis. Colors denote the Solid organic matter (SOM) and Water moisture content. High values are indicated by darker colors and low values are lighter colors.

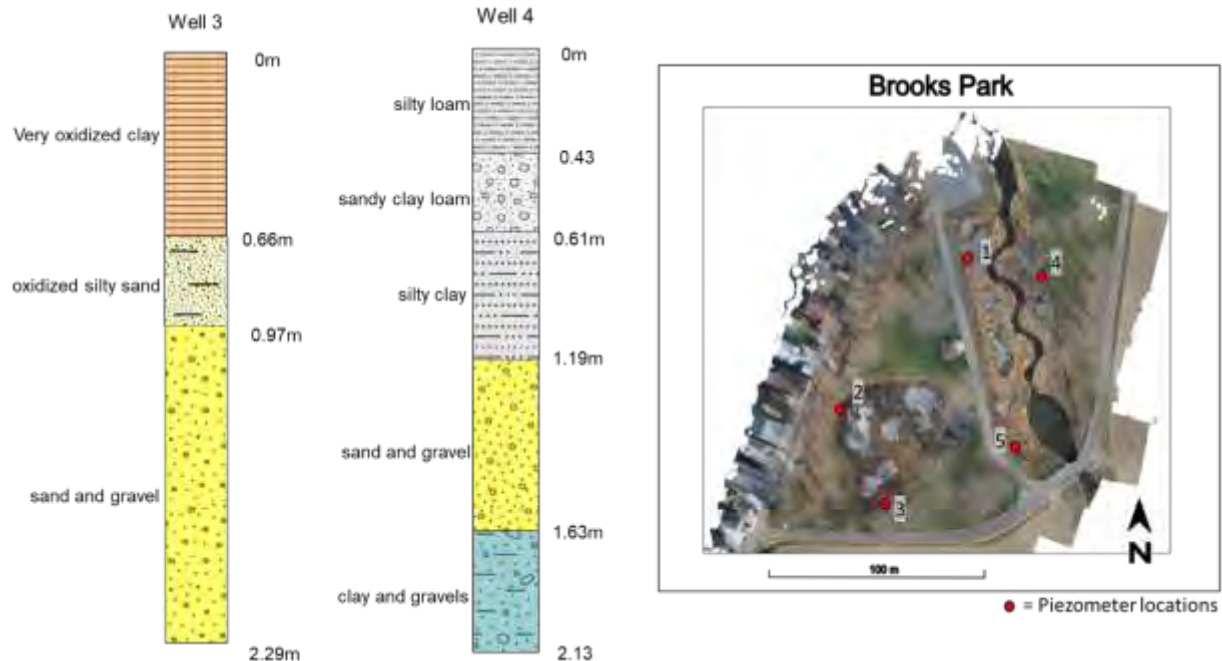


Figure 307. Groundwater Well Logs 3 and 4 for Brooks Park Wetland Creation & Water Quality Initiative Project. Locations for the wells can be found in the figure to the right. Wells 3 and 4 show sediments coarsening downward between 0.75 m to 1.5 m depth from clay to sand to gravel. Depending on moisture content at the time of the survey, sand and gravel have larger spaces between the grains, allowing for a higher proportion of pore water within the sediment.

Burntwood-Langenkamp Project

3-D Hydrodynamic Modeling

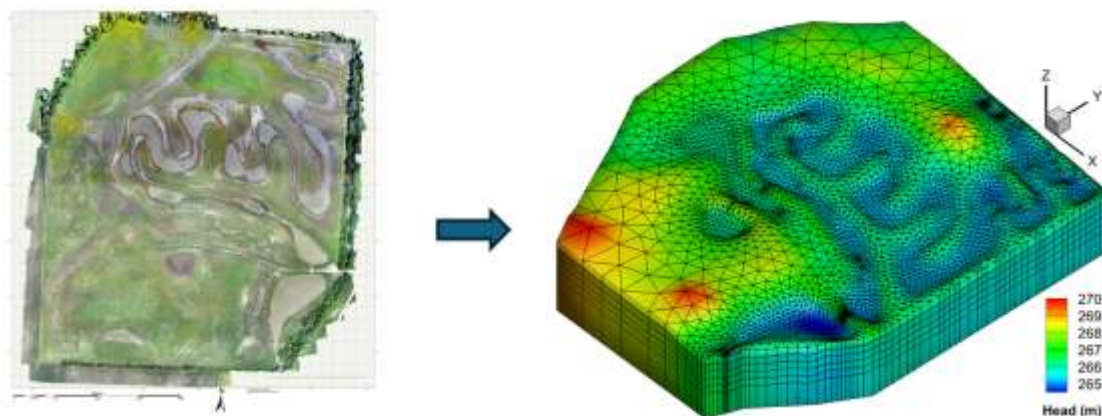


Figure 308. Development of a 3-D hydrologic model for the Burntwood-Langenkamp Project. The left panel shows an aerial image of the Project. The right panel shows the model domain, grid, and representative simulated hydraulic head values (in colors) in a 3-D framework.

Hydrogeophysics

Of each parameter measured by the BGSU laboratory, pH was the best predictor of EC_w ($R^2 = 0.58$). pH values ranged from 6.3 to 8.1. Since pH can affect nitrogen and phosphorus availability to plants as well as adsorption to soil, the relationship between pH and EC_a can be leveraged to better understand nutrient availability¹⁴ at Burntwood-Langenkamp Wetland Conservation Area.

While there is a moderate correlation between EC_a and EC_w ($R^2 = 0.41$), two clusters of data points appear on the plot, suggesting that separate sediment properties may be controlling EC_a depending on location within the site. When analyzed independently, the group of lower values (sampling locations 1, 10, 11, and 14 in southeast corner of Project) show no correlation with EC_a (0.5-m spacing). The second group with higher values (sampling locations 2, 4, 5, 6, 7, and 8) shows a slightly negative correlation ($R^2 = -0.22$). These two parameters were low to moderately correlated ($R^2 = 0.41$).

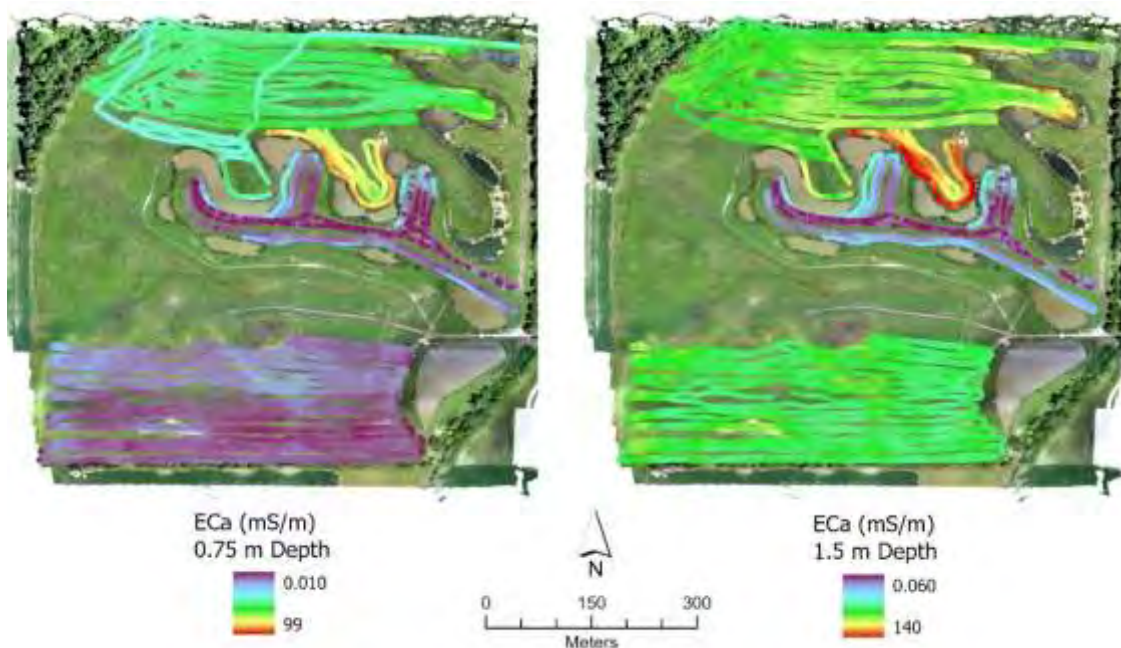


Figure 309. Apparent bulk soil electrical conductivity (ECa) at Burntwood-Langenkamp Wetland Conservation Area for (left) 0.5 m coil spacing (0.75 m depth) and (right) 1.0 m coil spacing (1.5 m depth).

¹⁴ Miller, J. (2016). Soil pH Affects Nutrient Availability. University of Maryland Extension; University of Maryland College of Agriculture and Natural Resources. https://extension.umd.edu/sites/extension.umd.edu/files/publications/FS-1054%20Soil%20pH%20and%20Nutrient%20Availability_Update_12_2021.pdf

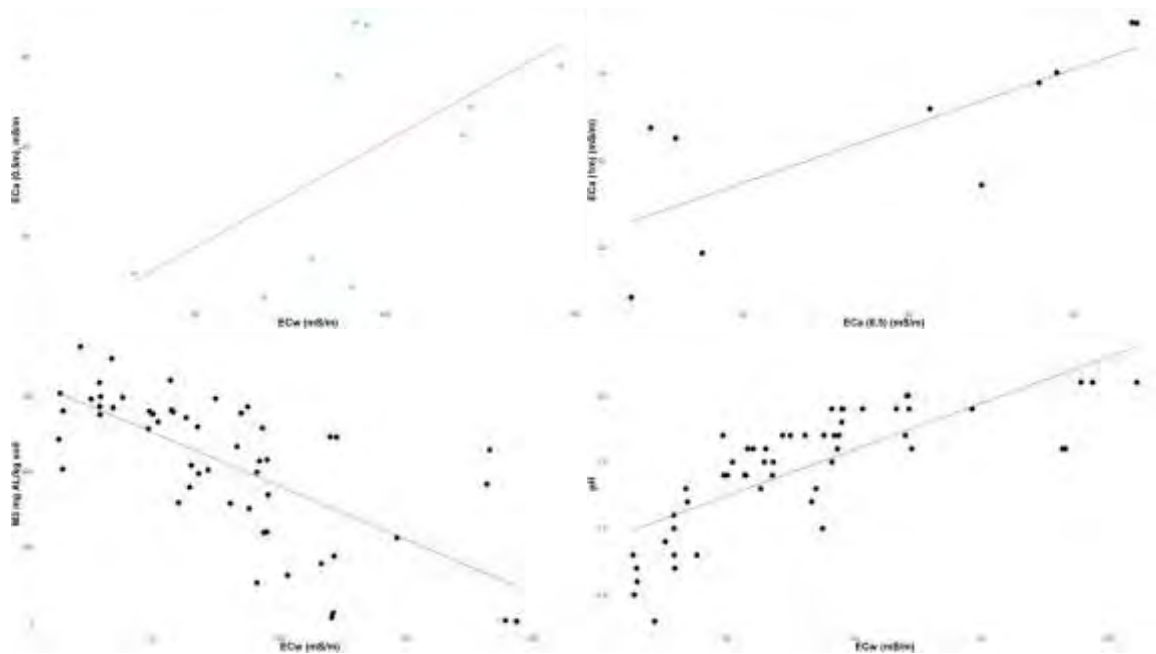


Figure 310. **ECa vs ECw (top left)** A linear regression of Burntwood-Langenkamp Wetland Conservation Area of the Bulk soil electrical conductivity (ECa) at the 0.75-m depth of investigation vs. pore water conductivity (ECw) collected at 30 cm. The value of $R^2 = 0.41$ indicates a moderate correlation. **ECa with Depth (top right)** linear regression of Burntwood-Langenkamp Wetland Conservation Area, estimating the relationship between ECa (mS/m) at 0.5m and 1m spacing for the EMI survey. The value of $R^2 = 0.607$ indicates a moderate to high correlation. **ECw vs M3 mg Al/kg soil (bottom left)** A linear regression of Burntwood-Langenkamp Wetland Conservation Area, estimating the relationship between ECw (mS/m) and M3 mg Al/kg soil at 0.5m spacing for the EMI survey. The value of $R^2 = 0.477$ indicates a moderate correlation. **ECw vs pH (bottom right)** linear regression of Burntwood-Langenkamp Wetland Conservation Area, estimating the relationship between ECw (mS/m) and pH at 0.5m spacing for the EMI survey. The value of $R^2 = 0.587$ indicates a moderate to high correlation.



Figure 311. Hydrogeophysical soil sampling locations for Burntwood-Langenkamp Conservation Area. Points 3, 5, 7, and 13 were removed from linear regression analysis since they did not have an associate value for ECa due to equipment errors during the survey.

Forder Bridge

3-D Hydrodynamic Modeling

One of the applications of the 3-D hydrodynamic models developed by the H2Ohio Wetland Monitoring Program team is to examine wetlands' function and optimize their potential in filtering or removing nutrients. Although models have not been calibrated yet at this stage, their capability of simulating complex hydrology enables researchers to identify “*idle*” pools (i.e., the wetland pools that do not receive or participate in filtering nutrient-rich water released to the wetland projects). Here, researchers present two example cases to demonstrate such an application.

The Forder Bridge Project was designed and built to have four wetland complexes, each consisting of a series of wetland pools. Comparing the locations of the wetland complexes to modeling results (Figure 10.2 of H2Ohio Wetland Monitoring Program 2023 Annual Report), however, it is unlikely that the water and solute originated from the culvert would reach two of the four wetland complexes (i.e., Wetland 1 & 3 Complexes). In other words, pools within these two complexes are basically idle and do not play a crucial role in nutrient reduction as expected.

To address the “idle” issue and increase the nutrient-reduction efficiency of the Forder Bridge, researchers recommend enhancing the hydrologic connectivity between the inlet stream and wetland complexes by installing pumps and underground pipes, which could transfer nutrient-rich water to those idle pools and even to the large “dryland” located in the eastern portion of the wetland site.

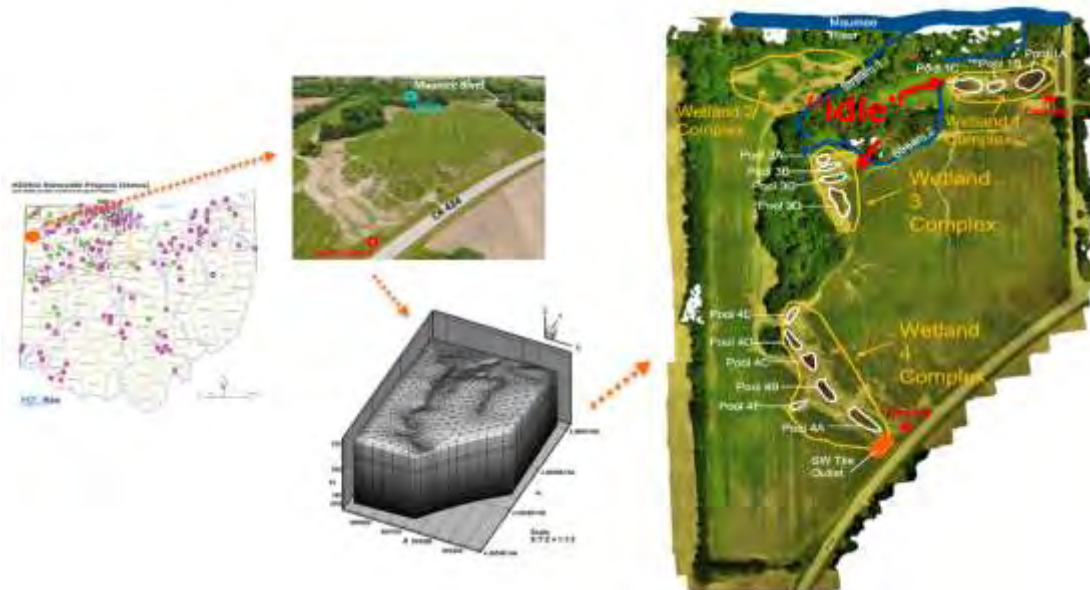


Figure 312. Development and application of 3-D models to identify “idle” wetland complexes at the Forder Bridge H2Ohio wetland project. Note that Wetland 1 & 3 Complexes (red arrows in right panel) are identified as “idle” based on a 3-D scenario simulation.

Hydrogeophysics

Apparent electrical conductivity (ECa) values for Forder Bridge were collected using a conductivity meter with two transmitter-receiver sensor spacings of 0.5 m and 1.0 m that gives two different average depth sensitivities of 0.75- and 1.5-m. ECa data collected in August of 2020 across the whole Project range from 17 to 92 mS/m for both coil spacings. In general, higher values were found along the upland areas adjacent to County Road 424, and lower values were found in the wetland complexes and lowland areas closer to the Maumee River. When compared to data collected in May of 2022, ECa values ranged from 7 to 69 for the two coil spacings. In the May 2022 survey, ECa patterns were reversed, being higher in the channel and lower on the banks near Wetland Complex 4. Wetter Project conditions during the May 2022 survey could’ve contributed to these differing patterns, since there would be more water in the channel during that time of the year. While NRCS Web Soil Survey maps roughly correlate with ECa data in the southeastern portions of the site, spatial data available for Forder Bridge have not been updated since 2019, meaning that reworked areas are likely to not be reflected in NRCS records.

North of the treatment train pools A through D (wetland complex 4), alternating bands of lower and higher ECa data ranging from about 24 to 37 mS/m extend across the Project in the southwest/northeast orientation. These features could be coarse and fine-grained sediment deposition, respectively, resulting from previous river flooding events, potentially indicating past flooding extent of the Maumee River.

Certain soil properties can be characterized by their response to electrical signals, meaning that ECa can be used as a proxy for measuring soil characteristics. These results will allow base crews to create targeted soil sampling campaigns, ensuring soil heterogeneity is captured with less effort and samples. Linear regression analysis between ECa at 0.75-m and selected soil properties showed that Soil Organic Matter (SOM, $R^2 = 0.63$), mg of phosphorus per kilogram of soil (mg/kg, $R^2 = 0.58$), pH ($R^2 = 0.46$), and soil moisture content (SMC, $R^2 = 0.35$) were the best correlated with ECa.

Interestingly, mg/kg and SOM were negatively correlated with ECa. To explain this relationship, other literature was consulted. Factors limiting microbial decomposition, such as soil salinity, can decrease the amount of SOM while increasing ECa^{15, 16}. Soil at Forder Bridge adjacent to County Road 424 (near the southern half of the site) could've experienced years of road salt application prior to construction, leaving them with a higher ECa. Then, construction of Wetland Complex 4 likely revealed lower conductivity soils beneath the surface, now present in the channel.

¹⁵ Peralta, N. R., and Costa, J. L. (2013). Delineation of management zones with soil apparent electrical conductivity to improve nutrient management. *Computers and Electronics in Agriculture*, 99, 218–226. <https://doi.org/10.1016/j.compag.2013.09.014>

¹⁶ Tripathi, S., Kumari, S., Chakraborty, A., Gupta, A., Chakrabarti, K., and Bandyopadhyay, B. K. (2005). Microbial biomass and its activities in salt-affected coastal soils. *Biology and Fertility of Soils*, 42(3), 273–277. <https://doi.org/10.1007/s00374-005-0037-6>

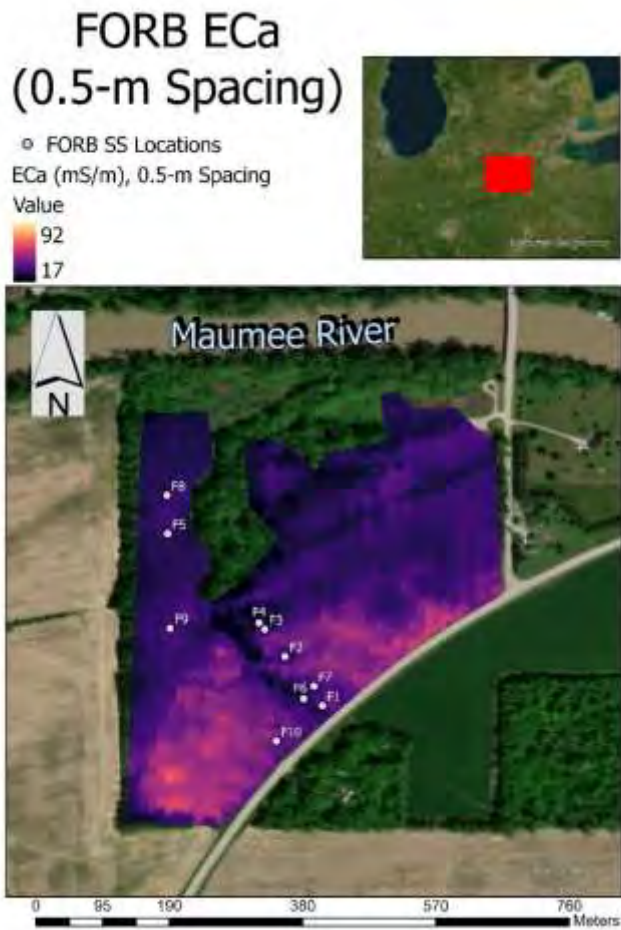


Figure 313. Apparent Bulk Conductivity (ECa, mS/m) for the 0.5-m EMI coil spacing taken at Forder Bridge. Data were collected 09/26/2020. ECa values ranged from 17 to 92 mS/m after outlier removal.



Figure 314. ECa data (0.5-m spacing) with NRCS Web Soil Survey soil zones overlayed over top.

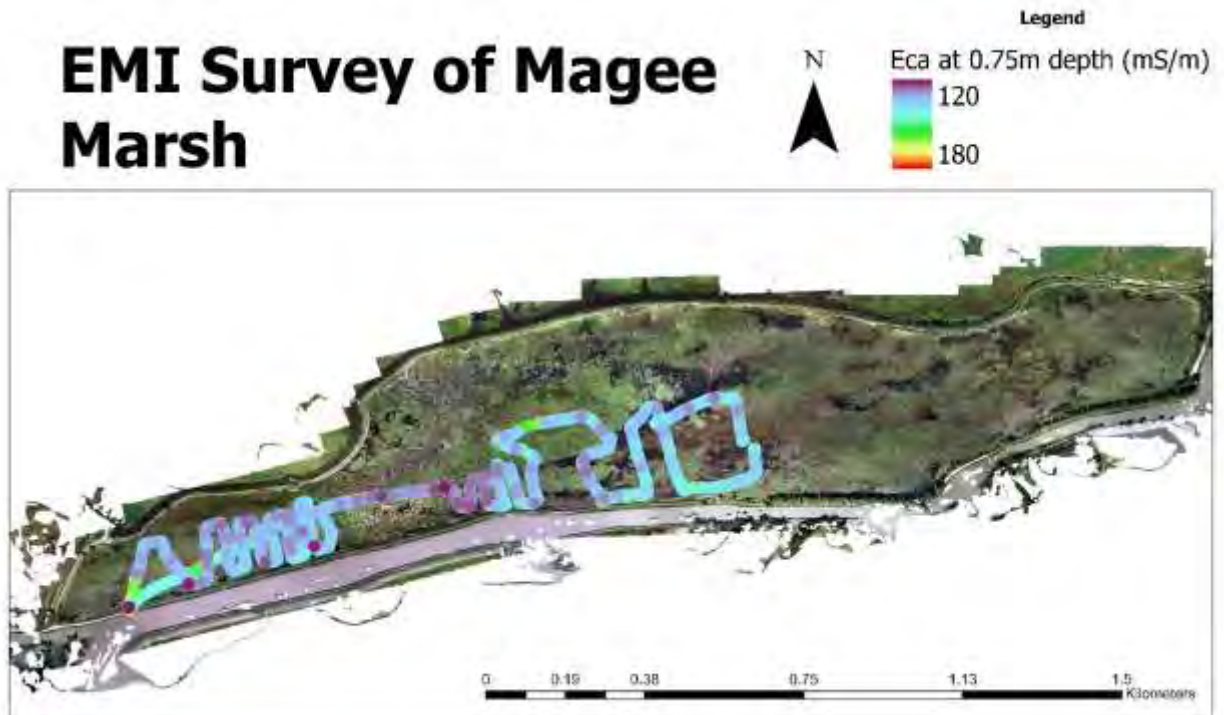
Magee Marsh

Hydrogeophysics

Bulk Electrical Soil Conductivity (ECa) was measured using a Geonics EM38-Mk2 sensor at 0.5-m and 1.0-m coil spacing at the Magee Marsh Project. These coil spacings correspond with approximate depths of investigation of 0.75-m and 1.5-m, respectively. The 0.75-m ECa values ranged from 120 to 180 milli Siemens per meter (mS/m), and the 1.5-m ECa values ranged from 63 to 91 mS/m (Figure 315). Near-surface water column conductivity was measured simultaneously with ECa using a Hanna Instruments probe (model number HI98194) and ranged from 37.1 to 44.1 mS/m. When linear regression analysis was performed, temperature and pH showed an R^2 of 0.1415. PH and ECa had an R^2 of 0.2849. ECa was not well-correlated with any of the measured parameters other than resistivity, which is the inverse of EC.

Both EMI surveys follow similar distribution patterns of highest values near the southwest edge of the Project and lowest values in the middle of the pool, but the 1.5-m depth values more closely correspond with bathymetric readings. Values for the 0.75-m survey show a higher overall range compared to the 1.5-m survey. Observations during Project visits confirmed that there is a layer of unconsolidated sediment beneath the surface of the water that extends to a depth of about 0.80 m and is underlaid by a consolidated layer. The consolidated layer could be lacustrine deposits, although soil cores are needed to confirm the actual stratigraphy. The unconsolidated layer shows a higher range in values for ECa than the sediment due to a higher percentage of pore water compared to the consolidated layer beneath it. Because the 0.75-m survey does not extend beneath the unconsolidated layer, these values are more likely to be representative of sediment property variation measured by base crews such as SPSC, total phosphorus, and total nitrogen. While the ECa map has yet to be ground-truthed, variations in ECa can aid base crews in designing soil sampling campaigns that encompass Project heterogeneity more efficiently.

EMI Survey of Magee Marsh



EMI Survey of Magee Marsh

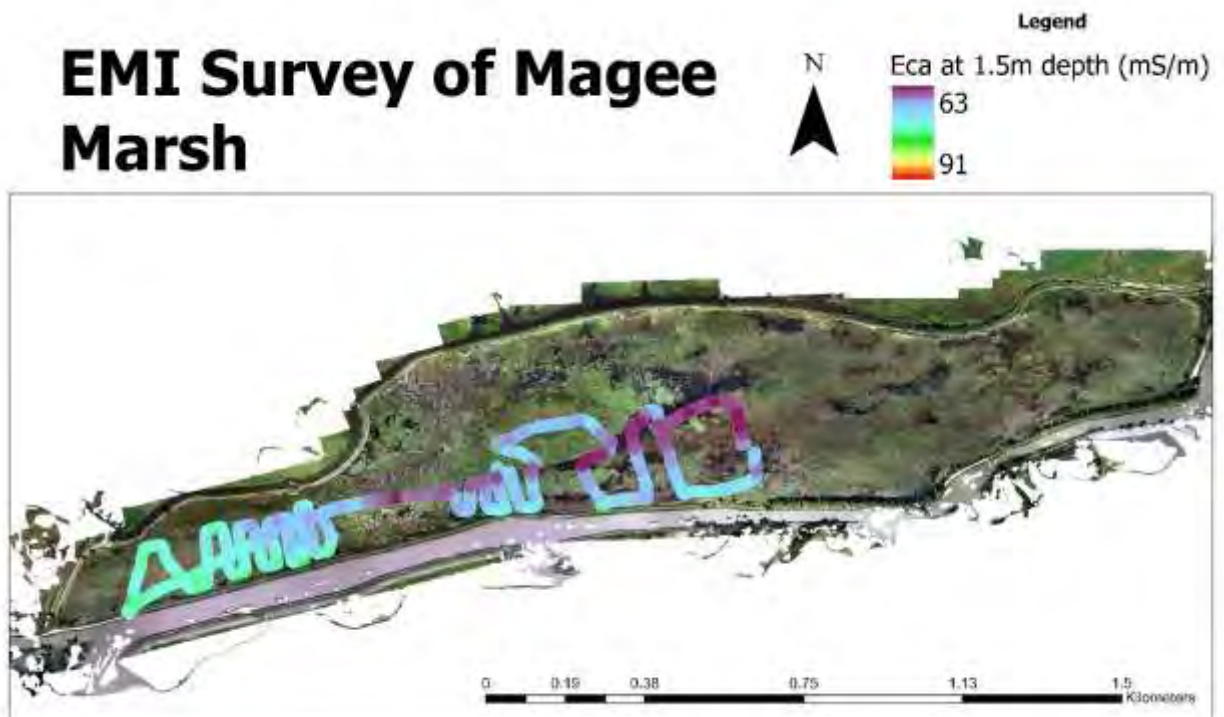


Figure 315. Electrical Soil Conductivity (ECa) for 0.5- (top) and 1.0-m (bottom) EMI coil spacing. 0.5-m and 1.0-m coil spacings correspond to approximate depth of investigations of 0.75 and 1.5 m, respectively.

Oakwoods East and West

3-D Hydrodynamic Modeling

The 3-D Oakwoods West model, originally developed in 2023, was further developed and enhanced in 2024, after which the model was successfully applied to simulate various hydrogeologic settings and scenarios at the Oakwoods West site. Such scenario-based simulations are necessary and essential, because they: i) enable researchers to explore the various uncertainties associated with the Oakwoods East and West wetland system which cannot be easily or even feasibly observed or monitored (such as surface runoff and fill-and-spill behavior of pools); ii) help fill in some important knowledge gaps on how the system actually works (e.g., transport of nutrients among depressional pools, Oakwoods West’s interaction with groundwater, interaction with Aurand Run, etc.); and iii) allow quick assessment of Oakwoods West’s nutrient-deduction efficiency (Table 3) when there is a data gap (i.e., influxes from tile outlets). Detailed description of the Oakwoods West model, scenarios, and simulation results can be found in a master’s thesis (Mohammed, 2024¹⁷), whose work was supported by the H2Ohio Wetland Monitoring Program as well as a complement ODHE HABRI project.

Table 3. Estimated DRP stored (%) at Oakwoods West using 3-D models driven by different model setup and hydrologic scenarios. All models assume an amount of ~20 kg of DRP input during the simulation period, July 2021 to December 2021.

Models and Scenarios	Model 1	Model 2	Model 3	Model 4	Model 5	Model 6	Model 7
DRP stored (%)	63.41%	58.94%	63.56%	51.71%	60.42%	61.97%	84.08%
Model and scenario description	<i>Model 1 = default setting + tile water discharge; Model 2 = Model 1 + retardation;</i> <i>Model 3 = Model 1 + high Aurand Run stage; Model 4 = Model 1 + low stream stage;</i> <i>Model 5 = Model 1 + high hydraulic conductivity (K); Model 6 = Model 1 + low K</i> <i>Model 7 = Model 1 + underground culverts installed to increase connection among pools at Oakwoods West.</i>						

Oakwoods West was designed and built to have more than 15 depressional pools. According to recent modeling results, however, it is unlikely that the water and solute originated from the

¹⁷ Mohammed, I. (2024). Simulating hydrologic complexities of a nutrient-reduction wetland in the Midwest of the United States. Master’s thesis, Bowling Green State University, Bowling Green, Ohio.

outlet at Pool-1 would reach those pools except for Pool-1 itself, which directly receives tile drainage. Indeed, most Oakwoods West pools are basically idle and do not play a crucial role in nutrient reduction as expected. To address the “idle” issue at OWKW, researchers would recommend to enhance the hydrologic connectivity among Pool-1 and the rest pools in the west by, for examples, installing culverts/pipes (*red polylines* ,Figure 316), pumps, and/or digging open ditches, which could help direct nutrient-rich water to the idle pools, maximize the nutrient mixing/removal zones (*marked in pink*), and thus increase the nutrient-reduction efficiency of the OAKW. Preliminary results from a synthesized, scenario-based simulation suggest an increase of P-storage efficiency from 63.6% to 84.1% (*bar plot*, Figure 316) at Oakwoods West if researchers are to enhance such connectivity among the west pools (*Mohammed et al.*, 2024).

In short, the models researchers developed can be used to implement a test or assessment of wetland’s capability and potential of reducing nutrients and provide managers with viable solutions or strategies for wetland restoration projects.

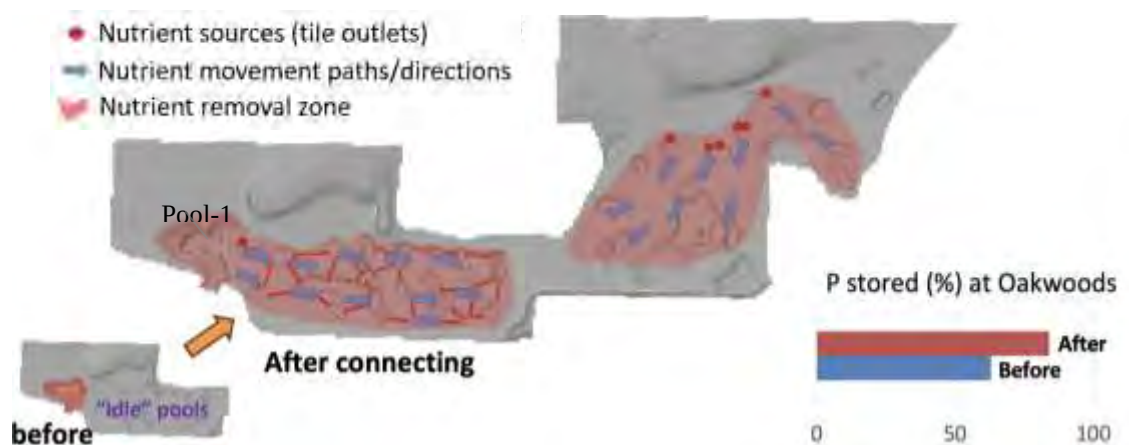


Figure 316. Comparison of nutrient-reduction function of Oakwoods West pools before and after connecting “idle” pools to the nutrient source (Pool-1).

Hydrogeophysics

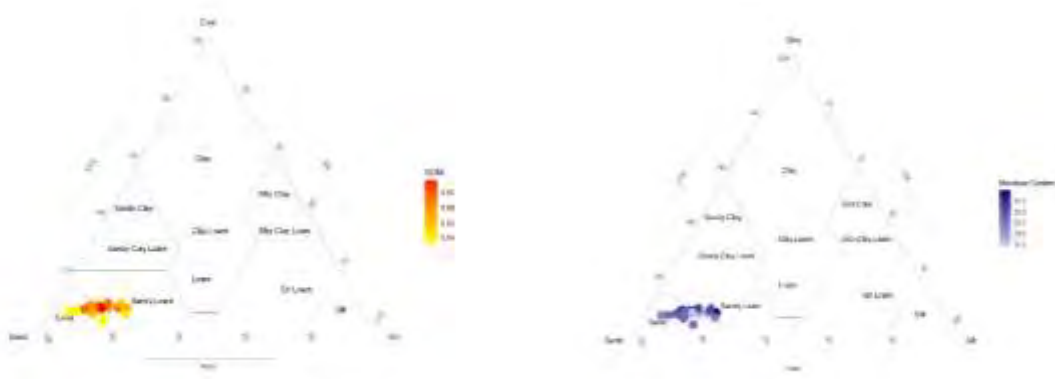


Figure 317. Soil texture triangles, in the USDA configuration, highlighting the classification of the soil samples taken at Oakwoods Nature Preserve East through soil and hydrometer analysis. Colors denote the Solid organic matter (SOM) and Water moisture content, high values are indicated by darker colors and low values are lighter colors.

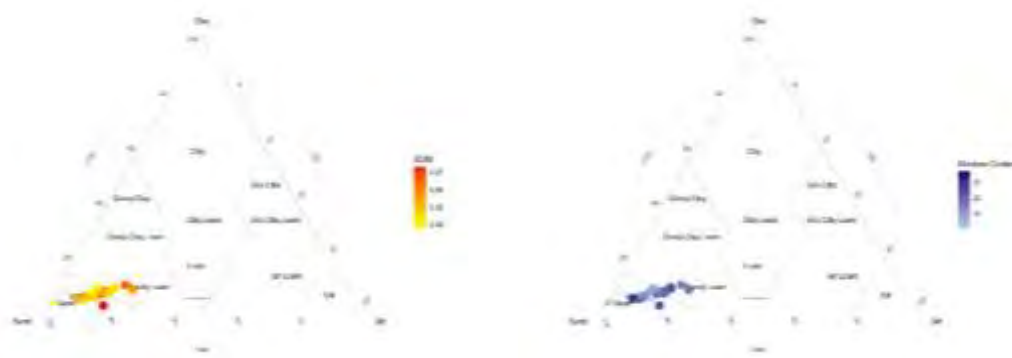


Figure 318. Soil texture triangle, in the USDA configuration, highlighting the classification of the soil samples taken at Oakwoods Nature Preserve West through soil and hydrometer analysis. Colors denote the Solid organic matter (SOM) and Water moisture content, high values are indicated by darker colors and low values are lighter colors.

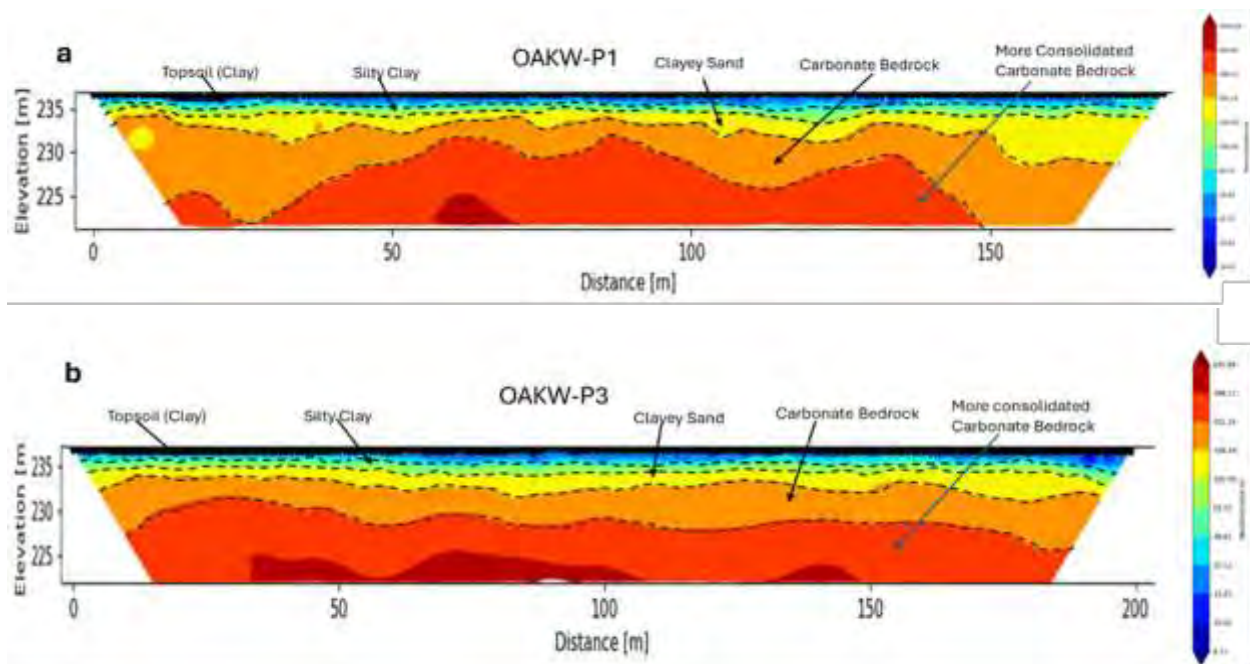


Figure 319. Inverse model resistivity images for: (a) OAKW-P1, and (b) 1.5 m depth OAKW-P3. These images were constrained to a depth of 15 m below the surface.

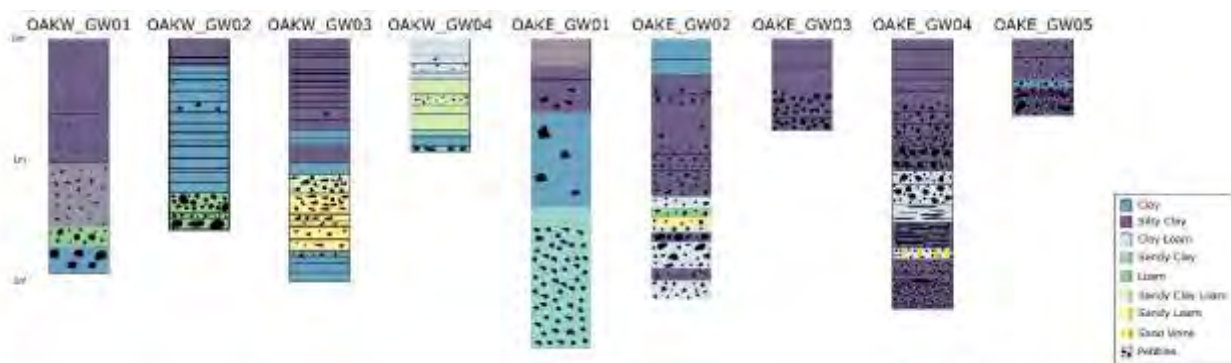


Figure 320. Lithologs for Oakwoods wetlands

Redhorse Bend

No additional results at this time.

St. Joseph's River Restoration

Hydrogeophysics

Field-measured Bulk Electrical Soil Conductivity (ECa) was measured using a Geonics EM38-Mk2 at 0.5-m and 1.0-m coil spacings. Note that the 0.5-m and 1.0-m correspond with 0.75m and 1.5m, respectively, for approximate depth of investigation

Field-measured Bulk Electrical Soil Conductivity (ECa) values for both the 0.5-m and the 1.0-m coil spacing (which correspond to different soil depth readings) ranged from 2 to 39 mS/m, with the highest values recorded in the northeastern portion of the Project directly east of Location of Interest SJRE_01. This high reading corresponds with the tile inlet shown in the design plans. Generally, higher ECa values for both surveys correspond to lower elevation areas at locations where higher moisture could collect. Currently, there are no soil samples to ground truth the ECa values, but groundwater wells installed at the Project show coarsening sediments from 0 to 3.6m (Well 1). Observations from Well 1 correspond with ODNR well log #693968, shown in Figure [ERT GWW3]. Information from Wells 1 and 2 can be used to gain insight into the sediments measured by the EMI survey. Increasing ECa with depth corresponds to sediments fining with depth in Well 1. Clay sediments are generally more conductive due to their higher surface area and capacity to hold water. There was no observable difference in sediments from 0.75 to 1.5m in Well 2 but changing moisture content with depth could have contributed to higher ECa values. Well 1 shows sediment getting finer with depth, going from silty clay to clay around 0.77m. Then, sediments begin to coarsen after 2.57m, showing clay with some gravels included. These observations correspond with ERT measurements from profile A2, which indicate increasing resistivity with depth.

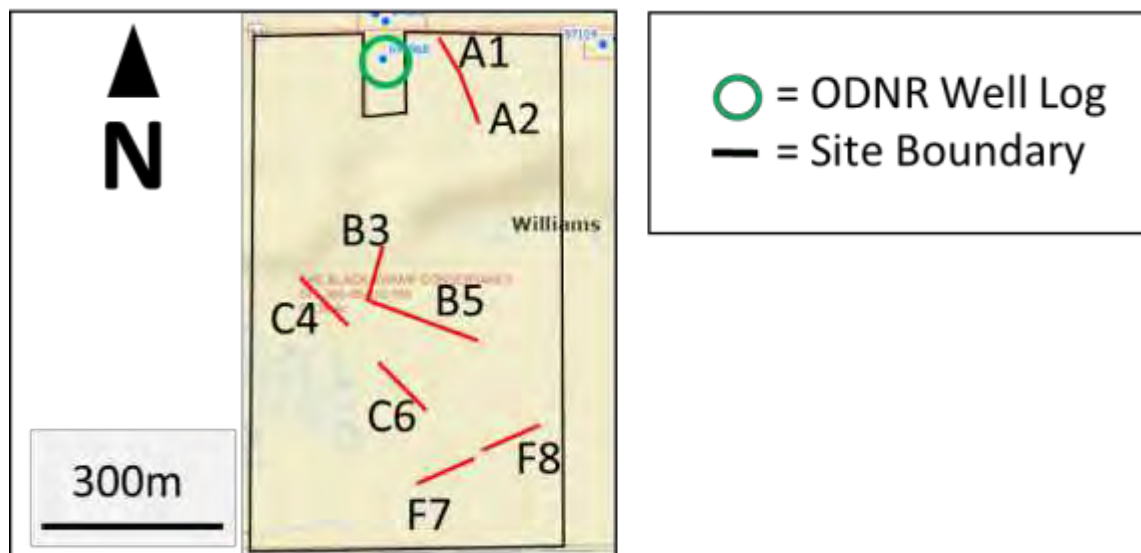


Figure 321. [SJRE ERT GWW]: shown in red lines are ERT profiles collected during the 2023 field season at SJRE. Letters with each profile correspond to the closest pool (Pool A, Pool B, etc.). The green circle highlights an ODNR well log used to ground truth deeper signals seen in the ERT profiles.

Profile A2

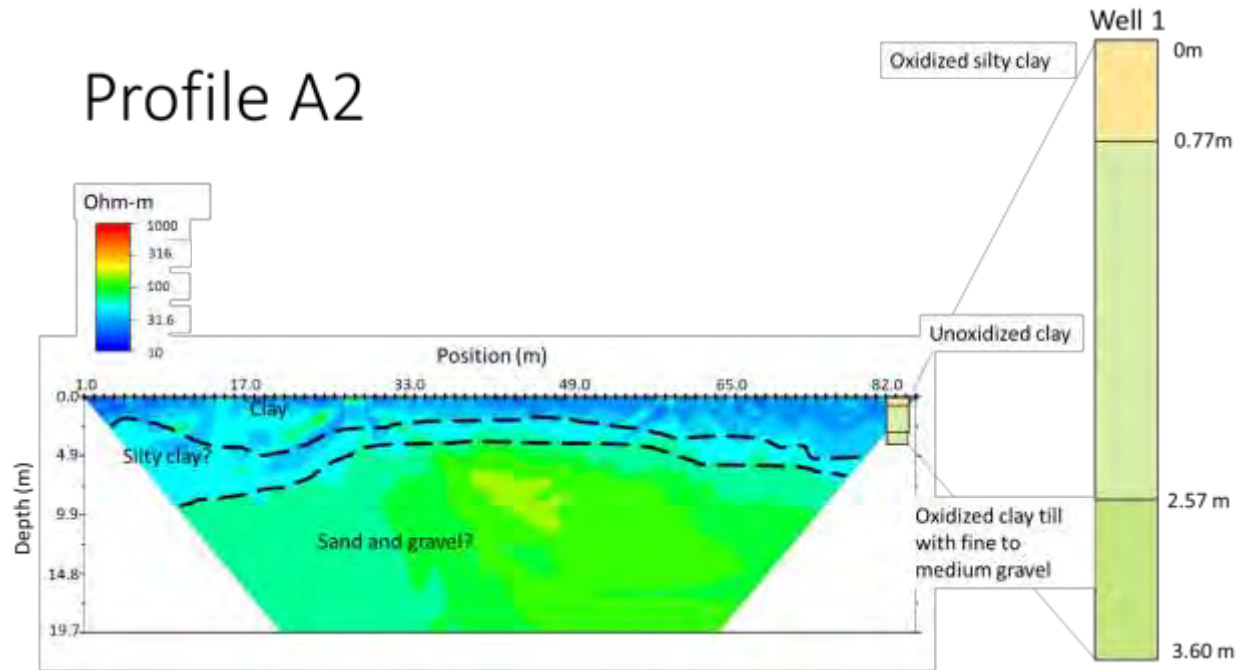


Figure 322. [SJRE ERT GWW2]: ERT profile A2 compared to Well 1 installed by the Hydrogeophysics team. Resistivity ranges from 10 to 1000 Ohmmeters, shown in the color scale on the left. Black dashed lines show interpreted layers within the ERT profile based on the well log.

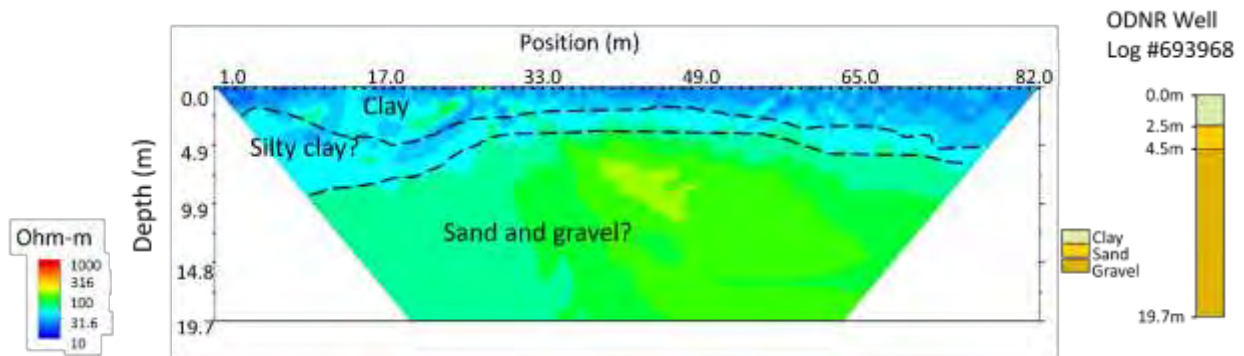


Figure 323. [SJRE ERT GWW3]: ERT profile A2 compared to the ODNr well log. Resistivity ranges from 10 to 1000 Ohmmeters, shown in the color scale on the left. Black dashed lines show interpreted layers within the ERT profile based on the well log.

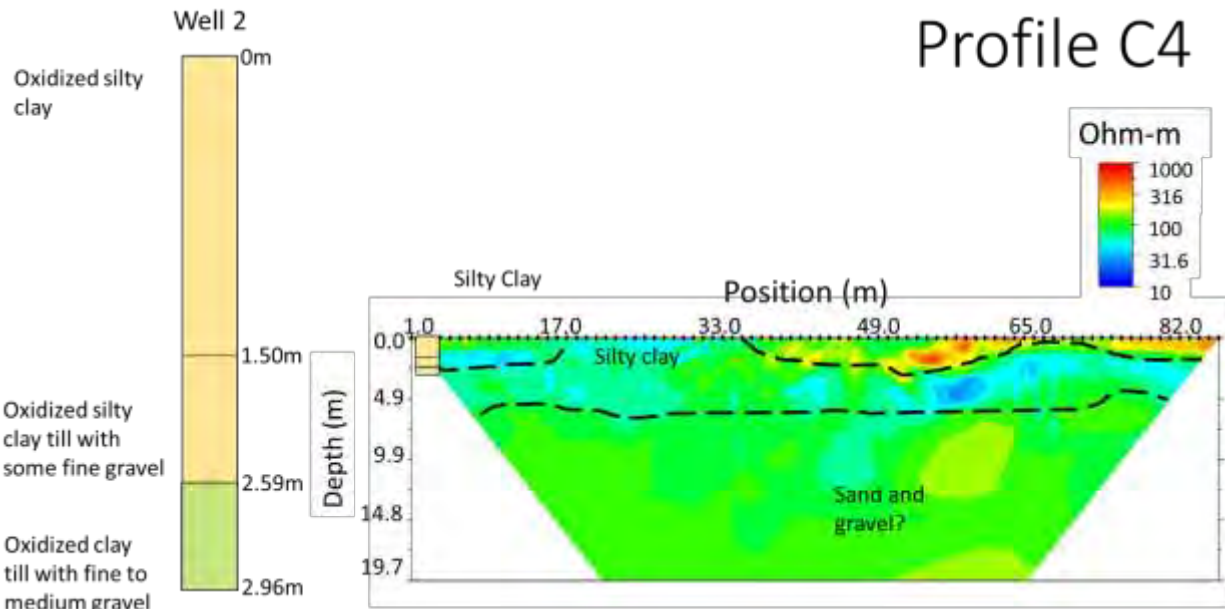


Figure 324. [SJRE ERT GWW4]: ERT profile C4 compared to Well 2 installed by the Hydrogeophysics team. Resistivity ranges from 10 to 1000 Ohmmeters, shown in the color scale on the left. Black dashed lines show interpreted layers within the ERT profile based on the well log.

*Assessing Connectivity Using Remote Sensing- Undergraduate Research Project

Student: Hana Esber

Advisor: Lauren Kinsman-Costello

The 2023 H2Ohio Wetland Monitoring Report¹⁸ highlights that St. Joseph River Wetland Restoration receives water from multiple sources, including northern tile drains, precipitation, and backflow from the St. Joseph River. The wetland feature that likely contributes the most to nutrient storage and filtration for the Project is Pool B. To assess the hydrological connectivity and nutrient functioning of Pool B, it is essential to understand the timing and spatial distribution of standing water in the pool. To gain a new perspective of the hydrologic patterns at St. Joseph River Wetland Restoration, 23 Sentinel 10-meter resolution images were captured during the Water Year 2024 and were analyzed for pixel moisture content by the Automated Water Extraction Index (AWEI). For Pool B, some seasonal variability is visible with fall of 2023 and 2024 having more negative values compared to summer 2024 (Figure 1). During summer 2024, the pool is able to retain open water (values greater than -8,000) and have healthy vegetation during this time.

¹⁸ Lake Erie and Aquatic Research Network, Wetlands and Water Quality Group. 2023. H2Ohio Wetland Monitoring Program: 2023 Annual Progress Report, Vol. 1. Ohio Department of Natural Resources, Office of Coastal Management. <https://osf.io/gef6d/>

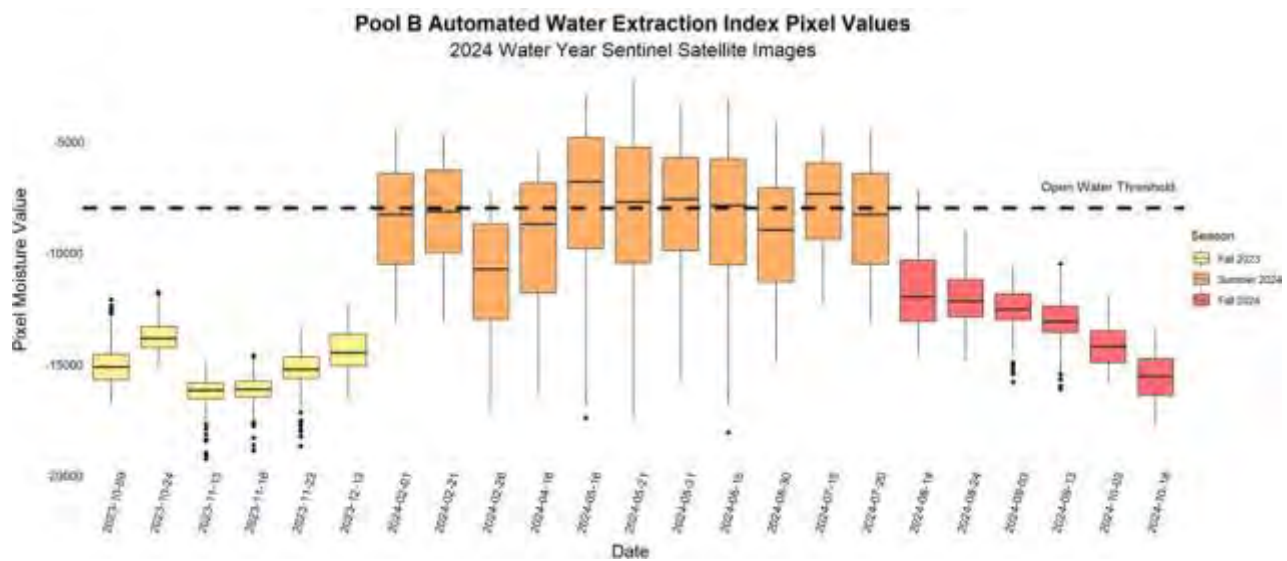


Figure 325. A display of the average moisture pixel values per day at Pool B (using the Automated Water Extraction Index and Sentinel 10m resolution images). Each image contains 408 total pixels which is 40,800 m² or about 11 acres. There are a total of 23 images during the WY 2024. Beginning with 10/09/2023 and ending with 10/18/2024, there are three seasons presented that represent late fall of 2023, summer of 2024, and a fall transition in 2024. A dotted line represents the -8,000 value threshold at which open surface water can be recognized.

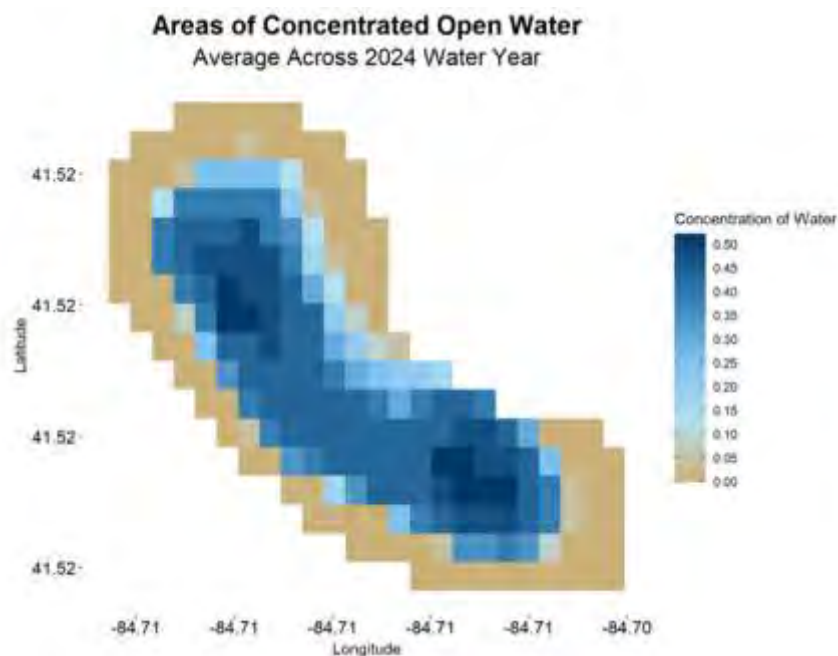


Figure 326. Raster image that displays where pixels that are categorized as open water are on average during WY 2024 in Pool B at St. Joseph River Wetland Restoration (using 23 images collected). This image does not show depth, but rather which parts of the pool have open water (pixels with values > -8000 using an Automated Water Extraction Index, AWEI) as a portion of

the 23 images throughout the year. Darkest blue pixels show a higher frequency of water coverage throughout the year. Main concentrations are located in northern and southern portions of the pool.

Satellite imagery revealed that Pool B had recognizable open water in different locations throughout the summer season (Figure 326). While a smaller central spatial area of the pool retained surface water year-round, the majority of the pixels with the highest frequency of standing water were concentrated in two distinct areas (one in the north and another in the south) that have relatively similar depths (Figure 326). These main inundated areas are near separate potential inflows for Pool B. The northern inundated area is closest to an inflow of upstream tile drainage, while the southern inundated area is connected to an agricultural ditch that back-floods from the St. Joseph River during flood events. This agricultural backflow likely differs in chemical composition from tile drain inputs. The influx of nutrient-laden river water may influence phosphorus filtration, as Pool B functions as a temporary floodplain during high water events. When water from the river enters the southern portion of Pool B, it will have a different residence time and effect on the nutrient movement compared to water entering from the northern portion of Pool B. All tile drain inputs must enter through the northern portion of the pool and egress through the southern portion, taking a longer period of time than water entering and exiting through the southern portion alone.

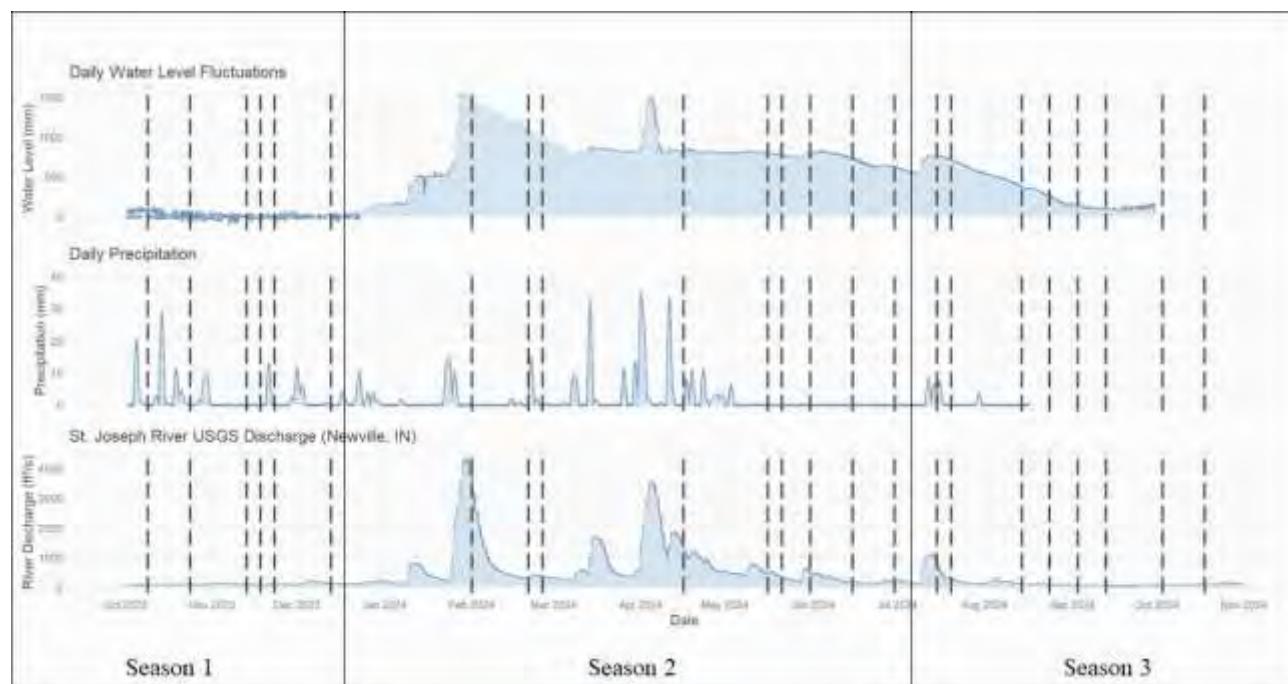


Figure 327. A figure displaying three different measures of water at St. Joseph River Wetland Restoration. The top panel exhibits daily water level fluctuations measured in the northern portion of Pool B in cm. This shows fluctuations within each day and between each day for WY 2024. The middle panel displays the daily precipitation measured at St. Joseph River Wetland Restoration measured in mm. The bottom panel is the St. Joseph River discharge measured at a

USGS gage stationed in Newville, IN. This discharge is measured in cubic feet second. The overlaid dotted black lines represent the 23 satellite images that were collected during WY 2024. Seasons 1, 2, 3 are representative of late fall transitioning to a growing season and then transitioning back to fall. There is a small section of no data present from February to March 2024 in the Daily Water Level Fluctuations recorded in Pool B.

Although the remotely sensed images were able to capture specific dates and the water present, there is a limitation to the interpretation of this data. Seasonality is shown well throughout the water year, but the images collected were too infrequent to depict specific storms or flooding sources at that time. A constant limitation that comes with quantifying storm events through remotely sensed imagery is that cloud cover is typically present with high precipitation from storms. Having more frequent imagery collection and capturing days close to storm events makes this a more accurate process, even with the elimination of images due to cloud cover.

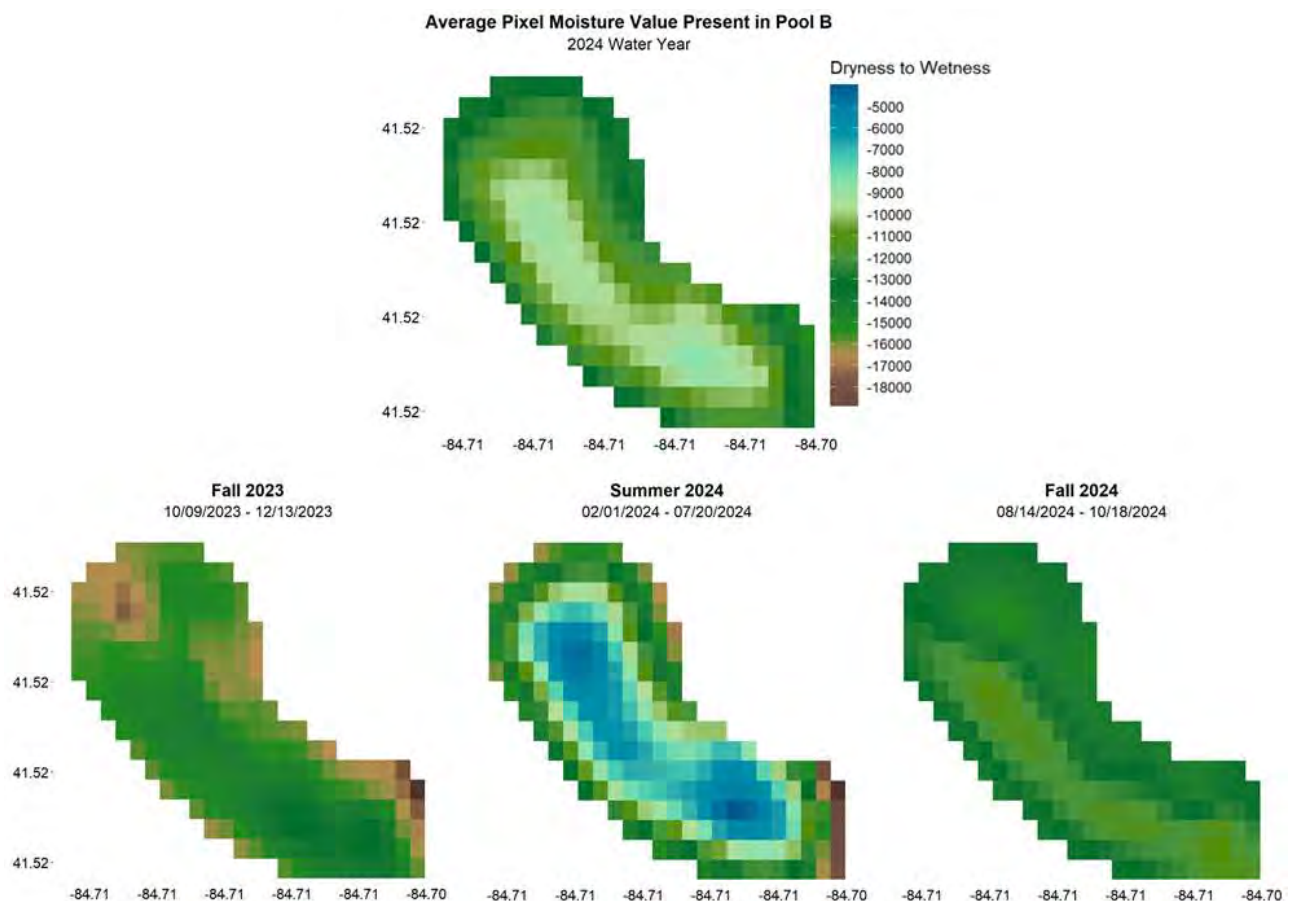


Figure 328. A multi panel image demonstrating the average pixel moisture value present in Pool B for WY 2024. The top image is the overall average pixel moisture level. More negative values (-18,000– -16,000) indicate less moisture or bare soil, increasing negative values transition into healthy vegetation (-15,000– -13,000), then aquatic or submerged vegetation (-10,000– -9,000), and open water (values > -8,000). The average water pixels recorded only for Pool B during fall

2023 and 2024 have large amounts of vegetation (green pixels) surrounding the pool. Summer 2024 has vegetation surrounding the pool and there are signs of aquatic vegetation in light green pixels on the outer portions with open water in the more interior areas denoted by the brightest blue pixels.

Although the overall average pixel moisture values for Water Year 2024 indicate there is no open water present, separating different phases of the water year reveals that there is recognizable open water present during summer 2024. During this time of the year, the outline of Pool B is clearly seen with water filling the interior of the pool (Figure 328). In fall of 2023 and 2024, hardly any recognizable open water was categorized by this spatial imagery (Figure 328). As vegetation begins to dominate in late summer, the functionality of the pool to retain open water decreases. The nutrient flux between the sediment and surface water starts to dissipate as there is little to no standing water remaining in the pool, leaving the sediment unsaturated and undisturbed.

These findings highlight the value of remote sensing for monitoring hydrological and nutrient dynamics, particularly when field access is limited. High-resolution imagery can complement on-site measurements, providing critical insights into water inflow sources and potential anomalies in nutrient cycling and water levels. When sensor systems fail to work, having frequent, high-resolution imagery can help complete the hydrologic patterns of the site. St. Joseph River Wetland Restoration is a hydrologically dynamic wetland with Pool B as the only pool with standing water throughout the year. Using this information can help inform decision making at Non-Focal Projects by looking at the overall seasonality of pools and how they tend to function over time.

Non-Focal Projects

Trumbull Creek

Sediment Core Incubation Experiments- Undergraduate Research Project

Student: Katie DeChant and Nora Haddon

Advisor: Lauren Kinsman-Costello

Methods

To test the effect of drying and re-wetting on nutrient fluxes in soils with different previous inundation regimes, researchers collected intact cores from flooded (inundated soil at time of sampling in the inner pool) and fringe (surrounding un-inundated soil of the dry ring around the pool) areas in the recently constructed Trumbull Creek wetland Project. Soil cores were collected from the lowland water level control structure pool (WLCS) and upland Borrow Pool 1 (BP1) in the Trumbull Creek Project in July 2024. Soil core barrels were 8 cm in diameter and 30 cm in height, with an average soil depth of 15.3 cm and an average headspace of 5.8 cm above the soil-water interface. To prevent interference of nutrients released through decomposition and photosynthesis, apparent vegetation and organisms were removed from the top surface of the

cores and were wrapped in aluminum foil to mitigate light exposure. Soil cores were incubated for three days with continuous inflowing and outflowing water. Researchers simulated a drying event by first removing standing water from the top of the soil core through a syringe without disrupting the soil surface, then allowing for cores to air-dry without a lid for three days in incubation. Following the drying event, cores were gently reflooded slowly, down the side of the tube with inflow water with a syringe to avoid sediment resuspension and incubated for three additional days. Water collected from the respective pools at time of core sampling was used to re-flood the cores with a peristaltic pump and ventilated over time to prevent anoxia. Measurements of nutrient concentrations (in addition to dissolved oxygen, conductivity, and pH) from out-flowing water of the cores were taken at three time points prior to the simulated drying event and at three time points after experimental re-flooding. The inflow water had variable nutrient concentrations, notable dissolved oxygen, and a slightly basic pH. Nutrient fluxes were calculated as follows: $(\text{outflow concentration} - \text{inflow concentration}) / (\text{surface area} \times \text{flow rate}) = \text{nutrient flux rate}$. Positive values indicate a net release of nutrients from the soil to the water column, while negative values indicate a net retention of nutrients in the soil.

Table 4. This data represents physicochemical characteristics of inflow water used to treat soil cores pre drying/re-flooding event and post drying/re-flooding event. Measurements were taken daily, and here average measurements of Dissolved Reactive Phosphorus (DRP), $\text{NH}_4\text{-N}$, nitrite+nitrate (NO_x), DO%, pH, and Conductivity are reported as well as standard deviation (average±standard deviation).

Pre/Post Flooding	Pool	DRP	$\text{NH}_4\text{-N}$	NO_x	DO (%)	pH	Conductivity
pre	WLCS	3.79±0.81	10.3±2.15	2.405±9.07e ⁻¹⁶	*96.65±1.06	*8.2±0.46	*50.55±17.5
	BP1	2.97±0.36	26.4±23.3	2.405±9.07e ⁻¹⁶	*96.85±1.2	*8.25±0.07	*56.95±7.99
post	WLCS	3.28±0.87	13.7±4.64	3.21±9.07e ⁻¹⁶	94.63±3.3	8.71±0.25	57.13±15.5
	BP1	4.36±0.66	75.3±64.5	3.21±9.07e ⁻¹⁶	93.8±2.8	8.59±0.29	67.1±8.88

*note that only one time point taken for these



Figure 329. Aerial image of Trumbull Creek Wetland Project showing pool locations. WLCS and BP1 are outlined.

(from -0.00172 mg/m²/day to 0.0911 mg/m²/day), which may indicate that outer fringe soil of this pool is particularly prone to nutrient release.

Borrow Pool 1 is wider and more shallow than WLCS pool which causes the surrounding ring of fringe soil to be more involved in flooding/re-drying events. Flooded soil released phosphate at a lower rate after the drying/re-flooding event than before it (from 0.352 mg/m²/day to 0.0258 mg/m²/day). While fringe soil had a higher rate of phosphate retention following the event than before it (from 0.0647 mg/m²/day to -0.143 mg/m²/day). This suggests that this pool facilitates DRP sorption and serves as a sink for DRP both inside and outside the pool.

There are notable differences in structure that contribute to differences in sorption. Based on frequent observations, the primary difference between the Water Level Control Structure pool and Borrow Pool 1 is the frequency of inundation of fringe soil, which may help explain different responses to drying/re-flooding.

The Water Level Control Structure pool (lowland pool) with less frequently inundated fringe soils, released more phosphate from fringe soils across the drying/re-flooding event likely because infrequent changes in water level cause more dramatic changes in oxygen conditions. The dramatic changes in oxygen conditions may impact phosphate release through the reduction of iron-oxides with bound phosphate, sudden dissolution upon re-flooding, and disruption of microbial activity through drying and reflooding. Drying periods may cause breakdown of organic matter, and re-flooding may cause an increase in enzymatic activity. On the other hand, Borrow Pool 1 (upland pool) has fringe soils that are more often inundated and probably filtered more phosphate across drying/re-flooding likely because of less dramatic oxygen condition changes. Notably, based on measurements of dissolved oxygen, none of the cores experienced anoxic conditions. If the water ever did become anoxic, it is expected that there would be greater release of phosphorus as iron oxides become reduced and iron dissolves. The varying responses to flooding suggest that lowland fringe soil of Trumbull Creek is more susceptible to phosphate release compared to upland fringe soil in drying and flooding events. However, both lowland and upland consistently inundated soils will limit phosphate release.

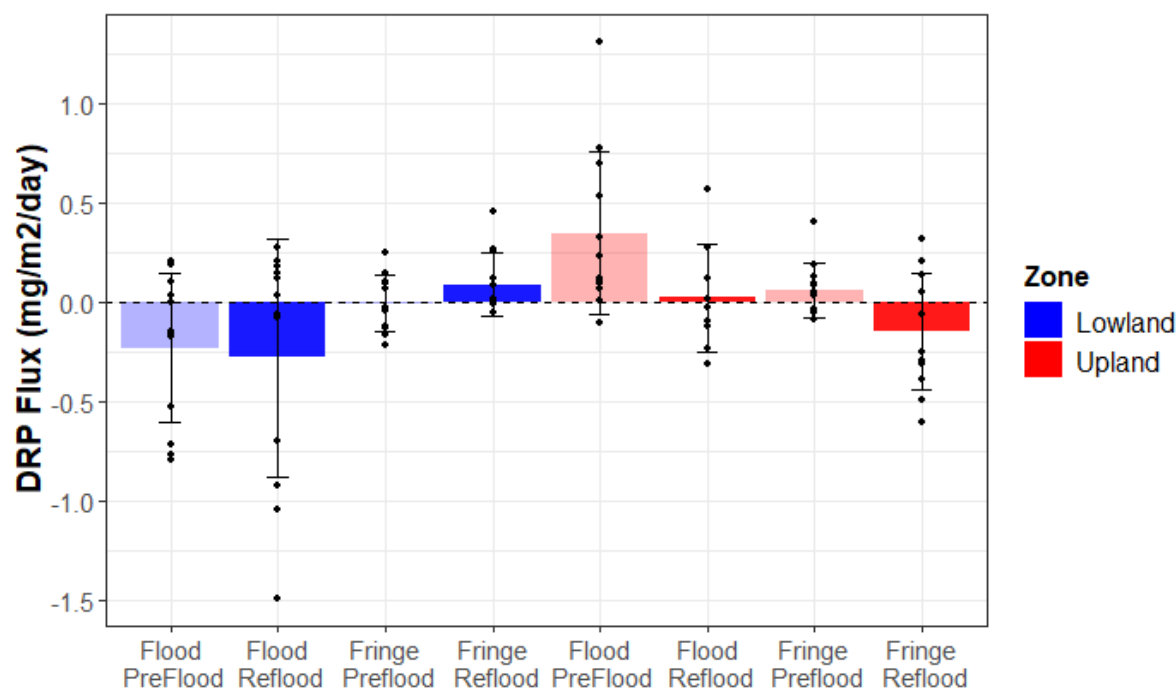


Figure 331. Bar graph representing the mean flux of dissolved reactive phosphorus (DRP) from incubated sediment cores ($n = 4$ cores per zone) over a period of 6 days, including a simulated drying event during the incubation. Bar magnitude represents the mean flux over the course of the experiment and error bars represent the standard deviation of the flux measurements over time and across replicates. The graph is overlaid by points representing the actual measured flux values during the experiment ($n = 12$ flux measurements per zone). Lowland samples were collected near the WLCS sampling location and upland samples were collected near the Borrow Pool 1 sampling location. Positive values indicate a flux from sediment to the surface water, while negative values indicate a flux from surface waters into the sediment.

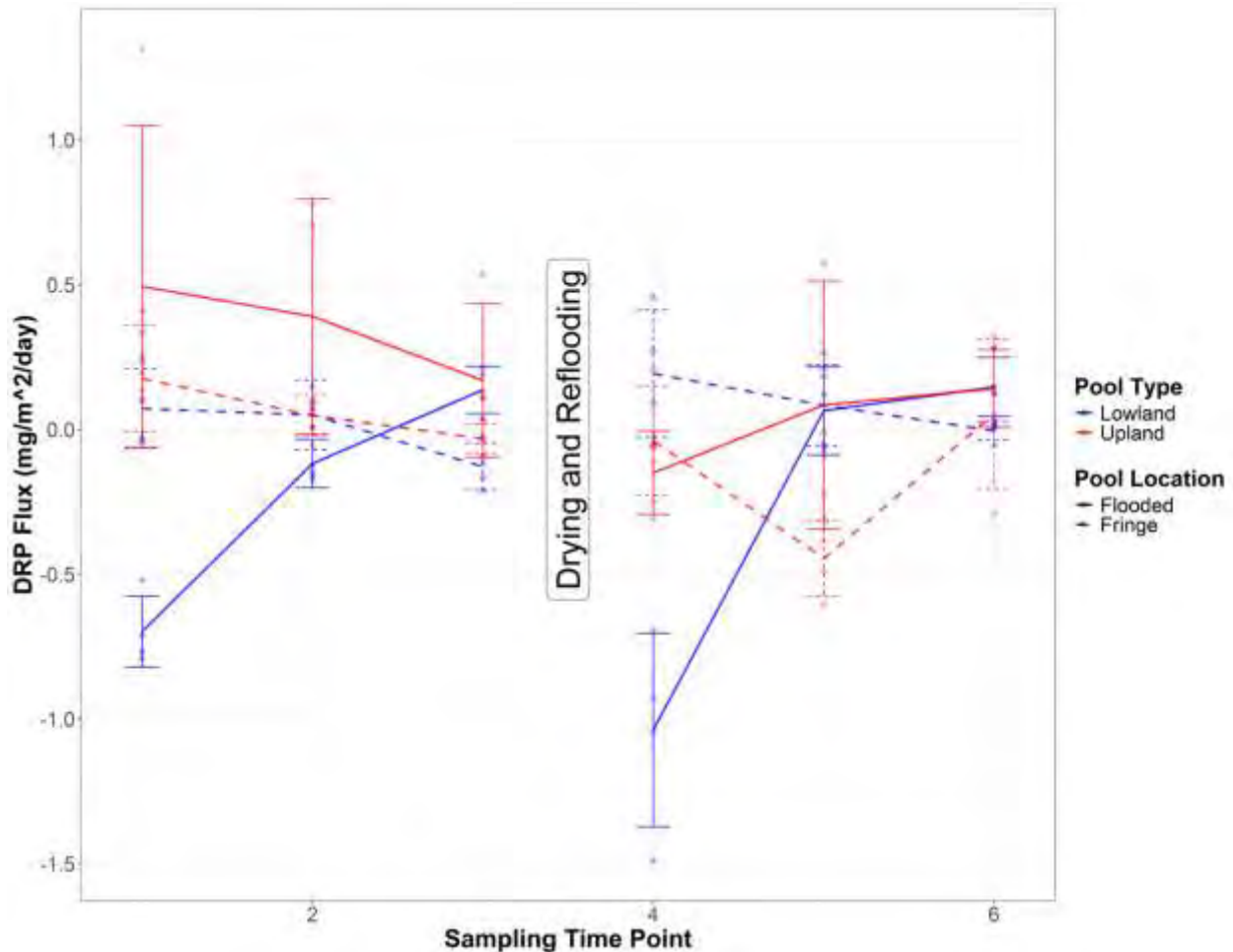


Figure 332. Time series graph showing the mean flux of dissolved reactive phosphorus (DRP) from incubated sediment cores (n=4 cores per zone) over a period of 6 days, including a stimulated drying event during the incubation. Magnitude of each point represents the mean flux over the course of the experiment and error bars represent the standard deviation of the flux measurements across replicates. The graph is overlaid by points representing the actual measured flux values during the experiment (n = 4 flux measurements per zone). Lowland samples were collected near the WLCS sampling location and upland samples were collected near the Borrow Pool 1 sampling location. Positive values indicate a flux from sediment to the surface water, while negative values indicate a flux from surface waters into the sediment.

Nitrogen

Researchers observed an overall positive flux in ammonium concentrations from flooded and fringe soils both before and after flooding events. Overall, across flooded and fringe soils there was an increase of about two times the magnitude of the flux during the second flooding event. Additionally, the flux values for the flooded soils were both higher, however the increase in flux post drying was greater in fringe soils. Fringe cores from the WLCS pool more than doubled their ammonium output after the rewetting cycle; the average flux increased from 11.9

mg/m²/day to 38.9 mg/m²/day. In the same pool, flooded soils nearly doubled in their ammonium output; the average flux increased from 24.9 mg/m²/day to 44.6 mg/m²/day. These results indicate that in the lowland WLCS pool, the fringe areas and soils demonstrated an increased flux in ammonium than flooded soils during the same flooding and drying event.

In cores from BP1, the patterns in the fringe and flooded cores are similar to that of the WLCS pool. The fringe cores from BP1 nearly tripled in ammonium concentration output after rewetting; the average flux increased from 9.02 mg/m²/day to 30.0 mg/m²/day. On the other hand, the flooded cores from BP1 only increased about 20% of their output; the average flux increased from 37.1 mg/m²/day to 46.4 mg/m²/day. This indicates that there are similar rates of ammonium release in the fringe soils, but not in the flooded soils in the upland pool. There was an increase in ammonium flux across both soil types in both the WLCS and BP1 pools. However, flooded soils in BP1 had a lesser increase in ammonium flux after drying and rewetting cycles than the flooded soils in WLCS.

Increases in ammonium concentrations may have been caused by excess ammonium in the soil from microbes and mineralization of plant and organic matter during the first flooding and drying event. This would lead to increased concentrations in the second flooding event when this accumulated ammonium is released. It is also possible that microbe communities turned over during the drying event and some of the ammonium that was already fixed was released into the soil and then leached from the soil into the water column during the second flood.

In sediments from the fringe, there was a smaller jump in ammonium concentrations from before the drying period and after the drying period than there were in the cores from the pool. This may be due to less readily available ammonium in the soils located at the edge of the pools. It is possible that more ammonium was taken up by plants in the fringe areas since that is the more direct transition path for ammonium in these areas. This would leave a smaller pool of ammonium initially so that the flux could not increase as much. In the pool areas, more consistent interaction between the sediment and overlying surface water may have led to larger outputs after the major disturbance of the drying event.

The flooded cores from the upland pool indicate that initial ammonium concentrations were far higher than in the lowland pool. The lowland pool is always inundated and may be better at regulating the diffusion gradient even during changing hydrological regimes, and could have had lower concentrations initially. In the upland pool, there are more regularly changing hydrological regimes, leading to periodic times of drying in the wetland. This suggests that upland pools are more vulnerable to ammonium release after flooding than the lowland pools.

Researchers observed an overall positive flux in nitrate concentrations from flooded and fringe soils both before and after flooding events. However, the results depict a spike in NO_x concentrations at the beginning of the first flooding cycle, then no more measured flux of the nutrient throughout the rest of the experiment. Researchers originally thought that it is possible that the concentrations started out abundant, and then were reduced to N₂ gas, however, this does

not seem likely since the concentrations of nitrite+nitrate were already lower to begin with indicating originally low concentrations and a quick leaching of nutrients during the experiment. Therefore, it is possible that nitrite+nitrate leached out of the system into the water from the soil, mobilizing it. It would be beneficial to analyze the gas samples for a spike in N_2 gas to determine the fate of the leached NO_x . If there is a spike in the N_2 , this would seem to indicate that denitrification was occurring which would explain the lack of NO_x at later sampling points. If there is no spike, it would indicate that the nutrient is simply being mobilized out of the soil. More work could be done to better understand the full picture of cycling and what is happening.

These experimental results indicate that the NO_x at the Project could have been going through denitrification and or leaching processes. It is most likely that the NO_x is being leached out of the system since it disappears from the system so quickly. This means that if the NO_x is being leached out of the system, it is becoming runoff and leaving the system as a pollutant, with the potential to impact other systems. This could further lead to eutrophication in other watersheds and additionally lead to an overload of nutrients in the system.

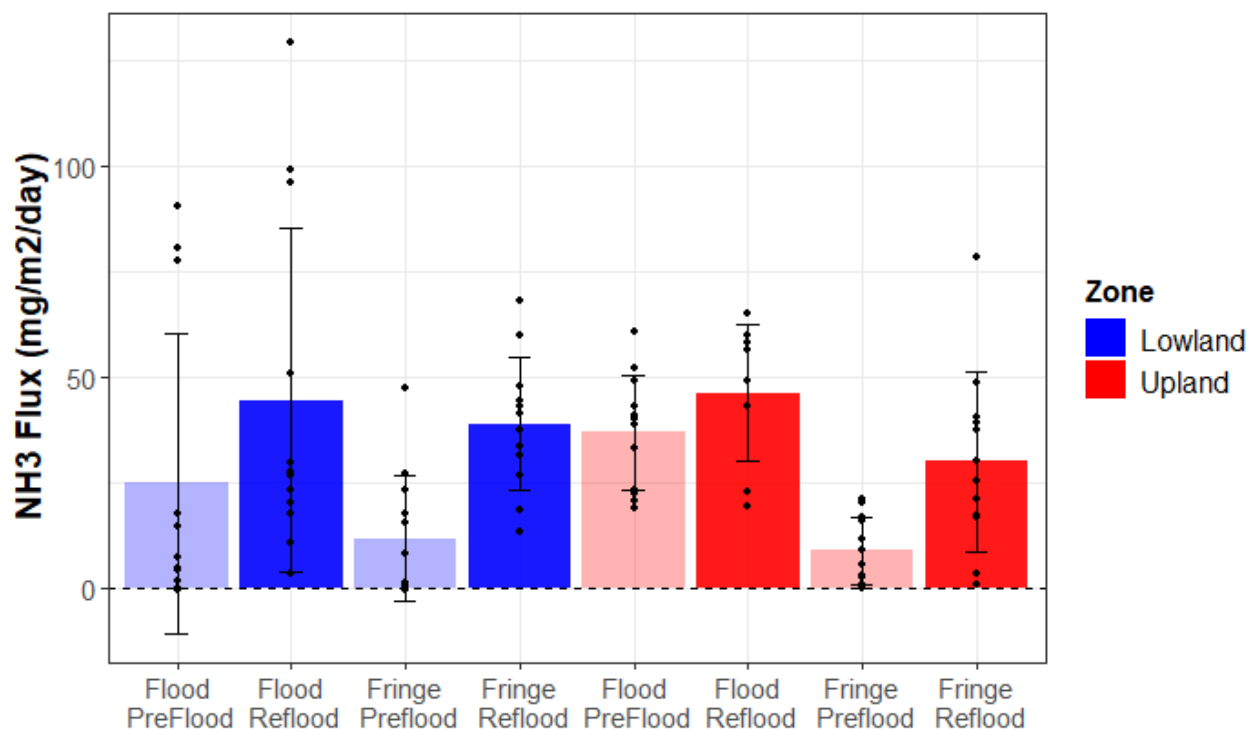


Figure 333. Bar graph representing the mean flux of ammonium (NH_4-N) from incubated sediment cores ($n = 4$ cores per zone) over a period of 6 days, including a simulated drying event during the incubation. Bar magnitude represents the mean flux over the course of the experiment and error bars represent the standard deviation of the flux measurements over time and across replicates. The graph is overlaid by points representing the actual measured flux values during the experiment ($n = 12$ flux measurements per Zone). Lowland samples were collected near the WLCS sampling location and upland samples were collected near the Borrow Pool 1 sampling

location. Positive values indicate a flux from sediment to the surface water, while negative values indicate a flux from surface waters into the sediment.

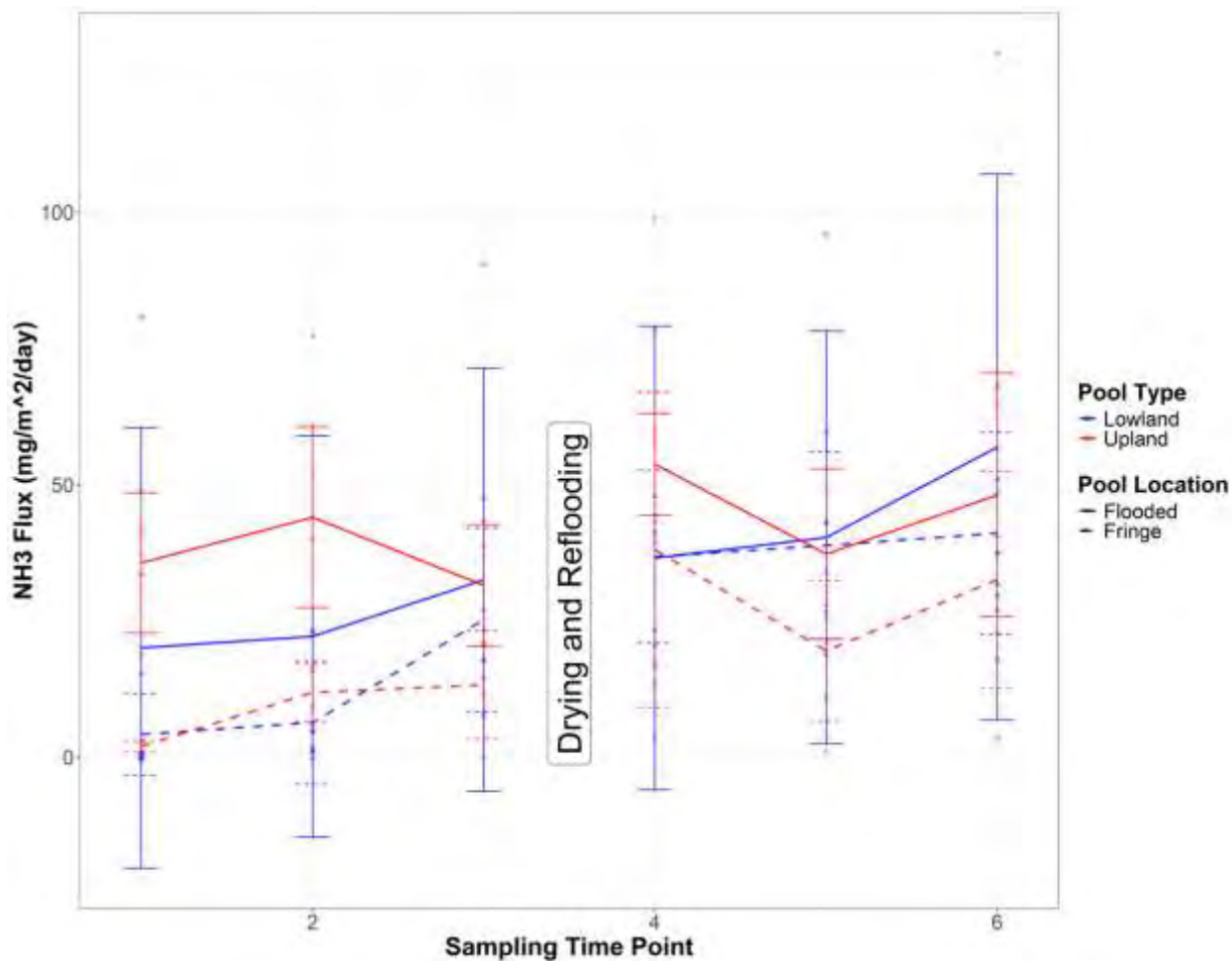


Figure 334. Time series graph showing the mean flux of ammonium (NH₄-N) from incubated sediment cores (n=4 cores per zone) over a period of 6 days, including a stimulated drying event during the incubation. Magnitude of each point represents the mean flux over the course of the experiment and error bars represent the standard deviation of the flux measurements across replicates. The graph is overlaid by points representing the actual measured flux values during the experiment (n = 4 flux measurements per Zone). Lowland samples were collected near the WLCS sampling location and upland samples were collected near the Borrow Pool 1 sampling location. Positive values indicate a flux from sediment to the surface water, while negative values indicate a flux from surface waters into the sediment.

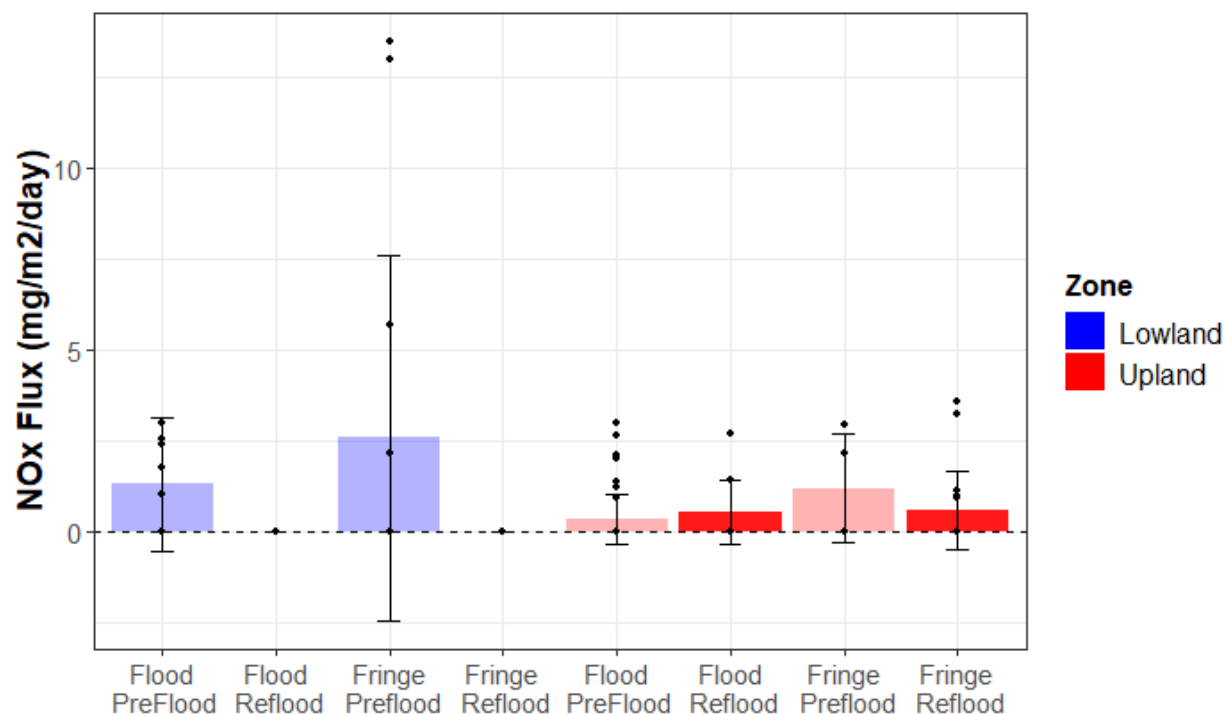


Figure 335. Bar graph representing the mean flux of nitrate (NO_3) from incubated sediment cores ($n = 4$ cores per zone) over a period of 6 days, including a simulated drying event during the incubation. Bar magnitude represents the mean flux over the course of the experiment and error bars represent the standard deviation of the flux measurements over time and across replicates. The graph is overlaid by points representing the actual measured flux values during the experiment ($n = 12$ flux measurements per Zone). Lowland samples were collected near the WLCS sampling location and upland samples were collected near the Borrow Pool 1 sampling location. Positive values indicate a flux from sediment to the surface water, while negative values indicate a flux from surface waters into the sediment.

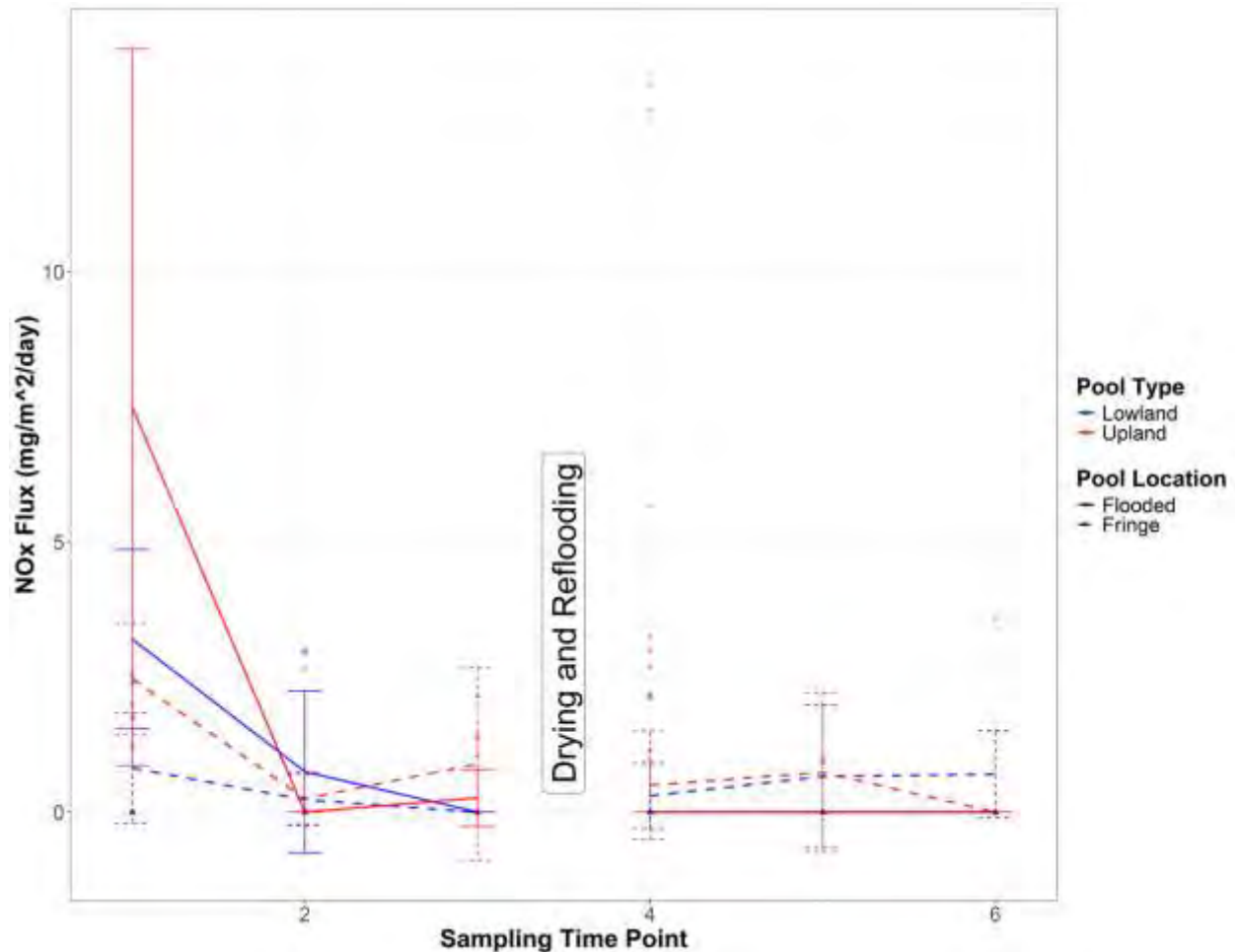


Figure 336. Time series graph showing the mean flux of nitrate (NO_3) from incubated sediment cores ($n=4$ cores per zone) over a period of 6 days, including a stimulated drying event during the incubation. Magnitude of each point represents the mean flux over the course of the experiment and error bars represent the standard deviation of the flux measurements across replicates. The graph is overlaid by points representing the actual measured flux values during the experiment ($n = 4$ flux measurements per Zone). Lowland samples were collected near the WLCS sampling location and upland samples were collected near the Borrow Pool 1 sampling location. Positive values indicate a flux from sediment to the surface water, while negative values indicate a flux from surface waters into the sediment.

Conclusions

The impact of changing nutrient fluxes from varying hydrological regimes is important for consideration of the individual wetland. Upland pools likely release much more ammonium, especially from the fringe, yet release less phosphate from both flooded and fringe areas. This suggests that upland pools are especially prone to ammonium release, but perform well as phosphate sinks. Lowland pools likely increase ammonium release from both fringe and flooded soil. They also release less phosphorus in flooded soils, but release more phosphate in fringe soils. Lowland pools may be especially vulnerable to nutrient release of ammonium and

phosphate from fringe soils with infrequent inundation. A judgement of what nutrient is more important for the wetland to filter throughout the lifetime of the area is important during design and construction. This also indicates that care should be taken to understand how water level changes may impact which soils (flooded or fringe) are more prone to nutrient release. Further research may reveal dynamics of anoxia of the soils and effects on fluxes and help to better describe the relationship of oxygen presence and absence to nutrient flux. Seasonality including different temperatures and precipitation patterns are important for understanding how soils respond throughout time with changing conditions; studying this may reveal important applications for management throughout the year.

References

Stegen, J., Burgin, A. J., Busch, M. H., Fisher, J. B., Ladau, J., Abrahamson, J., Kinsman-Costello, L., Li, L., Chen, X., Datry, T., McDowell, N., Tatariw, C., Braswell, A., Deines, J. M., Guimond, J. A., Regier, P., Rod, K., Bam, E. K., Fluett-Chouinard, E., ... Patel, K. F. (2025). Reviews and syntheses: Variable inundation across Earth's terrestrial ecosystems. *Biogeosciences*, 22(4), 995–1034. <https://doi.org/10.5194/bg-22-995-2025>

Soil Nutrients Across Microtopography Undergraduate Research Project

Student: Emily Cambell

Advisor: Lauren Kinsman-Costello

Introduction

A history of agricultural land use may leave a pool of legacy P in the soil so that restored wetlands may actually release, rather than retain, phosphorus as intended. The H2Ohio Trumbull Creek Project, supported by the ODNR and implemented by the non-profit mitigation bank Stream + Wetlands Foundation is one such example. Trumbull Creek is a formerly agricultural Project that receives water flow from precipitation and slowly drains water through a large area of constructed upland hummocks and hollows into larger borrow pools. The H2Ohio Wetland Monitoring Program has sampled soil from the Project for two years, to evaluate its nutrient status and P sorption capacity. In 2023, soil samples were taken from throughout the H2Ohio Trumbull Creek Project and stratified by microtopographic design features: hummocks, hollows, and borrow pools. In 2024, the Monitoring Program received supplemental support from Kent State University to compare soils from within the newly constructed H2Ohio Trumbull Creek Project to soils from the adjacent older restoration areas also implemented by the Stream + Wetlands Foundation. The 2024 sampling plan thus expanded to examine the Trumbull Creek Mitigation Bank, including three of the four neighboring wetlands, referred to as Phase 1, Phase 2 South, and Phase 2 North by the Stream + Wetlands Foundation (S+W) design plans.

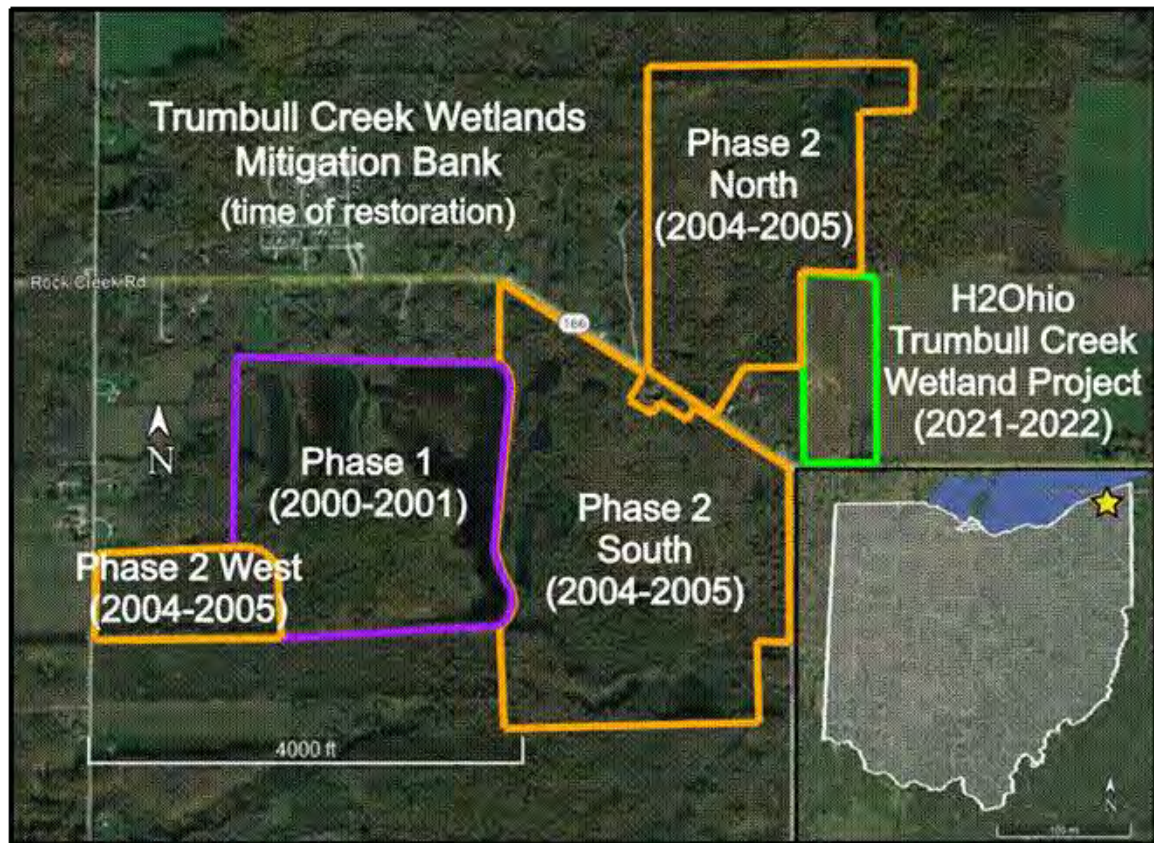


Figure 337. Map of Trumbull Creek Mitigation Bank Projects and location within Ohio. Delineated map of all parcels of land within the 492.8-acre Trumbull Creek Wetlands Mitigation Bank, located near Rock Creek Road and Route 166. The outlined parcels represent the ages of wetland restoration; Phase 1 was restored in 2000–2001 and is outlined in purple. Phase 2 North, South, and West were all restored in 2004–2005, and are outlined in orange. Phase 3, or the H2Ohio Trumbull Creek Wetland Project, was restored in 2021–2022 and is outlined in green. An inset map in the lower-right corner highlights the location of interest within Ohio, on the border of Ashtabula and Geauga counties. The satellite imagery was taken in November 2021 from Google Earth Pro. (credit to Greg Snowden & Chelsea Keefer for delineation from S+W design plans).

Figure 17-19: Sampling Locations Within Each of the Three Parcels

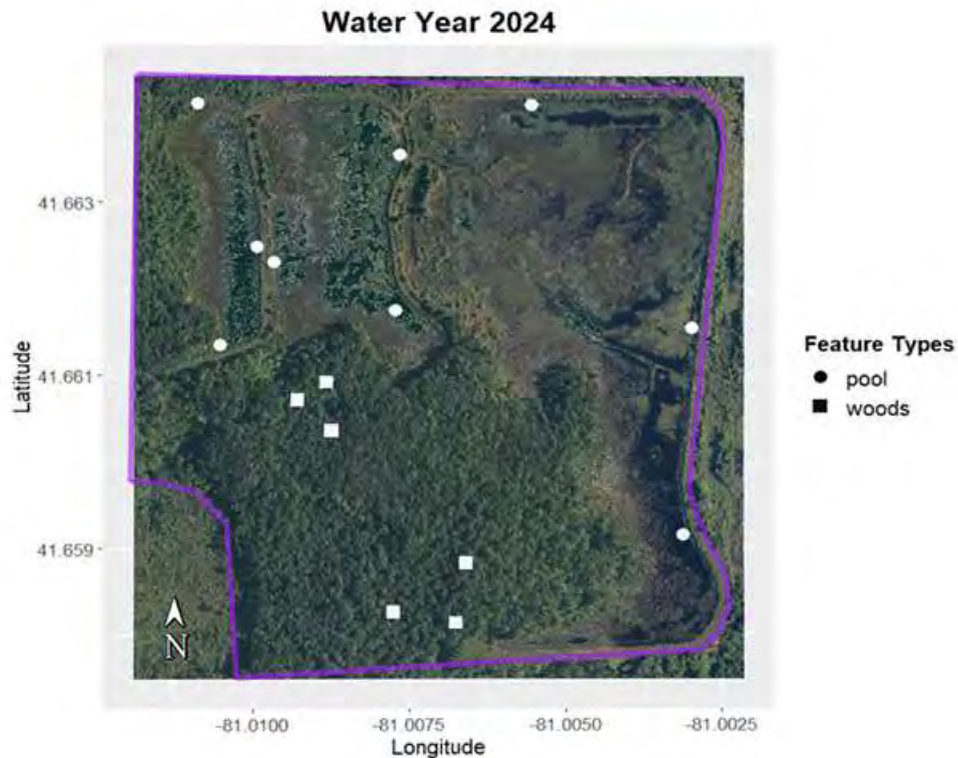


Figure 338. Map of sampling locations within Phase 1 of the Trumbull Creek Wetlands Mitigation Bank for the Water Year (WY) 2024. The background imagery, taken from the National Agriculture Imagery Program database, provides a high-resolution satellite view of the Project, taken in May 2023, to show the distinct microtopography clearly. The legend shows that circular markers represent sampling points in wetland pools and square markers represent sampling points within forested areas. Latitude and Longitude coordinates are shown for spatial reference.

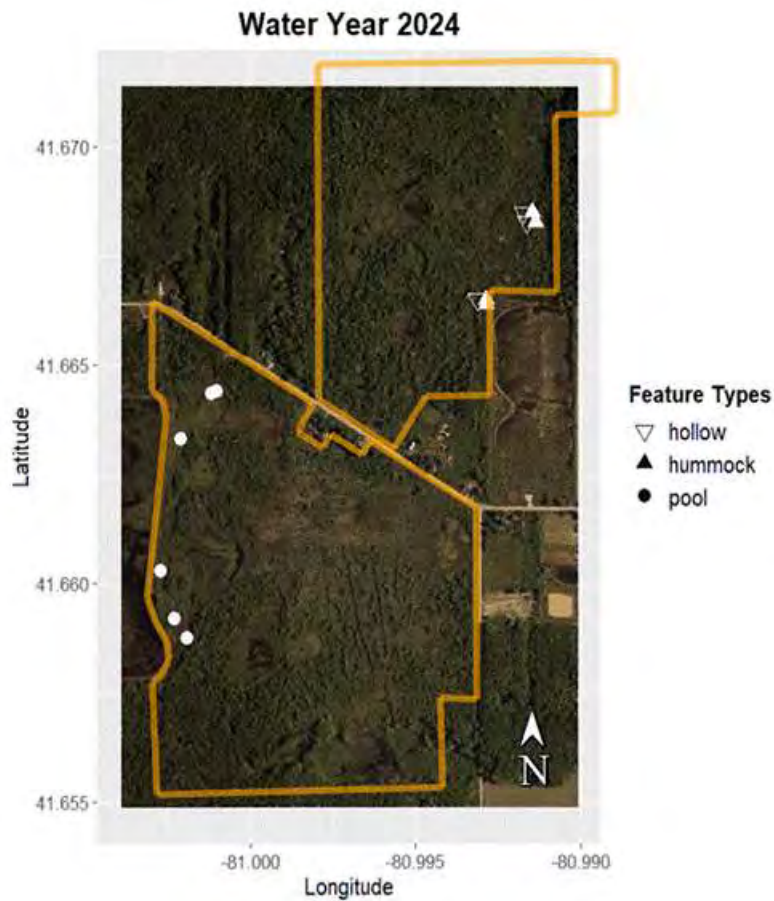


Figure 339. Map of sampling locations within Phase 2 North and Phase 2 South of the Trumbull Creek Wetlands Mitigation Bank for the WY 2024. The background imagery, taken from the National Agriculture Imagery Program database, provides a high-resolution satellite view of the Project taken in May 2023, to show the distinct microtopography clearly. The legend shows that down-facing triangles represent hollows, up-facing triangles represent hummocks, and circular markers represent sampling points in wetland pools. Latitude and Longitude coordinates are shown for spatial reference.

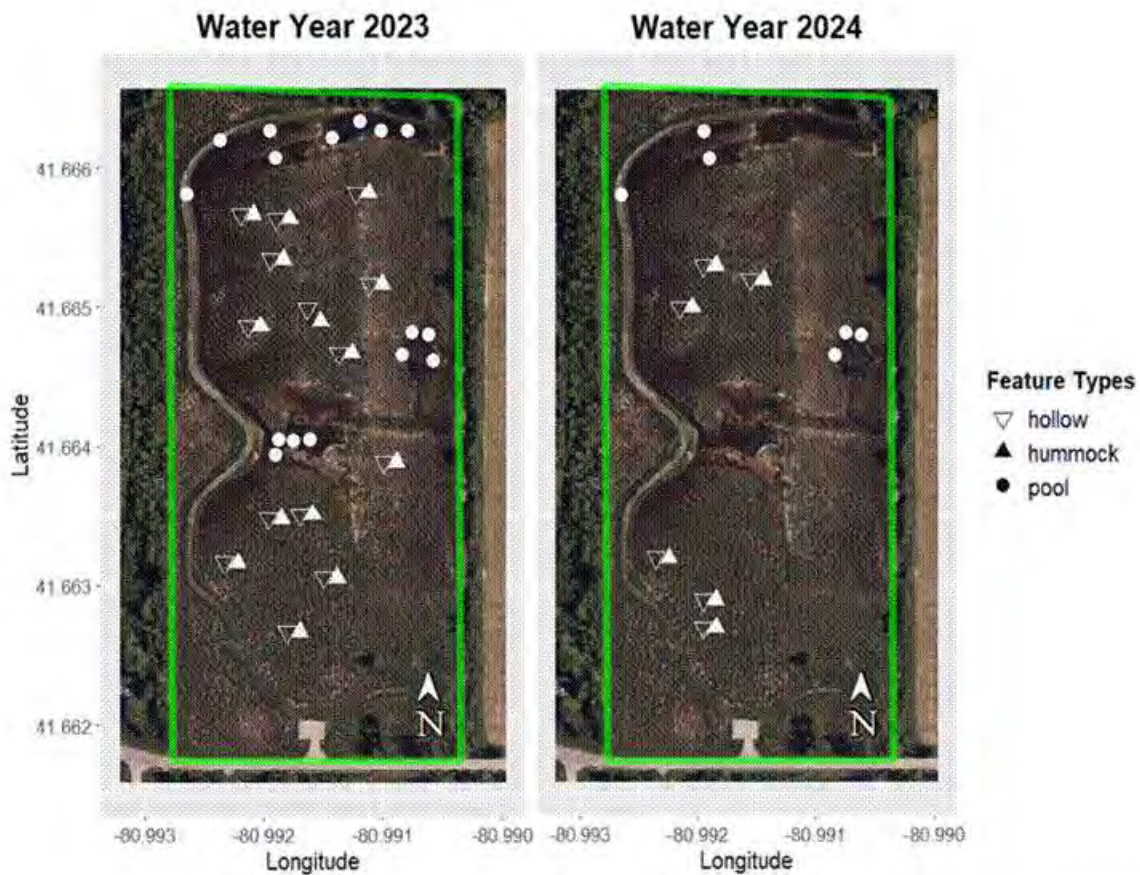


Figure 340. Map of sampling locations within Phase 3 of the Trumbull Creek Wetlands Mitigation Bank, also known as the H2Ohio Trumbull Creek Wetland Project, for the water years of 2023 and 2024. The background imagery, taken from the National Agriculture Imagery Program database, provides a high-resolution satellite view of the Project, taken May 2023, to show the distinct microtopography clearly. The legend shows that down-facing triangles represent hollows, up-facing triangles represent hummocks, and circular markers represent sampling points in wetland pools. Latitude and Longitude coordinates are shown for spatial reference.

Methods

Construction of the oldest Project, Phase 1, occurred between 2000 and 2001. No seeding of native wetland seed mixes occurred at the time of construction, instead relying on recruitment from a seed bank; In 2005, the installation of 110 balled and burlapped trees and shrubs of two species took place, along with 230 bare-root floating aquatic plants of four species and the installation of 118 plugs of herbaceous plants of 4 species. Phase 1 does not feature hummock-hollow pairs. Microtopography such as this may have once existed but has become

indistinguishable in the 20 years since construction. This region is forested and, therefore, has been categorized as “Woods” in all figures.

The construction of Phases 2 North and South occurred between 2004 and 2005. No seeding of native wetland seed mixes occurred at the time of construction, instead relying on recruitment from a seed bank. In 2006, the installment of 90,000 native bare-root trees and shrubs took place. Phase 2 North and Phase 2 South have spread out hummock-hollow pairs. They are approximately 17.93 m² with an aspect ratio of 11:7.

Construction of the H2Ohio Trumbull Creek Wetland Project occurred between October 2021 and April 2022, with initial seeding and herbaceous planting occurring in January 2022 and an additional reseeding and establishment of woody plants occurring in April 2022. The H2Ohio Project has more compact hummock-hollow pairs than seen in Phase 2. They are approximately 8.42 m² with an aspect ratio of 2:1. Due to the construction methods, the hummocks should consist of only topsoil, while the hollows consist of some topsoil and some clay, however, the exact composition of each hummock-hollow pair would be difficult to measure and varies between each pair. The hollows have less topsoil post-construction than pre-construction. There are no inlets into the H2Ohio Trumbull Creek Wetland Project and only one outlet at the WLCS. Water enters the Project via precipitation, moving slowly across the upland hummock-hollow microtopography toward the lowland pools and WLCS at the north end. The pools are variable in their inundation extent, so all pool samples were taken from the deepest, most frequently inundated soils in each pool.

All four wetland parcels have pools of variable sizes. Phase 1 has the largest pools, with surface areas of 21,237 m², 39,052 m², and 120,726 m². Phase 2 South has many medium-sized pools; two of the most distinct ones were sampled (Figure 339), with 9,242 m², and 8,556 m² surface areas. Phase 2 North does not have distinct pools and instead consists of a large wet marsh area; the marsh region was not sampled. The H2Ohio Trumbull Creek Wetland Project has the smallest pools overall, consisting of four borrow pools, two of which were sampled in 2024 (Figure 340), with surface areas of 632 m² and 2076 m². Hummock-hollow and pool surface area dimensions were measured using Google Earth satellite imagery.



Figure 341. Figure 342. Satellite imagery showing the difference in microtopography size in Phase 2 North and the H2Ohio Trumbull Creek Wetland Project. Satellite images of the border between Phase 2 North of the Trumbull Creek Wetland Mitigation Bank and the H2Ohio Trumbull Creek Wetland Project. The white circles are meant to show the differences in Hummock/Hollow microtopography size and structure, as both images are approximately the same scale. The satellite imagery in Figure 20 is from April 2012, while Figure 21 is from November 2021.

Mehlich-3-Extractable Phosphorus

The Mehlich-3 extractant targets phosphorus, iron, and aluminum only available to plants and microbes; these nutrients are likely to be retained by wetland sediment.

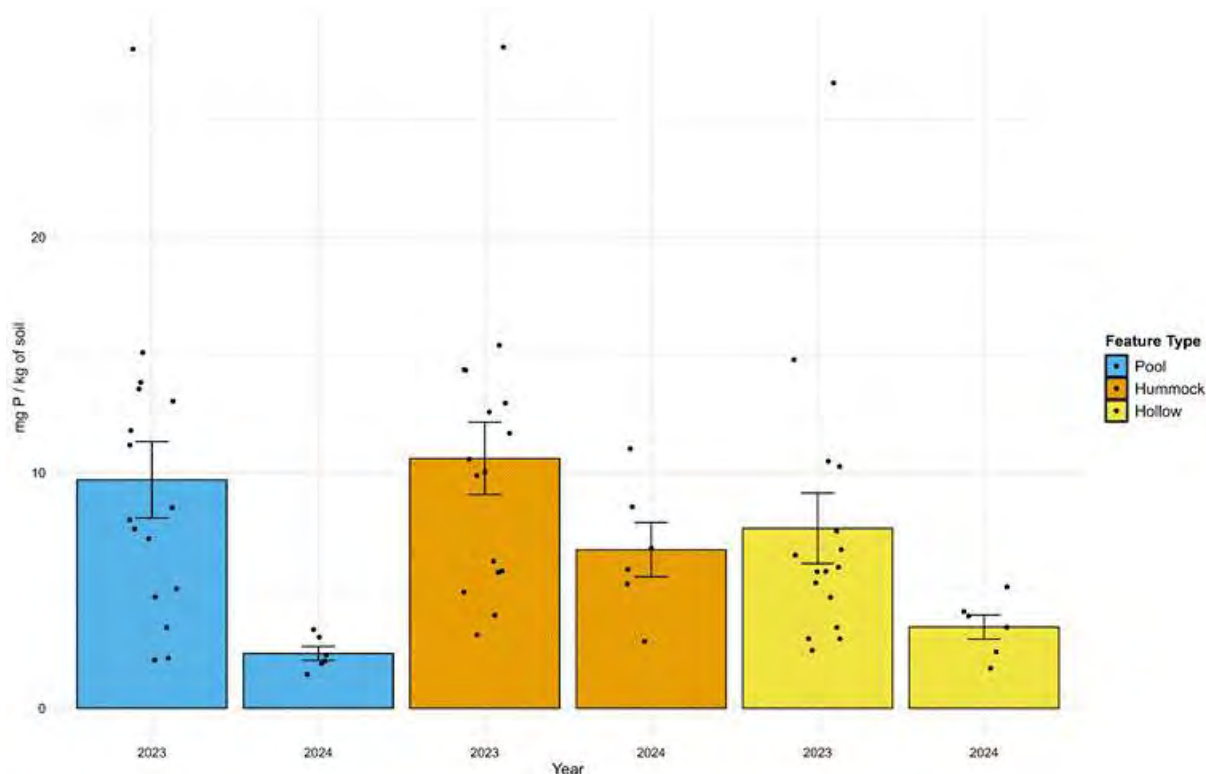


Figure 343. Mehlich-3-extractable phosphorus across the H2Ohio Trumbull Creek Project. Average Mehlich-3-extractable phosphorus, in mg/kg of soil, measured across three microtopography types at the restored H2Ohio wetland project, Trumbull Creek, during the summer of 2023 and 2024. Pools, hummocks, and hollows are the distinct micro-topographical features built into this wetland. A jitter effect was applied as individual data points to ensure all data is visible. Error bars represent standard error, displaying the precision of average phosphorus measurements for each microtopography type. The data reflects the change in soil phosphorus bioavailability within each microtopography grouping from 2023 to 2024, or two and three years since restoration, respectively.

The observed decline in Mehlich-3-extractable phosphorus from 2023 to 2024 at the restored H2Ohio wetland is likely not due to phosphorus leaving the Project, because the Project is isolated and has a small outflow. Therefore, the most likely explanation is that the decline is driven by plant uptake. It is likely that submerged aquatic vegetation and emergent wetland vegetation have flourished in and around the pools and hollows over the year, storing bioavailable phosphorus in the increasing plant biomass. Many of the hummocks feature growing tree saplings which will accumulate phosphorus more gradually than the herbaceous plants with shorter nutrient cycles. This may explain the smaller decrease seen in the hummocks compared to the hollows and pools.

Spatial variability in phosphorus concentrations were observed within the same wetland age and microtopography groupings. The oldest wetlands have the largest spatial variability or largest

range between phosphorus hotspots and coldspots. The smaller spatial variability in the H2Ohio Trumbull Creek Wetland Project may be due to its recent establishment so that there is less time for these hotspots to form, or due to the different designs/structures.

Given the large standard error bars, the true difference between the bioavailable phosphorus concentrations may not be as significant as they appear in Figure 2. Additionally, some of the observed decrease may be attributed to variability in soil conditions, rather than a declining trend in phosphorus bioavailability. Differences in soil moisture content between the sampling dates in 2023 and 2024 may be an indication of different annual precipitation levels, which could have led to a different distribution of nutrients within the observed soil layer of 0–5 cm, and sampled locations.

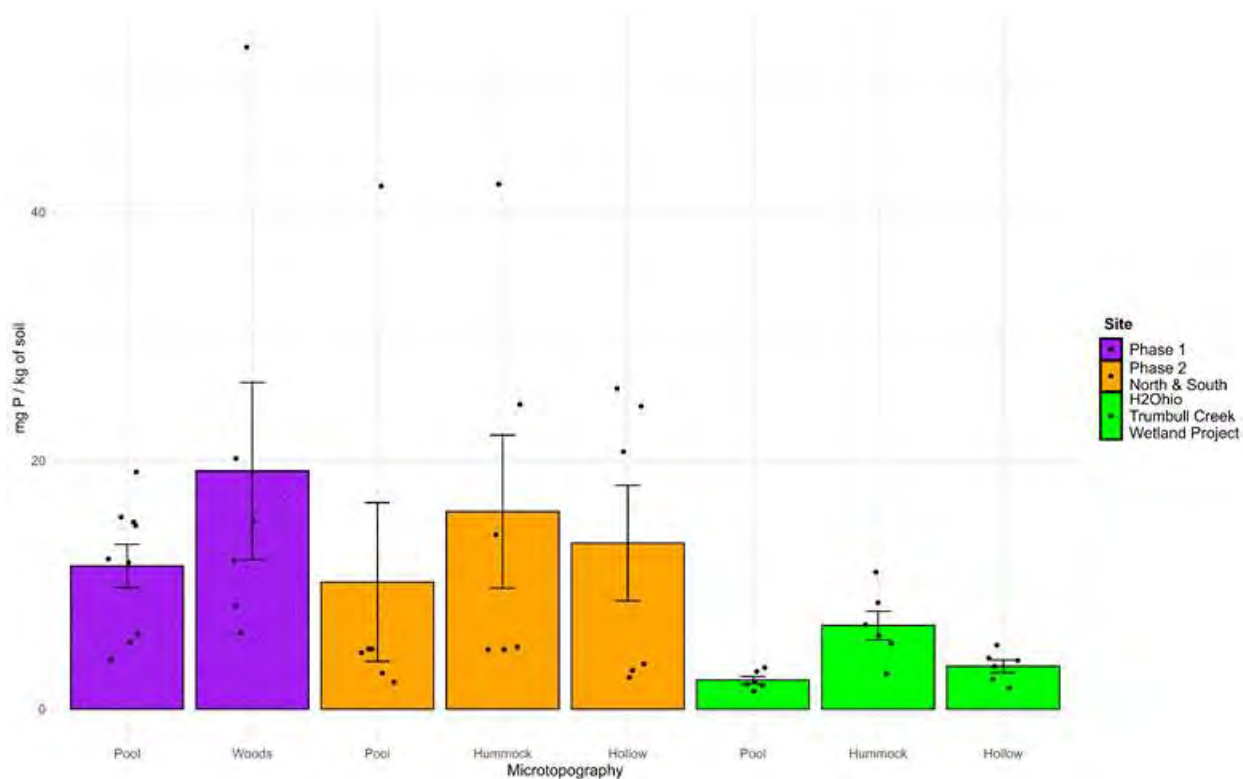


Figure 344. Mehlich-3-extractable phosphorus across the Trumbull Creek Mitigation Bank. Average Mehlich-3-extractable phosphorus, in mg/kg of soil, measured in 2024, and grouped by four microtopography types: pools, woods, hummocks, and hollows, across three parcels of the Trumbull Creek Wetland Mitigation Bank, with varying restoration ages. Phase 1, restored in 2000–2001, is filled in purple, Phase 2 North and South were restored in 2004–2005 and are filled in orange, and the H2Ohio Trumbull Creek Wetland Project, restored in 2021–2022, is filled in green. A jitter effect was applied as individual data points to ensure all data is visible. Error bars represent standard error, displaying the precision of average phosphorus measurements for each microtopography type. The data displays the differences in soil phosphorus bioavailability associated with both wetland age and microtopography.

In general, the older two wetlands exhibit higher bioavailable phosphorus concentrations than the newly restored Trumbull Creek H2Ohio Wetland Project. This difference may be due to the age of the wetlands, as the older Projects have had a much longer time to accumulate phosphorus in the soils. One caveat to consider is that the older two wetlands have a surface water flow from Phase 1 into Phase 2 South, which eventually drains in the north-east section of Phase 2 North. There is no surface water connection to the Trumbull Creek H2Ohio Wetland Project; The surface water flow allows more opportunity for Phases 1 and 2 to accumulate phosphorus than the Trumbull Creek H2Ohio Wetland Project.

Alternatively, this difference may be due to structural differences in wetland construction. Each wetland in the mitigation bank was created using slightly different designs and construction guidelines. (Figure 341 and Figure 21). Within each wetland age, another trend is found, in which the uplands (hummock-hollow pairs) exhibit higher bioavailable phosphorus concentrations than the pools. The pools exhibit the lowest bioavailable phosphorus concentrations of any microtopography grouping. In Phase 2 North and South, the hollows exhibit a higher average phosphorus concentration than the hummocks. In the Trumbull Creek H2Ohio Wetland Project, the hummocks exhibit a higher average phosphorus concentration than the hollows. This difference is explained by a bias introduced in sampling, as one of the two hummock/hollow patches for Phase 2 North was located next to the outflow for Phases 1 and 2, which could contribute to increased opportunities for phosphorus sorption in that patch, compared to if all sampling had taken place farther from the outflow (Figure 341). The patch sampled near the outflow shows significantly higher average phosphorus concentrations, in the hummocks and hollows, than the patch away from the outflow (further northeast).

Soil Phosphate Sorption Capacity (SPSC)

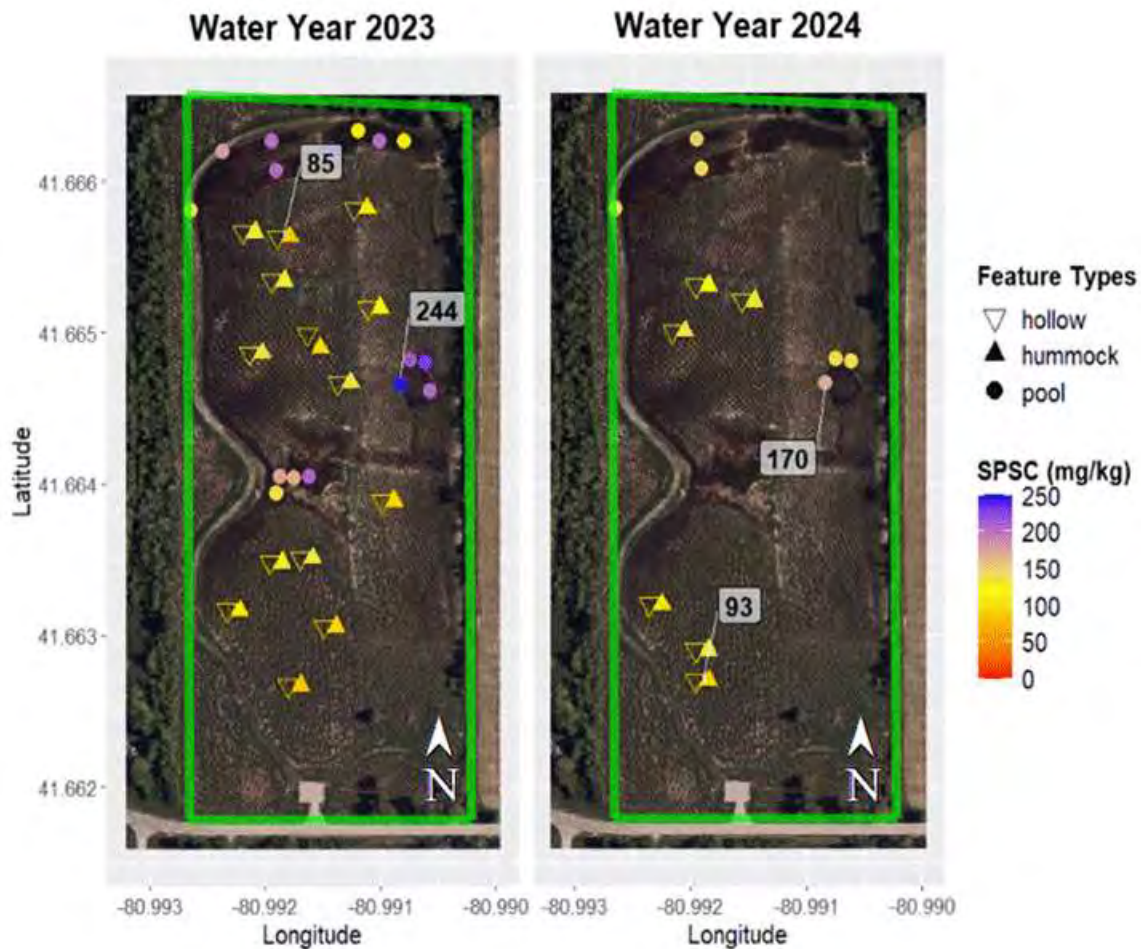


Figure 345. Soil Phosphate Storage Capacity at the H2Ohio Project from 2023 and 2024. Average Soil Phosphate Sorption Capacity (SPSC) throughout the H2Ohio Trumbull Creek Wetland Project from water years 2023 and 2024. Each shape denotes an approximate sampling location and is annotated with the mean SPSC for composite soil samples (0–5 cm). The ‘feature types’ legend shows that down-facing triangles represent hollows, up-facing triangles represent hummocks, and circular markers represent sampling points in inundated borrow pools. Latitude and Longitude coordinates are shown for spatial reference. The color of the circle indicates the range of SPSC values from 0 to 250. Negative SPSC values indicate potential for soils to release phosphate, while positive values indicate that soils have capacity to sorb phosphate, based on Mehlich-3 extractions of P, Fe, and Al.

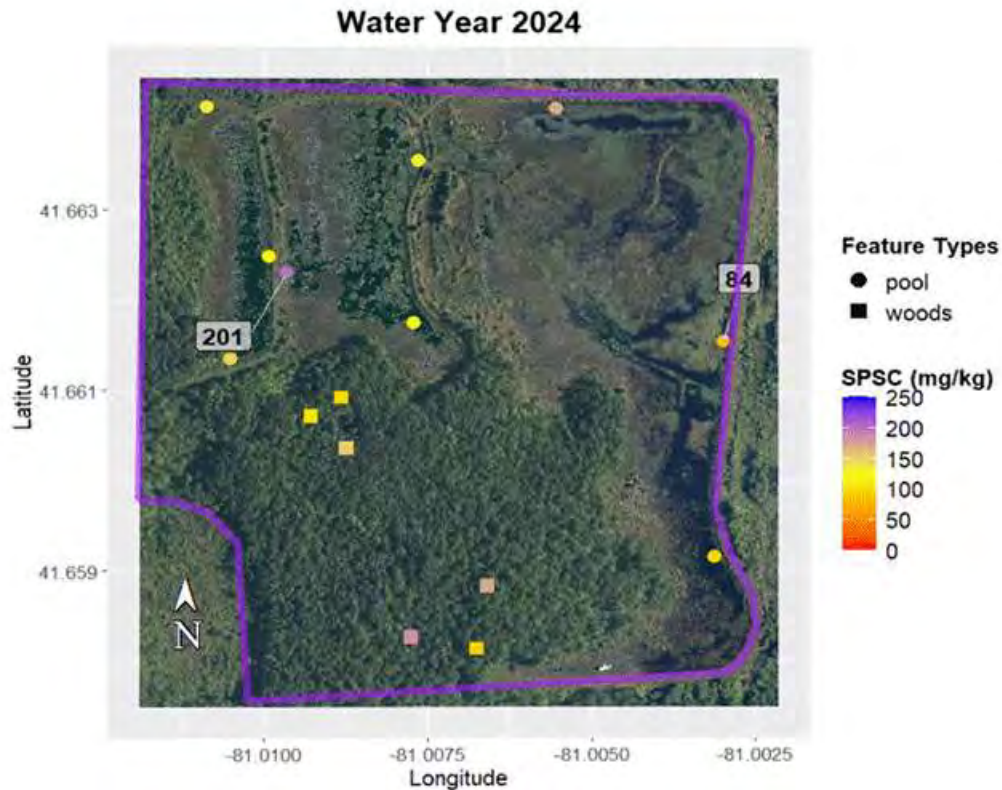


Figure 346. Soil Phosphate Storage Capacity at Phase 1 in 2024. Average Soil Phosphate Sorption Capacity (SPSC) throughout Phase 1 of the Trumbull Creek Wetlands Mitigation Bank from water years 2023 and 2024. Each shape denotes an approximate sampling location and is annotated with the mean SPSC for composite soil samples (0–5 cm). The ‘feature types’ legend shows that circular markers represent sampling points in wetland pools and square markers represent sampling points within forested areas. Latitude and Longitude coordinates are shown for spatial reference. The color of the circle indicates the range of SPSC values from 0 to 250. Negative SPSC values indicate potential for soils to release phosphate, while positive values indicate that soils have capacity to sorb phosphate, based on Mehlich-3 extractions of P, Fe, and Al.

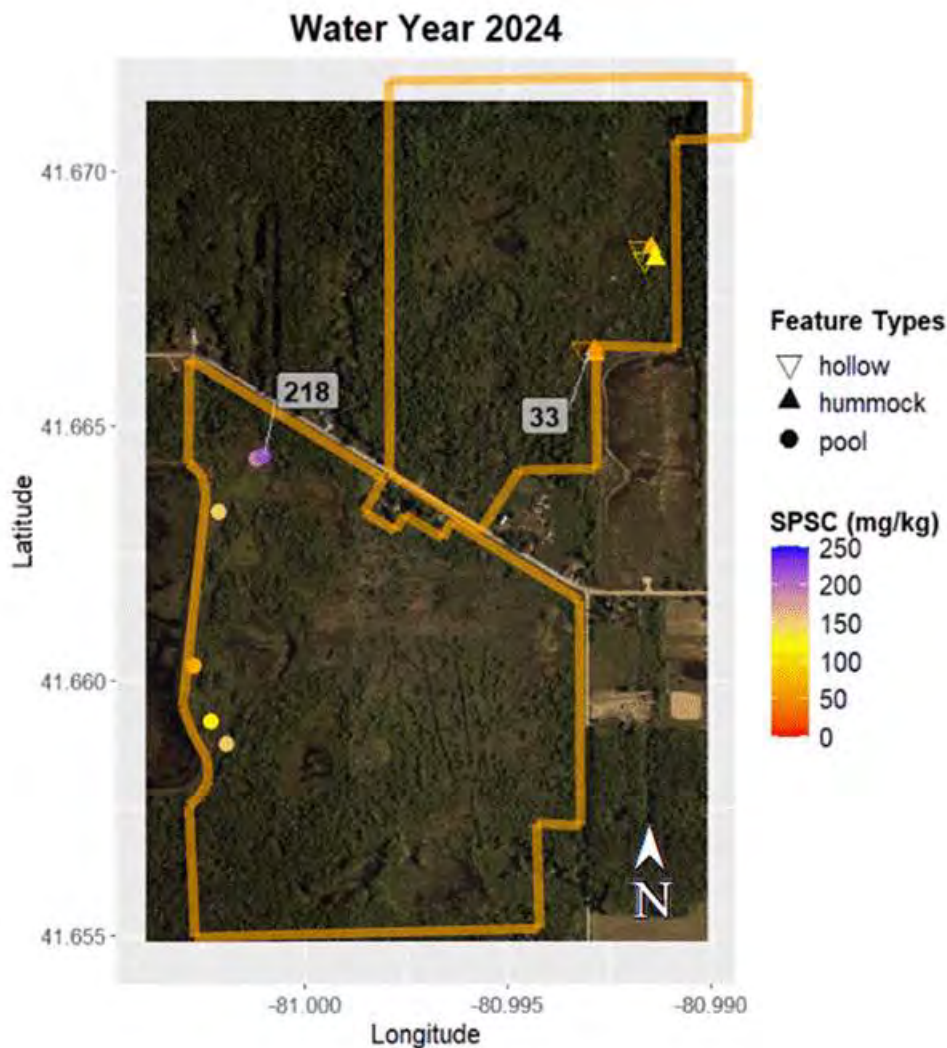


Figure 347. Soil Phosphate Storage Capacity at Phase 2 North and Phase 2 South in 2024. Average Soil Phosphate Sorption Capacity (SPSC) throughout Phase 2 North and Phase 2 South of the Trumbull Creek Wetlands Mitigation Bank from water years 2023 and 2024. Each shape denotes an approximate sampling location and is annotated with the mean SPSC for composite soil samples (0–5 cm). The ‘feature types’ legend shows that down-facing triangles represent hollows, up-facing triangles represent hummocks, and circular markers represent sampling points in inundated borrow pools. Latitude and Longitude coordinates are shown for spatial reference. The color of the circle indicates the range of SPSC values from 0 to 250. Negative SPSC values indicate potential for soils to release phosphate, while positive values indicate that soils have capacity to sorb phosphate, based on Mehlich-3 extractions of P, Fe, and Al.

Soil phosphate sorption capacity (SPSC) is an indicator of a soil’s capacity to sorb or release phosphate based on the ratio of Mehlich-3-extractable P to Mehlich-3-extractable iron and aluminum and the mass of Mehlich-3-extractable iron and aluminum, which indicate the

quantities of iron and aluminum oxides in soils. The soil type across the H2Ohio Trumbull Creek Wetland Project is similar, though the amount of clay in each microtopography grouping varies. The variation in clay content was noted as a qualitative comparison of “high clay content”, “low clay content” or “no clay content” in the field, creating an ordered factor of soil sample clay content rather than a quantitative measurement. This variation in clay content is potentially a factor in the spatial variability seen in the soil’s capacity to retain phosphorus. Another potential factor in the difference between the pools and uplands is the variation in the inundation period which would lead to different nutrient exposure. In general, where the soil is consistently inundated, there is higher sorption capacity. SPSC values were highest in the four borrow pools, moderate in the northern upland area, and lowest in the southern upland area. Based on the 2023 data, the easternmost pool appears to have the highest sorption capacity. (Figure 344) This easternmost pool is located the furthest upland and also exhibits the greatest variability in its inundation periods. Almost all of the sampled points had SPSC values greater than 100 mg phosphorus/kg of soil, indicating they are likely to retain phosphorus. Locations with lower SPSC values range from 80 to 99 mg/kg soil, suggesting they are not at risk of releasing phosphorus. Any SPSC value greater than 0 indicates that the soil does not pose a risk of releasing phosphorus (Nair et al., 2015).

It does not appear that the capacity for bioavailable phosphorus sorption has changed much between 2023 and 2024. Additional years of data are needed to better understand whether the soil is gaining or losing capacity for phosphorus. The soil's capacity to retain phosphorus should continue to be monitored, as this could provide insights into whether the H2Ohio Project is developing similarly to the older Projects, helping to understand if the spatial variability seen in SPSC is due to differences in age or Project design. Continued SPSC data could inform S+W and ODNr management decisions about the design of future projects, potentially improving the likelihood that they function as a sink for phosphorus or increase sorption capacity over time.

Iron content also plays a role in phosphate sorption as areas with higher iron content could have more opportunities to sorb phosphate.

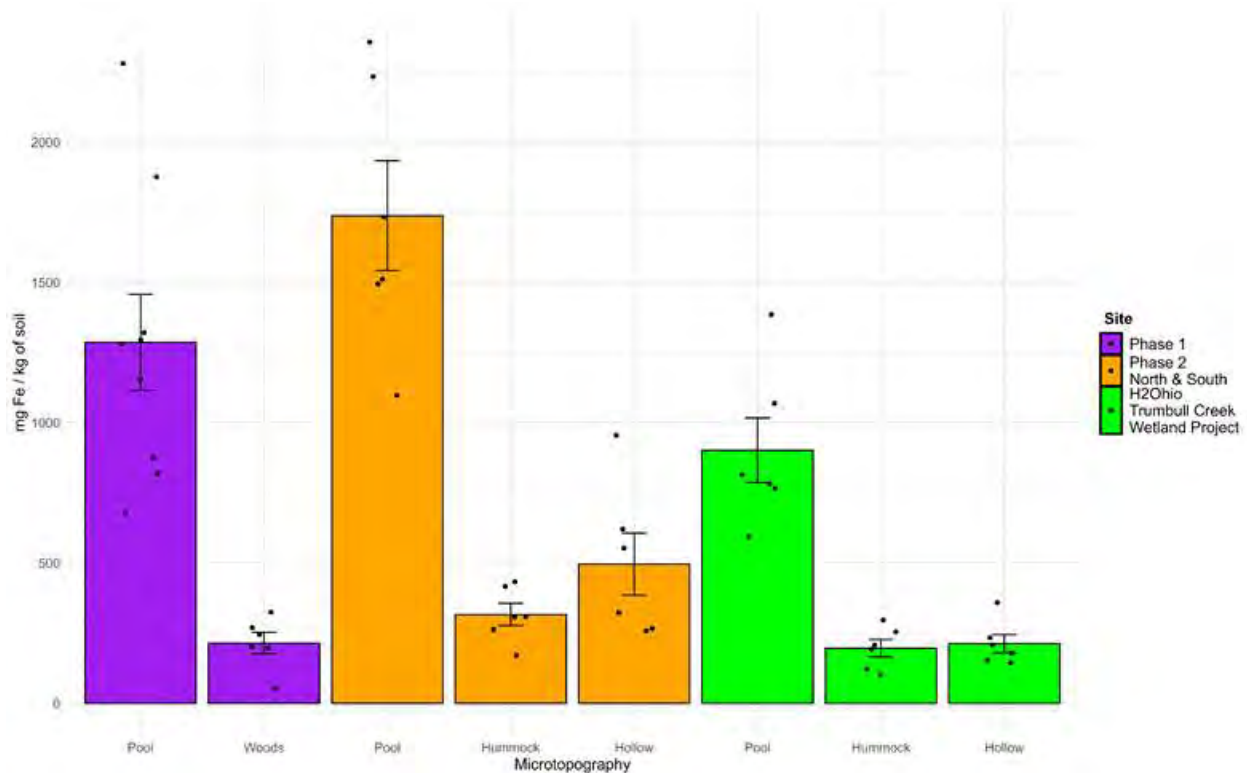


Figure 348. Mehlich-3-Extractable Iron Across the Trumbull Creek Mitigation Bank. Average Mehlich-3-extractable iron, in mg Fe/kg of soil, measured in 2024, and grouped by four microtopography types: pools, woods, hummocks, and hollows, across three parcels of the Trumbull Creek Wetland Mitigation Bank, with varying restoration ages. Phase 1, restored in 2000–2001, is filled in purple, Phase 2 North and South were restored in 2004-2005 and are filled in orange, and the H2Ohio Trumbull Creek Wetland Project, restored in 2021–2022, is filled in green. A jitter effect was applied as individual data points to ensure all data is visible. Error bars represent standard error, displaying the precision of average iron measurements for each microtopography type. The data displays the differences in soil iron bioavailability associated with both wetland age and microtopography.

The lowland portions of the Project are regularly inundated, and more likely to become hypoxic than the upland portions. Two of the borrow pools are located in the northern lowland region and two are located between the more southern upland regions. At the H2Ohio Project, the easternmost pool shows higher bioavailable iron content than the north-western “Water Level Control Structure pool”, which could contribute to the slightly higher phosphate sorption in the pool sediments of the easternmost pool. The pools overall have low bioavailable phosphate and high bioavailable iron, compared to the hummocks and hollows. This should indicate a low SPSC, however SPSC is highest in the pools (

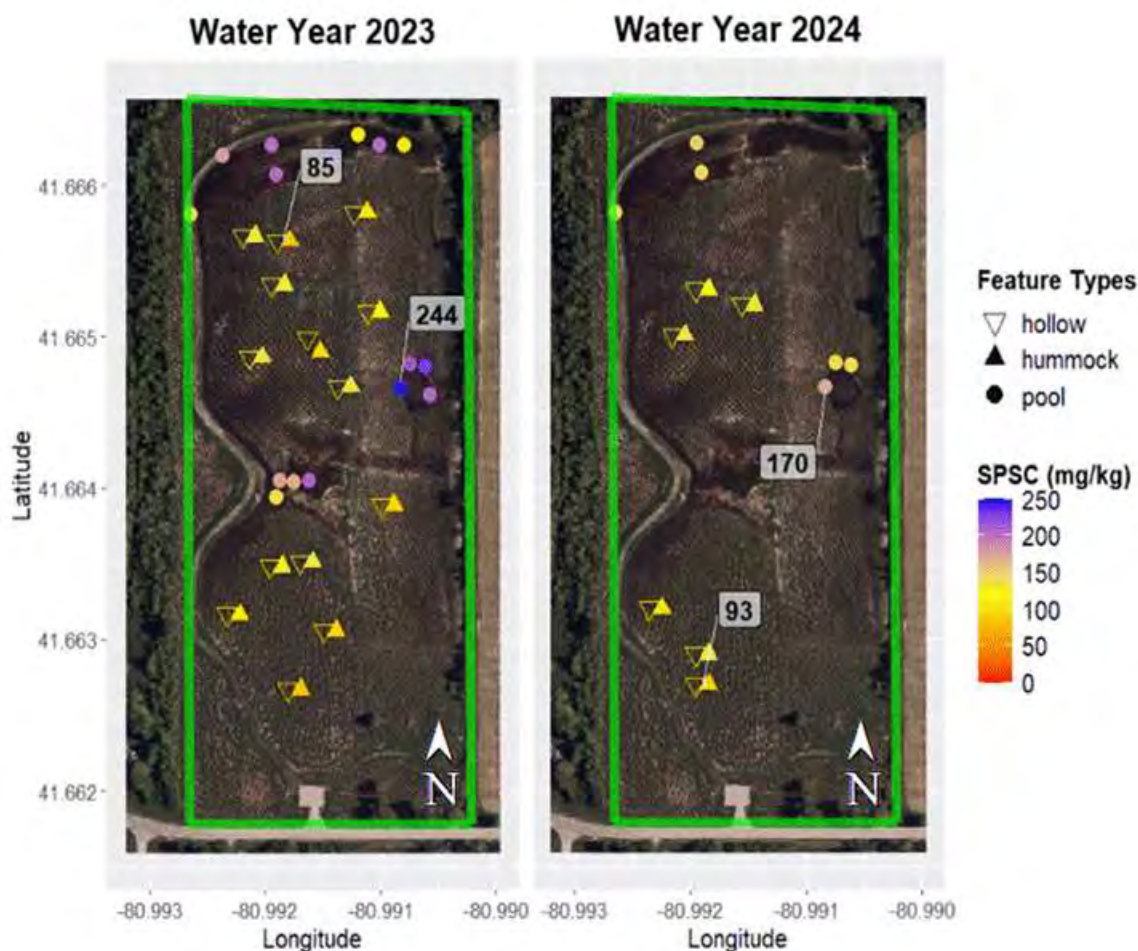


Figure 345), so likely the measured iron is the reduced form, which is most likely to bind to phosphate.

Conclusions / Management Recommendations

Many H2Ohio restored wetlands have similar vegetation and hydrology statuses as Trumbull Creek in that they have grass, shrubs and trees native to Ohio, designed flow paths and pools with similar depths. Many were used for agriculture and have only recently been restored to a lower level of function than the original wetland. Based on the trends of the older restored wetlands neighboring the H2Ohio Trumbull Creek Project, this Project and other H2Ohio Projects that are likely to filter phosphorus currently, have the potential to increase their capacity for phosphorus as they develop over the next 20+ years. Continued monitoring and management adjustments will be necessary to reach nutrient retention goals.

There is a watershed divide between the Grand River and Ohio River Basins, which separates the west and east portions of the H2Ohio Project. If Trumbull Creek were more hydrologically connected to the watershed, the SPSC data shows that it would be likely to catch and filter phosphorus before it could go downstream to Lake Erie. If SPSC data was collected prior to construction, it could be of use to Project managers in informing design decisions, such as how

connected a Project should be to the surrounding watershed. SPSC data would likely be lower prior to construction than it is now three years post-construction; it could have been of use to know where potential phosphate hotspots were prior to construction to inform design decisions. Knowing the SPSC data prior to construction could influence decisions to change the height of the water level control structure to ensure that phosphate does not leave the wetland.

Researchers cannot comment on other H2Ohio Projects or potential future projects, however, in the case of Trumbull Creek, it is possible that its high phosphate capacity is due to its lack of connection to the watershed. Researchers know that phosphate sorption is directly tied to the amount of iron and aluminum the Project has been able to accumulate; if the Project were more of a flow-through wetland, it could be losing iron and aluminum at the same rate or faster than it is able to gain it, and the phosphate capacity would not be maintained.

Additional Figures

Ohio and the labelled black line shows where the Trumbull Creek Wetland Project is located, along the Mill Creek Watershed and Bronson Creek Watershed divide. A blue line shows the drainage of Mill Creek, which is located below the Project, with dark blue arrows indicating the direction of flow.

Appendix II: Sampling Approaches

Focal Projects

Brooks Park Wetland Creation & Water Quality Initiative

Construction of the Brooks Park Project was completed in 2021. The Base Crew began routine monitoring in 2022. The unique hydrology of this Project influences where water samples are collected. Murphy's Run, a small tributary of Buckeye Lake, drains 1.2 square miles of primarily farmland and flows as the main input into the wetland pools of this Project during times of the year when Buckeye Lake water depth is lower (winter drawdown). Greater water depths in Buckeye Lake (summer pool) result in Buckeye Lake backflowing into the wetland, occasionally all the way into Murphy's Run. The Base Crew collects surface water and soil samples from six locations throughout this Project: two in Buckeye Lake, one in Murphy's Run ("Murphy's Run Inflow") and four locations representing key features of the wetland complex ("Main Pool", "West Pool", "Mid-wetland Stream", "Wetland Stream Outflow").

The Base Crew deployed water depth loggers (Onset HOBO® and Solinst Levellogger 5, Solinst Canada Ltd.) to measure high temporal resolution water depth at the mid-wetland stream and wetland stream outflow sampling locations starting in 2023. The Base Crew strategically chose these two locations to help determine when and how far Buckeye Lake is backflowing into the wetland. Researchers also deployed a water depth logger in a groundwater monitoring well nearest to Buckeye Lake to help determine groundwater's influence on the Project, and an AV sensor (SonTek- SL1500) under the bridge between Murphy's Run and Main Pool. At this location, the sensor is able to detect flows from Murphy's Run and large back flow events from Buckeye Lake.

Researchers conducted vegetation surveys for community composition at the Brooks Park Project in October 2021, August 2022, and September 2023 and sampled aboveground biomass and nutrient concentration during survey periods for 2022 and 2023. To measure sediment-water nutrient exchange, researchers collected and incubated three intact sediment cores from four locations representative of each major pool at the Brooks Park Project.

Burntwood-Langenkamp Wetland Conservation Area

Construction of the Burntwood-Langenkamp Project was completed in January 2022. The Base Crew began routine monitoring in 2022. Water from Burntwood Creek can enter the wetland through an inflow notch when water reaches a discharge rate in the adjacent creek (Burntwood Creek), or when it is actively pumped into the wetland. The discharge rate of Burntwood Creek at which water flows through the notch is estimated to be approximately 27 cubic feet per second, depending on the water level in the settling pool. Once in the wetland, the water flows into a deep settling pool then through over a mile of meandering marsh flats to the outflow at Coldwater Creek. The Base Crew monitors water depths manually at sampling locations and at standardized fixed staff gauges. The Base Crew continuously monitors water level at the inflow culvert and outflow water level control structure with water level sensors (Onset HOBO®). The

Base Crew collects surface water and soil samples from Burntwood Creek (inflow), the settling pool, other locations throughout the wetland, and the outflow (which flows out to Coldwater Creek)

The Specialty Crew conducted vegetation surveys and sampling of above- and belowground plant biomass at Burntwood-Langenkamp Project in July 2023. To measure sediment-water nutrient exchange at the Burntwood-Langenkamp Project, researchers collected and incubated triplicate sediment cores from four locations representative of the inflow and outflow of the wetland, along with the upper and lower sections of the meandering marsh stream and flats.

Forder Bridge Floodplain Reconnection

Construction at the Forder Bridge Project was completed in 2021, and the Base Crew began routine monitoring in 2022. The Forder Bridge Project is a Focal site; thus, the Base Crew visited monthly and sampled surface water when water was present. The Base Crew sampled soil twice per year, usually in the spring and fall. The Base Crew also sampled the Maumee River, including physicochemical measurements to compare the river to the wetland features.

Depressional Pools

Sampling locations 01–03 and 05–08 (Wetland Complex 1 and Wetland Complex 3) consist of isolated depressional pools. Complex 1 has three pools on the north side of the Project at an elevation above the Maumee River floodplain, and surface runoff from the meadow at a higher elevation sloping down to these pools is expected to be their primary source of water. Complex 3 is a set of four isolated depressional pools east of Stream 1 that are likely to receive surface runoff from the meadow to the east which slopes down to these pools and may be influenced by groundwater. Water samples are collected from each pool.

Floodplain Wetland

Sampling location 04 (Wetland Complex 2), west of Complex 1, is expected to function as a floodplain wetland but rarely floods due to its high elevation, about 1.8 m above the bank of the Maumee River. It only has standing water when the Maumee River is above about 5.8 m at the USGS gage Maumee River at Antwerp OH–04183500.

Treatment Train

Sampling locations 09–14 (Wetland Complex 4) is a set of four wetland pools in a treatment train flow path connected in series starting with a pool that receives agricultural drainage from outside the Project area from the SW Tile Outlet. Water flows from pool to pool and exits the fourth pool into Stream 1. Stream 1 meanders through woods north and northeast, ultimately flowing into the Maumee River. There are two other somewhat isolated pools in this complex, Pools E and F (Sample locations 13–14), that likely receive surface runoff from the surrounding area. Water samples and physicochemical parameters are measured at the inlets and outlets of each of the Wetland Complex 4 pools. The Base Crew collects samples and measures water velocity and water depth in the culvert (SW Tile Outlet) when water is present.

The Specialty Crew conducted vegetation surveys for community composition in August 2021, June and July 2022, and August 2023. The Specialty Crew sampled vegetation for above- and belowground biomass and nutrient concentrations in August 2021 and July 2022. For the sampling year 2022, the Specialty Crew surveyed and sampled Forder Bridge intensively to better understand species richness and diversity and determine an ideal sampling strategy for Forder Bridge and other Projects in the H2Ohio program.

To measure sediment-water nutrient exchange at the Forder Bridge Project, the Base Crew collected and incubated four intact sediment cores from locations representative of each major pool system.

The Forder Bridge Project was surveyed in 2022 for hydrogeophysical measurements to characterize subsurface soil and water characteristics, including Ground Penetrating Radar, Electromagnetic Induction, Electrical Resistivity Tomography, and soil moisture content, pH, soil organic matter, and porosity.

In 2024, the Forder Bridge Restoration Project was outfitted with a sensor system network intended to provide real-time, continuous water quality and atmospheric data. These sensors have the chief objectives of reporting surface water quality (specific conductance, water temperature, dissolved oxygen, and turbidity) and water level data within the established complexes of the Project to supplement nutrient load calculations and support hydrologic models. Water level sensors were installed within the deepest areas in Complexes 1, 2, 3, and 4. Complexes 1, 3, and 4 are outfitted with sensors measuring conductivity, water temperature, turbidity, and dissolved oxygen. Water level control sensors throughout the Project elucidate flow regimes such as storm events with high run-off. The Project also has five groundwater wells equipped with sensors that measure gauge height and conductivity within the wells. In addition, soil moisture around each well is measured at depths of 10 cm, 20 cm, and 50 cm. This provides information on the movement of groundwater beneath the surface of the Project. A station with atmospheric sensors is installed to measure wind, precipitation, temperature, humidity, and photosynthetically active radiation (PAR) to inform researchers of present conditions in the Project and to contribute to advanced modelling of processes occurring within the Project. Data is retrieved online in real-time and can be used by researchers to monitor and compare conditions between the different features within the wetland. This sensor network was funded through the Great Lakes Restoration Initiative budget.

Magee Marsh Turtle Creek Bay Wetland Reconnection Project

The Magee Marsh Project was constructed in 2021, and the Base Crew began routine monitoring in 2022. Dikes hydrologically isolate the Magee Marsh Project from the surrounding watershed except through actively managed water level control structures (WLCS) connecting it to Turtle Creek to the south and another wetland to the north. The objective of the sampling approach is to give researchers an understanding of nutrient gradients from west to east as Turtle Creek flows into Lake Erie and to compare surface water nutrients in the Magee Marsh Wetland and Turtle Creek (Fig. LOI map; hereafter Wetland and Creek, respectively).

Eight sampling locations exist across the Creek and the Wetland.

- WLCS1 and WLCS2 reconnect the Creek and the Wetland through the southern dike, and both have two sampling locations (one in the Creek and one in the Wetland).
- Two sampling locations are midway between WLCS1 and WLCS2 (one in the Creek and one in the Wetland).
- One sampling location is in the open-water center of the wetland.
- One sampling location is on the north side of the Wetland near the wetland pump, which is used to move water into adjacent wetland pools that are not associated with H2Ohio.

The Base Crew reduced sampling frequency in 2024 and collected surface water samples from all accessible locations with sufficient water once every other month. Some locations were difficult or dangerous to access, so collection was conditional upon aquatic vegetation densities and safety considerations, while other sampling locations were too dry to sample during parts of the year. As a result, sample sizes for some locations are limited. The Base Crew collected surface soil samples from the three sampling locations that were accessible to researchers and sampling equipment, inside the Wetland along Turtle Creek, once in 2024.

The drone and vegetation Specialty Crews collaborated at Magee Marsh Project to produce a drone-classified vegetation map. This was especially important due to the large size of the Project and the difficulty of access. The crews had to adapt methods for sampling vegetation to the constraints of coastal wetland sampling from a boat and surveyed only the western portion of the Project in 2023. The vegetation Specialty Crew collected vegetation community composition data along a transect in June 2023 with simultaneous collection of drone imagery and a low-altitude flight across the vegetation transect. The Base Crew subsequently sampled community composition and aboveground biomass in August 2023 using the stratified random sampling.

To measure sediment-water nutrient exchange at the Magee Marsh Project, the Base Crew collected and incubated intact sediment cores from locations representative of different vegetation patches found throughout the wetland. The number of cores collected from each patch varies from 3 to 8 based on the areal coverage of the patch (i.e., floating vegetation covers most of the wetland so eight cores were collected across that patch type).

In 2023, the Base Crew outfitted Magee Marsh Project with a complete sensor system network intended to provide real-time, continuous water quality and atmospheric data. These sensors have the chief objectives of reporting surface water quality (specific conductance, water temperature, and turbidity) and water level data within Turtle Wetland and Turtle Creek to supplement nutrient load calculations and support hydrologic models. The Base Crew installed physicochemical and water depth sensors at Wetland WLCS1 and at a downstream Project near Lake Erie while Wetland WLCS2 only received physicochemical sensors. A Project upstream in Turtle Creek received a water depth sensor. Upstream and downstream water depth sensors within Turtle Creek elucidate flow regimes such as seiche events or storm events with high run-off. The Base Crew placed sensors within the Wetland strategically near water level control structures to investigate effluent and influent water quality and volume as the water level control

structures are used. Data are retrieved online in real-time and can be used by researchers to monitor and compare Wetland and Creek conditions. The H2Ohio Wetland Monitoring Program budget funded this network.

Oakwoods Nature Preserve Wetland Restoration, East and West

Oakwoods East and Oakwoods West are two Projects essentially sampled as one Project by the H2Ohio Wetland Monitoring Program. Construction was completed in 2021. The Base Crew began routine monitoring in 2021 before construction of the West side was complete and before planting of vegetation.

Oakwoods East Routine Sampling

The Oakwoods East Project contains 24 constructed depressional wetland pools. The Base Crew samples surface water for nutrients and measure water depth monthly at fixed locations within representative pools. Pools 30, 31, 36, and 42 receive inputs from subsurface agricultural drainage. The Base Crew classifies these pools as “Flow-In/No-Flow-Out” (FINFO). The Base Crew collects surface water samples approximately monthly from pools with standing water and surface soil samples twice a year from each wetland pool. Because the tile inflows are at the bottom of the pools, direct measures of flow are challenging; therefore, the Base Crew estimates tile flow coming into the pool by measuring changes in water depth over discrete periods of time.

Oakwoods West Routine Sampling

Pool 1 at the Oakwoods West Project was designed as a floodplain wetland and is connected to Aurand Run, a tributary of the Blanchard River. Pool 1 also receives water from an 8-inch tile drain that delivers subsurface agricultural runoff from outside the Project. The Base Crew samples nutrient concentration and measures water depth monthly in Pool 1, in addition to flood event sampling. The Base Crew notes any surface connections to Aurand Run and any management via a water level control structure connecting Pool 1 and Aurand Run. The remaining pools (Pools 2–Pool 19) are isolated depressional pools, and the sampling approach is the same as in the Oakwoods East Project.

Hydrology Monitoring

The Base Crew pays considerable monitoring attention to Pool 1 because it is connected to the primary watershed collection body, Aurand Run, via a cut in a berm. Across two years of monitoring, the Base Crew adjusted sampling and sensor deployment to respond to the drastic water level changes that can occur within and across years. The Base Crew deployed multiple water depth sensors and gauges in Pool 1 because of the need to measure depths that can change over 1.8 m. Across the Oakwoods East and Oakwoods West Projects, the Base Crew installed staff gauges for standardized water depth measurements in several pools, including a “Crowd Hydrology” collaboration with H2Ohio Students Take Action and local area schools. Most gauges were added to the Crowd Hydrology website in November 2023, and citizen scientists, students, and researchers can use this tool to record changes in water depth at the Project.

Specialty Crew Sampling

The Specialty Crew surveyed vegetation community composition at the Oakwoods East and West Projects in August 2021, August 2022, and July 2023. The Specialty Crew sampled above- and belowground biomass and nutrient in 2022 and 2023.

To measure sediment-water nutrient exchange at the Oakwoods East Project, the Base Crew collected and incubated triplicate intact sediment cores from locations representative of two isolated depressional pools (Pool 39, Pool 40) and two “Flow-in /No-Flow-Out” wetland pools (Pool 30, Pool 42).

The Specialty Crew surveyed both the Oakwoods East and West Project in 2023 for hydrogeophysical measurements of subsurface soil and water characteristics, including Ground Penetrating Radar, Electromagnetic Induction, Electrical Resistivity Tomography, and soil infiltration tests. Hydrogeophysics data help delineate spatial variability and zones across the Project and inform a 3D hydrodynamic model. The Specialty Crew installed two groundwater monitoring wells in 2023.

Sensors Installed

Researchers installed 10 Vegapuls 22 (VEGA, Shiltach, Germany) sensors the Oakwoods East and West Project. Researchers installed Vegapuls sensors in Pools 1, 4, and 18 on the west side and in Pools 30, 31, 36, 39, 40, and 42 on the east side. At Wetland Pool 4 on the west side, researchers installed a conductivity sensor (cond.), dissolved oxygen sensor (DO), and turbidity sensor (turb) and also installed cond., DO, and turb sensors in Pool 42 and Aurand Run on the east side.

Redhorse Bend Preserve Wetland Restoration

Construction was complete at the Redhorse Bend Project in 2021. The H2Ohio Wetland Monitoring Program began routine sampling in 2022. Redhorse Bend Wetland consists of five main pools, a series of four smaller pools, a spring and an inflow/outflow ditch (Ditch 2) in the north portion of Redhorse Bend and a single pool and ditch in the southern portion. Much of the monitoring occurs in the northern portion of Redhorse Bend due to minimal hydrologic activity in the southern portion. During ambient or low flow conditions, monthly samples are collected from each main pool, the north inflow outflow ditch, the spring and the Sandusky River. During flooding conditions, the Sandusky River will enter Redhorse bend through Ditch 2 and then into Pools 1, 2, 3 and so on. During storm conditions, the Sandusky River will enter Redhorse bend through Ditch 2 and then into Pools 1, 2, 3 and so on. High flow samples are collected when the Sandusky River is over 3,800 cubic feet per second (cfs; assessed upstream at the USGS gage Sandusky River near Fremont OH - 04198000¹⁹). For extreme flow events, the river will flood into Ditch 2 and Pools 1, 2, 3 and so on as well as Pools A, B, C and D. During these events there is a complete connection between all pools and the river. The Base Crew collects samples once per event, but for extreme high flow events (over 10,000 cfs), the Base Crew collects samples multiple times during the “falling limb” of the storm event’s hydrograph (i.e.,

¹⁹ “Sandusky River near Fremont OH - 04198000.” [waterdata.usgs.gov](https://waterdata.usgs.gov/monitoring-location/04198000/). U.S. Department of Interior.
<https://waterdata.usgs.gov/monitoring-location/04198000/>

September 2023). The Base Crew collects storm condition samples from each pool and the inflow outflow ditch as allowed. If there is visible flow in or out any of the pools or the ditch, the Base Crew collects samples to determine nutrient concentration entering or leaving the wetland. For storm conditions, the Base Crew also leverages the Heidelberg University long-term monitoring location upstream to assess storm concentrations in the river.

The water sampling goal is to characterize ambient and storm flow concentrations across each wetland pool, the northern ditch (Ditch 2) and the adjacent Sandusky River. Annual soil sampling events collect three samples from each wetland pool (two along the edge of the pool and one in its deepest location), from the north ditch, and transects in the wet meadow floodplain and upland prairie. The Base Crew collects soil samples to analyze moisture content, total nitrogen and phosphorus, total phosphorus, iron, and aluminum. The Base Crew analyzes water extracts of soil samples for dissolved reactive phosphorus, total ammonium nitrogen, and nitrite+nitrate. These results are used to calculate soil phosphorus storage capacity, pH, and electrical conductivity.

The Specialty Crew surveyed vegetation surveys for community composition at the Redhorse Bend Project in late June 2022 and August 2023. The Specialty Crew sampled above- and belowground biomass and nutrient concentration during survey periods for 2022 and 2023. To measure sediment-water nutrient exchange at the Redhorse Bend Project, the Base Crew collected and incubated four intact sediment cores from locations representative of Ponds 1, 3, and 4.

Storm events were sampled on 01–12–2024, 01–30–2024, 04–05–2024, and 04–09–2024.

St. Joseph River Restoration

Construction at the St. Joseph's River Restoration Project was completed in 2021. The Base Crew began monitoring soon after. St. Joseph's River Restoration has flow-through, floodplain, and depressional pools. The Base Crew collects surface water samples approximately monthly during baseflow conditions, and additionally during high flow focuses on inlets and outlets of flow-through systems.

Routine Sampling

Flow-through

Four pools (A, B, C, G) are flow-through systems that capture water from three incoming tile drains and ultimately output to the St. Joseph River via a drainage ditch (east ditch). Pools A, C, and G are directly connected and form one large flow-through system at times of high flow. Pool B functions more or less separately from the A-C-G system. It receives only a portion of the water from one of the three tile drains that feed St. Joseph.

Flow-through + Floodplain

While Pools B and G function as flow-through wetlands, they also sometimes receive a large amount of flood water from the St. Joseph River and therefore simultaneously function as floodplain wetlands, contrary to their initial design intention.

Depressional Pool + Floodplain

Pools D, E, and F may receive surface runoff, groundwater, and/or rainfall, but function also as floodplain wetlands at times of high flow when the St. Joseph River is flooding the area.

Hydrology and Sensor-Based Water Quality Monitoring

In 2023, researchers installed a complete sensor system network intended to provide real-time, continuous water quality and atmospheric data. These sensors have the chief objectives of reporting surface and ground water flow through the Project to supplement nutrient load calculations and support hydrogeophysical models. Researchers installed water depth sensors at the North Pools A, B, and C. In addition, researchers installed sensors measuring ground water conductivity, temperature, and depth to the water table at Wells 1, 2, 3, 4 and 5. Data are retrieved online in real-time and can be used by researchers to investigate storm events and ambient conditions as water flows through the Project and biogeochemical processes take place.

Until mid-2023, the Base Crew measured water depths only at discrete locations when and where water and soil samples were collected. In 2023 the Base Crew placed markers at the deepest locations in pools for more standardized water depth measurements. During mid-summer 2023, the Base Crew placed sensors in Pools, A, B, and C that measure water levels several times per hour and report those via telemetry.

Vegetation Monitoring

The vegetation Specialty Crew surveyed community composition in August 2021, August 2022, and July 2023. The Specialty Crew sampled aboveground biomass and nutrient concentration during survey periods in 2022 and 2023 and belowground biomass in 2023.

Hydrogeophysical Assessments

Hydrogeophysical data helps delineate spatial variability and zones as well as stratigraphic units across the St. Joseph's River Restoration Project and inform a 3D hydrodynamic model. In 2022, hydrogeophysics researchers conducted ground penetrating radar (GPR), electromagnetic induction (EMI) and electrical resistivity tomography (ERT) surveys and installed three groundwater monitoring wells. During the 2023 field season, researchers installed two additional groundwater monitoring wells. Additional researchers plan to collect ERT, GPR, and soil samples in the 2024 field season.

Sensors Installed

The Base Crew installed four Vegapuls 22 (VEGA, Shiltach, Germany) sensors that monitor water level in pools A, B, C, and G at the Project. The Base Crew installed one ISCO autosampler in Pool B Output and equipped it with flow and low-profile velocity modules.

Non-Focal Projects

Coastal (University of Toledo)

Darby Refuge Wetland Reconnection Project

The Darby Project was constructed in 2021. The Base Crew began routine monitoring in 2022. The Darby Project consists of two wetland parcels (Pool 1 and Pool 4) and borders a ditch to the south, LaCarpe Creek to the west, and Lake Erie to the north. The parcels are permanently inundated, open-water wetlands surrounded by dike roads (Fig. LOI map). These parcels are hydrologically isolated from LaCarpe Creek and Lake Erie except through the three actively managed water level control structures (WLCS) in the ditch to the south which can flow to or from LaCarpe Creek (WLCS 1–3; Fig. LOI map). The sampling approach at the Darby Project is designed to investigate and compare surface water and soil nutrient concentrations across these wetland parcels, LaCarpe Creek, and the adjoining ditch.

There are nine sampling locations at the Darby Project. Five sampling locations exist within the wetland parcels: three in Pool 1 and two in Pool 4. Samples collected from the centers of Pool 1 and Pool 4 serve to assess open-water nutrient concentrations, while samples from the wetland side of each WLCS are collected to investigate nutrient concentrations near the points where water exchanges between the wetlands and the ditch. Samples collected at the four sampling locations within LaCarpe Creek and its ditch comprise nutrient-rich surface runoff from the surrounding agricultural land use. Researchers collected surface water samples from all accessible locations with sufficient water once per season. Researchers collected surface soil samples from the four sampling locations that were accessible to researchers and sampling equipment, inside the Wetland and within LaCarpe Creek near each WLCS, once in 2024.

North Ridge Hunt Club Wetland Restoration

The North Ridge Project was constructed in 2021 and the Base Crew began routine monitoring in 2022. Agricultural tiles direct nutrient-rich runoff into the ditch that borders the North Ridge Project on the north and east sides. The runoff is then pumped into the wetland complex from the southeast corner where it remains until it is released into Packer Creek to the south via a water level control structure (WLCS). The sampling approach for the North Ridge Project aims to assess and compare nutrient concentrations within the agricultural ditch, in each wetland pool, and within Packer Creek (Fig. LOI map), with a total of nine sampling locations. Researchers collected surface water samples from all accessible locations with sufficient water once per season. Researchers collected surface soil samples from five sampling locations within wetland pools that were accessible to researchers and sampling equipment once in 2024.

Ottawa National Wildlife Refuge Wetland Reconnection

The Ottawa NWR Project was constructed in 2021. The Base Crew began routine monitoring in 2022. The Ottawa NWR Project consists of two wetland parcels (Pool 3 and MS5), Veler Ditch, and Crane Creek. The parcels are permanently inundated, open-water wetlands that are surrounded by dike roads. These parcels are hydrologically isolated from Veler Ditch, Crane

Creek, and Lake Erie except through two actively managed water level control structures (WLCS) in Veler Ditch. Veler Ditch flows into Crane Creek and Lake Erie. The Ottawa NWR Project's sampling approach aims to investigate and compare surface water and soil nutrient concentrations across these bodies of water.

There are seven sampling locations in the Ottawa NWR Project (Fig. LOI map). Pool 3 and MS5 each contain two sampling locations. The Base Crew collects samples from the center of each pool to investigate open-water nutrient concentrations within the wetland parcels. The Base Crew collects samples near the WLCS in each pool to investigate nutrient concentrations near the points where water exchanges between the pools and Veler Ditch. Samples from within Veler Ditch and Crane Creek investigate nutrient-rich surface run-off from the surrounding agricultural land use. Researchers reduced surface water sampling frequency in 2024 from once per month to once per season. An eagle nest prevented access to several sampling locations during the spring and part of the summer, which resulted in a reduced sample size for those locations. Researchers collected surface soil samples from the four sampling locations that were accessible to researchers and sampling equipment, on either side of each WLCS, once in 2024.

West Central (Heidelberg University)

Andreoff Wetland Restoration

Construction was complete at Andreoff Wetland in 2022, and the H2Ohio Wetland Monitoring Program began sampling in 2022. Andreoff Wetland is an isolated wetland pool that retains water for the majority of the year at base water level. During periods of increased precipitation, the adjacent agricultural fields on the eastern border of Andreoff drain into the wetland pool creating distinct inflows. Once the pool begins to overflow, it will outflow into a roadside ditch. This was observed by researchers once in April 2024 following significant rain events and snowmelt. Otherwise, the wetland is isolated and retains water year-round. The Base Crew collects water samples seasonally from the main pool and inflows/outflows if applicable. The Base Crew supplements water nutrient samples with physiological measurements. The Base Crew collects soil samples annually from Andreoff; samples are taken from two transects in the main pool and one upland transect and analyze moisture content, total nitrogen and phosphorus, total phosphorus, iron, and aluminum. The Base Crew analyzes water extracts of soil samples for dissolved reactive phosphorus, total ammonium nitrogen, and nitrite+nitrate, and uses these results to calculate soil phosphorus storage capacity, pH, and electrical conductivity. The Base Crew collected event samples on 04-18-2024.

Blanchard River Floodplain Restoration

Construction was complete at Blanchard River Floodplain Wetland in October 2020. The Base Crew began routine monitoring in 2022. The Blanchard River Floodplain Wetland is a flow-through and depressional wetland system, located in Ottawa, OH. A series of vernal floodplain pools sit between a diversion channel and the Blanchard River, which follows a horse-shoe bend around the site. The upstream end of the channel has a concrete spillway approximately 3 m above the Blanchard River at base flow. The downstream portion of the channel is a base flow

stage height allowing backflow into the channel. At 1,000 to 1,500 cubic feet per second (cfs), backflow from the Blanchard River begins to visibly increase water level into the channel, and at flows greater than 2,000 cfs, the river enters the diversion channel via the spillway (Blanchard River at Ottawa OH - 04189260). Water in the upstream channel pools during drier months, indicating the possibility of high-water tables. The vernal floodplain pools are proportionally higher in elevation than the diversion channel and Blanchard River, suggesting that the area will not be flooded unless flows are at record levels. These vernal pools are accessed by crossing the concrete retaining wall, which is impossible to wade across during a flooding event. These pools fill up with seasonal rainfall, and they also fill when the nearby river gets high enough to flood the site, but the pools likely are not filled with shallow groundwater.

The goal of monitoring at the Blanchard River Floodplain wetland is to collect seasonal water samples and capture two to three storm events to calculate nutrient load reductions from the wetland and to better understand conditions in which the Blanchard River flood the diversion channel wetland. The Base Crew samples water from the diversion channel inflow, outflow, and midpoint of the channel. The Base Crew also collects soil samples from the inflow, outflow, and midpoint of the channel along with two additional samples within the channel between the outflow and midpoint and between the midpoint and inflow. The Base Crew also collects soil samples from five of the vernal pools in the floodplain area. The Base Crew analyzes these samples for moisture content, total nitrogen and phosphorus, total phosphorus, iron, and aluminum, and analyzes water extracts of soil samples for dissolved reactive phosphorus, total ammonium nitrogen, and nitrite+nitrate. The Base Crew uses these results to calculate soil phosphorus storage capacity, pH, and electrical conductivity.

The Base Crew collected storm samples on 01–11–2024.

Bright Conservation Area Wetland Restoration Initiative

Construction was complete at Bright Conservation Wetland in 2023. The Base Crew began routine monitoring in 2024. Bright Wetland (hereafter Bright) is a flow-through, floodplain wetland consisting of four main wetland pools. Pools 1 and 2 receive flow from upgradient agricultural fields via drainage tile before exiting to the Blanchard River via water level control structures. Pools 3 and 4 receive surface runoff from an agricultural field on the southern border of Bright. During storm events, the adjacent Blanchard River floods its banks into Bright Conservation wetland (< 1,000 cubic feet per second (cfs) according to USGS Blanchard River above Findlay OH - 04188400). During high flow, water moves from Pool 4 to Pool 3 to Pool 2 before exiting Pool 2 via a water level control feature #2. During extreme high flow (over 4,000 cfs), there has been evidence of connectivity across all four pools.

While Bright conservation is a Non-Focal Project, the Base Crew conducted monthly sampling events during the first year of monitoring to gain a better understanding of how water moves across the Project and during what conditions create noticeable hydrologic activity. During ambient samplings, the Base Crew samples each of the four pools at its deepest location. Due to the size and shape of Pools 1 and 2, additional locations, such as near the inflows and outflows are also

sampled. During high flow storm events, all pools are sampled along with any active inflows and outflows. Researchers installed water level sensors in each of the pools in June 2024 to better understand pool depth; however, the Base Crew collected little useful level data due to drought in the second half of 2024. The Base Crew collected water samples with the goal of calculating nutrient load reductions for the Blanchard River watershed.

The Base Crew collected three soil samples from each of the four pools; the Base Crew took two samples along the edge of the pool, and one from the deepest point in the pool. The Base Crew analyzes moisture content, total nitrogen and phosphorus, total phosphorus, iron, and aluminum. The Base Crew analyzes water extracts of soil samples for dissolved reactive phosphorus, total ammonium nitrogen, and nitrite+nitrate. The Base Crew uses these results to calculate soil phosphorus storage capacity, pH, and electrical conductivity.

The Base Crew collected storm event samples on 04-02-2024.

Buehler Farms Treatment Wetland

Construction at Buehler Project was completed in 2021, and the H2Ohio Wetland Monitoring Program began routine sampling in 2023. During pumping events, tile drainage in the adjacent ditch is pumped into the wetland via a pump in the southeast quadrant of the pool. The Base Crew samples water nutrients every 1–3 days following pumping events until conditions appear to have settled. The Base Crew collects water samples from northwest, northeast, southwest and southeast quadrants, making sure to sample the inflow and outflow. The water level in the main pool is controlled using an inline water level control structure. Once the maximum water level in the pool is reached, it drains into Muddy Creek. The Base Crew collects water and soil samples annually from the same locations where water samples are collected. The Base Crew collected water nutrient and soil samples on 7-16-2024.

Clary-Boulee-McDonald

Construction was completed at Clary-Boulee-McDonald Wetland in October 2021. The Base Crew began routine monitoring in 2022. Clary-Boulee-McDonald Wetland (hereafter Clary or Wolf Creek Wetland) is a floodplain wetland that is bisected by Wolf Creek, a segment of the Sandusky River. Prior to its conversion into wetland, Clary was tilled agricultural land. During its restoration, tiles were broken and three wetland pools were created. The existing swale was defined, and a wet meadow was created. During high flow Wolf Creek floods its banks into the wetland pools and swale. The nearest USGS gage used for reference is the USGS Sandusky River near Fremont OH gage (Sandusky River near Fremont OH - 04198000). The northern portion of the wetland consists of a wetland pool, swale and wet meadow and the southern portion consists of a wet meadow and two wetland pools. During high flows (2000 cubic feet per second at the Sandusky River), Wolf Creek floods its banks into the swale and Pools 1, 2, and 3 via cut banks. During dry periods Pool 1 and 3 rarely hold water. Pool 2 holds water year-round with the exception of period of drought and low-lying sections of the swale hold water year-round.

The goal of monitoring Clary is to collect seasonal water samples and capture two to three storm events per year to calculate nutrient load in Wolf Creek before it drains into the Sandusky River. The Base Crew also collects physiochemical measurements with each water sample to supplement phosphorus and nitrogen data for the location. The Base Crew collects water samples from the upstream and downstream portions of the swale, upstream and downstream in Wolf Creek, and Pool 2. Although Pools 1 and 3 do not hold water as frequently as other locations, if water was present in those pools a sample is collected. In 2024, researchers installed water level control sensors in the swale and Pool 2 to track water level fluctuations in relation to Wolf Creek to calculate conditions in which the creek would overflow into the wetland pools and swale.

Researchers collect soil samples from each of the water sampling locations with the exception of the two Wolf Creek locations. Researchers also collect a transect of three samples from each upland wet meadow. Researchers collect these samples to analyze moisture content, total nitrogen and phosphorus, total phosphorus, iron, and aluminum and analyze water extracts of soil samples for dissolved reactive phosphorus, total ammonium nitrogen, and nitrite+nitrate. Researchers use these results to calculate soil phosphorus storage capacity, pH, and electrical conductivity.

The Base Crew collected event samples on 01–11–2024.

Fruth Wetland Nature Preserve

Construction of the Fruth Wetland was completed in May 2021. The Base Crew began routing monitoring in May 2021. Fruth Wetland Nature Preserve (hereafter Fruth) is a depressional isolated wetland. The main events that influence the hydrology are seasonal variation in the groundwater table and precipitation. There are four pools in the western portion of Fruth Wetland. Pools 3 and 4 are within a diked area of Fruth that also contains microtopography with small hummocks and hollows. Pool 1 and 2 sit outside of the berm. Pool 1 is a collection of smaller pools that connect into one large pool when the water table is high. The area receives heavy precipitation; hence there are multiple sub-pools (A-D). Pool 1 (A-D) remains dry for much of the year. Pool 2 was invaded by cattails in 2023 and was dredged towards the end of the summer. The eastern wooded portion of Fruth consists of a swale and a series of vernal pools which likely hold precipitation runoff during the spring, however, have never been observed to contain water. Fruth was designed to drain to the north to two separate watersheds, Wolf Creek and the Portage Creek; however, there are no adjacent streams or ditches to serve inlets or outlets for this wetland.

The H2Ohio Wetland Monitoring Program's sampling goal is to characterize the seasonal variation in water quality in each pool as the water table fluctuates and to capture periods of time when the potential for phosphorus release is highest (high water temperature, low dissolved oxygen). For this wetland, it is especially important to quantify variation in surface water level to be able to assess the water volume stored in area. Therefore, each major pool has continuous water level monitoring physiochemical measuring sensors. Researchers installed groundwater

monitoring wells in 2022 and will continue to monitor to assess the nutrient concentrations in the subsurface water and subsurface water level changes.

Annual soil sampling events also collect three soil samples from each of the four main pools, two along the pool edges and one from the deepest location in the pool. Researchers also collect soil samples in a transect along the swale and from each vernal pool in the wooded area. Researchers analyze moisture content, total nitrogen and phosphorus, total phosphorus, iron, and aluminum. Researchers also analyze water extracts of soil samples for dissolved reactive phosphorus, total ammonium nitrogen, and nitrite+nitrate. Researchers use these results to calculate soil phosphorus storage capacity, pH, and electrical conductivity.

The Base Crew sampled storm events on 07-10-2024.

Sandusky River Headwaters Preserve Wetland and Habitat Restoration

Construction was complete at Sandusky River Headwaters Wetland in December 2020. The Base Crew began routine monitoring in May 2021. Sandusky River Headwaters Preserve Wetland (hereafter Headwaters) is a flow-through wetland consisting of two main wetland pools and a series of smaller vernal pools. Sandusky River Headwaters is split between the east and west wetland pools by a primary inflow stream. Flow from the primary inflow stream originates in a small agricultural field and flows down to Headwaters Wetland through forested hillside. The primary inflow then splits between the east and west wetlands, with slightly more flow going to the east wetland inflow.

East Wetland

The eastern portion of the Project consists of one larger, densely vegetated wetland pool that drains into a large wet meadow before it drains to the Sandusky River. There are also a series of smaller vernal pools to the east of the wetland that rarely hold water. During high flows over 1,000 cubic feet per second (cfs; Sandusky River near Bucyrus OH - 04196000), water drains from the pool into the wet meadow and overflows a small berm connecting to an old ditch channel that connects to the Sandusky River. The last time this occurred was April 3, 2024, during an event with a maximum flow of 2,470 cfs. Since the east wetland appears to receive more inflow than the west wetland and its shape varies more, it is also typically the pool that has outflow first.

West Wetland

In comparison to the east wetland, the west wetland is a larger and less vegetated pool. The west wetland also has a greater capacity to hold water due to its outflow elevation and bank height, even though it appears to receive less inflow. During ambient conditions, the outflows do not typically have water; however during high flow events (Sandusky River near Bucyrus exceeds 1,000 cubic feet per second, USGS Gage: 04196000), the outflow fills the wet meadow and overflows into a different small stream prior to flowing into the Sandusky River.

This is a Non-Focal project; therefore, samples are collected seasonally and during the peak of two to three major storm events per year. The Base Crew collects samples from the primary inflow (before it splits), the east and west wetlands, the east and west outflows, and the vernal pools if water is present in the pool. During ambient conditions, the Base Crew samples main pools and outflows in one location. During high flow events, the Base Crew may take samples in two locations depending on the location of the storm plume. The east wetland main pool retains water year-round even during drought, and the west wetland will often be dry during the late summer and fall. The Base Crew also samples the Sandusky River adjacent to headwaters. The Base Crew collects water samples are collected with the goal of determining inflow and outflow nutrient budget of the Sandusky River to determine functionality of the Sandusky River Headwaters Wetland in reducing nutrient loading.

Researchers collect annual soil samples from three locations in each of the east and west wetland, a transect of three samples at each outflow, and each of the vernal pools. Researchers analyze samples for moisture content, total nitrogen and phosphorus, total phosphorus, iron, and aluminum. Researchers analyze water extracts samples for dissolved reactive phosphorus, total ammonium nitrogen, and nitrite+nitrate. Researchers use these results to calculate soil phosphorus storage capacity, pH, and electrical conductivity. The Base Crew collected storm events samples on 04-03-2024.

Springville Marsh Wetland Extension

The Base Crew began routine sampling of the Springville Marsh Wet Meadow in August 2022. Springville Marsh was previously an agricultural field that was restored to wet meadow and upland prairie. There was not any construction or groundbreaking at this portion of the Springville Marsh. There are no adjacent streams or ditches that influence surface water hydrology at Springville Marsh. Since monitoring began at the Springville Marsh, the Base Crew has not collected any water nutrient samples as a result of the wet meadow being dry or having minimal water to collect. The Base Crew collects annual soil sampling of hydric and nonhydric soils to determine moisture content, total nitrogen and phosphorus, total phosphorus, iron, and aluminum. The Base Crew analyzes water extracts of soil samples for dissolved reactive phosphorus, total ammonium nitrogen, and nitrite+nitrate. Researchers use these results to calculate soil phosphorus storage capacity, pH, and electrical conductivity.

The Base Crew collected soil samples from Springville Marsh on 7-17-2024.

Sugarcamp 7 Blanchard Habitat

Construction was complete at the Sugarcamp 7 Wetland in April 2022. The Base Crew began routine monitoring in September 2022. Sugarcamp 7 is a flow-through and floodplain wetland. It consists of one large flow-through wetland along with a larger vernal pool and a multitude of small hummock and hollow pools (HH pools). The entire wetland area will flood under flood warning conditions based on the UGSG gage in Ottawa, OH (~6,000 cubic feet per second, cfs), which last occurred April 4, 2024 (7,590 cfs). Under high-flow conditions (~3,000 cfs), the

Blanchard River will overflow into the HH pool habitat. In the main pool, the tile drains and septic inputs are typically submerged under the pool water level and the grassed waterways overflow into the pool. The outflow is a defined channel where researchers have continuously logging water level sensors. The main pool holds water year-round while select HH pools and the larger vernal pool contain water only after major rain events.

As a Non-Focal site, the goal is to collect water samples seasonally to capture ambient flow conditions and two to three major storm events per year. The Base Crew collects water samples from each of the main pool inflows, the middle of the main pool to allow for mixing of the inflows, and the outflow. The Base Crew samples vernal pools and HH pools if sufficient water is present. Sugarcamp contains over fifty HH pools; rather than sampling every pool that has water, the Base Crew takes samples from a curved transects of six HH pools in the southwestern portion of Sugarcamp leading to the main pool. The Base Crew selected the pools that are sampled in this transect based on the amount of water regularly present in these pools.

Researchers collect soil samples on annual basis from the main pool, HH pools along the transect and the vernal pools. Researchers collect the main pool soil samples from three transects along the edges and middle of the pool running from the tile inflow to the outflow. The Base Crew analyzes these samples for moisture content, total nitrogen and phosphorus, total phosphorus, iron, and aluminum. The Base Crew analyzes water extracts of soil samples for dissolved reactive phosphorus, total ammonium nitrogen, and nitrite+nitrate. Researchers use these results to calculate soil phosphorus storage capacity, pH, and electrical conductivity.

The Base Crew collected storm event samples on 01–11–2024 and 04–16–2024

Upper Blanchard River Watershed Project

The Upper Blanchard River Restoration Wetland (hereafter Upper Blanchard or Upper) was completed in 2021. The Base Crew began routine sampling in 2022. Water from upstream agricultural runoff enters Upper Blanchard via an overwide inflow ditch. The inflow ditch retains water year-round and remains connected to the main pool. During storm events with high flow, greater than 3,000 cubic feet per second (cfs) at Tymochtee Creek and 300 cfs at Potato Run (Tymochtee Creek at Crawford, OH, Potato run near Wharton, OH), the overwide ditch will flow into the main pool before leaving the pool via an inline water level control structure to a roadside ditch. Upper Blanchard also has a branching pool to the north of the main pool with no noticeable connection to the main pool or inflow ditch. The branching pool also drains to the roadside ditch. The Base Crew collects water nutrient samples from each location (inflow ditch, main pool, outflow and branching pool) seasonally along with physiochemical measurements as flow and water level allow. The Base Crew captures events one to three days following a storm event on the ‘falling limb’ of the storm’s hydrograph. Water level, temperature and conductivity are continuously monitored through the H2Ohio Wetland Monitoring Programs Sensor Network effective 2024; prior to the sensor network installation discrete water level loggers were used to collect water level data. The Base Crew collects soil samples are collected from each location with the addition of one upland transect. The Base Crew analyzes these samples for moisture

content, total nitrogen and phosphorus, total phosphorus, iron, and aluminum. The Base Crew analyzes water extracts of soil samples for dissolved reactive phosphorus, total ammonium nitrogen, and nitrite+nitrate. Researchers use these results to calculate soil phosphorus storage capacity, pH, and electrical conductivity.

The Base Crew collected event samples on 01–31–2024, 04–18–2024, 05–15–2024, and 08–08–2024.

Northwest (Bowling Green State University)

Maumee River Floodplain

Construction at the Maumee River Floodplain Project was completed in spring of 2023. The Base Crew began routine monitoring in the summer of 2023. As a Non-Focal tier 1 project, the Base Crew samples Maumee River Floodplain for water three times per year and for soil once per year. The Base Crew takes water samples from each of the main pools (one central pool, two pools in the northwest corner), from the pre-existing wetland, and from one of the numerous hollows in the southwest corner of the project. The Base Crew takes soil samples from each of these locations as well as from designated upland locations for comparison.

Montpelier Wetland

The Montpelier Wetland Project was constructed in 2023, and the Base Crew began routine sampling the same year. Researchers also collected pre-construction soil samples in 2022.

Montpelier Wetland is divided into two parcels: north and south. The south wetland is an inland flowthrough system. Construction created a serpentine flow path to increase surface-groundwater interactions. One tile inlet discharges into the south wetland system at the east end. Water flows west toward a phosphorus filter at the outlet of the system.

The north wetland may have one tile inlet, but that needs to be located and confirmed. It otherwise seems to be a small set of depressional wetlands.

The Montpelier Wetland was a Non-Focal tier 2 Project in 2024. The Montpelier Wetland involves partner water sampling by Ohio State University led by Nathan Stoltzfus. The H2Ohio Wetland Monitoring Program collects soil samples once per year.

Oak Openings Preserve Wetland Restoration

The original construction of the Oak Openings Project was completed in 2021 and later modifications were completed in 2022. Starting in 2022, the Base Crew collects water samples approximately once per season and soil samples once per year. Oak Openings Preserve consists of eleven geographically isolated wetland (GIW) pools (Pools 1–11) and four pools that serve as a treatment train (Pools 12–15), treating water that is flowing down gradient across the surface of the Project on the east side. The Project is close to Ai Creek, which connects to Swan Creek and eventually to the Maumee River. The hydrologic connection between the pools of the Oak Openings Preserve Project and Ai Creek is unclear and, at most, transient, occurring only during a brief period of the year. The main inputs are probably rainfall and surface runoff, and

potentially transient connection to a drainage ditch to the west of the Project during heavy rain. In 2023, the Base Crew collected water samples from each of the wetland pools when standing water was present. The Base Crew collected soil samples from within each pool and from upland areas near the pools for comparison.

Sensors Installed

Researchers installed 5 Vegapuls 22 (VEGA, Shiltach, Germany) sensors at the Project to monitor water level. Researchers installed Vegapuls sensors in the Existing Wetland, and Pools 3, 7, 8, and 12 and equipped Pool 7 and Pool 8 with conductivity sensors. Researchers installed conductivity and turbidity sensors in Pool 12.

Otsego Schools' Fox-Shank Living Laboratory

Construction of the Otsego Schools' Fox-Shank Living Laboratory was completed in spring of 2023. The Base Crew began routine monitoring later the same year. The Base Crew collects water samples approximately once per season and includes the east and west sides of the Emergent Wetland, Tontogany Creek, and a representative set of hollow pools on the east, south, and west sides of the agricultural field (Root Wad Hollow, SE Hollow, Vernal Pool, Deadwood Hollow). The Base Crew collects soil samples in the experimental agricultural field, in the same locations where water samples are collected, and in the food forest between the agricultural field and the emergent wetland, in the wet meadow, and in upland areas in the meadow.

The Fox-Shank Living Laboratory has a unique feature: a small agricultural field intended for use by students, surrounded by wetlands. This offers a special opportunity to examine the interaction of agricultural drainage and wetlands. The presence of the agricultural field and the agricultural practices employed will be considered in the interpretation of data collected on the wetland function. The Fox-Shank Living Laboratory is also unique regarding its location within 30 m of Otsego Local Schools, a medium-sized rural school system. The school administration and teachers are very enthusiastic about using the wetlands for enhancing student learning and have conducted a variety of activities in the Project. Researchers are exploring establishing connections to existing community science platforms like Crowd Hydrology and Chronology to engage local K-12 students in collecting data to support monitoring at the Fox-Shank Living Laboratory.

Sensors Installed

Researchers installed two Vegapuls 22 (VEGA, Shiltach, Germany) sensors at the Project in the Northern Wetland and the Tontogany Creek to monitor water level.

St. Joseph Confluence

Construction at the St. Joseph Confluence Project was completed in 2021. The Base Crew began routine monitoring in the summer of 2021. Nearly all the pools at St. Joseph Confluence function primarily as isolated wetlands for most of the year. In late winter and early spring, they function as floodplain wetlands when the St. Joseph River overflows its banks. The Project tends to be dry for most of the year.

As a Non-Focal Project, the Base Crew samples St. Joseph Confluence Wetland Reconnection Project three times per year for water and once per year for soil. This is a very dry Project, so field crews try to sample in early spring when it is most likely to hold water.

Sensors Installed

Researchers installed three Vegapuls 22 (VEGA, Shiltach, Germany) sensors at the Project in Pools 1, 4, and 6 to monitor water level. Researchers also installed sensors in Pools 4 and 6 to monitor conductivity.

Van Order Wetland & Forest Restoration

Construction at the Van Order Project was completed in 2021. The Base Crew began routine monitoring soon after construction was complete in December 2021. Eight wetland pools were excavated to function primarily as geographically isolated wetlands receiving water from surface runoff within the Project. An agricultural ditch intersects with the southern end of Van Order, but it is unclear whether that ditch ever floods and overflows into wetland pools. Therefore, researchers sample the ditch and each wetland pool to monitor any unnoted hydrologic connection, given they only visit Van Order about three times per year. The Base Crew samples all wetland pools are sampled individually about once per season (if water is present) and soil samples once per year.

Weisgerber-Pohlman Nature Preserve

Construction at the Weisgerber-Pohlman Project was completed in 2022. The Base Crew conducted pre-construction monitoring was conducted in December 2021 and routine monitoring began in May 2022. Weisgerber-Polman is relatively small with five vernal pools (< 0.2 acres in area each) and a larger floodplain wetland area (~4 acres). The vernal pools seasonally flood and the floodplain wetland has intermittent connection to the Tiffin River. The Base Crew samples all sampling locations about once per season for water and once per year for soil. Researchers sample the Tiffin River and a nearby wetland that was pre-existing on the property to compare the river and pre-existing wetland to the newly formed wetland pools.

Sensors Installed

Researchers installed Baro and level logger in 2024 in Vernal Pool 3, a level logger in the West Floodplain, and a conductivity and turbidity sensor in Vernal Pool 3.

Southwest (Wright State University)

Baughman H2Ohio Wetland Restoration Project

Construction of the Baughman Ditch was completed in 2024. The Base Crew will begin monitoring in spring 2025, with Project characterization taking place since 2022. Since 2022, the Base Crew collected soil samples pre and post construction of the wetland pools. The wetland consists of three wetland pools on different properties connected via subsurface tiles that receive surface water flows and storm drainage tile flows. Water outflows from the final pool into a drainage ditch that runs into Pike Run, a small tributary of the Ottawa River.

Indian Creek-Hoffman Wetland and Stream Restoration

The Indian Creek Project was constructed in 2023. The Base Crew began sampling in February 2024. The wetland is a forested wetland that has multiple inflows. The wetland has three surface flow paths: forest, river side, and tile. The forest flow path receives water when nearby USGS gage #03272700 reaches a stage of ~7.5 ft. The river side flow path receives water when the same USGS gage reaches a stage of ~5.2 ft. The tile flow path receives water during rain events from field tiles draining the surrounding farmland. All flow paths mentioned outflow into downstream Indian Creek. Water samples are collected after rain events from upstream and downstream Indian Creek, the tile inflow, and multiple locations throughout the flow paths. Water level loggers (Onset HOBO®) were deployed in each flow path to determine when flow paths were becoming active, and if active, how much water was flowing through. The Base Crew also collects soil samples at the water sampling locations annually.

Mercer Wetland Complex Restoration

The Mercer Wetland Complex is being restored in multiple phases. Construction on Phases 1 and 2 was completed in 2023, and the Base Crew has monitored these portions of the Project since 2023. In the Phase 1 portion of the Project, water from Grand Lake St. Marys is pumped into a series of field tiles as a water source for a corn/soybean field. The water level in the field is controlled using two water level control structures (WLCS). Water from the field tiles then flows into a series of three wetland pools. These pools are connected by tile with water level controlled by WLCS before outflowing back into Grand Lake St. Marys. For Phase 2, water from Grand Lake St. Marys is also the inflow source being pumped into one of two wetland pools. The two pools are connected by tile and the water level is controlled by WLCS. Outflow from pool two is directed into a forested floodplain in which water level is also controlled using a WLCS before outflowing into Grand Lake St. Marys. The Base Crew collects water samples from Grand Lake St. Marys, the outflow pools, and each pool in the complex (9 locations) to be able to assess the nutrient reduction efficiency of each phase. The Base Crew collects soil samples from all water sampling locations except for Grand Lake St. Marys.

Springcreek Confluence Off-Channel Wetlands

Construction of the Springcreek Project was completed in 2021. The Base Crew began monitoring right after construction. Water from the Great Miami River can enter the wetland through an inflow notch into a large floodplain pool (south pool) when the river reaches a discharge of 5,529 cubic feet per second (cfs). Water from Spring Creek can also enter the wetland through an inflow notch in a separate floodplain pool (North Pool). The two floodplain pools were designed to be connected through a channel allowing water from the Spring Creek pool to enter the Great Miami River pool. However, the surface water elevation in Spring Creek pool rarely gets high enough for water to flow to the Great Miami River pool. The Base Crew collects surface water samples monthly and soil samples annually from upstream Spring Creek, upstream and downstream Great Miami River, and a few areas within the wetland to assess the nutrient load being reduced from the Great Miami River. Two water level loggers (Solinst

Levellogger 5, Solinst Canada Ltd.) were placed in north and south wetland pools to determine changes in pool volume over time.

Tipp City Off-Channel Wetlands

Construction of the Tipp City Wetland was completed in 2022. The Base Crew began monitoring right after construction with Project characterization taking place a year prior. Water from the Great Miami River enters a large riparian floodplain through an inflow notch when the river reaches a discharge of 2,627 cubic feet per second (cfs). The Base Crew collects water samples monthly and soil samples annually from the Great Miami River upstream, downstream, and two locations in the floodplain to assess nutrient load reduction. A water level logger (HOBO[®], Onset and Solinst Levellogger 5, Solinst Canada Ltd.) was placed in the wetland pool to determine changes in pool volume over time.

Walnut Creek Treatment Wetland Restoration

Construction of the Walnut Creek Treatment Wetland Restoration Project (hereafter Walnut Creek Project) was completed in 2023. The Base Crew began routine monitoring in 2023. Water from Walnut Creek enters the wetland via an overflow notch when the creek reaches a discharge of 1,063 cubic feet per second at the wetland inflow. At the inflow and outflow, there are deep settling pools to allow for the settling of particulate matter. The two settling pools are connected by a stretch of hummocks and hollows which receive water when the inflow settling pool is full. The water depth in the wetland pool and the outflow to Walnut Creek are controlled using two water level control structures (AgriDrain) on the outflow pool. The Base Crew collects water samples monthly and soil samples annually from Walnut Creek upstream, downstream, and three locations throughout the wetland to understand nutrient concentration at each wetland feature. Water level is continuously monitored at the outflow WLCS using a sensor (Onset HOBO[®]), and the data is used to calculate outflow discharge using a flow over flat weir equation.

Northeast (Kent State University)

Chippewa Lake Wetland Restoration

The Chippewa Lake Project was constructed in 2024, and the H2Ohio Wetland Monitoring Program began sampling in 2024. The restoration Project includes three phases, a restored channelized stream portion along the Chippewa Creek Inlet, wetland creation and stream restoration in an abandoned amusement park bordering on Chippewa Lake, and establishment of wetlands at a kayak launch along the outlet from the lake. The monitoring approach thus far has focused on the restored channelized stream along the inlet to Chippewa Lake. This Project is a flow-through wetland with a portion of Chippewa Creek diverted into a sinuous channel with a connection to a floodplain. The restored stream reach returns to the main Chippewa Creek channel before it empties into Chippewa Lake. Only a portion of the flow from Chippewa Creek is diverted into the wetland. There is a plug built into the inlet channel that acts as a dam diverting flow during baseflow conditions. During flooding events, the water will flow over the plug and continue down the channel. Water samples are taken at the inlet and outlet of the

constructed wetland, and from Chippewa Creek upstream and downstream of the wetland. Manual flow measurements are taken at the wetland inlet and outlet as well as from Chippewa Creek upstream and downstream of the wetland to calculate discharge and thereby nutrient loading to the wetland, and the portion of Chippewa Creek that is diverted into the wetland. The Base Crew collects samples monthly and following storm events to provide an understanding of nutrient filtration during baseflow and high-flow conditions.

Martin's Run Wetland and Stream Restoration Project

The Martin's Run Project was constructed in 2022 and the Base Crew began sampling in 2024. The goal of this restoration was to restore a channelized stream to natural sinuosity and reconnect the floodplain for nutrient and water retention. Martin's Run stream flows from east to west across the site. Two adjacent floodplains (north and south of the stream) are connected during high flow events each via a single overland ditch with stones armoring the stream. The floodplains include numerous pothole type pools dug throughout. Each floodplain has a single outflow which consists of a single storm water type fixed elevation drain. Additionally, there is one tile drain from an agricultural field to the south of the Project which drains into the southern floodplain under high flow conditions, though this is seldom observed by the monitoring team. The Base Crew takes water samples at all inlets and outlets to the stream and floodplains (when water is present) and at two large pools, one near the outlet of both the north and south floodplains. The Base Crew collects water samples monthly and after storm events. This provides an understanding of baseflow conditions and of how the floodplains function during larger discharge events. It also helps to understand the flux of nutrients in and out of the floodplains. The Base Crew takes manual flow measurements during each sampling event to calculate the estimated discharge for nutrient budgeting. Water level is continuously monitored in each of these floodplain pools to calculate the retention period of the floodplains.

Trumbull Creek H2Ohio

The Trumbull Creek Project was constructed in 2022. The Base Crew began sampling in 2023. The Trumbull Creek Project has distinct lowland areas consisting of regularly inundated pools and upland areas consisting of hummock and hollow microtopography. The Project is an inland wetland that sits on a watershed divide between Mill Creek and Bronson Creek. There is no direct surface water inflow, and the groundwater interactions are predicted to be minimal given the clay-dominated soil. The primary hydrologic input is precipitation, which collects in a series of hollow pools and lowland borrow pools (named because of the soil borrowed from that location to build the barrier around the Project). The hydrologic outflow is at a single water level control structure (AgriDrain) which passively controls the water level in the Project based on the set board height, which is seldom changed. Researchers designed sampling primarily to characterize the variability of water and soil across wetland features within the Project and to collect samples that inform an estimate of nutrient storage and potential release over time, rather than comparing the difference between water entering and leaving the site. The Base Crew collects water samples monthly and following storm events. This provides an understanding of baseflow conditions, and the response to large water inputs, specifically the response of

reflooded portions and the potential outflow of water from the site. The Base Crew collects soil samples once per year.

Focal and Non-Focal Projects: Hydrogeophysics

In 2024, the hydrogeophysics crew made progress on additional groundwater installation, Project surveys of bulk apparent conductivity via (Electromagnetic Induction transect surveys (Table 5). Additionally, the crew continued to collect soil samples to analyze physical properties and ground-truth to the field-transect surveys.

Table 5. Hydrogeophysics Crew Sampling Summary for Water Year 2020–Water Year 2024. Code For EMI (Electromagnetic Induction transect survey) column, C = data were collected, P = data were processed and ground-truthed using soil samples and well logs. For Wells column, the number indicates the number of groundwater wells installed. “*” indicates a Master's Project, where Ksat was also measured.

	WY 2020		WY 2021		WY 2022		WY 2023		WY 2024	
Project Name	EMI	Wells	EMI	Wells	EMI	Wells	EMI	Wells	EMI	Wells
Brooks Park							C, P	5	C, P	
Burntwood-Langenkamp							C, P	3		
Forder Bridge	C, P		C, P		C, P			5		
Fruth Wetland							C, P *	5		
Magee Marsh									C	
Maumee River Floodplain							C			
Oakwoods East							C, P		C, P	5
Oakwoods West									C	4
Redhorse Bend							C			
Saint Joe's River Restoration			C		C				C	
Sugarcamp 7			C							

Focal Projects: 3-D Hydrodynamic Modeling

3-D hydrodynamic models are developed for Focal Projects to simulate water movement and nutrient transport within the wetland domains in a physically based manner. The models, driven by real weather data, allow researchers to integrate various data collected by the Wetland Monitoring Program (e.g., hydrology, chemistry, geophysics, vegetation, drone imagery, etc.) to make better quantification of mass balance and assessment of wetland Projects' nutrient removal efficiency. Specific steps to develop 3-D models were described and explained in the H2Ohio Wetland Monitoring Program 2023 Annual Report¹⁸.

In 2024, the 3-D Modeling crew developed a prototype, uncalibrated model for the Burntwood-Langenkamp Wetland Conservation Area (BWLK) Project and continued the development of the Oakwoods Nature Preserve (OAKW) East and West model. Meanwhile, the crew started to apply the models researchers had developed to identify issues associated with the completed H2Ohio wetlands, aiming to help ONDR improve wetland design and management for future restoration projects (Table 6).

Table 6. Summary of 3-D modeling progress and plans on Focal wetland sites (as of 2024).

Names of Focal sites	Prototype model developed (Yes/No)	Has the model been calibrated (Yes/No)	Notes and plans
BROP	Yes	No (<i>beginning in 2025</i>)	Subsurface geology/stratigraphy data was provided by the Geophysics Team in January 2025 and will be integrated into the 3-D model. Model calibration will start in spring 2025.
OAKE	Yes	No	Need tile influx data to drive and calibrate the model. OAKW model has been applied to identify wetland design issues. The model will be tuned based on the 3-D geology data provided by the Geophysics Team.
OAKW	Yes	No	Same model as OAKE.
FORB	Yes	No	Need 3-D geology data from the Geophysics Team and inflow data (at culvert) to drive and calibrate the model. FORB model has been applied to identify wetland design “idle pool” issues.
SJRE	Yes	No	Need 3D geology data from the Geophysics Team and inflow data (from tiles) to drive and calibrate the model.
BWLK	Yes	No	Under development and tuning up
MAGM	No (<i>beginning in 2025</i>)	No	The Drone team is correcting the bathymetry data. The Geophysics Team has surveyed elevations of some key reference points (staff gauge, pipe end elevations). Model development may begin in summer or fall 2025 pending availability of corrected bathymetry.
REDB	No (<i>beginning in 2026</i>)	No	Plan to start model development in 2026

Focal Projects: Vegetation

H2Ohio Focal Project vegetation sampling occurs exclusively in areas dominated by wetland vegetation and employs community composition surveys and destructive sampling of above- and belowground plant tissues (biomass). Community composition surveys are distributed across the maximum potential vegetation area (an expert-generated polygon of potential wetland area) using stratified random sampling design across all wetland polygons to capture species richness

and diversity. In-field vegetation surveys of community composition and species abundance occur only at those locations determined to be dominated by wetland vegetation or soils.

Above- and belowground vegetation sampling occurs in a subset of the community composition survey locations, with some samples targeting monoculture patches of key morphospecies that contribute to nutrient storage in wetlands to enable clear identification of sources of belowground biomass. Because destructive sampling of plant biomass is labor-intensive both in the field and in the lab, particularly for belowground biomass, not all Focal Projects were sampled for biomass in all monitoring years (2021-2024). As of 2024, only half of all Focal Projects are monitored for vegetation each year. St. Joseph's River Restoration was selected as a Project for annual monitoring to maintain a consistent record, while monitoring at all other Focal Projects occurs every other year. Sampling biomass in coastal wetland projects is an additional labor challenge requiring adaptation of methods used in inland wetland projects.

Definitions of Vegetation Terms

Vegetation Nutrient Stock at Peak Biomass

Vegetation monitoring occurs at peak biomass (July-August), when most species will have reached their maximum growth for the season. Measuring nutrient concentration and total biomass at this point results in an estimate of the maximum potential nutrient stock found in the vegetation pool for the year. Increases or decreases in the vegetation stock cannot be fully attributed to nutrients coming in or going out of the wetland, but this estimate of the maximum stock of nutrients residing in vegetation from year-to-year provides context for nutrient fluxes within the wetland (e.g., in and out of shallow soil nutrient pools, surface water, etc.), which is especially important when inflows and outflows are harder to quantify or management recommendations are being developed.

Nutrients in vegetation likely originate from bioavailable nutrients in the soil (especially shallow soils in wetlands, due to anoxia inhibiting root activity at greater depths) and directly from the water column. While the H2Ohio Wetland Monitoring Program currently is not tracking the exact nutrient inputs or tracing the fate of nutrient exports from vegetation, in the process of absorbing nutrients, plants convert more labile forms of nutrients into more recalcitrant forms that make it less likely for nutrients to leave the wetland. Additionally, perennial vegetation is known to resorb nutrients found in aboveground plant material into belowground storage organs (e.g., rhizomes) which persist overwinter for one or more years. In some cases, perennial plants can retain as much as 80% of their summer nutrients over winter. Therefore, much of the dead plant matter that decomposes in the fall and winter is likely to contain reduced nutrient concentrations compared to summer estimates. And some of this plant material is buried rather than decomposing.

Plants also have effects on nutrient storage in wetlands by increasing rates of sedimentation, stimulating denitrification, and increasing oxygen concentrations in soils and the water column, which are not being directly measured by the Monitoring Program, but opportunities exist for inferring these effects as data accumulates.

Vegetation Species Nutrient Density

Nutrient density is the product of average dry biomass per unit area (g/m²) and average nutrient concentration (%) for a species. The results provide an estimate of the average nutrient storage per unit area (i.e., g/m²) and enable comparisons of species' contribution to nutrient storage that account for different growth forms/densities (biomass) as well as how different species acquire and allocate nutrients within their tissues.

Maximum Potential Wetland Area

To select potential sampling locations, a polygon generated by expert estimates of the maximum possible wetland extent is used to randomly generate sampling points. During sampling, if the point is not visibly dominated by wetland vegetation or soils, the point is not surveyed.

Active Vegetated Wetland Area

Active vegetated wetland area is defined as areas that are dominated by obligate or facultative wetland species in any given year. These areas change year-to-year based on hydrology and vegetative development over time. Vegetation monitoring only occurs in these active vegetated areas of the wetland that are visually identifiable, as wetland delineations have not been conducted in new restorations to provide a consistent boundary.

Vegetation Expert Patch Maps

Using ground-collected community composition data and drone imagery, expert members of the Vegetation Monitoring team produce annual vegetation maps that outline vegetation patches, which are collections of one or more species that form visually identifiable vegetation communities.

Morphospecies

A species identification based on vegetation form and/or morphological traits visible in the field.

For species that are not easily identified in the field, a higher taxonomic classification may be used as the final species identification in cases where species-level identification is unlikely to impact nutrient retention factors (e.g., *Typha sp.* is the morphospecies

identification used but could refer to *T. latifolia*, *T. angustifolia*, or *T. x glauca*). Common reasons for the use of morphospecies in favor of a species-level identification include species that cannot be identified without extensive microscopy work or genetic testing as well as some cases of juvenile individuals that occupy < 10 % of a sampling quadrat.

Species Richness

A count of the total number of species and morphospecies observed when sampling a Project.

Simpson's Diversity

Simpson's Diversity Index²⁰ is a tool used to quantify biodiversity of habitats. Wetland Monitoring Program calculations are performed using the vegan Package in R. Diversity metrics are rarefied²¹(using rarefy() in vegan) as a normalization tool to minimize sampling bias from differences in sample sizes (monitoring intensity) between monitored Projects and across years.

Floristic Quality Assessment Index

FQAI²² is calculated using Coefficients of Conservatism (C-values) assigned to individual species by expert analysis for the region of Ohio. Higher C-values indicate that a species will only be found in relatively undisturbed or high-quality habitats. Species with lower C-values tend to be ruderals or weedy species that initially colonize the early-restoration habitats, which may be replaced with species of higher C-values as wetland ecosystem development progresses, or may not, depending on Project features and management.

Wetland Indicator Status

²⁰ Simpson, E. Measurement of Diversity. Nature 163, 688 (1949).
<https://doi.org/10.1038/163688a0>

²¹ Willis, A. D. (2019). Rarefaction, alpha diversity, and statistics. Frontiers in microbiology, 10, 492464. <https://doi.org/10.3389/fmicb.2019.02407>

²² Andreas, Barbara K., John J. Mack, and James S. McCormac. 2004. Floristic Quality Assessment Index (FQAI) for vascular plants and mosses for the State of Ohio. Ohio Environmental Protection Agency, Division of Surface Water, Wetland Ecology Group, Columbus, Ohio. 219 p.

WIS values were assigned based on the Ohio Vascular Plant Database²³ and the table below (adapted from the USDA PLANTS database²⁴).

Table 7. Key for Wetland Indicator Status (WIS) codes. Adapted from the USDA PLANTS Database.

Wetland Indicator Status	Code	Description
Upland	UPL	Almost never occur in wetlands
Facultative Upland	FACU	Usually occur in non-wetlands, but may occur in wetlands
Facultative	FAC	Occur in wetlands and non-wetlands
Facultative Wetland	FACW	Usually occur in wetlands, but may occur in non-wetlands
Obligate Wetland	OBL	Almost always occur in wetlands

Summary of Vegetation Nutrient Stock Calculations

Project-scale vegetation nutrient stocks (kg or lbs.) are the sum of nutrient mass estimates for all wetland vegetation patches within each project. Researchers calculate these values using community composition, biomass, and nutrient concentration data, combined with expert vegetation patch maps.

Community composition surveys and drone imagery are used to identify vegetation species, their abundances, and the total Project area they occupy. Project wetland areas are delineated into vegetation patches made of distinct vegetation communities in two ways: remote vegetation classifications of drone imagery ground-truthed by community composition surveys or expert classification of drone imagery informed by community composition and expert knowledge of projects.

Measurements of biomass (g/m²) and nutrient concentration (% phosphorus (P) or % nitrogen (N)) are collected for individual morphospecies. Multiplying mean biomass times nutrient concentration for each species results in mean estimates of nutrient density for that species (g P/m² or g N/m²) used in the final calculation. However, biomass and nutrient estimates are not

²³ See preceding footnote above.

²⁴ USDA, NRCS. 2024. The PLANTS Database (<http://plants.usda.gov>, 3/25/2024). National Plant Data Team, Greensboro, NC USA.

available for every species, project, or year. To estimate nutrient masses with incomplete information, researchers used a tiered system of data sourcing for biomass and nutrient concentration data, where researchers used the most specific data available in the estimates. For instance, when researchers are missing nutrient or biomass estimates for a species at a particular Project in a particular year (Tier 1), but have those estimates from the same Project in a different year (Tier 2), researchers combine biomass and nutrient estimates from the other year with percent cover and patch delineations from the current year. In cases where estimates are missing from a particular project, researchers use the means for that species from other projects (Tier 3). In cases where there are no estimates, researchers use the mean from all species across all projects (Tier 4).

To get the nutrient mass of the active wetland area of an entire Project (g P or g N), researchers first calculate the species' abundance as the mean percent cover (%) observed across the whole patch. The species' abundance is multiplied by its mean nutrient density (g/m²) and then added each species' nutrient mass together (a weighted average of species nutrient masses). Researchers then multiply by the area of each patch (km²) and sum the total of all patches, resulting in a project-scale nutrient stock (kg P or kg N).

Appendix III: Nutrient Budget Calculations

Runoff Prevention Method Used Across Projects

Runoff prevention refers to the retention of phosphorus by a wetland caused by the conversion from farm field to wetland. When a farm field is converted to a wetland it no longer receives fertilizer inputs, and tile drains in sediments are broken, disconnecting the sediment from flow and increasing the retention of nutrients in the sediment.

To calculate the runoff prevention for each Project measurements of P loading were used from edge of field studies in Northwestern Ohio across a range of soil types, and farming conditions²⁵. Researchers applied the average and standard deviation of edge of field P loading for each different soil type and applied those values to H2Ohio sites that were converted from active farm field to predict the amount of P runoff would leave the Project if the Project were still actively farmed. Researchers assumed that runoff prevention for sites that were not previously active farm fields was zero. For each Project researchers determined the dominant soil type using USDA NRCS soil maps, as the soil group that made up the majority of the sediment. Pease et al. 2018 contained loading values in kg/ha for five different soil types: clay, clay loam, loam, silt loam, silty clay loam. For each Project the total area was multiplied by the value and standard deviation from Pease et al. 2018 to predict the runoff prevention of each wetland.

²⁵ Pease, L. A., K. W. King, M. R. Williams, G. A. LaBarge, E. W. Duncan, and N. R. Fausey. 2018. Phosphorus export from artificially drained fields across the Eastern Corn Belt. *Journal of Great Lakes Research* 44:43–53.

With this method researchers assume that nutrients are not leaving the system, which is largely accurate for isolated sites, but not accurate for flow-through and floodplain sites because water and nutrients are able to leave the system. However, most flow-through sites filter nutrients, in which case researchers estimates of runoff prevention are still largely accurate but may overlap with estimates of active filtration.

Focal Project Nutrient Budget Methods

Brooks Park Wetland Creation & Water Quality Initiative

The Brooks Park Wetland Creation & Water Quality Initiative (Brooks Park Project) is a restoration Project draining a small tributary of Buckeye Lake, Murphy's Run, constructed in 2021. Researchers have collected water and soil samples since summer 2021. The AV sensor started collecting flow data in March 2024, and water level loggers began collecting water depth in September 2023. Researchers estimate that Brooks Part filtered 57 lbs. total phosphorus (TP), 4,316 lbs. total nitrogen (TN), 22 lbs. dissolved reactive phosphorus (DRP), 3,718 lbs. nitrite+nitrate (NO_x), and 93 lbs. total ammonium nitrogen (NH₄-N) in Water Year (WY) 2024.

Sampling Setup

Researchers collected surface water samples at several locations throughout the wetland: Murphy's Run, Settling Pool, Mid Wetland Stream, Wetland Stream Outflow, Buckeye Lake, Lake West of Castle Island, and West Pool. Due to Buckeye Lake's propensity to backflow into the wetland, an AV sensor was placed in Murphy's Run to determine periods of backflow. When AV sensor flows are positive Murphy's Run is flowing into the wetland. When AV sensor flows are negative, Buckeye Lake is flowing into the wetland. Buckeye Lake water elevation from USGS Watkin's Island station was also used to determine periods of backflow into the wetland

Nutrients

Researchers downloaded nutrient concentrations for Brooks Park from the GitHub repository and replaced concentrations below detection limits (BDL) with 1/2BDL. Researchers defined detection limits as follows: SRP 0.03, TP 0.1, NO_x AQ1 0.06, NO_x AQ300 0.04, TN 0.25, NH₄-N latchet 0.001, NH₄-N AQ1 0.02, NH₄-N AQ300 0.01.

Researchers used a pivot table to calculate seasonal (all years of data) nutrient concentration averages for Murphy's Run during sampling events where USGS data indicated flows were ≥ 1 MGPD. This calculation included 25 sampling events from November 2021 to April 2024. Researchers chose this approach because during low flow sampling events, the Murphy's Run sample is likely Wetland Settling Pool water/lake water. Researchers used a pivot table to calculate seasonal nutrient concentration averages for Murphy's Run during sampling events where USGS data indicated flows were ≤ 1 MGPD. Researchers applied Murphy's Run inflow concentrations based on average daily USGS flow.

Researchers calculated seasonal average nutrient concentrations for locations 2–7 using a pivot table and data from years 2023 and 2024. Researchers excluded data from years 2021 and 2022 because the wetland was still maturing, which could affect average concentrations over time.

Hydrology

Researchers processed hydrology AV sensor data in the SonTek SL software using a configuration file made for the shape of the stream channel (under road crossing–cement lined bridge with even stream bottom). When AV sensor flows are positive Murphy's Run is flowing into the wetland. When AV sensor flows are negative, Buckeye Lake is flowing into the wetland. Researchers also downloaded hydrology data for South Fork Licking River from USGS Station #03145000 to determine stream flow for Murphy's Run by watershed weighting. The drainage area for the USGS station is 133 mi², and the drainage area of Murphy's Run at the wetland inflow is 1.2 mi². To determine stream flows for Murphy's Run, researchers multiplied daily average stream flows for the South Fork Licking River by 0.009 (1.2 mi²/133 mi²). High flow events for Murphy's Run were considered to be 1 MGPD or greater.

Researchers used Buckeye Lake water elevation from USGS Station #395540082291600 to determine periods of Buckeye Lake backflowing into the wetland. This is important as the wetland outflow location used for the nutrient load calculation changes based on how far Buckeye Lake backflows into the wetland. For example, the Wetland Stream outflow location is no later “wetland water” if Buckeye Lake is backflowing into the wetland.

Nutrient Load

A daily nutrient load filtered was calculated as:

$$\text{load retained} = [(inflow\ concentration - outflow\ concentration) * 0.0022046 * volume] / [0.26417 * 1000]$$

Where load filtered is in pounds, concentrations are in mg/L, volume is in gallons, 1000 converts mg to g, 0.0022046 converts g to lbs., and 0.26417 converts L to gallons. When AV sensor showed positive flows, the inflow was considered to be Murphys Run (#1). When AV sensor showed negative flows, the inflow was considered to be Buckeye Lake. The outflow location changed based on Buckeye Lake elevation data as follows for Murphy's Run: #3 < 889.5, #6 < 891, and #5 < 891.5. The outflow location changed based on Buckeye Lake elevation data as follows for Buckeye Lake: #3 > 889.5, 6 > 891, and #5 > 891.5. Seasonal average concentrations calculated in step 4 were applied across seasons.

Note that in August 2024, sampling locations 5 and 6 were dry so the average seasonal concentration for sampling location 2 was used for Murphy's Run load reduction and sampling location 3 was used for Buckeye Lake load reduction. From October 1, 2023 to March 4, 2024, watershed weighted USGS South Fork Licking River values were used to calculate load due to AV sensor not yet being deployed.

Burntwood-Langenkamp Wetland Conservation Area

The Burntwood-Langenkamp Wetland Conservation Area (hereafter Burntwood Project) is a flow-through treatment train treating water from Burntwood Creek, a tributary of Grand Lake St.

Mary's, constructed in winter 2021. Researchers began routinely collecting water and soil samples beginning in spring 2022 and began continuous water level data collection in July 2022 at the wetland outflow. In Water Year (WY) 2024, researchers estimate the Burntwood Project filtered 240 lbs. total phosphorus (TP), 5,961 lbs. total nitrogen (TN), 121 lbs. dissolved reactive phosphorus (DRP), 5,407 lbs. nitrite+nitrate (NO_x), and 5 lbs. total ammonium nitrogen (NH₄-N).

Sampling Approach

Researchers collected water samples from several locations throughout the wetland. However, for nutrient load reduction calculation purposes, the only sampling locations that matter are the inflow (Burntwood Creek) and the wetland outflow. Water level data has been continuously monitored at the wetland outflow since July 2022 to determine the volume of water leaving the wetland. There was an attempt to create a rating curve of water depth vs. discharge at the wetland inflow in order to calculate the flows entering the wetland from Burntwood Creek. Unfortunately, due to backflow at the wetland inflow notch, a rating curve was not able to be established.

Nutrients

Researchers downloaded nutrient concentrations for Burntwood Project from the GitHub repository and replaced concentrations BDL with 1/2BDL. Detection limits are as follows: SRP 0.03, TP 0.1, NO_x AQ1 0.06, NO_x AQ300 0.04, TN 0.25, NH₄-N latchet 0.001, NH₄-N AQ1 0.02, NH₄-N AQ300 0.01. Inflow concentrations (Burntwood Creek #1) and Outflow concentrations (Outflow pool #5) were applied over a ~week period until next sampling event.

Hydrology

Continuous water level data at the outflow can be downloaded via Bluetooth using an app (HOBObconnect) on a mobile device. Water level data is collected at 30-minute intervals, and an average daily depth is calculated from this data. The daily water depths are converted to volume using a simple flow over flat-weir equation:

$$\text{if } H \leq 0.27W, Q = 3.19924(W - 0.74H)H^{1.48}$$

$$\text{if } H > 0.27W, Q = 3.0318WH^{1.37}$$

Where H is the height of water above the stop log in inches, W is the width of the weir (for Burntwood Project W=29.31), and Q is the flow rate in gallons per minute (GPM). Volumes calculated using the equations above are then converted to gallons per day (GPM*60*24, GPD) and correspond to the total volume of water leaving the wetland.

Wetland outflow volumes for treatment trains are lower than inflow volumes due to evapotranspiration, water seeping into sediment, and vegetation uptake. Therefore, using the wetland outflow volumes for the wetland inflow volume would be an underestimate. Therefore the Penman Monteith equation was used to calculate the average daily water volume lost to evapotranspiration. The equation is as follows:

$$ET_0 = \frac{0.408\Delta(R_n - G) + \gamma \frac{900}{T + 273} u_2 (e_s - e_a)}{\Delta + \gamma(1 + 0.34u_2)}$$

Where ET_0 reference evapotranspiration [mm day^{-1}], R_n net radiation at the crop surface [$\text{MJ m}^{-2} \text{ day}^{-1}$], G soil heat flux density [$\text{MJ m}^{-2} \text{ day}^{-1}$], T mean daily air temperature at 2 m height [$^{\circ}\text{C}$], u_2 wind speed at 2 m height [m s^{-1}], e_s saturation vapor pressure [kPa], e_a actual vapor pressure [kPa], $e_s - e_a$ saturation vapor pressure deficit [kPa], D slope vapor pressure curve [$\text{kPa } ^{\circ}\text{C}^{-1}$], γ psychrometric constant [$\text{kPa } ^{\circ}\text{C}^{-1}$]. Historical weather data was inserted to obtain evapotranspiration rate in inches/day. Historical weather data was gathered from <https://www.wunderground.com/history> from the Fort Wayne International Airport (KFWA) weather station. Evapotranspiration rates were converted to average daily volumes lost to evapotranspiration as follows:

$$\text{Volume lost to Evapotranspiration (gallons)} = \frac{11.2 * 325,852 * ET_0}{12}$$

Where 11.2 is the wetland acreage, 325,852 is gallons in an acre-foot, and ET_0 the evapotranspiration rate in inches/day, and 12 is inches to feet. The volumes lost to evapotranspiration were then added to average daily wetland outflow volumes to obtain average daily wetland inflow volumes.

Nutrient Loads

Daily nutrient inflow and outflow loads were calculated as:

$$\text{load} = [\text{concentration} * 0.0022046 * \text{volume}] / [0.26417 * 1000]$$

Where load filtered is in pounds, concentrations are in mg/L, volume is in gallons, 1000 converts mg to g, 0.0022046 converts g to lbs., and 0.26417 converts L to gallons. Daily loads filtered were then calculated as inflow load–outflow load, positive values indicative of loads filtered and negative values indicative of loads exported.

Forder Bridge Floodplain Restoration

Forder Bridge is a restoration Project in the Upper Maumee watershed that was constructed in 2021. Water and soil samples have been collected and analyzed since its construction was completed. The sensor network for Forder Bridge started collecting data in April 2024. The newly active sensor network highlights the value of high-frequency sensor data and the potential for Focal Project sensor networks to inform researchers approach at Non-Focal sites. **It is estimated that in Water Year 2024 Forder Bridge filtered approximately 7.4 lbs. of total phosphorus and filtered approximately 34 lbs. of total nitrogen.**

All ODNR predictions, and many researcher-measured metrics of nutrient retention rely on the use of the drainage area of a Project to predict the volume of water that moves through the site. The drainage area of an individual Project is typically delineated using remote sensing, often through StreamStats, or digital elevation models. At Forder Bridge the development of the sensor

network has allowed researchers to assess the accuracy of remote sensed estimation of the drainage area which at Forder Bridge is inaccurate to the realities of what is occurring at the site.

During the construction of the wetland, the treatment chain was predicted to drain a series of tile-drained active agricultural fields to the south and was expected to receive and filter management relevant quantities of phosphorus and nitrogen. The former agricultural field receives water from adjacent agricultural fields through a culvert. After entering the wetland, water flows through a newly restored treatment chain of wetland pools designed for nutrient filtration before flowing into the Maumee River. As part of the H2Ohio Wetland Monitoring Program a water depth sensor (Vegapuls 22, VEGA, Shiltach, Germany) was installed in the first pool of the treatment chain in April 2024, and a rainfall tip bucket (Campbell TE-525) was installed to monitor precipitation at the site.

Delineation of Drainage Area

To delineate the topographically defined drainage area to the Project using the best available data, researchers used one-meter digital elevation model created by USGS using LIDAR data from the 2019-2020 USGS Lidar: Ohio Statewide–Phase 1 collection (USGS 2023). The USGS LIDAR data was collected at 1-m resolution in 2019. The 1 m resolution digital elevation model was filled and breached, and flow directions were determined with the “d8” routing scheme, using a 100-cell threshold for flow accumulation, and the drainage area was generated for a pour point of the whole area of the first pool in the treatment chain using the flowdem package in R². The topographic drainage area of the Project was estimated to be 159.6 acres. To assess how artificial drainage may differ from the topographically defined drainage area, researchers spoke a county partner (district administrator of the Paulding County Soil and Water Conservation District), a local expert, who told researchers that the wetland drains 16.3 acres of the northern fields, and that a culvert that the H2Ohio Wetland Monitoring Program was previously unaware of drains a majority of the southern field in a different direction (Figure 350). Researchers predicted surface water runoff-based rainfall data from the sensors applied to the drainage area using the National Resource Conservation Service (NRCS) curve number method²⁶. Researchers additionally added a prediction of sub-surface runoff from the largely tiled drainage area as 31% of total rainfall based on an analysis of similar tiled fields²⁷. A curve number of 91 was selected because the majority of the drainage area is row crop, and the soils were determined to be hydrologic group D (Ohio Department of Natural Resources SOILS MapServer).

²⁶ USDA-NRCS, 2004b. United States Department of Agriculture Natural Resources Conservation Service, National Engineering Handbook, Title 210 Engineering, Part 630 Hydrology, Chapter 10. Estimation of Direct Runoff from Storm Rainfall.

²⁷ Pease, L. A., K. W. King, M. R. Williams, G. A. LaBarge, E. W. Duncan, and N. R. Fausey. 2018. Phosphorus export from artificially drained fields across the Eastern Corn Belt. *Journal of Great Lakes Research* 44:43–53.

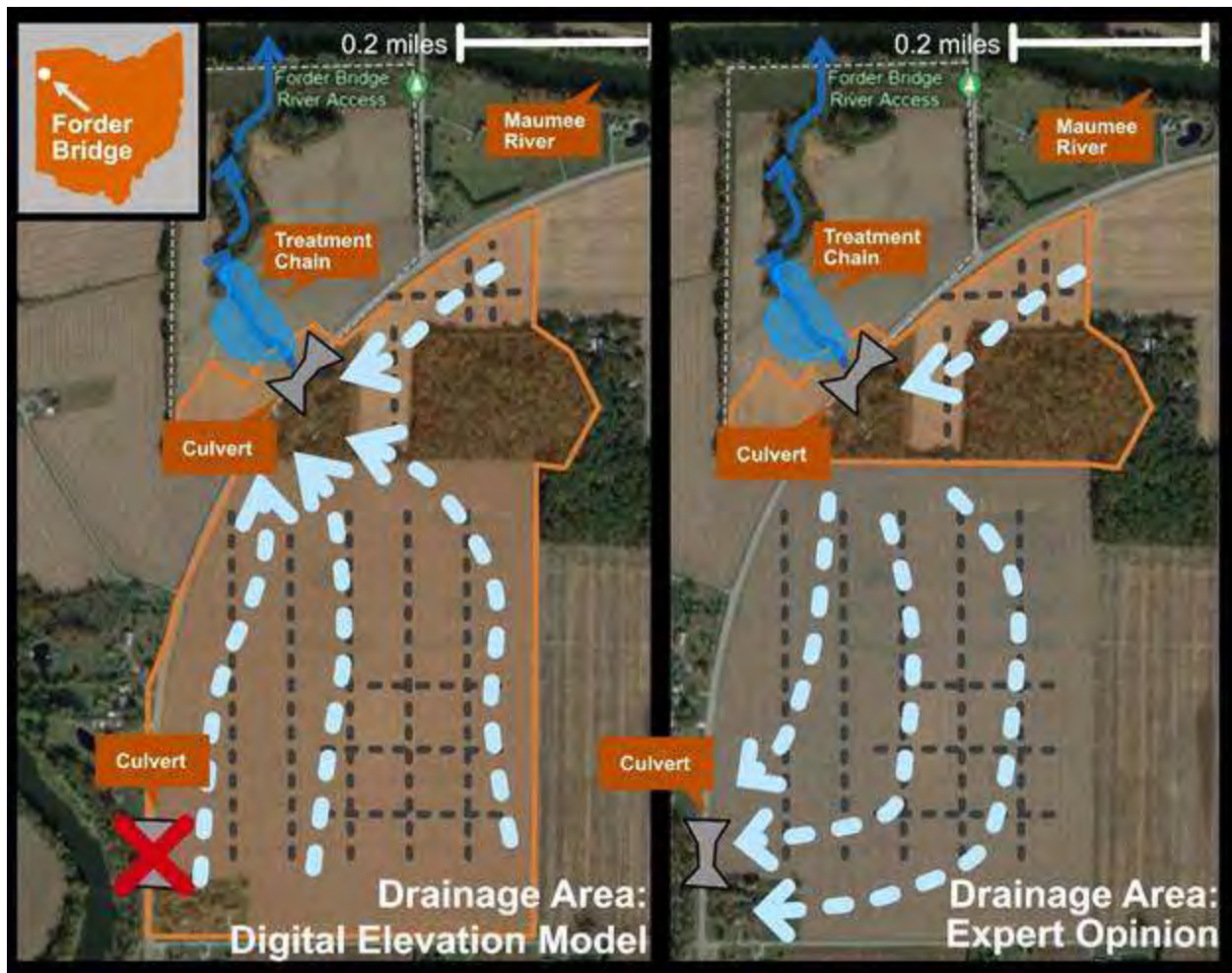


Figure 350. Comparison of the drainage area of the Forder Bridge wetland restoration calculated solely based on topography of the surrounding area using a digital elevation model (left) and calculated by reducing the drainage area as indicated by expert opinion. Dark blue arrows indicate the flow of water through the Project. The dark dashed lines indicate tile drained areas. The light blue dashed arrows indicate surface and subsurface flow of water in the drainage area, and the orange outline represents the drainage area of the Project. White dashed lines indicate the parcel boundary of the wetland Project.

To assess the implications of contrasting drainage area and input volume estimations on estimates of nutrient filtration by this restored wetland, researchers estimated nutrient loads into and out of the Project assuming that all water entering the Project left the Project. The Monitoring Program collected monthly water samples at the inflow to the treatment chain, and the outflow of the wetland where it flows into the Maumee River as detailed in the Monitoring Program framework (H2Ohio Wetland Monitoring Program, 2024). Total phosphorus concentration was measured for each sample and researchers estimated monthly phosphorus filtration by multiplying total phosphorus concentrations at the inflow and outflow from monthly samples by monthly flow estimates using rainfall and the estimated drainage areas, then summed

all months together for annual phosphorus filtration. The difference in estimated drainage area led to a large difference in estimation of wetland function, with the 2023 estimate ranging from 4 lbs. phosphorus filtered when estimating flow based on expert knowledge of the Project, to 45 lbs. phosphorus filtered when estimating flow by high resolution digital elevation model (H2Ohio Wetland Monitoring Program 2023). Given that these two methods predicted phosphorous filtration that varied by more than an order of magnitude, it became necessary to evaluate the predictions in the context of empirical hydrological data.

Comparison of Predictions to Sensor Data

To estimate discharge into the wetland from direct measurements, researchers continuously monitored water depths in the wetland pool directly downstream of the culvert inflow. Researchers calculated change in depth between each timepoint (15-minute intervals), deleted all negative values (so that only increases in water depth that would correspond to inflows were counted), and multiplied the change in depth by the total area of the pool (1100 m^3) to calculate all increases in volume in the pool. Researchers assumed that the area of the pool did not change with the increasing volume of water. Researchers assumed that the pool was not gaining water when it was decreasing in volume for the purposes of the H2Ohio Wetland Monitoring Program estimation, but researchers would miss some volume of inflow when the rate of outflow was higher than the rate of inflow, so Monitoring Program values underestimate true flow. However, researchers expect that the degree of underestimation is small due to how flashy the system is.

In this wetland, the drainage area indicated by expert knowledge predicted the volume of water received by the Project better than a high-resolution DEM that included the topological elevation of the surrounding area because expert knowledge also took into account additional features that the high-resolution DEM could not account for. Sensor data measurements suggest that between 15 April 2024 and 29 July 2024, 1900 m^3 of water flowed through the Project. During the same period, applying smaller drainage area to rainfall data using the NRCS curve number method predicts 1500 m^3 of flow, and applying the high-resolution DEM using the larger drainage area predicts $27,000 \text{ m}^3$ of flow (Table 8). The estimate of drainage volume based on expert knowledge was lower than Monitoring Program conservative sensor-based estimate which is likely due to either the expert delineation of drainage area being a rough estimate, and thus missing some small portion of area drained by the wetland, or the conversion of pool water level to volume being a rough estimate, and thus overestimating the amount of water in the pool.

Table 8. Comparison of different methods of estimating flow and P loading between 15 April 2024 and 29 July 2024

Method	Drainage Area (acres)	Flow (m ³)	P loading (lbs.)	P loading (kg)
DEM	159.6	27,000	19.9	9
Expert Knowledge	16.3	1,500	1.1	0.5
Depth Sensor	N/A	1,900	1.5	0.7

Nutrient Budget Calculations at Forder Bridge

For 2023 and 2024 budgets for Forder Bridge researchers used the drainage area of the Project delineated by expert knowledge, and rainfall data to estimate the volume of water flowing through the Project every day as described above. Using estimated volumes as opposed to measured changes in water depth avoids underestimation of flow when pools reach their holding capacity, allows for a consistent budgeting approach for both 2023 (before the sensors were active) and 2024, and additionally demonstrates a method that is applicable to Non-Focal Projects.

During the time period of data collection, precipitation on Project at the Forder Bridge restoration was similar to total precipitation accumulated measured 8 miles away in Paulding, OH (NOAA, GHCND:USC00336465). For the 2024 Water Year (October 1, 2023-September 30, 2024), total accumulated precipitation measured at Forder Bridge from April 10-September 30, 2024 was added to total accumulated precipitation in Paulding, OH from October 1, 2023-April 9, 2024. For the 2023 Water Year, (October 1, 2022-September 30, 2023), accumulated precipitation measured at the Paulding, OH station was summed. Researchers use the NRCS Curve Number method to estimate, based on soil characteristics, the amount of rainfall that is converted to surface runoff. To select an appropriate curve number Researchers found the hydrologic soil group of the Project using the ODNR SOILS MapServer. Based on literature²⁸, researchers estimate that 30% of all input volume (from precipitation) is routed through subsurface tile drains in tile drained areas and added that volume to surface flow volumes estimated using the NRCS Curve Number method.

Forder Bridge receives water directly from a tile outlet that flows intermittently, and because inflow events are often not sampled directly when water is actively being discharged from the tile outlet, concentrations measured in the most upstream unit of the treatment train, which the tile directly inputs to, are averaged with any measurements of the tile outlet for an inlet concentration. Outlet concentrations for the wetland were measured at the stream that flows into the Maumee River. The average nutrient concentration for each month was calculated with both 2023 and 2024 data because concentrations for a single day can be highly variable and cause bias

²⁸ Pease, L. A., K. W. King, M. R. Williams, G. A. LaBarge, E. W. Duncan, and N. R. Fausey. 2018. Phosphorus export from artificially drained fields across the Eastern Corn Belt. *Journal of Great Lakes Research* 44:43–53.

in a nutrient budget²⁹. To calculate nutrient budgets, flow estimates were multiplied by average inflow concentrations to calculate the nutrient load into the wetland and multiplied by average outflow concentrations to calculate the nutrient load out of the wetland. For each month the net load for each nutrient was calculated as the inflow load minus the outflow load.

Oakwoods Nature Preserve Wetland Restoration Project East and West

Estimation of Runoff Prevention

Oakwoods Nature Preserve Wetland Restoration Project East and West (hereafter Oakwoods) consists of 43 wetland pools. 38 of these pools are isolated depressional (aka Geographically Isolated Wetlands = GIWs) which means they have no discrete water inlets nor outlets. Five pools have drainage tile outlets and one of these, Pool 1, is also a floodplain pool with a connection to Aurand Run, the stream that flows adjacent to the southwest edge of the Project and is the primary water collection body for this watershed. The other four pools have no outlets. These are classified as Flow-in/No-Flow-Out (FINFO) pools. The effects of Oakwoods on P and N transport in the surrounding watershed are due to:

1. Reduction in P and N export due to reduction or elimination of surface runoff and subsurface drainage and cessation of fertilization of the former agricultural fields that comprise this Project
2. Filtration or release of P and N by Pool 1 with respect to Aurand Run plus the filtration of P and N delivered by the drainage tile that outlets in this pool
3. Filtration of P and N by the FINFO pools (30, 31, 36, 42)

Each of these will be addressed separately.

A 3D hydrological model developed by Dr. Ganming Liu's team shows that surface runoff only occurs in a small part of the east side of the Project. That flow is into a relatively large wooded area and is more than 200 m from the watershed collection body, Aurand Run. So, this runoff is not deemed to export significant P nor N to Aurand Run.

Project construction involved locating all subsurface agricultural drainage tiles and crushing the outlets and plugging the tiles so that subsurface flow is eliminated.

While export of nutrients to groundwater cannot be ruled out, geophysical surveys revealing shallow clay confining layers and shallow bedrock (< 0.5 m in some locations) suggest minimal exchange with groundwater at this Project. In addition, soil P concentrations are relatively low, and soils have relatively high capacity to sorb phosphate based on the SPSC metric, so mobilization of phosphate in soil leachate to groundwater is unlikely. The

²⁹ Anderson, K. J., B. Adhikari, O. F. Schloegel, R. Marques Mendonca, M. P. Back, N. Brocato, J. A. Cianci-Gaskill, S. E. McMurray, C. Bahlai, D. M. Costello, and L. Kinsman-Costello. 2024. We know less about phosphorus retention in constructed wetlands than we think we do: A quantitative literature synthesis. *Ecological Indicators* 169:112969.

validity of this assumption is being evaluated using groundwater monitoring wells to directly assess rates of surface water-groundwater exchange and nutrient concentrations in groundwater.

Thus all P and N that were exported by surface runoff and subsurface drainage when this land was farmed has been eliminated. This should continue indefinitely until hydrology or land use changes.

The amount of P and N exported from the farm fields was estimated using the findings of edge-of-field studies of farm fields that had similar soil type, slope, and soil phosphorus content³⁰. The USDA NRCS Web Soil Survey shows that nearly all of the soil in the locations of the wetland pools is soil type Pewamo silty clay loam with a 0 to 1 percent slope. Analysis of soil samples from upland areas at Oakwoods that had not been disturbed during wetlands construction was used to estimate M3-P soil content prior to construction as 26 mg/kg dry soil.

The best edge-of-field data found for similar fields was in a report published by a team led by Kevin King². They monitored 38 fields and 10 of these had silty clay loam soil texture with soil test P in the range 20–46 and slopes in the range 0–3% most similar to the Oakwoods fields (). The average annual total P (dissolved reactive phosphorus (DRP) + particulate phosphorus (PP) load export for these fields was 0.92 kg P/ha with a standard deviation of 0.52 kg P/ha and a 10–90 percentile range of 0.39–1.6 kg P/ha. The average annual DRP load export was 0.42 kg P/ha with a standard deviation of 0.38 kg P/ha and a 10–90 percentile range of 0.11–0.97 kg P/ha. Researchers have not found edge of field data for similar agricultural fields for nitrogen export so cannot estimate that for these fields.

³⁰ Pease, L. A., King, K. W., Williams, M. R., LaBarge, G. A., Duncan, E. W., & Fausey, N. R. (2018). Phosphorus export from artificially drained fields across the Eastern Corn Belt. *Journal of Great Lakes Research*, 44(1), 43–53. <https://doi.org/10.1016/j.jglr.2017.11.009>

Table 9. Estimated TP loads kg/ha from Pease, et al. 2018 for 10 fields most similar to the Oakwoods farm fields.

Field ID	TP export load	DRP export load
L1	0.44	0.12
L2	0.40	0.16
M1	0.56	0.32
M2	0.28	0
N1	1.72	1.08
N2	1.28	0.76
Q1	0.96	0.24
Q2	0.80	0.12
R1	1.64	0.96
Mean	0.92	0.42
Median	0.88	0.28
Std Dev	0.52	0.38
10 percentile	0.39	0.11
90 percentile	1.6	0.97

The total area of the Oakwoods farm fields was 111 acres (57 ha). This gives an estimate of the annual P export from the farm fields of 120 ± 54 lb. TP and 53 ± 22 lb. DRP. Note that these values are rounded to two significant figures. While this is a somewhat large range, it nevertheless gives an order of magnitude estimate of the reduction in P load export by this Project due to land use conversion and elimination of fertilization, surface runoff and subsurface tile drainage.

Reduction of export of “New” P loads in 2024

Phosphorus (P) and nitrogen (N) inflow from outside the Project only occurs in Oakwoods West in Pool 1 and in Oakwoods East in Pools 30, 31, 36, and 42.

Pool 1 is a floodplain pool. It receives water from Aurand Run when the water level rises above the level of the land between the two bodies and then some of that water returns to Aurand Run when the water level recedes to the level of the connection. Pool 1 also receives outflow from a drainage tile. Dr. Jay Martin (Ohio State University) provided the wetland design map for Oakwoods (he participated in the design evaluation) and explained that this drainage tile delivers subsurface drainage collected from the land within the Project boundaries, north of Pools 2, 6, and 7. This is a relatively small area and that land is expected to have relatively low concentrations of water extractable P and N since no fertilizer has been applied for at least three years and rain has been able to wash P and N out of the soil during that period. Water samples collected in Aurand Run show that the P and N concentrations are relatively low. Since the water flowing into Pool 1 has low P and N concentrations there is little potential for it to reduce those concentrations below the ambient levels.

Researchers only have water level data in Pool 1 starting May 16, 2024 and water level in Aurand Run only started in spring 2025 so researchers do not have any data regarding the connection between Aurand Run and Pool 1 prior to that time. A sudden rise in water level July 10, 2024 in Pool 1 suggests that there was a flood event at that time. The profile of that event suggests that water resides in Pool 1 for 1–3 days before outflowing back into Aurand Run. The maximum water level in Pool 1 is about 1.8 m and it appears that the connection occurs at about 1.2 m so the volume of flood water is estimated as the top .6 m in the diameter of Pool 1 at that elevation equals 7,572,309 L. Researchers only started collecting water samples with an automated water sampler during spring 2025 so in Water Year (WY) 24 only have grab samples collected at single moments in time and not during the flood period which was estimated to occur only once in WY 24. To estimate the P and N load export reductions due to the floodplain function and the P and N that arrives in the outflow from the drainage tile, the concentrations of P and N in other pools on the west side during times when water levels were low is used as an estimate of the concentrations that outflow into Aurand Run as the flood water level recedes. The concentrations in the other pools are not expected to have been affected by water from Aurand Run and at low water level those concentrations would not have been diluted by rain. The concentrations in Aurand Run upstream of the connection to Pool 1, during the highest water flow periods is used to estimate the concentrations flowing into Pool 1 during the flood period. Only two samples were collected at those times and their concentrations were the highest of the samples collected at that location. To identify times when drainage tile outflow and Aurand Run level was likely high, a rain index was generated which is the sum of rain (measured at the NOAA weather station at the Findlay Airport approximately 1.5 mile from Oakwood) on Day 1, 50% of Day 2, 25% of Day 3, and 10% of day 4 to estimate the effect of soil moisture and antecedent conditions on water level and runoff. The means were then calculated for analyte concentrations of samples collected when the rainfall index was > 0.7 inch for Pool 1 and compared to the means for Pools 2–19 when the rainfall index was < 0.25 inch in Water Years 2022 and 2023 (WY 22–23). The difference for WY 22–23 was used to calculate filtration of 1.9 lb. TP, 15 lbs. total nitrogen (TN), 8 lb. NO_x, 0.7 lb. DRP, and 0 lb. NH₄-N. However, the analyte mean concentrations in Pools 2–19 for Water Year 2024 (WY 24) were higher than the means for Pool 1 which suggests that Pool 1 did not filter P or N in the water that it received during that Water Year. That might be due to relatively low P and N concentrations in Aurand Run and in the outflow from the drainage tile and/or less runoff and drainage than in the two previous Water Years. Researchers are collecting continuous water level data now in Pool 1 and Aurand Run and have an automated water sampler collecting water samples as of March 2025 so should be able to generate much better estimates of P and N export reduction for the Oakwoods West Project for at least part of WY 25.

In the Oakwoods East Project, the four FINFO pools, Pools 30, 31, 36, and 42, receive flow from a total of six agricultural drainage tiles. It is believed that this drainage comes from the land north of the Oakwoods Nature Preserve. If agricultural drainage is being delivered to these pools with no discrete water outlet, the concentrations would be expected to increase with time and to be higher than pools that do not receive this flow. The data for WY 22–23 showed statistically

higher mean concentrations of TP, TN, NO_x, and nearly significant for total ammonium nitrogen, but not for DRP than for WY 24. This might be due to obstruction of water flow in those tiles; when water level is low, accumulated sediment is observed in the outlets of these tiles occluding from 30% to 80% of the opening. A large drainage tile that was located under the entire east side of the Project running east to west was excavated during Project construction and found to be full of sediment. It is suspected that sediment accumulated because the fall of this tile was so shallow due to the flat topography of this area that water flow was so slow that sediment in the water settled out and accumulated to a level that impeded water flow through the tile. The same might be true of the tiles outflowing into the FINFO pools. Thus, no additional filtration of P and N was found due to the function of the FINFO pools in WY 24.

Summary

The only reduction of P and N exports to the watershed attributed to the Oakwoods Nature Preserve is the reduction in export due to the cessation of agricultural fertilizer application and the elimination of surface runoff by the excavation of 43 wetland pools as well as the de-commissioning of the subsurface agricultural drainage tiles (runoff prevention). This is estimated to reduce TP and DRP export annually, relative to when these fields were farmed, by 117± 65 lb. and DRP by 54±48 lb. But in Water Year 2024, researchers do not estimate any additional reduction in P and N export due to the floodplain function of Pool 1 or the FINFO function of Pools 1 in the west Project and Pools 30, 31, 36, and 42 in the East Project.

Magee Marsh Turtle Creek Bay Wetland Reconnection

Bathymetric Model

Magee Marsh Turtle Creek Bay Wetland Reconnection Project (hereafter Magee Marsh), located in Ottawa county connects the 165-acre Turtle Creek Bay wetland within Magee Marsh to Lake Erie. This coastal wetland features Water Level Control Structures (WLCS) to control the volume of water in the wetland as a means to manage agricultural runoff in the event of rise in lake level. During high flow events, upstream flow from Turtle Creek can be diverted into the wetland where excess sediments and nutrients will be captured, keeping them from flowing directly into Lake Erie.¹



Figure 351. Magee Marsh Water Budget (2023–2024)

Accurate modeling of wetland hydrodynamics is crucial for effective water budget and nutrient filtration estimation. The methodology described here integrates remote sensing data with in-situ hydro-geophysics surveys and water level measurements to develop a high-resolution bathymetric model and quantify daily change in wetland water volume. The modeling framework consists of three components: terrain (DEM) processing, water surface modeling, and volume estimation.

Terrain (DEM) Model Preparation

A high-resolution Digital Elevation Model (DEM) was generated from the drone imagery of the Project collected by the H2Ohio Wetland Monitoring program Drone team. The flight took place in August, 2024 when the wetland had no standing water. The imagery was further processed to eliminate vegetation interference and retain only bare-earth elevation. Following that, the DEM dataset was orthorectified and validated against ground survey conducted by the Monitoring Program Geophysics team within the same wetland. The resulting DEM was then resampled to a standardized 0.5-meter resolution using bilinear interpolation and clipped to the wetland boundary extent.

Water Surface Modeling

The water surface generation employed a planar interpolation approach based on water level observations. Water level data were obtained from the Magee Marsh sensor network system, specifically from the Vegapuls 21 (VEGA, Shiltach, Germany) sensor serving as the primary source of water level measurements. The sensor is located near WCS-1 (Figure 352) at the south-western part of the wetland. Water level data is recorded by the sensor at a fixed 10-min interval, which was then aggregated to create a daily average water level.



Figure 352. Magee Marsh Sensor Network: Device Locations

Additionally, precipitation data were retrieved from the on-site sensor network weather station, providing input for assessing any changes in the water budget.

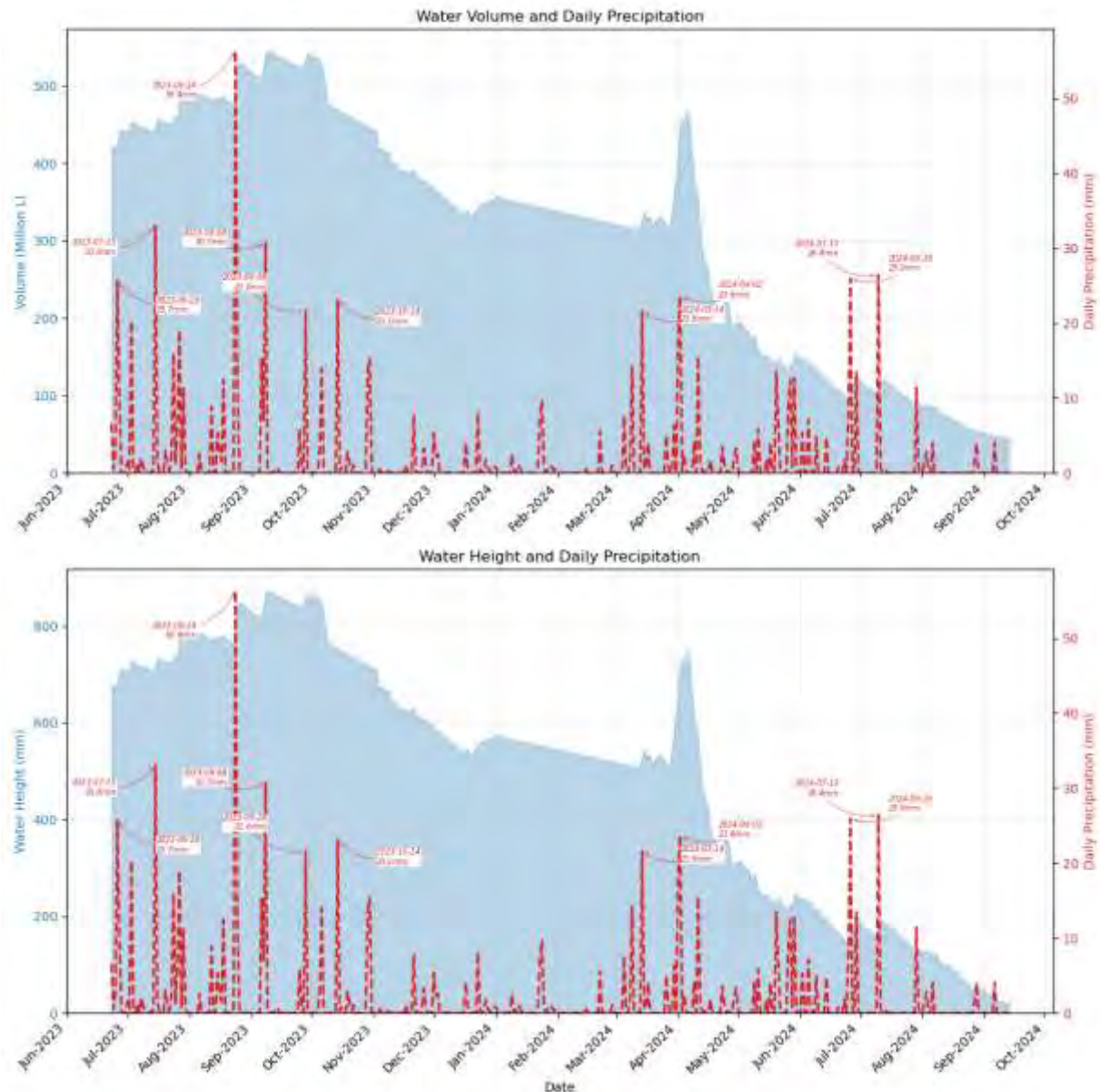


Figure 353. Magee Marsh Water Volume and Daily Precipitation

For spatial analysis, sensor measurements were transformed into geospatial format as point feature class to enable integration with the terrain DEM. After transformation, each daily measurement represents a theoretical water surface through a constant-value raster at the observed water level over the underlying terrain. The resultant intersection process generates a continuous depth surface described by the following equation,

$$D_{x,y} = E_w - E_{t,x,y}$$

Where $D_{x,y}$ represents depth at position x,y , E_w denotes water surface elevation, and $E_{t,x,y}$; terrain elevation at position x,y .

Water Volume Estimation

Volume calculations employ a cell-based approach, integrating depth values across the inundated area. The process determines the mean depth of inundated cells and multiplies this by the total inundated surface area. This relationship is expressed as,

$$V = D_i \times A$$

Where, V is the total volume, D_i is the mean depth across inundated cells and A is the inundated extent.

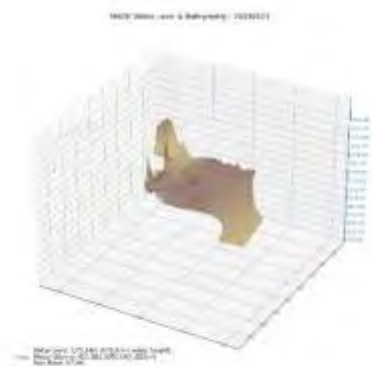


Figure 354. Magee Marsh Volume Estimation (3D render). Each cell represents 0.5m²

The inundation extent (A) is determined by identifying raster cells where the computed depth was positive, delineating the wetland's surface water coverage.

$$A = n \times c$$

Where, n is the count of inundated cells and c is the cell size (0.5 m).

In addition to the volume estimates, the proportion of wetland water coverage was also calculated, providing insight into spatial changes in inundation patterns within the wetland.

Result and Conclusion

The outlined calculations were executed within an automated geospatial processing pipeline utilizing ArcPy and NumPy-based raster operations. This workflow ensured consistency across time-series analyses and generation of consistent outputs.

The primary outputs from this model includes high-resolution bathymetry map and raster layer, offering a detailed representation of the Magee Marsh submerged topography.

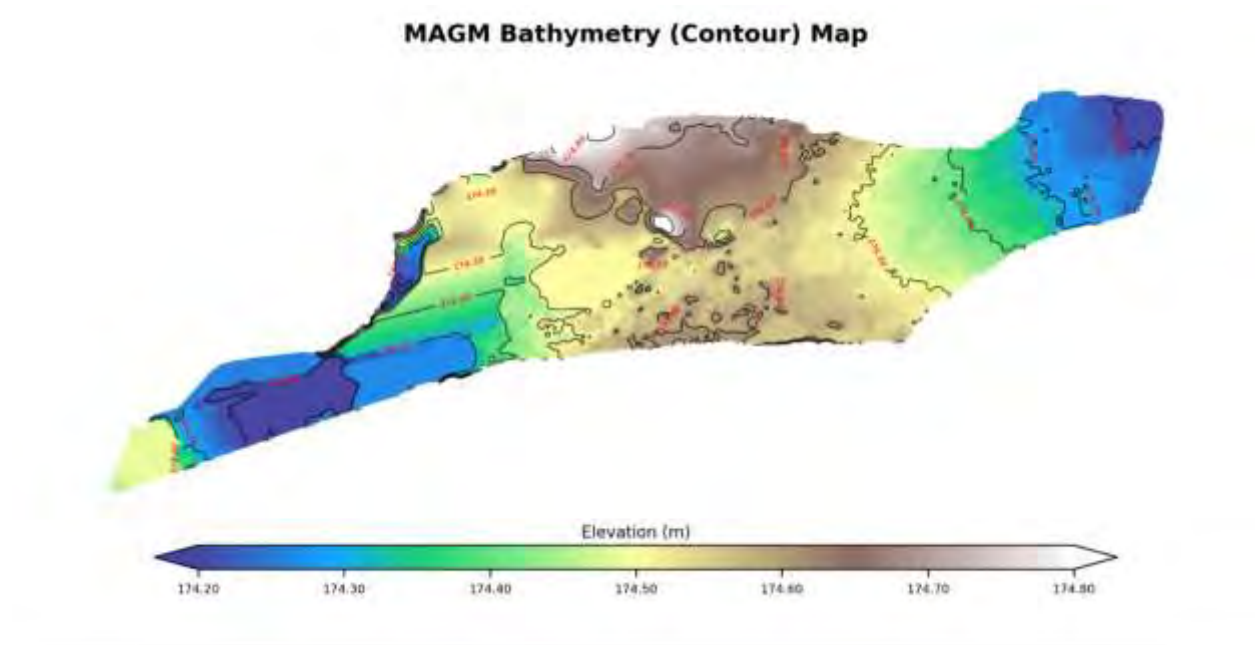


Figure 355. Magee Marsh Bathymetry Map

Additional outputs include daily estimated water volume, inundated surface area, mean water depth, and percentage of wetland area inundation for each temporal observation from June, 2023 to October, 2024.

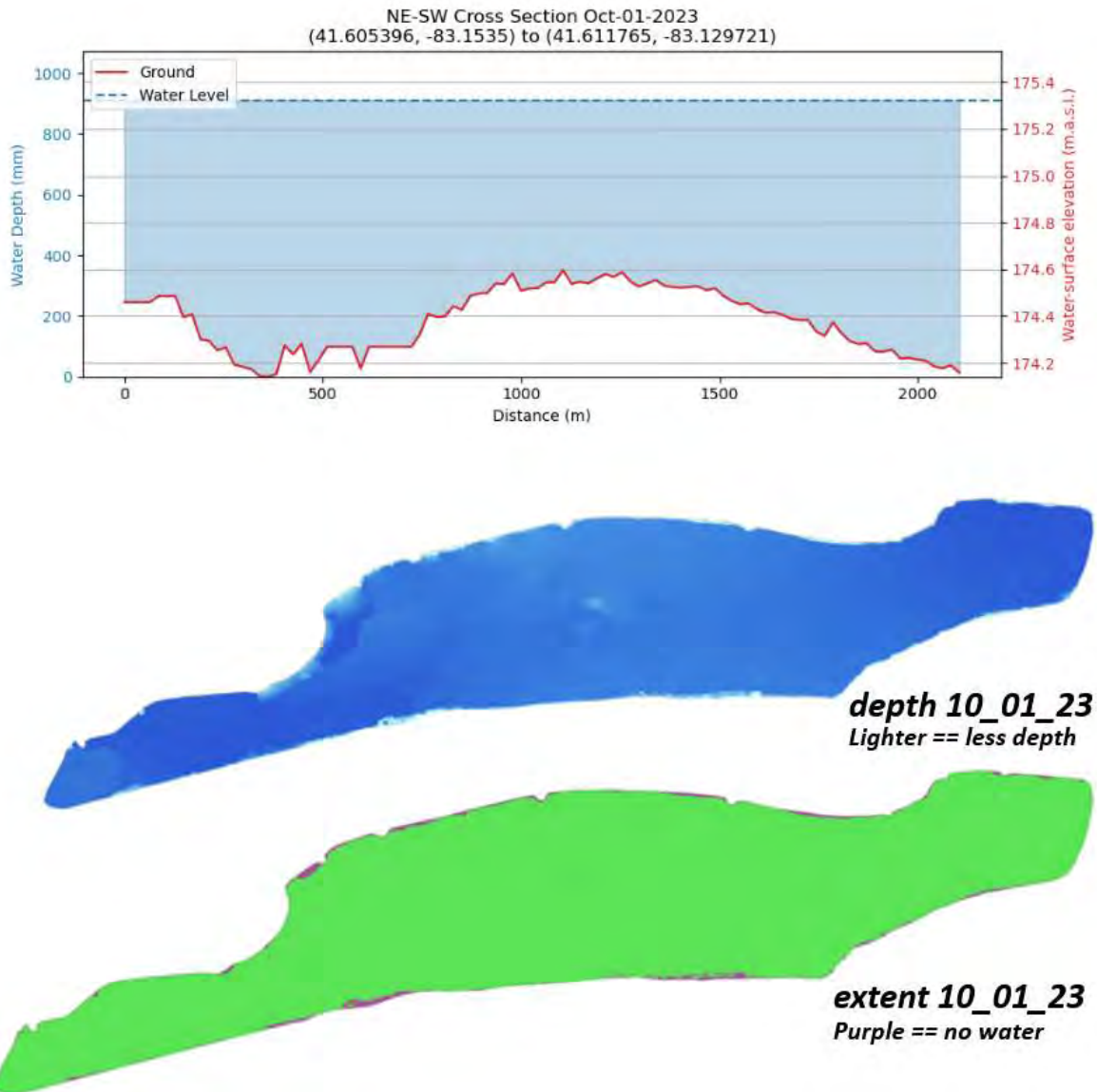


Figure 356. Model Outputs: Highest Recorded Water Level & Water Volume (10/1/2023)

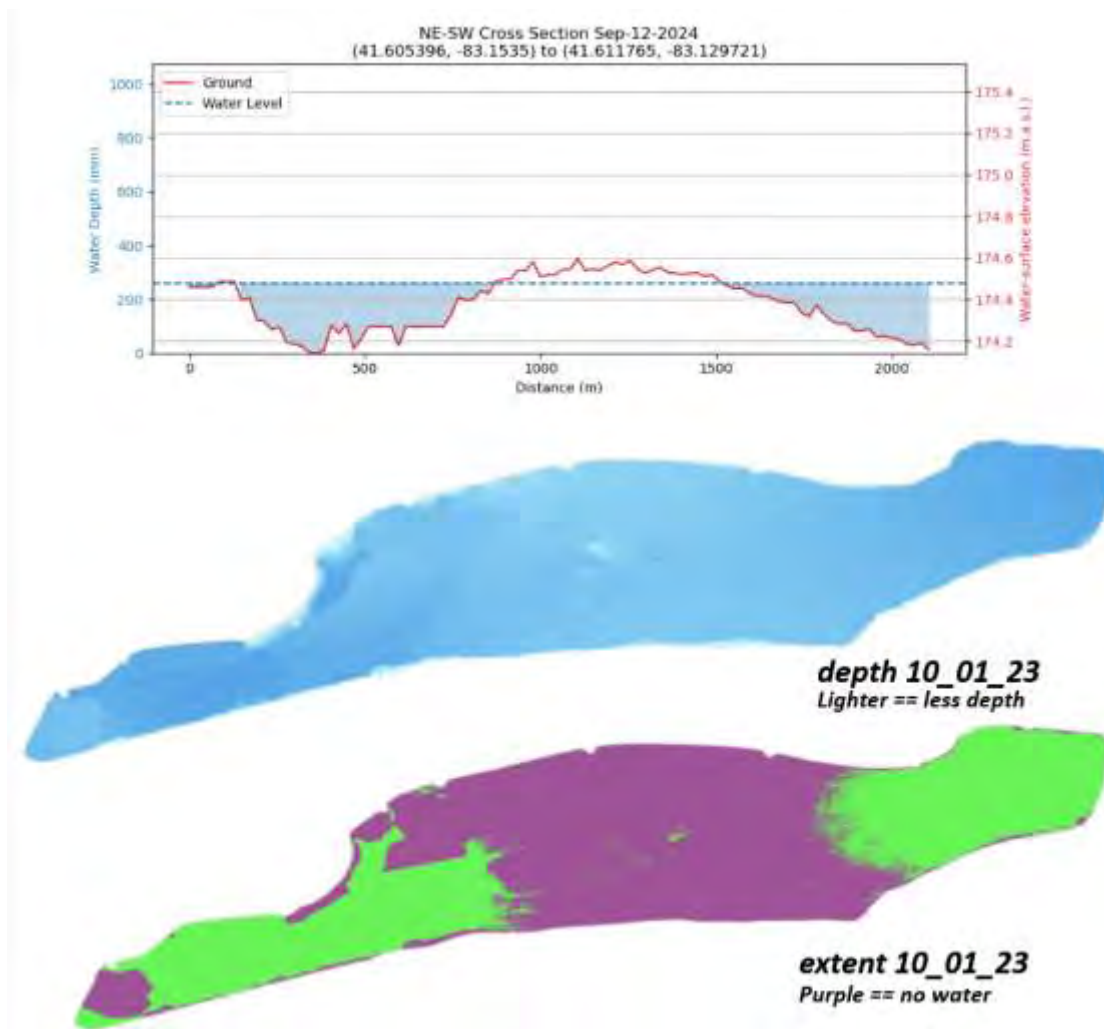


Figure 357. Model Outputs: Lowest Recorded Water Level & Water Volume (09/12/2024)

This methodology outlines a systematic approach to wetland volume calculation, suitable for temporal analysis of wetland hydrology. Furthermore, it provides a reliable framework for assessing hydrodynamic changes in wetlands, with a focus on enhanced accuracy of wetland bathymetric modeling, water budget estimation and nutrient filtration capability.

Future improvements of this model have the potential to incorporate additional hydrological parameters, such as flow, evapotranspiration, and multiple water level sensors.

Nutrient Budgeting

The nutrient filtration for Magee was calculated in the same manner as in 2023, with significant improvement in the precision of water volume change estimates in 2024 due to improved wetland bathymetry and the installation of a water level sensor. While water movements into and out of the wetland can be calculated with confidence, there remains uncertainty about the

nutrients filtered due to two main factors: 1) the fate of water pumped from the wetland is unknown, it was either filtered in an adjoining wetland or released back to Turtle Creek. 2) The nutrient concentration of Turtle Creek water entering the marsh during the one 10-day period of connection (March 27–April 6; Figure 353) in 2024 is unknown because the event was not reported by marsh managers to enable sampling. Given the unknowns, researchers have made a best estimate of the range of nutrients that could have been filtered in the wetland if the water entering the wetland was filtered and not immediately pumped back into Turtle Creek and if Creek nutrient concentrations entering the wetlands were at the highest concentrations measured in the creek that spring.

Methods

The method for calculating nutrient filtration for Magee Marsh depends on three types of data: Water levels, wetland bathymetry, and nutrient concentrations (creek and wetland). The first two data types are used to calculate water volumes into and out of the wetland. Volume estimates are combined with nutrient concentrations to calculate bulk nutrient loads into and out of the wetland.

Volume: Detailed bathymetry of Magee Marsh was provided by the drone team during a period when the wetland was dry. The bathymetric model provides wetland water surface area at any given water depth. The change in water volume between any two water level measurements (levels a and b) can be found using the trapezoid rule: $[(\text{surface area for water level a} + \text{surface area for water level b})/2] \times \text{change in water depth}$. Researchers used this concept applied to 0.5 m cells encompassing the entire wetland. Using square meters for area and meters for depth generates volume changes in cubic meters which can be converted to gallons or other units. The results of the new bathymetric model closely agree with the coarse approximation used in 2023.

Nutrient Load: Bulk nutrient movements into and out of the wetland are calculated as simply nutrient concentration $\times$ water volume. However, these calculations are complicated by the availability of appropriate nutrient data. Inflowing nutrient load is calculated based on nutrient concentration and volume of Creek water flowing into the wetland. Unfortunately, researchers did not have matching creek nutrient data for the one 10-day inflow event in 2024, therefore as in 2023 calculations, researchers used the highest creek nutrient concentrations measured in 2024 to estimate the highest potential nutrient inflow load of the 10-day event. Researchers are also uncertain as to the fate of the nutrients leaving the wetland through pumping. The water was either immediately pumped back into Turtle Creek (zero nutrient filtration) or was filtered in an adjoining wetland. Therefore, the possible nutrient load reduction for Magee Marsh for 2024 ranged from zero to 100% of the nutrients theoretically entering during the 10-day connection event.

Redhorse Bend Preserve Wetland Restoration

The Redhorse Bend Preserve Restoration Project (hereafter Redhorse Bend) is a 54-acre parcel with 28-acres of floodplain habitat restored from a former agricultural field along a prominent bend in the Sandusky River in Fremont, Ohio. Berms along the river were lowered to enhance

floodwater access to the restored floodplain wetlands, intended to increase the ability to retain floodwater and treat pollutants. Redhorse Bend is bisected by a highway (US-20) and the northern part of the wetland Project contains a majority of the restored wetland habitat while the southern part of the parcel consists primarily of meadow habitat. The property is currently managed by Sandusky County Parks and will be open for public access at some point in the future.

Sampling Setup

In the northern half of Redhorse Bend, water from the Sandusky River enters the Redhorse Bend Wetland system from a ditch (ditch 2) at the northern border that connects the river to a series of five large wetland pools (pools 1–5) during high flow conditions (over ~3,800 CFS). A series of smaller wetland pools (pools A–G) run perpendicular to the larger pools along the river and also receive floodwater during high flow. On the southern part of the Redhorse Bend, one isolated pool (pool 6) receives surface runoff from the highway and the adjacent restored meadow. During high flow, water enters and exits the wetland through the northern ditch. During extremely high flow events (over 12,000 CFS), the river enters the wetland through the lowered berms as well and the pools will become connected into one large pool.

Researchers' sampling goal is to characterize ambient and storm flow concentrations across each wetland pool, the Sandusky River adjacent to the Redhorse Bend, and the northern ditch. For ambient or low-flow conditions, samples are collected monthly. For storm conditions, samples are collected during flow events over 3,800 CFS (assessed upstream at the USGS gage 04198000 near Fremont). For minor storm condition events, samples are collected once, but for major events (over 10,000 CFS) samples are collected multiple times during the falling limb of the hydrograph of the event. Researchers also leverage a long-term monitoring location (National Center for Water Quality Research, Heidelberg University) upstream to assess storm event concentrations in the river.

Nutrients

Nutrient concentrations for Redhorse Bend were downloaded from the H2Ohio Wetland Monitoring Program's GitHub repository. Concentrations below detection limit (BDL) were replaced with $\frac{1}{2}$ BDL. Detection limits are as follows: SRP 0.03, TP 0.1, NO_x AQ1 0.06, NO_x AQ300 0.04, TN 0.25, NH₄ latchet 0.001, NH₄ AQ1 0.02, NH₄ AQ300 0.01. Average seasonal, base flow and storm flow concentrations were calculated for pools 1–5, pool A, and ditch 2 when applicable.

Hydrology

During ambient conditions, most of the major pools (1–5) contain water from shallow groundwater due to the high water table in the area associated with being close to the river and at the bottom of a slight hillslope. A groundwater spring with distinct chemistry enters the wetland at pool 1B containing deep groundwater. Thus, during a storm event, researchers don't expect that much flood water exits the wetland through the subsurface and instead most exits from the

northern ditch or is stored. Only during drought conditions will the major pools become dry. The smaller pools adjacent to the river (pools A–G) are dry during most conditions.

Water levels were recorded by both HOBO data loggers and manually using a meter stick by researchers during site visits. Average pool depths for pools 1–5 and pool A were calculated using a combination of observed pool depths, and the relationship between the Sandusky river discharge volume and water entering the site for both ambient and storm conditions. Pool areas were calculated from Google Earth images of the site. Because the pools are responsive/related to Sandusky River water levels, and the resultant changes in groundwater levels, researchers estimate pool volumes on a daily time step based on Sandusky River discharge volume.

Observed depths, and river discharge were fit to a logistic regression to obtain the following relationships:

- $\text{Pool1} = 60.25\ln(\text{River } Q) + 491.37$
- $\text{Pool2} = 66.82\ln(\text{River } Q) + 167.1$
- $\text{Pool3} = 134.99\ln(\text{River } Q) + 310.53$
- $\text{Pool4} = 134.22\ln(\text{River } Q) + 99.573$
- $\text{Pool5} = 65.097\ln(\text{River } Q) + 37.2$
- $\text{PoolA} = 30.652\ln(\text{River } Q) - 157.89$

All relationships have an R² value above 0.991, except Pool A, which is 0.71.

Daily volumes are estimated, and water is not considered to be flowing in or out of the wetland unless river volume exceeds 3800 cfs, at which point river water can enter the site through the connection to pool 1. On the falling limb of the hydrograph, pools are assumed to drain from pool 5 back through to pool 1 and into the river (Figure 358). During ambient conditions, water does not exchange between the site and the pools, and there is little to no loss to groundwater.

Nutrient Load

Researchers multiplied the daily change in pool volume by pool concentrations to quantify the nutrient load into or out of the wetland each day and summed for 2024. Where researchers were missing nutrient concentrations, researchers used the most recent concentrations for ambient conditions and average concentrations for storm events.

To calculate storm event loads entering the wetland, researchers used the concentration of the water entering the pool and the volume increase to get inflow load and the reverse for outflow load. For example, a pool's concentration would reflect the ambient and the storm inflow concentration: River → Pool 1 ambient +/- River → Pool 2 ambient +/- Pool 1 and so forth (Figure 358). To calculate loads leaving the wetland during the falling limb of the event, researchers used the concentration in the pool multiplied by the volume decrease.

Net load is calculated as the sum of the changes in volume of each pool multiplied by the respective concentrations for that "day". So during storms it is positive, and after a storm it is negative as the pools drain. During ambient conditions, it can move up and down a bit due to the level of the river/ground water. Net load reduction for the site was relatively low in 2024 because

there were only a couple of storms that would have provided a net positive load, and the pools were dry or nearly dry by the end of June.

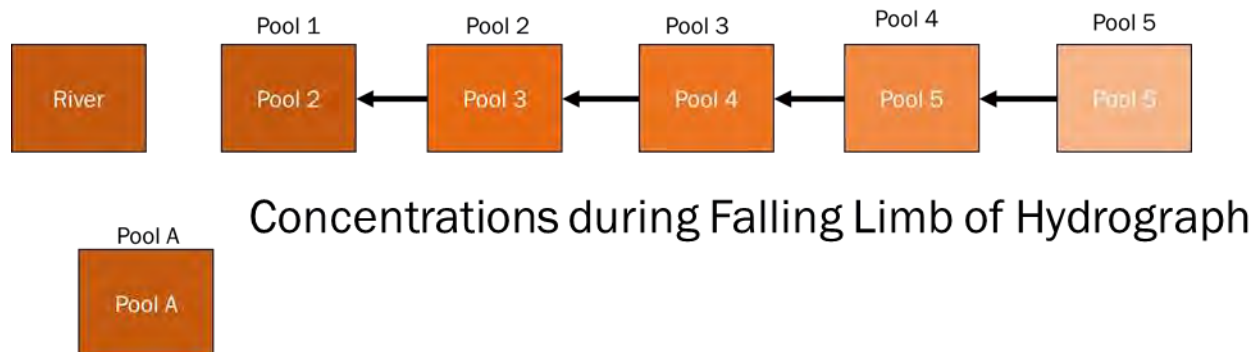
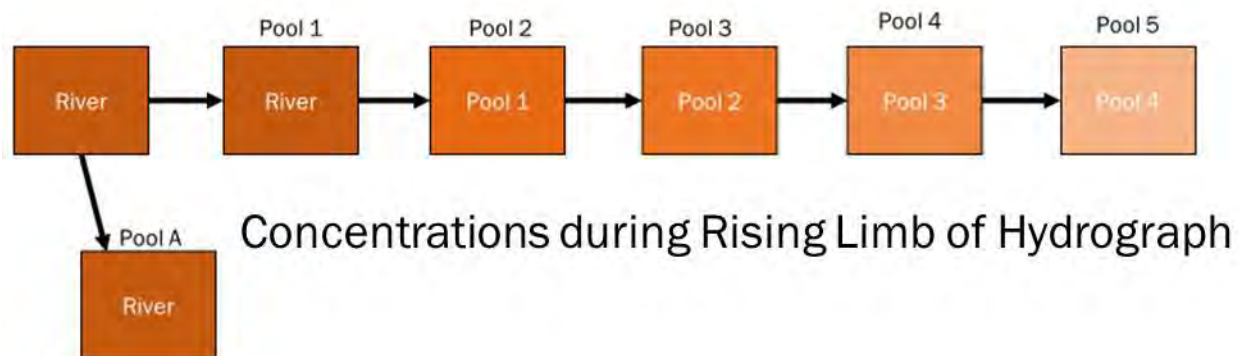


Figure 358. Schematic illustrating relationships (e.g., directionality of flow) between pool concentrations during the rising (beginning) and falling (ending) limbs of a storm event.

St. Joseph River Farm and Floodplain Restoration Project

St. Joseph River Farm and Floodplain Restoration Project (hereafter St. Joseph) is a restoration Project in the Upper Maumee watershed that was constructed in 2021. Water and soil samples have been collected and analyzed since its construction was completed. The sensor network for St. Joseph started collecting data in June, 2023. The newly active sensor network highlights the value of high-frequency sensor data over manually collected data. This Project is an excellent

example of a wetland with complex hydrology. Researchers estimate that in Water Year 2024 St. Joseph released approximately 15 lbs. of total phosphorus and reduced the export of total nitrogen by approximately 600 lbs., nitrite+nitrate by approximately 370 lbs., total ammonium nitrogen by approximately 18 lbs., and dissolved reactive phosphorus (DRP) by approximately 6 lbs.

St. Joseph is on 94 acres of fields that were previously farmed. Thirty-three acres of this land was converted into wetland pools by excavation. Three large agricultural tile outlets and ditched drainage pathways deliver water to a mix of flow-through, floodplain, and isolated wetland pools. Near the East Ditch junction with the St. Joseph River, the southeast area of this Project is flooded by water from the large ditch on the east side of the Project when the St. Joseph River level rises. The mixture of flow-through, isolated, and floodplain pools makes nutrient budgeting especially challenging because different wetland features require different methods to calculate the amount of P and N they remove, and some pools have both flow-through and floodplain functions. The H2Ohio Wetland Monitoring Program reports budgets for the main flow path and presents the data collection in progress to improve estimates of nutrient export by this complex system.

Main Flow Path Budget

We collected water samples approximately monthly at the three inlets (SJRE01–03) and the outlet of Pool B (SJRE05) and at other locations when water was present. Researchers estimated the topographical drainage area of the land draining into the Project using a high-resolution digital elevation model (DEM) and estimated sub-surface runoff through the tile network using an estimate of the extent of the surrounding area drained into the tiles provided by a county partner (Brian Fritsch, Drainage Engineer and GIS Coordinator of the Williams County Engineer's Office). To predict the proportion of rainfall that runs off the landscape as surface water researchers used the NRCS curve number method³¹. The majority land cover type of the drainage area is row crops So for this estimate researchers used a curve number of 75, consistent with measured curve numbers for NW Ohio tile drained row crop fields³². Researchers estimated subsurface drainage as 31% of rainfall on the area drained by the tiles as is typical for tile drainage from Ohio farmlands³³.

This budget comes with a series of important assumptions including: 1. Drainage area is accurate, 2. All water entering the wetland leaves the wetland, 3. Phosphorus is not lost through permeation into groundwater, 4. Baseflow phosphorus (P) reduction is the same as storm flow

³¹ USDA-NRCS, 2004b. United States Department of Agriculture Natural Resources Conservation Service, National Engineering Handbook, Title 210 Engineering, Part 630 Hydrology, Chapter 10. Estimation of Direct Runoff from Storm Rainfall.

³² Wessel, B. M., Bolster, C. H., King, K. W., & Shedekar, V. S. (2022). Rainfall-runoff models compared for tile-drained agricultural fields in the Western Lake Erie Basin, Ohio. *Journal of Hydrology*, 610, 127959. <https://doi.org/10.1016/j.jhydrol.2022>.

³³ Pease, L. A., King, K. W., Williams, M. R., LaBarge, G. A., Duncan, E. W., & Fausey, N. R. (2018). Phosphorus export from artificially drained fields across the Eastern Corn Belt. *Journal of Great Lakes Research*, 44(1), 43–53.

phosphorus reduction, 5. P concentrations of water samples are representative of P concentrations throughout periods when samples were not collected. 6. The average tile outlet P concentrations in the samples that were manually collected at discrete time points represents the average P concentration in all tile outflow. See below for more details on how these assumptions might affect Monitoring Program load estimates. Note that P concentrations in water during high flow are often higher than during baseflow. Since nearly all concentrations used for this estimate were collected during baseflow conditions, most likely P load inflowing to the Project is substantively underestimated. Also, the P concentration at the outlet of Pool B was assumed to represent the concentration flowing out of the Project since that is the predominant outflow location. However, only manually collected samples were taken and concentrations during outflow and inflow in Pool B due to flooding by the St. Joseph River via the East Ditch have not yet been measured. An Isco automated water sampler was installed at that location in early March 2025 and will be used to collect water samples during high flow conditions so that the next annual report should have a more robust evaluation of the concentrations during high flow events. It is uncertain how this affects the estimates reported but those should be considered tentative and very likely to change as better and more complete data are obtained.

We estimated the filtration of P and N by St. Joseph in the 2024 Water Year (WY) using rainfall data from the closest NOAA weather station at Edon, OH (Station ID GHCND:USC00332513) rather than rainfall data collected by the onsite rain gauge because that gauge failed to collect data for extended time periods. For each month researchers multiplied the predicted discharge from each tile drain by the average concentration of that month. For some months there was not enough flowing or standing to collect water samples at some, or all inlets and outlets, so there is no data at some locations of interest for some months

With this method researchers estimate that during WY 24 the St. Joseph wetlands Project released approximately 15 lbs. of total phosphorus (TP) and filtered approximately 600 lbs. of total nitrogen, 370 lbs. nitrite+nitrate (NO_x), 18 lbs. total ammonium nitrogen ($\text{NH}_4\text{-N}$) and 6 lbs. dissolved reactive phosphorus (DRP). The release of TP might be due to the accumulation of decomposing plant detritus at the Pool B outlet. There is dense plant growth in large parts of this pool that dies each fall and winter. The flow towards that outlet end of the pool carries a relatively large amount of that decaying vegetation to that end where it accumulates, in part due to the relatively steep bank at that end of the pool that prevents much of it from flowing out even during high flow events. During warmer months, anoxic conditions were detected above the sediment at the outlet which could be attributed to such decomposition. anoxia can result in chemical reduction of iron and manganese which results in release of dissolved P. Particulate P can also be present as the plant detritus is reduced to small particle sizes and that can be present in the water samples used to estimate TP concentration. This loss of P might be substantially reduced by dredging the decomposing detritus out of the Pool B outlet area periodically.

Addressing Assumptions

While the surface drainage area of St. Joseph is likely accurate, there is substantive uncertainty regarding the subsurface drainage area because that depends on where ag field tiles are located,

their spacing, and depth, and it has not yet been possible to determine that. Subsurface agricultural tiles in northwestern Ohio can cause more than 30% of rainfall to leave the land through subsurface drainage, which could significantly increase Monitoring Program estimates of filtration above what is estimated as the 13% of rainfall that researchers are currently predicting for the surface runoff of the Project. At the same time, the H2Ohio Wetland Monitoring Program budget does not account for water evaporation and water permeation into soil, or transport to or from groundwater. Groundwater has the potential to decrease estimates of filtration by acting as another outflow, but water storage by the system likely reduces the volume of water leaving the wetland and will likely increase estimates of phosphorous filtration^{34,35}.

Similarly, Monitoring Program measurements of monthly phosphorus concentration require assumptions as listed above. The current budget uses an average of phosphorus concentration at the 3 tile drains to represent the concentration entering the wetland, but researchers know that some tile drains are more active than others. This could affect researcher estimates of the amount of phosphorus entering the system, but these effects would likely not be extremely large. What is more important is storm events.

Currently the budget assumes that phosphorus filtration is the same during base flow and storm events, but previous research shows that storm flow can cause major shifts in the filtration of P and N in wetlands³⁶. 2023 data is consistent with this but is limited to a single data point where researchers see a shift from 96% phosphorus reduction during baseflow to 51% phosphorus reduction during storm flow as water moves through the wetland. Collection of more data during high flow events using automated water samplers will enable generating more accurate estimates of P and N transport, and now a sampler is installed to collect this type of data at the Pool B outlet. Researchers hope to be able to install a sampler also at the Pool B inlet sometime this year. During Water Year 24 there were relatively long periods when most of St. Joseph is dry, so water samples were not collected but there were times during this period when some water entered the Project and carried some phosphorus with it but did not flow out. Researchers did not have water samples and could not measure concentrations during these periods. They used data from other months to predict that range of possible concentrations entering the system. Researchers can calculate a range of phosphorus loading when there are no samples taken by multiplying the predicted flow with the lowest concentration in a previous month, and then the

³⁴ Krasnostein, A. L., & Oldham, C. E. (2004). Predicting wetland water storage. *Water Resources Research*, 40(10). <https://doi.org/10.1029/2003WR002899>

³⁵ Meinikmann, K., Hupfer, M., & Lewandowski, J. (2015). Phosphorus in groundwater discharge— A potential source for lake eutrophication. *Journal of Hydrology*, 524, 214–226. <https://doi.org/10.1016/j.jhydrol.2015.02.031>

³⁶ McClain, M. E., et al. (2003). Biogeochemical Hot Spots and Hot Moments at the Interface of Terrestrial and Aquatic Ecosystems. *Ecosystems*, 6(4), 301–312.

highest concentration in a previous month. This provides researchers with a range of possible filtration by the system, when water samples cannot be taken.

Non-Focal Project Nutrient Budget Methods

Montpelier Wetland Restoration

The Montpelier Wetland Restoration wetland system (hereafter Montpelier wetland) consists of the 6-acre wetland and the phosphorus removal filter. The system is designed in series, where the outflow from the wetland flows through the phosphorus filter prior to leaving the site. This stacked/combo approach leverages the benefits of the natural wetland ecosystem and nutrient cycling combined with the water quality and dissolved reactive phosphorus (DRP) removal benefits of an engineered phosphorus removal filter.

For the Wetland Monitoring Report, researchers are reporting the overall effectiveness of the wetland and phosphorus removal filter system. However, researchers also have water quality data that allows for assessing the benefits of the wetland and phosphorus filter independently. Researchers estimate that of the 4.6 lbs. of DRP that entered the wetland, the wetland removed 0.8 lbs. (17%) and the P-filter removed 2.4 lbs. (53% of inflow) for a total of 3.2 lbs. (70%) removed. For total phosphorus (TP), 31.5 lbs. entered the wetland, 25.7 lbs. (82%) were removed by the wetland and 2.2 lbs. (7%) were removed by the P-filter for a total of 27.9 lbs. (89%) TP removed. The Project removed 88% nitrate and 78% total nitrogen, while the P-filter did not reduce or affect the removal.

Flow is monitored at the wetland inlet by a .6 m H flume with bubbler level readings recorded every five minutes. Flow is monitored at the outlet with an 8-inch Thelmar portable weir. Researchers measure the level in five-minute intervals with both a bubbler level sensor and an area velocity sensor. These level readings are converted to a flow rate within Flowlink. Water samples are taken every six hours when there is flow into the wetland and more frequently during events. Flow below 0.003 cubic feet per second (cfs) was corrected to 0 because values that fall below 0.003 cfs (or 0.91 cm) are typically only noise in the data caused by rainfall on the flume, but not representative of an actual event. Nutrient concentrations were multiplied by flow rate and summed to calculate nutrient loads at the inlet of the wetland, the inlet of the phosphorus filter, and the outlet of the wetland.

Springcreek Confluence Off-Channel Wetlands

The Springcreek Confluence Off-Channel Wetlands (hereafter Springcreek Project) consists of two large floodplain pools along the Great Miami River constructed in summer 2021. Researchers began collecting water and soil samples after construction was completed and monitoring continuous water level data after construction in both wetland pools. In Water Year (WY) 2024, researchers estimate that the Springcreek Project filtered 33 lbs. dissolved reactive

phosphorus (DRP), 41 lbs. total phosphorus (TP), 1066 lbs. nitrite+nitrate (NO_x), 1052 lbs. total nitrogen (TN), and 15 lbs. total ammonium nitrogen (NH₄-N).

Sampling Approach

Researchers collected water samples from several locations including Great Miami River Upstream, Great Miami River Downstream, Spring Creek Upstream, and both wetlands pools connected to the Great Miami River (South Pool) and Spring Creek (North Pool). Continuous water level data collection in the North Pool and South Pool began in November 2021 using a Solinst Levellogger (Solinst Canada Ltd.).

Nutrients

Researchers downloaded nutrient concentrations for the Tipp City Project from the GitHub repository and replaced concentrations BDL with 1/2BDL. Detection limits are as follows: SRP 0.03, TP 0.1, NO_x AQ1 0.06, NO_x AQ300 0.04, TN 0.25, NH₄-N latchet 0.001, NH₄-N AQ1 0.02, NH₄-N AQ300 0.01. Researchers calculated average seasonal nutrient concentrations for Spring Creek Upstream, North Pool, Great Miami River Upstream, and South Pool.

Hydrology

Continuous water level data recorded at 30-minute intervals was downloaded and processed in the Solinst (Solinst Canada Ltd.) software. Researchers calculated average daily water depth using the data. From the average daily water depths, an average daily pool volume can be calculated using a bathymetry survey collected by the Miami Conservancy District (MCD) and U.S. Fish and Wildlife Service (USFWS) in March 2022 (Figure 359Figure 362).

The bathymetry survey data was used to calculate the volume of water in each pool at different surface water elevations (Table 10).

Table 10. Wetland pool volumes corresponding to water surface elevation calculated from bathymetry survey conducted in March 2022.

Elevation (ft)	North Pool Volume (Gallons)	South Pool Volume (Gallons)
816	-	-
817	1	42
818	254	3,777
819	1,596	55,073
820	9,105	252,878
821	44,414	682,007
822	145,886	1,359,109
823	349,207	2,391,431
824	664,310	3,808,511
825	1,095,106	5,647,365
826	1,637,266	7,740,870
827	2,517,266	10,956,870
828	3,397,266	14,172,870

Elevation and pool volume were fit to cubic polynomial regressions to obtain the following equations:

$$\text{North Pool Volume} = 3786.2x^3 - 9 \times 10^6x^2 + 8 \times 10^9x - 2 \times 10^{12}$$

$$\text{South Pool Volume} = 9619.3x^3 - 2 \times 10^7x^2 + 2 \times 10^{10}x - 5 \times 10^{12}$$

Where x is the surface water elevation of the corresponding pool in feet and volume is in gallons. Surface water elevations were calculated as average daily depth added to elevation at the location of the sensor. South Pool sensor is at an elevation of 822.5 ft, and North Pool sensor is at an elevation of 822.

A daily change in volume was calculated by subtracting the current day's volume from the previous day. Positive daily change in volumes corresponds to inflow, and negative daily change in volumes corresponds to outflow. All of the positive daily changes in volumes can be summed up to determine a seasonal inflow volume.

Note that there are brief periods of time (only during extreme flow events and only lasting a week or less) where some of the South Pool volume is not just river, it could also be overflow from the North Pool.

Nutrient Loads

Seasonal nutrient loads filtered were calculated as:

$$\text{load retained} = [(\text{upstream concentration} - \text{wetland concentration}) * 0.0022046 * \text{volume}] / [0.26417 * 1000]$$

Where load filtered is in pounds, concentrations are in mg/L, volume is in gallons, 1000 converts mg to g, 0.0022046 converts g to lbs., and 0.26417 converts L to gallons. The upstream concentration is a seasonal average of the Great Miami River concentrations or Spring Creek Concentrations. The wetland concentration is a seasonal average of South Pool or North Pool concentrations.

Tipp City Off-Channel Wetlands

The Tipp City Off-Channel Wetlands (hereafter Tipp City Project) is a large floodplain wetland located along the Great Miami River constructed in winter 2022. Researchers collected water and soil samples monthly and for events following construction. Water level data in the wetland pool was continuously monitored using a Solinst Levelogger (Solinst Canada Ltd.). In Water Year (WY) 2024, researchers estimate that the Tipp City Project filtered 23 lbs. dissolved reactive phosphorus (DRP), 37 lbs. total phosphorus (TP), 1,162 lbs. nitrite+nitrate (NO_x), 1,121 lbs. total nitrogen (TN), and 64 lbs. total ammonium nitrogen (NH₄-N).

Sampling Approach

Researchers collected surface water samples from upstream Great Miami River, downstream Great Miami River, and two locations within the wetland pool. Continuous water level data has been collected from the wetland pool at 30-minute intervals since December 2022 using a Solinst Levelogger (Solinst Canada Ltd.) to determine wetland pool volume.

Nutrients

Researchers downloaded nutrient concentrations for the Tipp City Project were downloaded from the GitHub repository and replaced concentrations BDL with 1/2BDL. Detection limits are as follows: SRP 0.03, TP 0.1, NO_x AQ1 0.06, NO_x AQ300 0.04, TN 0.25, NH₄-N latchet 0.001, NH₄-N AQ1 0.02, NH₄-N AQ300 0.01. Seasonal nutrient concentrations were calculated for Upstream Great Miami River and the wetland pool (combining sampling locations #2 Wetland Near Inflow and #3 Mid Wetland Near HOB0).

Hydrology

Continuous water level data recorded at 30-minute intervals was downloaded and processed in the Solinst (Solinst Canada Ltd.) software. Researchers calculated an average daily water depth using the data. From the average daily water depths, an average daily pool volume can be calculated using a bathymetry survey collected by the Miami Conservancy District (MCD) and U.S. Fish and Wildlife Service (USFWS) in February 2023 (Figure 360).

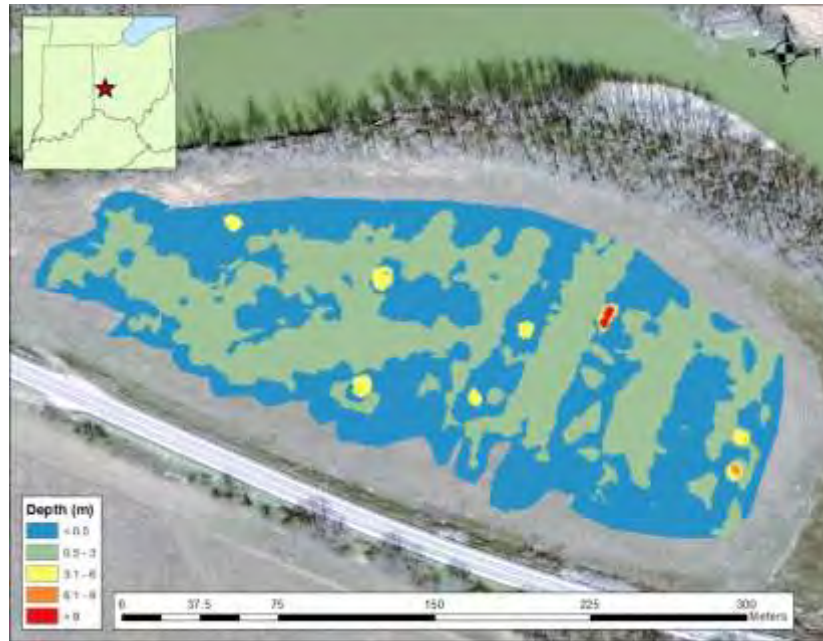


Figure 360. Bathymetry survey map of the Tipp City Off-Channel Wetlands collected by the Miami Conservancy District and U.S. Fish and Wildlife Service in February 2023.

The acreage of each “slice” (different depth areas designated by colors; Figure 360) were determined using Google Earth Pro. The blue and green slices cover 7 acres. The yellow slice covers 0.07 acres. The orange and red slices cover 0.03 acres. The yellow, orange, and red slices are permanently flooded. This is known because the water level logger is located in the green slice and is always in water. The volume of the slices were calculated as:

$$volume = acres * water\ depth * 325,852$$

Where volume is in gallons, water depth is in feet, and 325,852 is gallons in an acre-foot. Because the yellow, orange slices are permanently flooded, a volume of 577,411 gallons is added to the calculated volume of the blue and green slice.

A daily change in volume was calculated by subtracting the current days volume by the previous day. Positive daily change in volumes corresponds to inflow, and negative daily change in volumes corresponds to outflow. All of the positive daily changes in volumes can be summed to determine a seasonal inflow volume.

Nutrient Loads

Seasonal nutrient loads filtered were calculated as:

$$load\ retained = [(upstream\ concentration - wetland\ concentration) * 0.0022046 * volume] / [0.26417 * 1000]$$

Where load filtered is in pounds, concentrations are in mg/L, volume is in gallons, 1000 converts mg to g, 0.0022046 converts g to lbs., and 0.26417 converts L to gallons. The upstream concentration is a seasonal average of the Great Miami River concentrations. The wetland

concentration is a seasonal average of Wetland Near Inflow and Mid Wetland Near HOB concentrations.

Williamsburg Wetland

Overview

Researchers collect water quality samples at the Williamsburg Wetland on an event-driven basis³⁷. When the East Fork Little Miami River (EFLMR) stages up to an elevation exceeding the wetland inlet (or outlet), the river flows into the wetland. It is under this scenario (“inflow event”, or “event”) that water quality sampling is initiated (During Water Year (WY) 2024, researchers collected water quality samples during eight inflow events from January–May 2024 (Table 11). Researchers also collected wetland hydrology data for WY 2024. Hydrology data includes water level and velocity during and between inflow events. There is one month of missing reservoir water level data (March 2024) due to loss of and inability to recover the logger.

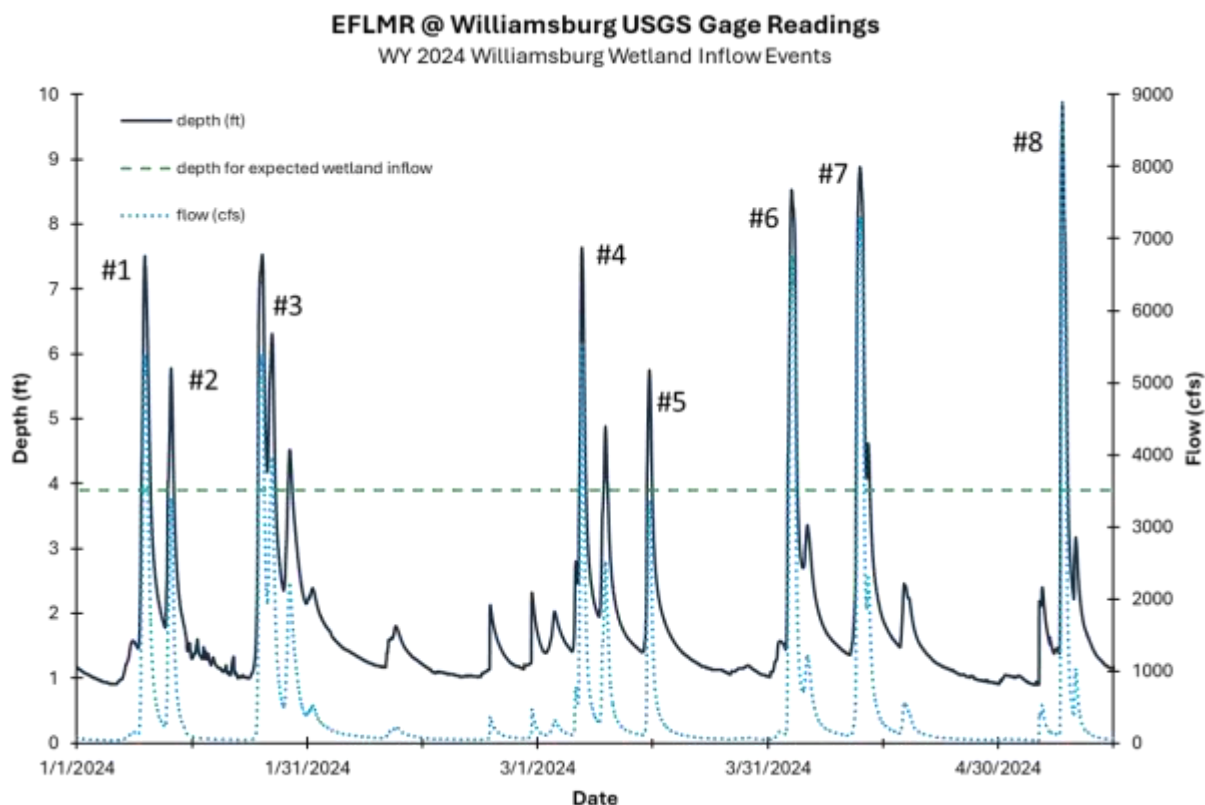


Figure 361. USGS gage (#03246500) data from January 1–May 15, 2024. The 8 storm events that resulted in wetland inflow are labeled #1–8. The green dashed line indicates the gage height

³⁷ U.S. EPA, U.S. Environmental Protection Agency, 2002. Urban Stormwater BMP Performance Monitoring: a Guidance Manual for Meeting the National Storm Water BMP Database Requirements.

(3.9 ft) at which wetland inflow is predicted. The flow during the rising limb for this gage depth is approximately 1700 cubic feet per second.

Table 11. Inflow event dates, cumulative on-site precipitation, and wetland input volume.

Event #	Start Date	End Date	Cumulative Precipitation (in.)	System Input Volume (cu ft)
1	1/9/2024	1/12/2024	1.4	2,937,376
2	1/12/2024	1/16/2024	0.66	663,142
3	1/23/2024	1/28/2024	1.78	5,079,163
4	3/5/2024	3/12/2024	1.18	2,254,008
5	3/14/2024	3/21/2024	0.65	510,084
6	4/2/2024	4/9/2024	1.38	5,405,657
7	4/11/2024	4/18/2024	2.06	6,050,982
8	5/7/2024	5/14/2024	2.81	7,749,371

Sampling Setup

Water quality samplers are located at five locations within the Project: wetland system inlet (SYSINL); reservoir inlet (RESINL); reservoir outlet (RESOUT); bypass channel (WBWBP); and system outlet (SYSOUT). Water level and velocity loggers are adjacent to sampler intakes, with two additional water level loggers located (1) in the attenuating wetland (reservoir), and (2) in the middle of the treatment wetland. Figure 362 illustrates wetland treatment zones and flow paths. There are also hydrographs, covering all eight inflow events, for rising limb and falling limb sampling sites, respectively (Figure 363, Figure 364).

Due to challenges with velocity measurements, constant-volume water quality samples were collected for all Water Year (WY) 2024 inflow events. In other words, flow-proportional water quality samples were infeasible for WY 2024, so constant-volume water quality samples were collected by level-driven, time-paced auto-sampling programs. Water quality samples were collected over two segments of every event hydrograph: rising limb and falling limb. With few exceptions, one composite sample per event was collected over the rising limb at SYSINL, WBWBP, RESINL (“rising limb”) sites. For RESOUT and SYSOUT (“falling limb”) sites, the number of composite samples ranged between 2–5 per inflow event.

An event mean concentration (EMC) for wetland influent and effluent were determined using the rising and falling limb composite samples, respectively. For rising limb sites, one composite sample was collected over the rising limb of the hydrograph. The influent EMC was determined as the direct concentration of the composite sample analyzed by the laboratory. For falling limb

sites, multiple composite samples were collected over different portions of the falling limb. Each of these composite samples were provided separately for lab analysis. The effluent EMC was calculated as the arithmetic average of all falling limb composite sample concentrations for each inflow event.

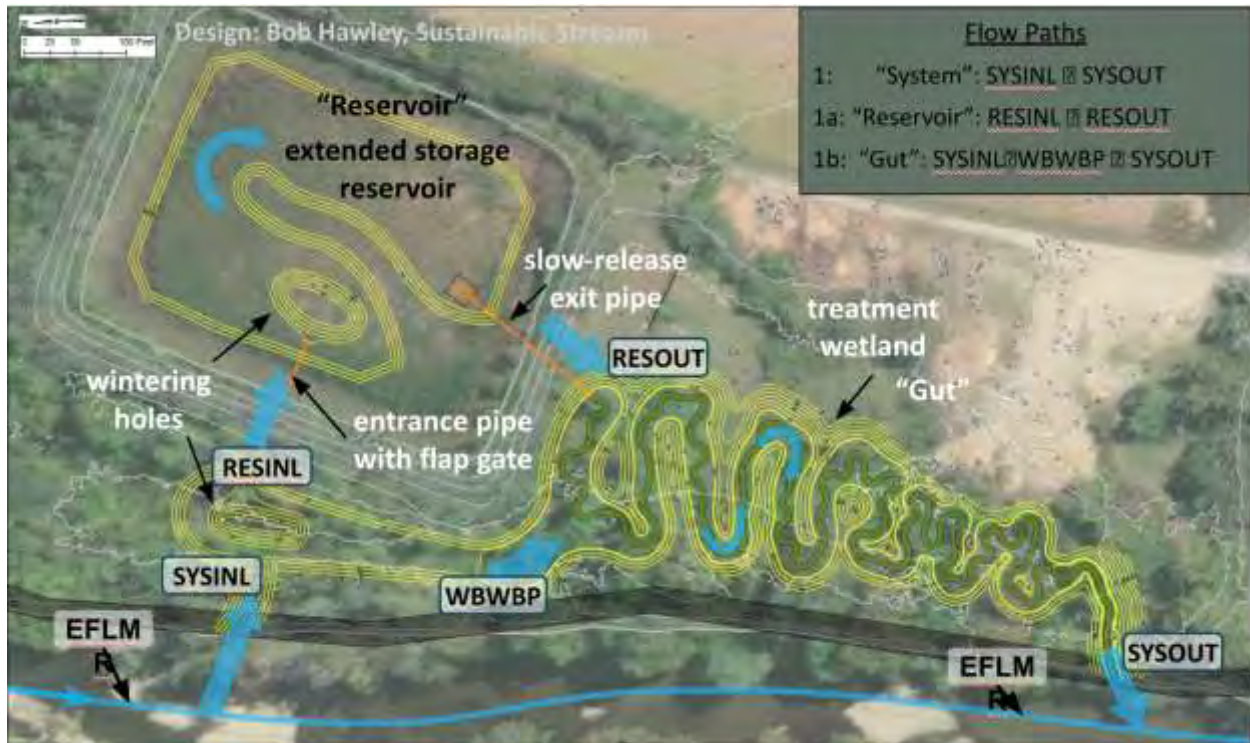


Figure 362. Wetland plan view showing the different flow paths and treatment zones (Reservoir and Gut).

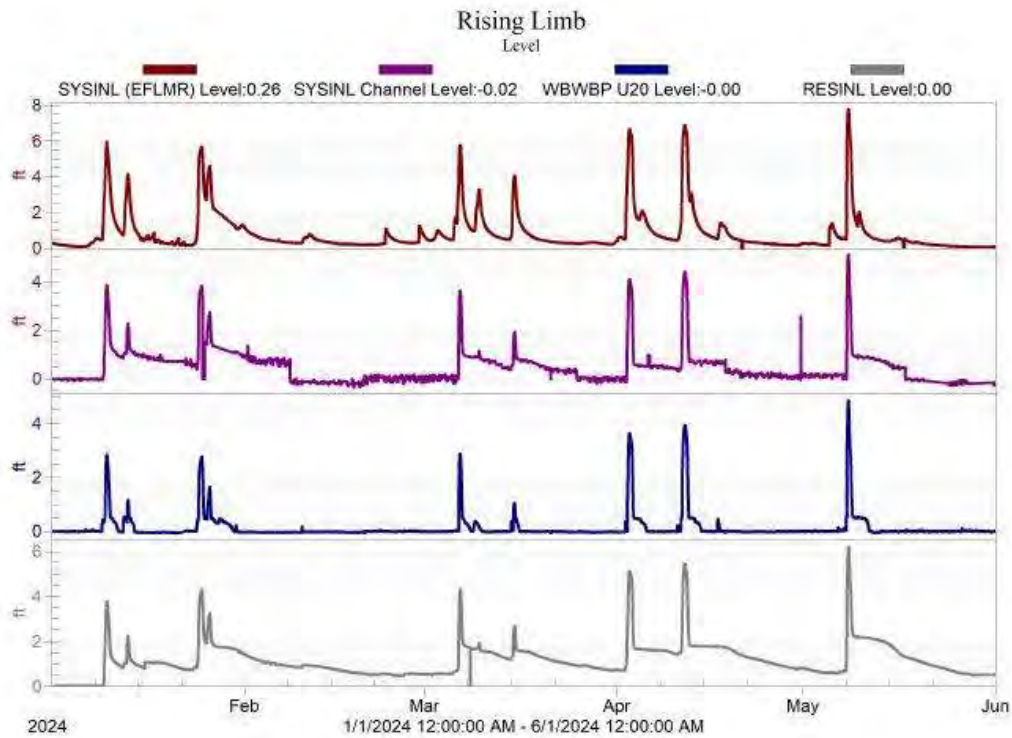


Figure 363. Wetland water level data for rising limb sampling sites covering the 8 inflow events for water year 2024. These 8 events occurred between January–May, 2024 and are labeled #1–8.

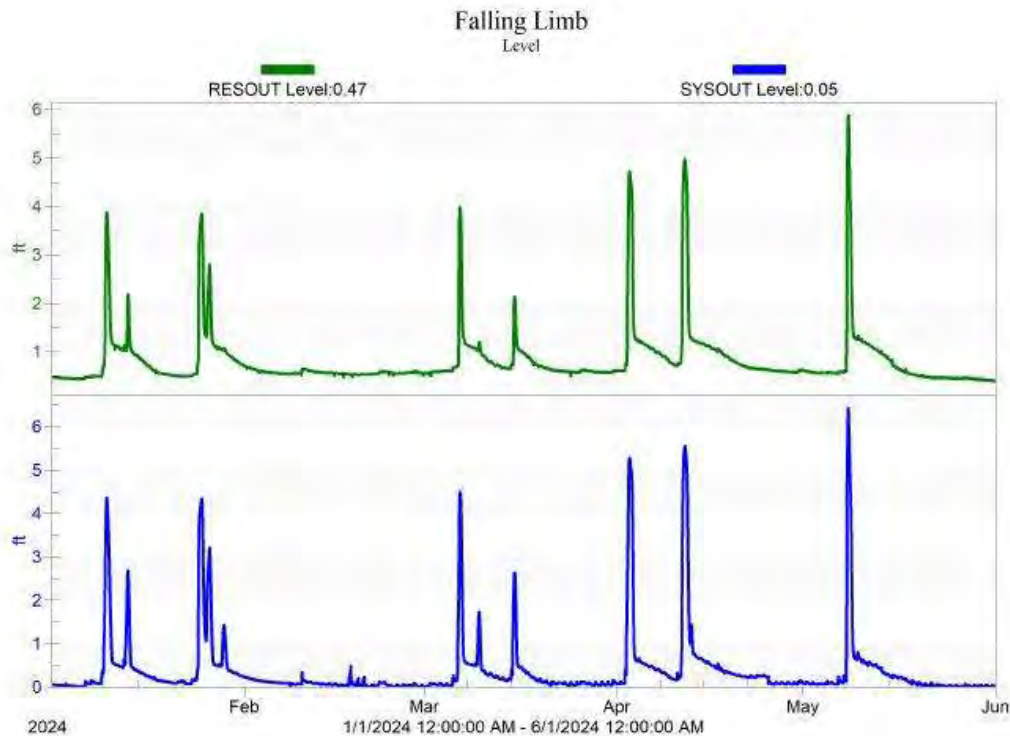


Figure 364. Wetland water level data for falling limb sampling sites covering the 8 inflow events for water year 2024. These 8 events occurred between January–May, 2024 and are labeled #1–8.

Nutrient and solids laboratory analytical methods

Two Ohio EPA-certified laboratories (Clermont County Wastewater Laboratory and Pace Analytical) analyzed water quality samples were analyzed for total suspended solids (TSS) and nutrients (TP, DRP, TKN, NO₂+NO₃, TON, TN). Laboratory methods and detection limits are listed in Table 2.

Nutrient load calculations

Stage-Storage Model

Due to the flow measurement challenges, researchers developed a stage-storage model to estimate wetland water treatment volumes. In February 2024, researchers used a UAS (drone) survey to collect RGB imagery of the wetland complex. Researchers post-processed the image data to generate a digital surface model (DSM) and imported the DSM into ArcGIS and down sampled the high-resolution DSM to a raster file of manageable and sufficient size for contour development in Civil 3D. Researchers then imported the raster file into Civil 3D as a surface. Then, researchers extracted contours from the surface and “trimmed” and “closed” them to

remove contours exceeding the wetland area of interest for stage-storage generation. Using the “stagestorage” command, researchers generated a stage storage report for the Reservoir and Gut (separately) and exported it as CSV .txt files.

Researchers copy/pasted the Civil 3D-generated text files into MS Excel spreadsheets. Due to an unresolved problem with the original UAS DSM file, wherein the elevation data appeared correct in ArcGIS but incorrect when imported into Civil 3D, researchers applied an elevation offset to the stage storage data in Excel and determined the offset of 115 ft by spot-checking multiple points between ArcGIS and Civil 3D. Researchers applied this offset in Excel, generating adjusted contour elevations. Next, researchers added additional 0.1 ft depth increments to increase resolution of the 1 ft stage-storage contours generated by Civil 3D. Researchers calculated areas and volumes for these additional incremental depths.

First, researchers estimated a pseudo radius for the Civil 3D-generated 1 ft contours by assuming a circular geometry of the contour area. Next, researchers calculated 0.1 ft incremental radii using linear interpolation between the calculated 1 ft radii. Researchers estimated areas using the calculated radii while assuming a circular contour geometry and calculated conic incremental volumes for all 0.1 ft contour increments. (Note: The difference between Civil 3D and manual calculations for cumulative conic volume ranges from 2% at the highest elevations to 47% difference at the lowest elevations for the Gut, and from 2% at the highest elevations to 51% difference at the lowest elevations for the Reservoir. The large difference at lower elevations is partially an artifact resulting from Civil 3D not calculating volumes when there are multiple contours per elevation, as is often the case in wetlands with uneven ground surfaces.) Finally, researchers implemented the stage storage relationships in Excel as lookup tables for monthly hydrology data.

Calculating Water Volumes for Inflow Events

Researchers analyzed monthly hydrology data (graphical and tabular) to identify the start, peak, and end of each inflow event. The stage-storage lookup table provided volumes for each of these three points on the hydrograph, e.g., initial, peak, and final volume.

Convert WQ Concentration and Volume to Load

Influent and effluent loads were calculated as follows¹ (p.18):

Influent Load = influent EMC*(peak vol.–initial vol.)

Effluent Load = effluent EMC*(peak vol.–final vol.).

Load reductions were calculated as follows:

Load reduction = influent load - effluent load

% Load reduction = 100 * (influent load - effluent load) / influent load.

In some cases, water quality sampling was discontinued prior to full drawdown of the wetland to the initial or normal pool water level. In these cases the final water level was selected to be consistent with the time of the final water quality sample. In some cases there were dual-peak

inflow events (second peak within 24 hours). In these cases the influent and effluent volumes were calculated for each peak and summed for a total influent and effluent volume for the dual-peak inflow event. Tables 3–6 contain wetland treatment results as calculated using the aforementioned methods.

Walnut Creek Treatment Wetland Restoration

The Walnut Creek Treatment Wetland Restoration Project (hereafter Walnut Creek Project) is a floodplain treatment train located along Walnut Creek constructed in spring 2023. Researchers have routinely collected water and soil samples since the completion of construction. Water level data has been continuously collected at the wetland outflow using a HOBO water level sensor. Researchers estimate that the Walnut Creek Project filtered 488 lbs. of total phosphorus (TP), 4,701 lbs. of total nitrogen (TN), 289 lbs. of dissolved reactive phosphorus (DRP), and 6,786 lbs. of nitrite+nitrate (NO_x). The Walnut Creek Project exported 13 lbs. of total ammonium nitrogen (NH₄-N).

Sampling Approach

Researchers collected water samples from several locations throughout the wetland. However, for nutrient load reduction calculation purposes, the only sampling locations that matter are the inflow (Walnut Creek) and the wetland outflow. Water level data has been continuously monitored at the wetland outflow since March 2023 to determine the volume of water leaving the wetland.

Nutrients

Researchers downloaded nutrient concentrations for the Walnut Creek Project were downloaded from the GitHub repository, replacing concentrations BDL with 1/2BDL. Detection limits are as follows: SRP 0.03, TP 0.1, NO_x AQ1 0.06, NO_x AQ300 0.04, TN 0.25, NH₄-N latchet 0.001, NH₄-N AQ1 0.02, NH₄-N AQ300 0.01. Researchers calculated average seasonal concentrations and applied those calculations over the season for the inflow using concentrations from Walnut Creek #1. Outflow concentrations were applied over a ~month period until the next sampling event using concentrations from Outflow pool #4.

Hydrology

Continuous water level data at the outflow is downloaded and processed using the HOBOWare pro software. Water level data is collected at 30-minute intervals, and an average daily depth is calculated from this data. The daily water depths are converted to volume using a simple flow over flat-weir equation:

$$\begin{aligned} \text{if } H \leq 0.27W, Q &= 3.19924(W - 0.74H)H^{1.48} \\ \text{if } H > 0.27W, Q &= 3.0318WH^{1.37} \end{aligned}$$

Where H is the height of water above the stop log in inches, W is the width of the weir (for Walnut Creek Project W=29.31), and Q is the flow rate in gallons per minute (GPM). Volumes

calculated using the equations above are then converted to gallons per day (GPM*60*24, GPD) and correspond to the total volume of water leaving the wetland.

Wetland outflow volumes for treatment trains are lower than inflow volumes due to evapotranspiration, water seeping into sediment, and vegetation uptake. Therefore, using the wetland outflow volumes for the wetland inflow volume would be an underestimate. Therefore, the Penman Monteith equation was used to calculate the average daily water volume lost to evapotranspiration. The equation is as follows:

$$ET_0 = \frac{0.408\Delta(R_n - G) + \gamma \frac{900}{T + 273} u_2 (e_s - e_a)}{\Delta + \gamma(1 + 0.34u_2)}$$

Where ET_0 reference evapotranspiration [mm day^{-1}], R_n net radiation at the crop surface [$\text{MJ m}^{-2} \text{ day}^{-1}$], G soil heat flux density [$\text{MJ m}^{-2} \text{ day}^{-1}$], T mean daily air temperature at 2 m height [$^{\circ}\text{C}$], u_2 wind speed at 2 m height [m s^{-1}], e_s saturation vapor pressure [kPa], e_a actual vapor pressure [kPa], $e_s - e_a$ saturation vapor pressure deficit [kPa], Δ slope vapor pressure curve [$\text{kPa } ^{\circ}\text{C}^{-1}$], γ psychrometric constant [$\text{kPa } ^{\circ}\text{C}^{-1}$]. Historical weather data was inserted to obtain a evapotranspiration rate in inches/day. Historical weather data was gathered from <https://www.wunderground.com/history> from the Fort Wayne International Airport (KFWA) weather station. Evapotranspiration rates were converted to average daily volumes lost to evapotranspiration as follows:

$$\text{Volume lost to Evapotranspiration (gallons)} = \frac{11.2 * 325,852 * ET_0}{12}$$

Where 5.5 is the wetland acreage, 325,852 is gallons in an acre-foot, and ET_0 the evapotranspiration rate in inches/day, and 12 is inches to feet. The volumes lost to evapotranspiration were then added to average daily wetland outflow volumes to obtain average daily wetland inflow volumes.

Nutrient Load

Daily nutrient inflow and outflow loads were calculated as:

$$\text{load} = [\text{concentration} * 0.0022046 * \text{volume}] / [0.26417 * 1000]$$

Where load filtered is in pounds, concentrations are in mg/L, volume is in gallons, 1000 converts mg to g, 0.0022046 converts g to lbs., and 0.26417 converts L to gallons. Daily loads filtered were then calculated as inflow load–outflow load, positive values indicative of loads filtered and negative values indicative of loads exported.