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An Evaluation of Soil Phosphorus Storage Capacity (SPSC) at Proposed Wetland Restoration Locations in the Western Lake Erie Basin

Jacob F. Berkowitz, Christine M. VanZomeran, Nia R. Hurst,
and Kristina J. Sebastian

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Abstract

Historical loss of wetlands coupled with excess phosphorus (P) loading at watershed scales have degraded water quality in portions of the western Lake Erie Basin (WLEB). In response, efforts are underway to restore wetlands and decrease P loading to surface waters. Because wetlands have a finite capacity to retain P, researchers have developed techniques to determine whether wetlands function as P sources or sinks. The following technical report evaluates the soil P storage capacity (SPSC) at locations under consideration for wetland restoration in collaboration with the Great Lakes Restoration Initiative (GLRI) and the H2Ohio initiative. Results indicate that the examined soils display a range of P retention capacities, reflecting historic land-use patterns and management regimes. However, the majority of study locations exhibited some capacity to sequester additional P. The analysis supports development of rankings and comparative analyses of areas within a specific land parcel, informing management through design, avoidance, removal, or remediation of potential legacy P sources. Additionally, the approaches described herein support relative comparisons between multiple potential wetland development properties. These results, in conjunction with other data sources, can be used to target, prioritize, justify, and improve decision-making for wetland management activities in the WLEB.

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Preface

This study was conducted for the USACE Buffalo District under MIPR W81EU602896379 under Project 478112-U4375451, “Great Lakes Restoration Initiative,” a non-point source technical support project administered through the Environmental Protection Agency and the United States Army Corps of Engineers (USACE) Buffalo District. The program administrator was Mr. Anthony Friona of USACE Buffalo District.

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1 Introduction

1.1 Background

Established in 2010, the Great Lakes Restoration Initiative (GLRI) works to protect and restore the largest system of fresh surface water in the world. To that end, the initiative seeks to address nonpoint source phosphorus (P)* pollution, which has been linked with degraded water quality in the Great Lakes (United States Environmental Protection Agency 2020; Baker et al. 2017; Maccoux et al. 2016). More recently, the H2Ohio initiative was established to reduce excess P loading to surface waters, restore and create wetlands, and undertake other actions to improve water quality in Ohio and Lake Erie. These two efforts represent innovative regional approaches to nutrient and natural resource management (United States Environmental Protection Agency 2020).

Both the GLRI and H2Ohio initiatives place particular emphasis on reducing P loading into the western Lake Erie Basin (WLEB), where poor water quality and repeated harmful algal bloom events negatively affect fisheries and waterfowl habitat, access to clean drinking water, recreation, and local economies (Figure 1). Within the region, excess P from agricultural, urban, and suburban areas induces eutrophication and degrades water quality. A variety of best management practices (BMPs) have been implemented on farms, at the edges of fields, and in urban and suburban areas to decrease nutrient runoff (Sharpley et al. 2006). However, excess nutrients persist and may be exacerbated by projected future climate conditions, requiring additional strategies to improve water quality in the western Lake Erie Basin and throughout the Great Lakes (Bosch et al. 2014). The restoration and creation of wetlands are rapidly emerging as a novel BMP designed to further reduce P export from target watersheds including those located in the Great Lakes region, while also providing benefits to the habitat, decreasing flood risk, improving water

*. For a full list of the spelled-out forms of the chemical elements used in this document, please refer to *US Government Publishing Office Style Manual*, 31st ed. (Washington, DC: US Government Publishing Office, 2016), 265, <https://www.govinfo.gov/content/pkg/GPO-STYLEMANUAL-2016/pdf/GPO-STYLEMANUAL-2016.pdf>.

quality, and providing opportunities for recreation and education (VanZomeran et al. 2019).

Constructed and restored wetlands have previously been used to capture particulate and dissolved P prior to surface water export in a variety of settings, including as engineered treatment wetlands, although they remain less common than other agricultural BMPs (for example, reduced tillage or grassed buffer strips) (Berkowitz et al. 2020). Wetlands reduce P through biotic (for example, vegetation) and abiotic (for example, particulate capture) processes. Long-term P retention is mediated by abiotic soil-P chemical interactions, in which P is retained by sorption onto clay particles, iron (Fe) and aluminum (Al) oxides and hydroxides, or soil organic materials (Kleinman et al. 2015). However, the long-term P retention capacity of soils is limited by the quantity and availability of sorption sites. If the available P storage capacity of a soil is surpassed, the soil can be converted from a P sink to either a flow-through system, in which P is neither sequestered nor lost, or a potential P source, in which P is exported from the system (VanZomeran et al. 2019).

The accumulation of high P concentrations in soils has been described as *legacy P*, in which long-term nutrient loading surpasses the capacity of a soil to retain additional P, and soil-bound P may become available for export to surface waters over time (Sharpley et al. 2013). The establishment and persistence of legacy P conditions can result in unintended P release and decrease or mute the effects of other nutrient-reduction BMPs. Therefore, understanding and quantifying the abundance and status of soil P sorption sites is essential when considering the development of wetlands as nutrient-reduction BMPs. In response, the following report evaluates soil P storage capacity (SPSC) at select locations in the western Lake Erie Basin.

Figure 1. Algal bloom in Lake Erie in 2011 (Michalaka et al. 2013, 2). Note the location of the Maumee River in the southwestern corner of the Lake Erie Basin. Michigan lies to the west, and Ohio lies to the south. The Canadian province of Ontario lies to the north.

1.2 Objective

The following report documents soil characteristics, including SPSC, at select locations in northwestern Ohio. This region is a critical area of concern for nutrient reduction to western Lake Erie, and the construction or restoration of wetlands can serve as a potential BMP to reduce P input to surface waters. However, additional research is required to evaluate soil-P interactions under BMP scenarios to avoid unintentional P release and identify candidate parcels for wetland BMP development. In response, this study investigated soil-P dynamics at multiple locations under consideration for wetland BMP implementation. The following data can help identify areas capable of retaining additional P, screen candidate parcels for soil P storage capacity, and provide a template to guide wetland restoration planning activities at local and regional scales.

1.3 Approach

This study reports SPSC data across multiple soil types in several northeast Ohio watersheds for the purpose of identifying potential locations for wetland BMP placement. Specifically, this report applies the

findings of two case studies to describe (1) background information on soil properties that relate to SPSC, (2) methods for determining SPSC, (3) data from case studies evaluating SPSC conducted in support of the GLRI (section 2) and H2Ohio initiatives (section 3), and (4) knowledge gaps and opportunities for additional research.

2 Evaluation of Soil P Storage Capacity (SPSC) in Maumee River Watershed for Wetland Best Management Practices (BMP) Development in Support of the Great Lakes Restoration Initiative (GLRI)

2.1 Background

The Maumee River watershed is a highly agricultural watershed of over 16,300 km² that drains into the WLEB.* As a GLRI priority area, the Maumee River watershed is the focus of several modeling efforts to address P loading into the WLEB (Scavia et al. 2017; Bosch et al. 2011). The Maumee River watershed is the largest P exporter to the WLEB, averaging 2,617 metric tons of P per year (Maccoux et al. 2016). Long-term trend analysis shows loads of both total P (TP) and dissolved reactive P (DRP) are increasing relative to levels measured in the 1990s, resulting in renewed efforts to reduce P inputs through additional BMP development, including wetlands designed for P retention (Stow, et al. 2015). In response, a screening effort was conducted to evaluate the SPSC at multiple candidate parcels in the watershed under consideration for wetland BMP implementation.

2.2 Methods

A collaborative effort between the US Army Corps of Engineers–Buffalo District, the US Army Engineer Research and Development Center (ERDC), and LimnoTech identified candidate parcels for wetland BMP development through a combination of soil and water assessment tool (SWAT) modeling approaches, geospatial analysis, and soil-map unit interpretation. Berkowitz, et al. (2020) provide details on the site selection and ranking approach. The analysis identified five potential wetland BMP development sites for evaluation of SPSC. The selected parcels were within the St. Marys River and Auglaize River watersheds, sub watersheds located

*. For a full list of the spelled-out forms of the units of measure used in this document, please refer to *US Government Publishing Office Style Manual*, 31st ed. (Washington, DC: US Government Publishing Office, 2016), 248–52, <https://www.govinfo.gov/content/pkg/GPO-STYLEMANUAL-2016/pdf/GPO-STYLEMANUAL-2016.pdf>.

in the southwest part of the Maumee River watershed (Figure 2) (appendix A).

Figure 2. Maumee watershed, with site locations identified by number. (1 mile = 1609.34 meters)*

Fifty-two soil samples were collected 6–8 August 2018 for analysis at the five candidate parcels. At each sample location, the top 0–5 cm of the surface soil was collected. A subsurface soil sample was also collected

*. For a full list of the unit conversions used in this document, please refer to *US Government Publishing Office Style Manual*, 31st ed. (Washington, DC: US Government Publishing Office, 2016), 345–7, <https://www.govinfo.gov/content/pkg/GPO-STYLEMANUAL-2016/pdf/GPO-STYLEMANUAL-2016.pdf>.

below the interface of the A/B or E/B horizons. This approach allowed for analysis of surface conditions within the zone of highest soil P (Baker et al. 2017) and subsoil conditions to inform subsequent P-optimal wetland project design. A P-optimal literature review was utilized to ensure the best analytical practices (Currie et al. 2017).

Soil samples were homogenized, dried at 30°C, and ground for water-soluble phosphorus (WSP) and Mehlich 1 extractions. WSP was determined by deionized water extraction for 1 h followed by filtration through a 0.45 µm membrane filter (Kuo 1996; Richardson and Reddy 2013). WSP was analyzed using a SEAL AQ2 Discrete Analyzer (SEAL Analytical, West Sussex, England; EPA-145-A Rev. 1). Method detection limits were 0.005 mgPL⁻¹ for WSP. Mehlich 1–extractable P, Fe, and Al were determined by Mehlich 1 soil solution (0.0125 mol L⁻¹ H₂SO₄ and 0.05 mol L⁻¹ HCl) extraction for five minutes followed by filtration through a Whatman No. 42 filter (Reddy et al. 2013; Mehlich 1984). Mehlich 1–extractable P, Fe, and Al were analyzed using a Seal AQ2 Automated Discrete Analyzer (SEAL Analytical, West Sussex, England; AGR-201-A Rev. 1, EPA-149-A Rev. 1, UKAS-509-A, respectively). Method detection limits were 0.015 mgPL⁻¹, 0.02 mg Fe L⁻¹, and 0.01 mg Al L⁻¹.

The SPSC and P saturation ratio (PSR) were determined using the following formulas (Nair et al. 2011), where the threshold PSR_{M1} of 0.10 was used according to Nair et al. (2004) and Dari et al. (2018):

$$SPSC(mg\ kg^{-1}) = (Threshold\ PSR_{M1} - Soil\ PSR_{M1}) \left(\frac{[Mehlich\ 1\ Fe]}{56} + \frac{[Mehlich\ 1\ Al]}{27} \right) 31, \quad (1)$$

where the *PSR* is calculated as the molar ratio of Mehlich 1–extractable P to Mehlich 1–extractable Fe and Al:

$$PSR_{M1} = \frac{\left(\frac{[Mehlich\ 1\ P]}{31} \right)}{\left(\frac{[Mehlich\ 1\ Fe]}{56} + \frac{[Mehlich\ 1\ Al]}{27} \right)}. \quad (2)$$

Statistical analysis applied Analysis of Variance (ANOVA) where assumptions of normality (Shapiro and Wilk 1965) and homogeneity of variance (Oklin 1960) were met. Data were square-root or log transformed as needed to meet model assumptions. Post hoc testing used the Tukey

test. The nonparametric Kruskal-Wallis test evaluated differences between factors when data failed to meet model assumptions (Dunn 1964). All statistics were evaluated using SPSS version 20.0 (IBM).

2.3 Results and discussion

2.3.1 Soil P storage dynamics

Soil sampling locations within each potential constructed wetland location were selected according to the dominant soil series. Soils map units included the Roselms, Paulding, Saranac, Blount, Del Ray, Pewamo, and Shoals series (Table A-1). Drainage classes for these soils ranged from somewhat poorly drained to very poorly drained. Basic hydric descriptions were completed at each sample location according to the guidance provided in Vasilas and Berkowitz (2016) and US Army Corps of Engineers (2010). The soils examined met one or more field indicators of hydric soils, except for sample location #37 and two sites within sample area #52, where extensive plowing or soil disturbance and fill material were observed, and hydric soil indicators were absent. Commonly observed hydric soils indicators included F3—Depleted Matrix, F6—Redox Dark Surface, and A11—Depleted Below Dark Surface. Notably, the current wetland status of the parcels was not evaluated, and some sample locations may lack wetland hydrology or hydrophytic vegetation because of historical and ongoing agricultural activities (for example, drainage, plowing) (Vasilas, Hurt, and Berkowitz 2018).

Examining the soil data, WSP (a relative measure of potential P release) was higher in the surface soils (mean $\pm$ standard error = 8.9 ± 5 mgPL⁻¹) than in the subsurface soils (1.4 ± 0.3 mgPL⁻¹, $p < 0.001$, Figure 3). The full soil analysis data set is available in appendix C. Although slightly higher in some locations, these WSP values are similar to reported values in upland soils under plant and animal production systems, where WSP ranged from 0.2 to 5.0 mgPL⁻¹ (Dari et al. 2018). Two locations had exceptionally high WSP in the surface soil (13 mgPL⁻¹ and 130 mgPL⁻¹, sample sites #52-4 and #36-5, respectively). Higher WSP values indicate more P is available to desorb from surface soils and become a potential source of P to downstream waters. As a result, data suggest that the surface soils contain more P on soil-exchange sites than subsoils and are more likely to represent a potential P source. The vertical stratification of soil P within the upper 5 cm has been previously reported in the

midwestern United States (Baker et al. 2017), and the accumulation of surface soil P was not unexpected.

Figure 3. Comparison of mean soil parameters in surface and subsurface soils. Note that surface soils exhibited higher water-soluble phosphorus (WSP) and P saturation ratios (PSR) while displaying lower soil P storage capacity (SPSC) (denoted here as *capacity factor*). Error bars represent one standard error of the mean.

The PSR varied from 0.006 to 0.766 in the surface soil (0.23 ± 0.06) and 0.003 to 0.288 in the subsurface (0.046 ± 0.01). Phosphorus sorption ratio values were higher in subsurface soils than in surface horizons ($p < 0.001$), suggesting subsoils have more available P sorption sites than surface soils. These PSR values are similar to reported values in Dari et al. (2018) except for one soil in sample area #36 that had an elevated PSR of 1.5. Capacity factors also differed between sample depths, with surface soils displaying more negative SPSC values ($-34 \pm 31 \text{ mgPkg}^{-1}$) than subsurface results ($11 \pm 3.6 \text{ mgPkg}^{-1}$; $p < 0.001$). Higher PSR and lower

SPSC values in surface soils provide further evidence of vertical stratification of accumulated P at the surface (Baker et al. 2017), suggesting some surface soil removal or remediation may be warranted during P-optimal wetland project design and implementation to increase soil P retention capacity.

A PSR of 0.1 has been identified as a critical threshold to differentiate between potential P sinks and P sources (Nair et al. 2004). Within the current data set, soils with PSRs > 0.1 displayed higher WSP on average ($12 \pm 7.3 \text{ mgPL}^{-1}$) than samples with PSRs < 0.1 ($1.2 \pm 0.3 \text{ mgPL}^{-1}$; $p < 0.001$). The critical threshold PSR also differed between SPSCs, with PSRs < 0.1 displaying higher sorption capacity ($15 \pm 3 \text{ mgPkg}^{-1}$) than soils with PSRs > 0.1 ($-64 \pm 44 \text{ mgPkg}^{-1}$; $p < 0.001$), which had lower sorption capacities. As reported in other studies, WSP was also closely related to SPSC, where WSP increased when SPSC was below zero (figure 4) (Dari et al. 2018; Nair et al. 2004). These findings provide further evidence that accounting for SPSC remains a critical factor when evaluating potential P-optimal wetland project locations.

Figure 4. Relationship between WSP and SPSC (denoted as *capacity factor*). Note that WSP generally remains low at SPSC > 0.0 (orange triangles) and increases below SPSC = 0.0 (green circles). This relationship suggests that more P may be available for off-site transport when SPSC is reduced, and additional P will likely be retained in soils with higher SPSC values. Two high WSP outliers (12.62 and 130.06 mg P/L) were removed to improve the figure scale.

An analysis of soil series data was conducted to evaluate the potential to utilize soil map units to predict soil P storage dynamics. Soil series and geological history can be found in appendix A and soil series descriptions in appendix D. Land use for each sample is located in Table B-1.

Examining the extractable Fe and Al data, no clear pattern differentiates soil P sorption components by sample depth (that is, Fe and Al are not consistently higher or lower in subsoils versus surface soils across soil types). Similarly, significant variability was found in the WSP and SPSC data across the soil series sampled (Figure 5).

Despite the lack of clear correlation between soil series data and the results presented herein, each of the soil series examined displayed some capacity to retain additional P in one or both horizons. These findings suggest that soil series may provide a tool to aid in preliminary site evaluations, which can be supported through additional site-specific investigations of soil conditions. For example, Blount silt loam and

Pewamo silt clay loam occupy >50% of a 100,000 ac area in Auglaize County, Ohio. The Blount series appears to exhibit less WSP and more P storage capacity than the Pewamo series in the current data set. Notably, soil-P dynamics depend on land-use history, fertilizer application patterns, farming practices, and other factors. As a result, additional site-specific and regional soils analysis will be required to link soil series mapping information with SPSC across large spatial scales, and a larger data set may prove more useful for evaluating the utility of soil survey data to predict soil-P dynamics.

Figure 5. Relationship between soil series and soil-P dynamics (WSP and SPSC values). Note that, although there is considerable variability in the data, the majority of common soil series in the region displayed some capacity to retain additional P. However, P sorption dynamics vary according to site conditions and land-use history.

2.3.2 Prioritizing candidate parcels for wetland BMP development

Examining soil conditions at the five priority wetland properties yielded a variety of outcomes, with important implications for wetland BMP design and implementation. Notably, site #21 exhibited PSR values < 0.1 and positive SPSC in all soils examined, including both surface and subsurface

soils. As a result, site #21 displayed the capacity to retain P across all sampled areas (Figure 6), suggesting development of a wetland BMP at that location could be accomplished without soil remediation or soil removal. Note that, while all areas displayed positive SPSC, the magnitude of study results varied between locations (range = 0.02–45.4 mgPkg⁻¹).

Figure 6. SPSC in surface and subsurface soils at sample location numbers 37, 52, 36, 30, and 21. The green plus signs represent SPSC values > 2 mgPkg⁻¹, the yellow triangles represent SPSC between 2 and 0 mgPkg⁻¹, and the orange circles represents < 0.0 mgPkg⁻¹.

Site #36 displayed moderate capacity to retain P, with two of the five surface soils and four of the five subsurface soils containing positive P sorption capacity (Figure 6). However, one surface soil (#36-5) was particularly saturated with P (-773 mgPkg^{-1}), representing the highest value observed within the data set. These findings suggest that some areas within site #36 should be avoided, or surface soils removed, prior to development of a wetland BMP designed for nutrient retention.

All surface soils in location #30, and a subset of those in location #52, contained negative sorption SPSC, suggesting a potential source of P. Conversely, the majority of subsurface soils at these two sample locations contained positive sorption SPSC and the capacity for additional P retention. As a result, some surface soils in these locations may require removal or remediation prior to wetland BMP project implementation, whereas most subsurface soils would likely be suitable for further site development.

- Site #37 exhibited evidence of soil disturbance and historic placement of fill materials, especially in the western portion of the project area. As a result, only two locations were selected for on-site evaluation (Figure 6). Results suggest limited P sorption capacity exists within subsoils, while surface soils varied between potential P sinks and sources. If additional investigation of site #37 is conducted, the eastern portions of the study area are recommended because of the absence of fill materials.

2.4 Summary and recommendations

The SPSC results varied across the five locations examined, with positive, negative, and near-zero values observed. In general, surface soils displayed lower remaining capacity to retain P, in agreement with observed vertical stratification of soil P reported in other studies (VanZomeren, et al. 2019; Nair, et al. 2004). However, each location contained some soils with additional P storage capacity. This variable capacity highlights the need to incorporate on-site measures of soil conditions during wetland BMP site selection and design. The soils investigated at site #21 were the only property with $\text{PSR} < 0.1$ and positive SPSC in both the surface and subsurface soils, displaying the highest potential P sorption capacity across a broad geographic area. Additionally, site #21 displayed several of the highest P retention capacities observed, with several locations exhibiting $\text{SPSC} > 45 \text{ mgPkg}^{-1}$. As a result of these findings, conducted in concert with

other analyses, a pilot project is currently underway to design and construct a P-reduction wetland BMP in the vicinity of study location #21.

Notably, the presence of low SPSC values at a subset of the other candidate parcels should not preclude those areas for consideration as wetland BMP development sites. Management considerations, including design location and construction techniques, may be necessary at locations #30, #36, #37, and #52 to avoid unintentional P release and maximize P retention. Specific management actions may include avoidance of problematic areas, such as the sample point in the northeastern portion of site #36, which is particularly saturated with P (-773 mgPkg^{-1}). Alternatively, the application of soil amendments in areas with soils containing near-zero or negative SPSC can increase P storage capacity, although more research is needed to fully investigate the effects of amendments on soil-P dynamics.

The combination of the off-site approaches used to identify candidate parcels in conjunction with the on-site approaches outlined herein proved effective in assessing locations for wetland BMP development potential. The linkage between ground-based, remote-sensing, and modeling techniques will require additional coupling to address large, basin-scale initiatives underway through the GLRI program (Berkowitz, et al. 2020).

An analysis of soil series data was conducted to evaluate the potential to utilize soil map units to predict soil P storage dynamics. Soil series and geological history can be found in appendix A and soil series descriptions in appendix D. Land use for each sample is located in Table B-1. Examining the extractable Fe and Al data, no clear pattern differentiates soil P sorption components by sample depth (that is, Fe and Al are not consistently higher or lower in subsoils versus surface soils across soil types). Similarly, significant variability was found in the WSP and SPSC data across the soil series sampled (Figure 5).

Despite the lack of clear correlation between soil series data and the results presented herein, each of the soil series examined displayed some capacity to retain additional P in one or both horizons. These findings suggest that soil series may provide a tool to aid in preliminary site evaluations, which can be supported through additional, site-specific investigations of soil conditions. For example, Blount silt loam and Pewamo silt clay loam occupy >50% of a 100,000-acre area in Auglaize County, Ohio. The Blount series appears to exhibit less WSP and more P

storage capacity than the Pewamo series in the current data set. Notably, soil-P dynamics depend on land-use history, fertilizer application patterns, farming practices, and other factors. As a result, additional site-specific and regional soils analysis will be required to link soil series mapping information with SPSC across large spatial scales, and a larger data set may prove more useful for evaluating the utility of soil survey data to predict soil-P dynamics.

2.4.1 Prioritizing candidate parcels for wetland BMP development

Examining soil conditions at the five priority wetland properties yielded a variety of outcomes, with important implications for wetland BMP design and implementation. Notably, site #21 exhibited PSR values < 0.1 and positive SPSC in all soils examined, including both surface and subsurface soils. As a result, site #21 displayed the capacity to retain P across all sampled areas (Figure 6), suggesting development of a wetland BMP at that location could be accomplished without soil remediation or soil removal. Note that, while all areas displayed positive SPSC, the magnitude of study results varied between locations (range = $0.02\text{--}45.4\text{ mgPkg}^{-1}$).

3 Evaluation of SPSC for Wetland BMP Development in Support of the H2Ohio Initiative

3.1 Background

Recent interest has focused on the restoration of wetlands throughout the state of Ohio as part of the H2Ohio initiative. These efforts include development of wetland restoration sites to decrease P concentrations entering surface waters while improving habitat and providing other ecosystem functions and values. Of particular interest is the re-establishment of historic hydro patterns, fish passages, and functionality of coastal wetlands disconnected from Lake Erie by a series of dikes and other structures. Additionally, the restoration of historic floodplain wetlands previously converted to agricultural uses has the capacity to improve water quality in inland locations. In response, this study investigated the SPSC of both coastal and floodplain wetlands in select locations within the Maumee, Cedar-Portage, and Sandusky watersheds in northwest Ohio.

3.2 Methods

Project partners from the Ohio Department of Natural Resources identified study locations according to accessibility and interest in developing wetland restoration projects designed to improve water quality at local and regional scales. This assessment resulted in the selection of eight locations for sampling and analysis (Figure 7). A total of 79 soil samples were collected during November 2019. Once each study location was identified, soil survey maps were used to stratify soil-sampling locations according to the distribution of soil series, focusing on the most widely distributed series mapped within each target parcel.

Figure 7. H2Ohio sample locations in northern Ohio. (1 mile = 1609.34 meters)

At each location, soil samples were collected from two to four soil horizons closest to the soil surface. This approach has also been used in other studies to account for the stratification of P in surface soil layers and inform the placement and design of wetland restoration projects (Baker et al. 2017). Soil samples were homogenized, dried at 30°C, and ground prior to analysis for WSP and Mehlich 3 extraction. Note that the Mehlich 3 extraction differs from the Mehlich 1 extraction used in the previous case study (section 2). The change in extraction methods was made in response to trends in soil nutrient analysis, which are increasingly applying the Mehlich 3 method because it may better reflect plant-available P than Mehlich 1 in many soils. Mehlich 3 is also becoming increasingly more common throughout the midwestern United States region and was selected to better align with these trends. As a result, the data presented in section 2 are not directly comparable to those presented herein.

As in the previous case study, WSP was determined by deionized water extraction for 1 h followed by filtration through a 0.45 µm membrane filter (Kuo 1996; Richardson and Reddy 2013). The WSP concentration analysis was performed using a SEAL AQ2 Automated Discrete Analyzer (SEAL Analytical, West Sussex, England; EPA-145-A Rev. 1). Method detection

limits were 0.005 mg PL^{-1} for WSP. Mehlich 3–extractable P, Fe, and Al were determined by Mehlich 3 soil solution ($0.2 \text{ M CH}_3\text{COOH} + 0.25 \text{ M NH}_4\text{NO}_3 + 0.015 \text{ M NH}_4\text{F} + 0.013 \text{ M HNO}_3 + 0.001 \text{ M EDTA}$) extraction for 5 min, followed by filtration through a $0.45 \mu\text{m}$ membrane filter (Mehlich 1984; Reddy 2013). Mehlich 3–extractable P was analyzed using a Seal AQ2 Automated Discrete Analyzer (SEAL Analyzer, West Sussex, England; AGR-201-A Rev. 1), with a method detection limit of 0.015 mg PL^{-1} . Mehlich 3–extractable Fe and Al were analyzed using combustion inductively coupled plasma-atomic emission spectroscopy (United States Environmental Protection Agency 1994).

The following equation was used to determine SPSC and PSR using the following generalized formulas described in Nair et al. (2011):

$$SPSC(\text{mg kg}^{-1}) = (\text{Threshold } PSR_{M3} - \text{Soil } PSR_{M3}) \left(\frac{[\text{Mehlich 3 Fe}]}{56} + \frac{[\text{Mehlich 3 Al}]}{27} \right) 31, (3)$$

where the PSR is calculated as the molar ratio of Mehlich 3–extractable P to Mehlich 3–extractable Fe and Al

$$PSR_{M3} = \frac{\left(\frac{[\text{Mehlich 3 P}]}{31} \right)}{\left(\frac{[\text{Mehlich 3 Fe}]}{56} + \frac{[\text{Mehlich 3 Al}]}{27} \right)}. \quad (4)$$

The current analysis applied a PSR critical threshold value of 0.01 on the basis of the interpretation of the data presented in Figure 8. This critical threshold was selected for three reasons: (1) WSP increased above the 0.01 threshold, (2) the threshold resulted in SPSC decreasing with increases in WSP, and (3) the threshold yielded negative SPSC values in a sample location exhibiting ongoing or recent agricultural production activities, thus adhering to expected results. Note that threshold PSR values vary with soil type and extractable Fe and Al concentrations, with other studies having used thresholds of 0.10, for example (Dari et al. 2018). However, many of those studies were based on acidic soils, which typically contain lower Al and Fe concentrations than those evaluated herein. Thus, the application of a 0.01 PSR threshold in the current report is designed to reflect the higher pH values of soils in the study area. The lower threshold values also reduce SPSC values, providing a conservative estimate of P storage potential while supporting relative comparisons across a broad range of study location

conditions (for example, coastal marshes, floodplains, forested areas, active agricultural fields, completed restoration projects).

Figure 8. Relationship between WSP and PSR_{M3} used to identify the critical threshold value of 0.01, above which increases in WSP are observed (left panel). Relationship between SPSC and WSP also followed expected patterns, as WSP increased when SPSC was below zero (right panel).

3.3 Results

The soils within the study locations are comprised of silty clay loam, silty clay, silt loam, and ground moraine from the Nappanee, Toledo, Rossburg, Mentor, Lenawee, Blount, Chagrin, and Shoal series (Soil Survey Staff 2020). The soils in the study area developed from lake deposits, Wisconsin (14,000–24,000 years old) ground moraine, wave-planed ground moraine, and ridge moraine geologic units (Larsen, Shrake, and Swinford 2005; Pavey et al. 2005; Venteris et al. 2008). In general, surface deposits consist of Wisconsin-aged silt, clay, or loam tills with varying amounts of carbonate. In some coastal locations, marl deposits were encountered, reflecting the influence of historic occurrences of epiphytic bacteria in shallow surface waters and lake fringes. Detailed information regarding the soil series, geologic substrates, and analytical soil testing results associated with each sample location can be found in Table C-2.

Site conditions, representative soil photos, and visualizations of SPSC concentrations are displayed in Figures 9–16. Study locations exhibited a range of SPSC values (–105 to 14.0 mgPkg^{–1}), which is not unexpected given the variety of landforms and land-use patterns included in the study.

Despite the observed variability in SPSC, seven of the eight study locations exhibited some capacity to adsorb additional P (that is, SPSC values $>0.0 \text{ mgPkg}^{-1}$). Additionally, it should be noted that the SPSC approach only considers soil surface adsorption processes, and all study sites are anticipated to sequester particulate P if surface waters are introduced with adequate holding times for sediment entrapment and settling.

As seen in other studies, SPSC values remained lower in surface soils (average $\pm$ standard error = $-9.2 \pm 4.2 \text{ mgPkg}^{-1}$) than in subsurface layers ($1.3 \pm 2.4 \text{ mgPkg}^{-1}$), and SPSC generally increased with soil horizon depth (full data set available in Table C-2). For example, 61% of surface soil samples exhibited near-zero or negative SPSC, compared to 43% of subsurface soils. Soil P stratification with depth is common, especially in operational and historically agricultural areas (Baker et al. 2017).

Results varied across landscape positions, with coastal soils generally exhibiting lower SPSC ($-0.70 \pm 1.2 \text{ mgPkg}^{-1}$) than inland, floodplain locations within the WLEB ($11.4 \pm 4.0 \text{ mgPkg}^{-1}$) (Table 1). This report represents one of the first studies to apply the SPSC approach to inland coastal marshes, and additional work will be required to contextualize results from coastal wetland systems in Ohio and elsewhere.

However, the results provide immediate utility for conducting relative comparisons between study locations and evaluating soil conditions within each study parcel. Coastal systems in the region have been subject to a variety of alterations, including direct and indirect nutrient inputs from agriculture and other sources (Heath 1992; Wang and Mitsch 1998). As a result, the lower SPSC values in those areas are not unexpected. Land use influenced SPSC, as observed with the values of $-20.2 \pm 7.1 \text{ mgPkg}^{-1}$ soil in active agricultural areas compared with other land cover categories (Table 2).

Table 1. Summary of SPSC (mgkg^{-1}) values at each study location. (SE = standard error).

Study location	Average SPSC $\pm$ SE	Range	Sample size	Landform	Watershed
Maumee Bay State Park	-7.3 ± 3.3	-54.6 to 1.2	10	Coastal	Portage
Ottawa National Wildlife Refuge	7.1 ± 1.3	0 to 14.3	11	Coastal	Portage
Standing Rush, LLC	1.3 ± 2.8	-20 to 11.3	16	Coastal	Sandusky
Oakwoods Nature Preserve	-39.6 ± 10.2	-105 to -11.1	14	Inland	Maumee
Wolf Creek	2.5 ± 3.4	-14.6 to 13.9	4	Inland	Sandusky
Fruth Outdoor Center	8.8 ± 2.2	2.9 to 12.5	10	Inland	Sandusky
Redhorse Bend	-0.7 ± 3.6	-11 to 6.1	10	Inland	Sandusky
Hecks Bridge	2.1 ± 3.8	-28.2 to 14.7	4	Inland	Sandusky

Table 2. Mean SPSC values (mgkg^{-1}) within each land use observed in the study. (SE = standard error; n = number of samples.)

Land use	SPSC	SE	n
Active agriculture	-20.2	7.1	20
Emergent wetland	-4.8	6.0	4
Forested marsh	-1.5	4.0	6
Emergent marsh	-0.5	2.2	31
Forested wetland	5.9	1.8	14
Recreational field	7.6	3.6	4

Figure 9. Standing Rush site conditions, sample locations, soil map units, and SPSC. The green plus sign represents SPSC values $>2 \text{ mgPkg}^{-1}$, the yellow triangles represent SPSC between 2.0 and 0.0 mgPkg^{-1} , and the orange circles represent $<0.0 \text{ mgPkg}^{-1}$ in surface and subsurface samples.

Figure 10. Maumee Bay State Park site conditions, sample locations, soil map units, and SPSC. The green plus sign represents SPSC values $>2 \text{ mgPkg}^{-1}$, and the orange circles represent $<0.0 \text{ mgPkg}^{-1}$ in surface and subsurface samples.

Figure 11. Ottawa National Wildlife Refuge site conditions, sample locations, soil map units, and SPSC. The green plus signs represent SPSC values $>2 \text{ mgPkg}^{-1}$, and the orange circle represents $<0.0 \text{ mgPkg}^{-1}$ in surface and subsurface samples.

Figure 12. Redhorse Bend site conditions, sample locations, soil map units, and SPSC. The orange circles represent $<0.0 \text{ mgPkg}^{-1}$ in surface and subsurface samples.

Figure 13. Fruth Outdoor Center site conditions, sample locations, soil map units, and SPSC. The green plus signs represent SPSC values $>2 \text{ mgPkg}^{-1}$, the yellow triangle represents SPSC between 2.0 and 0.0 mgPkg^{-1} , and the orange circles represent $<0.0 \text{ mgPkg}^{-1}$ in surface and subsurface samples.

Figure 14. Hecks Bridge site conditions, sample locations, soil map units, and SPSC. The green plus signs represent SPSC values $>2 \text{ mgPkg}^{-1}$ in surface and subsurface samples.

Figure 15. Wolf Creek site conditions, sample locations, soil map units, and SPSC. The green plus sign represents SPSC values $>2 \text{ mgPkg}^{-1}$, the yellow triangles represent SPSC between 2.0 and 0.0 mgPkg^{-1} , and the orange circle represents $<0.0 \text{ mgPkg}^{-1}$ in surface and subsurface samples.

Figure 16. Oakwoods Nature Preserve site conditions, sample locations, soil map units, and SPSC. The green plus signs represent SPSC values $>2 \text{ mgPkg}^{-1}$, and the orange circles represent $<0.0 \text{ mgPkg}^{-1}$ in surface and subsurface samples.

These results support relative comparisons that can be applied to evaluate P sorption potentials within a single parcel or at regional scales. For example, within the Maumee Bay State Park data set, SPSC values were higher in the eastern portion of the study area (Figure 10) than in other areas. This difference suggests that additional P sorption would be expected in the

eastern portion if P-rich waters were introduced into the marsh. Results can also guide the design of future restoration or management activities within a single parcel. For example, four of the five soil locations examined at Maumee Bay State Park exhibited positive SPSC values in the subsoil horizons, while three of five surface soils yielded negative SPSC values. This analysis helps to identify areas where avoidance, removal, or amendment of select soil layers could increase the P storage capacity in the study area. Examining the Fruth Outdoor Center data (Figure 13) highlights this approach. Negative SPSC values were identified in the vicinity of the existing restored emergent wetland (data points 48–49, 51), and positive SPSC values occurred within the recreation field (data points 53, 54–55). These positive values suggest that the recreation field represents an opportunity for additional wetland restoration implementation within that parcel—especially if the surface soils near data point 52 can be excavated and removed during project construction.

The results of this study can also help rank potential wetland restoration projects to maximize water-quality benefits. For example, the Redhorse Bend location exhibited negative SPSC in all samples, while the Heck's Bridge site displayed positive SPSC in all samples (Figure 12 and Figure 14, respectively). These data suggest that wetland development projects conducted at Heck's Bridge have a higher likelihood of adsorbing additional P while minimizing the risk of P release. Similarly, the Ottawa National Wildlife Refuge displayed higher SPSC values than the Standing Rush marsh, helping to further refine and prioritize management plans along the coast of Lake Erie. Additional research may be required for the Standing Rush marsh because of the unique historical occurrence of epiphytic bacteria and accumulation of marl, resulting in soil processes that limit Fe and Al accumulation.

Soil series information has been applied in a variety of contexts to extrapolate study results to broader spatial scales. The current analysis suggests that land use provides a better predictor of SPSC than soil series. For example, variances of the Toledo series occurred at four of the eight sample locations and yielded a wide range of SPSC values (-92.3 to 14.3 mgPkg^{-1}), with the lowest values (<-32.4 mgPkg^{-1}) occurring in active agricultural areas. However, as the availability of SPSC data in the region grows, an analysis of soil survey information may prove beneficial using larger data sets than currently available.

3.4 Summary and recommendations

The SPSC approach, while providing informative data, is not designed to be the sole basis for evaluation of potential wetland development and restoration sites. The SPSC method has proven useful for evaluating soil P sorption dynamics, is relatively expedient and inexpensive, and can be applied in multiple capacities (for example, survey of potential project areas, identify areas for avoidance or remediation). However, the SPSC approach does not account for particulate P fate and transport, surface-water residence times, P loading rates within a given project area, or a variety of other factors related to wetland P-reduction strategies. As such, the results presented herein should be used to supplement other data streams and should not be the only characteristic considered when making determinations.

4 Conclusions

Soils within the study areas exhibited a range of SPSC, reflecting the ability of wetlands to operate as potential P sinks or sources in response to landscape position and land-use history. The majority of study locations exhibited some capacity to sequester additional P through soil adsorption. Additionally, the analysis supports development of rankings and comparative analysis within a specific parcel, informing management through design, avoidance, removal, or remediation of potential legacy P sources. The data herein support relative comparisons between potential wetland BMP development properties. These results, in conjunction with other data sources, can be used to target, prioritize, justify, and improve decision-making for wetland management activities. More research will be required to (1) fully understand the implications of the SPSC approach across soil types, including coastal wetlands, which have not received adequate attention; (2) develop better relationships or models linking field results with predictors of SPSC, including soil series and land-use characteristics; (3) build regional inventories of SPSC to extrapolate results to larger spatial scales; and (4) further incorporate soil testing into the large water-quality improvement initiatives such as GLRI and the H2Ohio program.

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Appendix A: Soil Series and Geologic Data

Soil Series Abbreviations, (% slopes):

- Pa = Paulding clay, 0%–1%
- RsA = Roselms silty clay, 0%–3%
- Pt = Pits, quarry
- SaS3AF = Saranac-Spencerville silty clay loams, 0%–1%, frequently flooded
- Gn = Genesee silt loam, 0%–2%, occasionally flooded
- DeA = Del Rey silt loam, till substratum, 0%–3%
- TpA = Toledo silty clay, 0%–1%, flooded
- NpA = Nappanee silty clay loam, 0%–3%
- To = Toledo silty clay, 0%–1%
- Tp = Toledo silty clay, 0%–1%, flooded
- Rs = Rossburg silt loam, occasionally flooded
- MeB = Mentor silt loam, 1%–4%
- Le = Lenawee silty clay loam, 0%–1%
- Blg1A1 = Blount silt loam, ground moraine, 1%–2%
- Ch = Chagrin silt loam, occasionally flooded
- Sh = Shoals silt loam, 0%–2%, frequently flooded
- PmA = Pewamo silty clay loam, 0%–1%

Geology Descriptions:

- Da = Antrim Shale
- Sl = Lockport Dolomite
- Oc = Cincinnati group
- O = Organic Deposits, Holocene-Age
- a = Alluvium, Holocene-Age
- C = Clay, generally Wisconsinan-age
- L = Silt generally, Wisconsinan-age
- T = Till, undifferentiated in subsurface, unspecified age
- TF = Silty clay till, high carbonate content, Wisconsinan-age
- SG = Sand and Gravel, generally Wisconsinan-age
- D = Dolomite
- () = patchy, discontinuous
- - = The number preceding is the thickest point and will thin out to the adjacent contour, unless there is not one, which would mean that it thins out until the edge of the labeled contour.

- Numbers = Average thickness of layer (number $\times$ 10 ft); for example, 4 is 40 ft, and 13 is 130 ft. No number generally assumes 10 ft average thickness.

Table A-1. Soil series and surficial geology classification.
(Soil Survey Staff 2020; Pavay, et al. 2005; Venteris, et al. 2008; Larsen, Shrake and Swinford 2005; Slucher, et al. 2006.)

Site name	Sample	Soil series	Geology
City of Defiance	21-1	Pa	Da
City of Defiance	21-2	Pa	Da
City of Defiance	21-3	RsA	Da
City of Defiance	21-4	Pa	Da
City of Defiance	21-5	RsA	Da
City of St. Marys	30-3	Blg1A1	Sl
City of St. Marys	30-4	Pt	Sl
City of St. Marys	30-5	SaS3AF	Sl
City of St. Marys	30-6	SaS3AF	Sl
Auglaize County	36-1	Pt	Sl
Auglaize County	36-2	Blg1A1	Sl
Auglaize County	36-3	Blg1A1	Sl
Auglaize County	36-4	Pt	Sl
Auglaize County	36-5	Pt	Sl
City of St. Marys	37-1	Pt	Oc
City of St. Marys	37-4	Sh	Oc
Private Owner St. Marys	52-1	Sh	Oc
Private Owner St. Marys	52-2	Sh	Oc
Private Owner St. Marys	52-3	Blg1A1	Oc
Private Owner St. Marys	52-4	Gn	Oc
Private Owner St. Marys	52-5	Blg1A1	Oc
Private Owner St. Marys	52-6	Pt	Oc
Private Owner St. Marys	52-7	Pt	Oc
Private Owner St. Marys	52-8	DeA	Oc
Private Owner St. Marys	52-9	DeA	Oc
Standing Rush, LLC	1 to 2	Water	(O)/C2/L2/T2/D or sand gravel pit
Standing Rush, LLC	3 to 6	NpA	T2/D
Standing Rush, LLC	7 to 16	TpA	(O)/C2/L2/T2/D or sand gravel pit
Maumee Bay State Park	17 to 26	To	C/TF13/D
Ottawa National Wildlife Refuge	27 to 37	Tp	O/TF4/D

Site name	Sample	Soil series	Geology
Redhorse Bend	38 to 39	Tp	a/(L)/T4-/(SG)/D
Redhorse Bend	40 to 43	Rs	a/(L)/T4-/(SG)/D
Redhorse Bend	44 to 47	MeB	a/(L)/T4-/(SG)/D
Fruth Outdoor Center	48 to 49	Le	(LC)/T5/D
Fruth Outdoor Center	50 to 53	Blg1A1	(LC)/T5/D
Fruth Outdoor Center	54 to 55	Le	(LC)/T5/D
Fruth Outdoor Center	56 to 57	Blg1A1	(LC)/T5/D
Hecks Bridge	58 to 61	Ch	T16-/(SG2)/D
Wolf Creek	62 to 65	Rs	a/T/D
Oakwoods Nature Preserve	66 to 69	Blg1A1	T2/D
Oakwoods Nature Preserve	70 to 79	PmA	(T)/D

Table A-2. Sample watersheds.

Sample ID	County	Watershed
21	Auglaize	Maumee
30	St. Marys	Maumee
36	Auglaize	Maumee
37	St. Marys	Maumee
52	St. Marys	Maumee
Fruth Outdoor Center	Seneca	Sandusky
Hecks Bridge	Seneca	Sandusky
Maumee Bay state park	Lucas	Portage
Oakwoods Nature Preserve	Hancock	Maumee
Ottawa National Wildlife Refuge	Ottawa	Portage
Redhorse Bend	Sandusky	Sandusky
Standing Rush, LLC	Erie	Sandusky
Wolf Creek	Sandusky	Sandusky

Appendix B: Study Location Land Use

Table B-1. Land use (PO = private owner).

Site description	Sample	Land use
Auglaize County	36-1	Row crop
Auglaize County	36-2	Row crop
Auglaize County	36-3	Row crop
Auglaize County	36-4	Row crop
Auglaize County	36-5	Row crop
City of Defiance	21-1	Row crop
City of Defiance	21-2	Row crop
City of Defiance	21-3	Row crop
City of Defiance	21-4	Row crop
City of Defiance	21-5	Row crop
City of St. Marys	30-3	Row crop
City of St. Marys	30-4	Row crop
City of St. Marys	30-5	Row crop
City of St. Marys	30-6	Row crop
City of St. Marys	37-1	Grass
City of St. Marys	37-4	Grass
St. Marys (PO)	52-1	Row crop
St. Marys (PO)	52-2	Row crop
St. Marys (PO)	52-3	Row crop
St. Marys (PO)	52-4	Row crop
St. Marys (PO)	52-5	Row crop
St. Marys (PO)	52-6	Row crop
St. Marys (PO)	52-7	Row crop
St. Marys (PO)	52-8	Row crop
St. Marys (PO)	52-9	Row crop
Standing Rush, LLC	1	Marsh
Standing Rush, LLC	3	Marsh
Standing Rush, LLC	7	Marsh
Standing Rush, LLC	10	Marsh
Standing Rush, LLC	14	Marsh
Maumee Bay State Park	17	Forested marsh
Maumee Bay State Park	19	Forested marsh
Maumee Bay State Park	21	Forested marsh
Maumee Bay State Park	23	Marsh
Maumee Bay State Park	25	Marsh

Site description	Sample	Land use
Ottawa National Wildlife Refuge	27	Marsh
Ottawa National Wildlife Refuge	30	Marsh
Ottawa National Wildlife Refuge	33	Marsh
Ottawa National Wildlife Refuge	34	Marsh
Ottawa National Wildlife Refuge	36	Marsh
Redhorse Bend	38	Agricultural
Redhorse Bend	40	Agricultural
Redhorse Bend	42	Agricultural
Redhorse Bend	44	Agricultural
Redhorse Bend	46	Agricultural
Fruth Outdoor Center	48	Emergent wetland
Fruth Outdoor Center	50	Emergent wetland
Fruth Outdoor Center	52	Recreational field
Fruth Outdoor Center	54	Recreational field
Fruth Outdoor Center	56	Forested wetland
Hecks Bridge	58	Forested wetland
Hecks Bridge	60	Forested wetland
Wolf Creek	62	Forested wetland
Wolf Creek	64	Forested wetland
Oakwoods Nature Preserve	66	Agricultural
Oakwoods Nature Preserve	68	Forested wetland
Oakwoods Nature Preserve	70	Forested wetland
Oakwoods Nature Preserve	72	Agricultural
Oakwoods Nature Preserve	74	Agricultural
Oakwoods Nature Preserve	76	Agricultural
Oakwoods Nature Preserve	78	Agricultural

Appendix C: Soil Data Summary

Table C-1. Soil analytical data from section 2; all units are mgkg⁻¹ except PSR, which is unitless. (S= surface horizon, SS= subsurface horizon)

Sample	Soil horizon	Nutrients			Soil P saturation ratio (M1)	Capacity factor	Water-soluble P (mgP/kg)
		P	Fe	Al			
21-1	S	0.344	7.792	0.92	0.064063	0.193	0.96
21-1	SS1	0.732	2.36	153.41	0.004125	17.0131	0.98
21-2	S	1.744	3.812	30.604	0.046821	1.9808	1.57
21-2	SS1	1.34	59.708	378.36	0.002867	45.4066	0.22
21-3	S	2.74	55.572	367.08	0.006059	42.4825	0.21
21-3	SS1	1.452	61.528	358.8	0.003255	43.1496	0.34
21-4	S	7.092	80.168	228.08	0.023158	23.5328	0.58
21-4	SS1	5.092	108.516	273.52	0.013611	32.3193	0.26
21-5	S	0.208	0.788	11.98	0.014657	1.2111	0.63
21-5	SS1	0.048	0.376	0.432	0.068168	0.0224	0.27
30-3	S	35.704	19.992	208.04	0.142857	-10.7112	6.14
30-3	SS1	11.204	21.828	196.96	0.047032	12.6183	1.3
30-4	S	35.004	4.04	115.96	0.258569	-21.4664	5.76
30-4	SS1	5.164	27.812	222.6	0.019057	21.9334	1.09
30-5	S	42.86	9.376	197.76	0.184544	-19.6352	3.93
30-5	SS1	18.416	23.196	209.24	0.072768	6.8919	1.35
30-6	S	47.148	5.02	177.88	0.227755	-26.4468	5.75
30-6	SS1	16.968	7.12	172.28	0.084106	3.2064	7.23
36-1	SS1	19.388	17.72	183.4	0.087975	2.65	1.23
36-1	S	42.464	21.72	218.32	0.161652	-16.1953	1.19
36-2	S	9.744	31.512	190.44	0.041271	13.8657	0.64
36-2	SS1	4.532	52.304	195.84	0.017856	20.8487	3.2
36-3	S	12.436	21.096	185.08	0.055474	9.9817	1.1
36-3	SS1	2.488	39.2	150.56	0.012787	16.9685	0.28
36-4	S	29.356	10.444	215.68	0.115842	-4.0146	2.34
36-4	SS1	17.756	12.792	228.6	0.065873	9.1988	0.71
36-5	S	827.31	98.996	422.76	1.531521	-773.297	130.06
36-5	SS1	76.448	36.532	213.52	0.288075	-49.9104	1.33
37-1	S	1.236	2.232	1.42	0.431272	-0.9494	7.55
37-1	SS1	0.112	0.46	1.368	0.061359	0.0705	0.56
37-1	SS2	0.116	0.356	7.76	0.012738	0.7947	0.33
37-4	S	11.56	2.76	779.7	0.012891	78.1139	6.92
37-4	SS1	0.472	0.204	13.92	0.029326	1.1375	0.71
52-1	S	64.54	6.628	200.52	0.275935	-41.1504	6.53
52-1	SS1	7.872	3.328	225.48	0.030193	18.2007	0.49
52-2	S	6.772	1.504	10.892	0.507715	-5.4382	5.98
52-2	SS1	4.32	4.988	75.44	0.048334	4.6178	1.12

52-3	S	43.588	8.832	206.84	0.179839	-19.3508	2.78
52-3	SS1	0.348	0.228	16.408	0.01835	1.5485	0.17
52-4	S	65.26	1.66	73.36	0.766439	-56.7453	12.62
52-4	SS1	17.768	1.24	105	0.14655	-5.6438	1.92
52-5	S	50.284	4.36	148.32	0.291152	-33.0133	3.18
52-5	SS1	0.024	0.46	0.42	0.03257	0.0497	0.39
52-6	S	11.032	2.544	35.128	0.2643	-6.858	6.54
52-6	SS1	10.364	9.772	195.84	0.045009	12.6623	0.59
52-7	S	12.032	13.692	55.02	0.170062	-4.9569	6.26
52-7	SS1	1.724	15.896	173.68	0.00828	19.097	0.58
52-8	S	15.156	5.496	187.68	0.069355	6.6967	1.28
52-8	SS1	3.316	13.492	231.4	0.01214	23.999	0.58
52-9	S	5.148	1.276	48.8	0.090736	0.5256	2.24
52-9	SS1	1.476	36.54	251.72	0.004773	29.4479	0.56

Table C-2. Soil analytical data from section 3; all units are mgkg⁻¹ except PSR, which is unitless. (S = surface horizon; SS = subsurface horizon.)

Sample	Soil horizon	Nutrients P	Fe	Al	Soil P saturation ratio (M3)	Capacity factor	Water Soluble P (mg-P/kg)
Standing Rush 1	S	11.07	76.3	37.7	0.1294	-10.21	1.07
Standing Rush 2	SS1	57.24	190	140	0.2153	-54.58	1.2
Standing Rush 3	S	7.44	72.3	30.3	0.0994	-6.69	1.04
Standing Rush 4	SS1	8.94	125	65.1	0.0621	-7.50	0.78
Standing Rush 5	SS2	6.55	456	252	0.0121	-1.13	0.68
Standing Rush 6	SS3	0	208	2.12	0.0000	1.18	0
Standing Rush 7	S	5.22	46.5	17	0.1153	-4.77	1.06
Standing Rush 8	SS1	10.74	72.5	30.1	0.1438	-9.99	1.05
Standing Rush 9	SS2	2.39	39.9	3.92	0.0899	-2.12	0.76
Standing Rush 10	S	8.52	94	38.6	0.0884	-7.56	1.09
Standing Rush 11	SS1	7.27	132	45.4	0.0581	-6.02	0.65
Standing Rush 12	SS2	0	66.7	7.51	0.0000	0.46	0
Standing Rush 13	SS3	1.66	187	44.6	0.0107	-0.11	0
Standing Rush 14	S	10.79	252	99.6	0.0425	-8.25	1
Standing Rush 15	SS1	3.17	313	155	0.0090	0.34	0
Standing Rush 16	SS2	0	75.7	9.19	0.0000	0.52	0
Maumee Bay 17	S	8.63	590	862	0.0066	4.53	0.96
Maumee Bay 18	SS1	11.37	571	898	0.0084	2.10	0.94
Maumee Bay 19	S	31.78	569	756	0.0269	-19.95	1.95

Sample	Soil horizon	Nutrients			Soil P saturation ratio (M3)	Capacity factor	Water Soluble P (mg-P/kg)
P	Fe	Al					
Maumee Bay 20	SS1	13.19	511	782	0.0112	-1.38	0.95
Maumee Bay 21	S	15.32	621	898	0.0111	-1.57	1.52
Maumee Bay 22	SS1	7.78	640	1010	0.0051	7.36	1.07
Maumee Bay 23	S	17.28	618	880	0.0128	-3.76	1.51
Maumee Bay 24	SS1	8.63	638	919	0.0061	5.45	1.37
Maumee Bay 25	S	6.64	582	1080	0.0043	8.98	1.33
Maumee Bay 26	SS1	4.12	600	1050	0.0027	11.26	0.86
Ottawa Large 27	S	7.47	554	720	0.0066	3.86	0.61
Ottawa Large 28	SS1	4.9	570	738	0.0042	6.73	0.71
Ottawa Large 29	SS2	8.52	560	898	0.0064	4.89	0.64
Ottawa Large 30	S	4.42	571	893	0.0033	8.99	1.08
Ottawa 2B 31	SS1	7.9	572	700	0.0071	3.30	0.9
Ottawa 2B 32	SS2	6.14	544	875	0.0047	6.92	0.84
Ottawa 2B 33	S	7.42	639	855	0.0056	5.93	1.15
Ottawa 2A 34	S	13.04	563	863	0.0100	-0.01	1.14
Ottawa 2A 35	SS1	4.77	593	1090	0.0030	11.03	0.82
Ottawa 2A 36	S	1.07	695	840	0.0008	12.42	0.78
Ottawa 2A 37	SS1	1.31	657	1040	0.0008	14.27	0.83
Red horse Tp 38	S	104.38	561	781	0.0865	-92.31	4.79
Red horse Tp 39	SS1	44.46	397	683	0.0443	-34.42	1.83
Red horse RS 40	S	117	526	791	0.0976	-105.01	5.63
Red horse RS 41	SS1	38.14	499	787	0.0323	-26.34	1.58
Red horse RS 42	S	30.42	427	650	0.0310	-20.59	1.53
Red horse RS 43	SS1	21.96	402	748	0.0203	-11.15	1.52
Red horse MeB 44	S	47.28	459	983	0.0342	-33.45	2.85
Red horse MeB 45	SS1	36.9	490	1140	0.0234	-21.10	1.42
Red horse MeB 46	S	49.93	527	1220	0.0295	-33.01	1.51
Red horse MeB 47	SS1	36.45	478	1340	0.0202	-18.42	1.34
YMCA 48	S	32.11	566	1250	0.0184	-14.62	1.93
YMCA 49	SS1	26.54	543	1130	0.0166	-10.56	1.67
YMCA 50	S	4.01	599	1140	0.0024	12.39	1.01
YMCA 51	SS1	21.5	563	1040	0.0143	-6.44	1.21
YMCA 52	S	14.7	424	1010	0.0105	-0.76	0.86
YMCA 53	SS1	0.91	334	1090	0.0006	13.45	0.58
YMCA 54	S	8.39	357	895	0.0068	3.86	0.84
YMCA 55	SS1	0	357	1040	0.0000	13.92	0

Sample	Soil horizon	Nutrients			Soil P saturation ratio (M3)	Capacity factor	Water Soluble P (mg-P/kg)
		P	Fe	Al			
YMCA 56	S	11.35	513	794	0.0095	0.61	2.28
YMCA 57	SS1	2.24	504	1090	0.0015	13.06	0.76
Heck Bridge 58	S	11.51	555	989	0.0080	2.92	1.12
Heck Bridge 59	SS1	1.89	458	949	0.0014	11.54	1.1
Heck Bridge 60	S	7.35	567	1070	0.0048	8.07	0.99
Heck Bridge 61	SS1	0.98	489	936	0.0007	12.47	1.67
Wolf Creek 62	S	14.47	570	1040	0.0096	0.63	1.5
Wolf Creek 63	SS1	8.27	485	1020	0.0057	6.13	0.93
Wolf Creek 64	S	24.48	550	913	0.0181	-10.95	1.94
Wolf Creek 65	SS1	13	504	999	0.0091	1.26	1.3
Hancock County 66	S	12.7	376	1290	0.0075	4.19	0.66
Hancock County 67	SS1	2.75	393	1320	0.0016	14.58	1.33
Hancock County 68	S	3.67	275	743	0.0037	6.38	1.82
Hancock County 69	SS1	0	301	984	0.0000	12.96	0
Hancock County 70	S	8.07	549	811	0.0065	4.28	1.72
Hancock County 71	SS1	0	372	969	0.0000	13.18	0.74
Hancock County 72	S	29.19	469	1160	0.0183	-13.28	1.5
Hancock County 73	SS1	10.25	473	1180	0.0063	5.92	0.9
Hancock County 74	S	0	495	1040	0.0000	14.68	4.73
Hancock County 75	SS1	23.96	433	1030	0.0168	-9.74	2.33
Hancock County 76	S	36.82	535	1180	0.0223	-20.31	1.64
Hancock County 77	SS1	1.22	380	1180	0.0008	14.43	0.72
Hancock County 78	S	43.95	462	1150	0.0279	-28.19	1.97
Hancock County 79	SS1	4.8	372	1150	0.0031	10.46	0.76

Appendix D: Soil Series Descriptions

Blg1A1—Blount silt loam, ground moraine, 0%–2% slopes

Map Unit Setting

National map unit symbol: 2skcv
 Elevation: 700–1,300 ft
 Mean annual precipitation: 34–42 in
 Mean annual air temperature: 48–54 °F
 Frost-free period: 140–180 d
 Farmland classification: Prime farmland if drained

Map Unit Composition

Blount, ground moraine, and similar soils: 85%
 Minor components: 15%
 Estimates are based on observations, descriptions, and transects of the map unit.

Description of Blount, Ground Moraine

Setting

Landform: Ground moraines on till plains
 Landform position (two-dimensional): Footslope
 Landform position (three-dimensional): Interfluvium
 Down-slope shape: Linear
 Across-slope shape: Linear
 Parent material: Wisconsin till derived from limestone and shale

Typical profile

Ap—0–10 in: silt loam
 Bt—10–33 in: silty clay
 BC—33–39 in: clay loam
 Cd—39–79 in: clay loam

Properties and qualities

Slope: 0%–2%
 Depth to restrictive feature: 31–54 in to densic material
 Natural drainage class: Somewhat poorly drained
 Runoff class: High
 Capacity of the most limiting layer to transmit water (Ksat): Low to moderately high (0.01–0.20 in/hr)
 Depth to water table: About 6–12 in
 Frequency of flooding: None
 Frequency of ponding: None
 Calcium carbonate, maximum in profile: 35%
 Salinity, maximum in profile: Nonsaline to very slightly saline (0.0–2.0 mmhos/cm)
 Available water storage in profile: Moderate (about 6.2 in)

Interpretive groups

Land capability classification (irrigated): None specified
 Land capability classification (nonirrigated): 2w
 Hydrologic Soil Group: D
 Hydric soil rating: No

Minor Components

Pewamo, ground moraine

Percent of map unit: 9%
 Landform: Ground moraines on till plains
 Landform position (two-dimensional): Toeslope
 Landform position (three-dimensional): Base slope
 Down-slope shape: Linear
 Across-slope shape: Concave, linear
 Hydric soil rating: Yes

Glynwood, ground moraine

Percent of map unit: 6%
 Landform: Ground moraines on till plains
 Landform position (two-dimensional): Shoulder, backslope
 Landform position (three-dimensional): Side slope, nose slope
 Down-slope shape: Convex
 Across-slope shape: Linear
 Hydric soil rating: No

Ch—Chagrin silt loam, occasionally flooded

Map Unit Setting

National map unit symbol: 5pvx
 Elevation: 640–1,040 ft
 Mean annual precipitation: 32–42 in
 Mean annual air temperature: 48°F–55°F
 Frost-free period: 133–182 d
 Farmland classification: All areas are prime farmland

Map Unit Composition

Chagrin and similar soils: 85%
 Minor components: 15%
 Estimates are based on observations, descriptions, and transects of the map unit.

Description of Chagrin

Setting

Landform: Flood plains
 Down-slope shape: Linear
 Across-slope shape: Linear
 Parent material: Alluvium

Typical profile

H1—0–9 in: silt loam
 H2—9–28 in: silt loam
 H3—28–60 in: stratified fine sand to silt loam

Properties and qualities

Slope: 0%–2%
 Depth to restrictive feature: More than 80 in
 Natural drainage class: Well drained
 Runoff class: Low
 Capacity of the most limiting layer to transmit water (Ksat): Moderately high to high (0.60–2.00 in/hr)
 Depth to water table: About 48–72 in
 Frequency of flooding: Occasional
 Frequency of ponding: None
 Available water storage in profile: High (about 9.7 in)

Interpretive groups

Land capability classification (irrigated): None specified
 Land capability classification (nonirrigated): 2w
 Hydrologic Soil Group: B
 Hydric soil rating: No

Minor Components

Shoals

Percent of map unit: 12%
 Landform: Flood plains

Bedrock at 20–40 in

Percent of map unit: 3%

Le—Lenawee silty clay loam, 0%–1% slopes***Map Unit Setting***

National map unit symbol: 2wcf7
 Elevation: 560–980 ft
 Mean annual precipitation: 28–38 in
 Mean annual air temperature: 45–52°F
 Frost-free period: 135–230 days
 Farmland classification: Prime farmland if drained

Map Unit Composition

Lenawee and similar soils: 93%
 Minor components: 7%
 Estimates are based on observations, descriptions, and transects of the map unit.

Description of Lenawee***Setting***

Landform: Lakebeds (relict)
 Down-slope shape: Linear
 Across-slope shape: Linear
 Parent material: Clayey glaciolacustrine deposits

Typical profile

Ap—0–9 in: silty clay loam
 Bg—9–39 in: silty clay loam
 Cg—39–80 in: silty clay loam

Properties and qualities

Slope: 0%–1%
 Depth to restrictive feature: More than 80 in
 Natural drainage class: Poorly drained
 Runoff class: Negligible
 Capacity of the most limiting layer to transmit water (Ksat): Very low to low (0.00–0.01 in/hr)
 Depth to water table: About 0 in
 Frequency of flooding: None
 Frequency of ponding: Frequent
 Calcium carbonate, maximum in profile: 21%
 Salinity, maximum in profile: Non-saline (0.0–0.6 mmhos/cm)
 Available water storage in profile: Moderate (about 7.0 in)

Interpretive groups

Land capability classification (irrigated): None specified
 Land capability classification (nonirrigated): 2w
 Hydrologic Soil Group: D
 Ecological site: Wet Lake Plain Flats (F099XY013MI)
 Hydric soil rating: Yes

Minor Components***Del rey***

Percent of map unit: 7%
 Landform: Lakebeds (relict)
 Microfeatures of landform position: Rises
 Down-slope shape: Linear
 Across-slope shape: Linear, convex
 Hydric soil rating: No

MeB—Mentor silt loam, 1%–4% slopes***Map Unit Setting***

National map unit symbol: 5pg0
 Elevation: 580–1,200 ft
 Mean annual precipitation: 27–40 in

Mean annual air temperature: 45°F–54°F
 Frost-free period: 140–195 days
 Farmland classification: All areas are prime farmland

Map Unit Composition

Mentor and similar soils: 85%
 Minor components: 15%

Estimates are based on observations, descriptions, and transects of the map unit.

Description of Mentor

Setting

Landform: Outwash plains, lake plains, terraces
 Parent material: Glaciolacustrine deposits

Typical profile

H1—0–10 in: silt loam
 H2—10–53 in: silt loam
 H3—53–60 in: stratified silty clay loam to sandy loam

Properties and qualities

Slope: 1%–4%
 Depth to restrictive feature: More than 80 in
 Natural drainage class: Well drained
 Runoff class: Low
 Capacity of the most limiting layer to transmit water (Ksat): Moderately high to high (0.60–2.00 in/hr)
 Depth to water table: About 48–72 in
 Frequency of flooding: None
 Frequency of ponding: None
 Calcium carbonate, maximum in profile: 5%
 Available water storage in profile: High (about 11.4 in)

Interpretive groups

Land capability classification (irrigated): None specified
 Land capability classification (nonirrigated): 2e
 Hydrologic Soil Group: B
 Ecological site: Lake Plain Flats (F099XY007MI)
 Hydric soil rating: No

Minor Components

Glynwood

Percent of map unit: 5%
 Landform: End moraines, ground moraines

Saylesville

Percent of map unit: 5%
 Landform: Lake plains
 Landform position (two-dimensional): Back slope
 Landform position (three-dimensional): Side slope
 Down-slope shape: Linear
 Across-slope shape: Linear

Colwood

Percent of map unit: 5%
 Landform: Drainage ways on terraces, drainage ways on outwash plains, drainage ways on lake plains, depressions on terraces, depressions on outwash plains, depressions on lake plains
 Hydric soil rating: Yes

NpA—Nappanee silty clay loam, 0%–3% slopes

Map Unit Setting

National map unit symbol: 5q9q
 Elevation: 600–800 ft

Mean annual precipitation: 27–36 in
 Mean annual air temperature: 45°F–52°F
 Frost-free period: 140–170 d
 Farmland classification: Prime farmland if drained

Map Unit Composition

Nappanee and similar soils: 85%
 Minor components: 15%
 Estimates are based on observations, descriptions, and transects of the map unit.

Description of Nappanee

Setting

Landform: Lake plains
 Landform position (two-dimensional): Summit, shoulder
 Landform position (three-dimensional): Rise
 Down-slope shape: Linear
 Across-slope shape: Linear
 Parent material: Till

Typical profile

H1—0–8 in: silty clay loam
 H2—8–34 in: silty clay
 H3—34–60 in: silty clay

Properties and qualities

Slope: 0%–3%
 Depth to restrictive feature: More than 80 in
 Natural drainage class: Somewhat poorly drained
 Runoff class: High
 Capacity of the most limiting layer to transmit water (Ksat): Moderately low to moderately high (0.06–0.20 in/hr)
 Depth to water table: About 12–24 in
 Frequency of flooding: None
 Frequency of ponding: None
 Calcium carbonate, maximum in profile: 20%
 Available water storage in profile: Moderate (about 6.8 in)

Interpretive groups

Land capability classification (irrigated): None specified
 Land capability classification (nonirrigated): 3w
 Hydrologic Soil Group: C/D
 Ecological site: Lake Plain Flats (F099XY007MI)
 Forage suitability group: Unnamed (G099XY000OH)
 Hydric soil rating: No

Minor Components

Lenawee

Percent of map unit: 3%
 Landform: Depressions, flats, drainage ways
 Hydric soil rating: Yes

Latty

Percent of map unit: 3%
 Landform: Depressions, flats, drainage ways
 Hydric soil rating: Yes

Hoytville

Percent of map unit: 3%
 Landform: Depressions, drainage ways, flats
 Hydric soil rating: Yes

Toledo

Percent of map unit: 3%
 Landform: Depressions, flats, drainage ways
 Hydric soil rating: Yes

St. Clair

Percent of map unit: 3%
 Landform: End moraines, lake plains, ground moraines
 Landform position (two-dimensional): Summit, shoulder, back slope
 Landform position (three-dimensional): Side slope
 Down-slope shape: Linear
 Across-slope shape: Linear

PmA—Pewamo silty clay loam, 0%–1% slopes***Map Unit Setting***

National map unit symbol: 2t6lv
 Elevation: 700–1,300 ft
 Mean annual precipitation: 32–42 in
 Mean annual air temperature: 48°F–54°F
 Frost-free period: 140–180 d
 Farmland classification: Prime farmland if drained

Map Unit Composition

Pewamo and similar soils: 85%
 Minor components: 15%
 Estimates are based on observations, descriptions, and transects of the map unit.

Description of Pewamo***Setting***

Landform: Depressions on till plains, drainage ways on till plains
 Landform position (two-dimensional): Toe slope
 Landform position (three-dimensional): Base slope
 Down-slope shape: Concave, linear
 Across-slope shape: Concave
 Parent material: Wisconsin till derived from limestone and shale

Typical profile

Ap—0–11 in: silty clay loam
 Btg1—11–34 in: silty clay
 Btg2—34–47 in: silty clay
 BCg—47–57 in: clay loam
 Cg—57–79 in: clay loam

Properties and qualities

Slope: 0%–1%
 Depth to restrictive feature: More than 80 in
 Natural drainage class: Very poorly drained
 Runoff class: Negligible
 Capacity of the most limiting layer to transmit water (Ksat): Moderately high (0.20–0.60 in/hr)
 Depth to water table: About 0–12 in
 Frequency of flooding: None
 Frequency of ponding: Frequent
 Calcium carbonate, maximum in profile: 30%
 Salinity, maximum in profile: Non-saline to very slightly saline (0.0–2.0 mmhos/cm)
 Available water storage in profile: Moderate (about 8.5 in)

Interpretive groups

Land capability classification (irrigated): None specified
 Land capability classification (nonirrigated): 2w
 Hydrologic Soil Group: C/D
 Hydric soil rating: Yes

Minor Components***Blount***

Percent of map unit: 9%

Landform: End moraines on till plains, ground moraines on till plains
 Landform position (two-dimensional): Footslope
 Landform position (three-dimensional): Interfluvium
 Down-slope shape: Linear
 Across-slope shape: Linear
 Hydric soil rating: No

Minster

Percent of map unit: 6%
 Landform: Depressions on till plains
 Landform position (two-dimensional): Toe slope
 Landform position (three-dimensional): Base slope
 Down-slope shape: Concave
 Across-slope shape: Concave
 Hydric soil rating: Yes

Pt—Pits, quarry

Map Unit Setting

National map unit symbol: pmlf
 Mean annual precipitation: 34 to 42 inches
 Mean annual air temperature: 48 to 55 degrees F
 Frost-free period: 140 to 180 days
 Farmland classification: Not prime farmland

Map Unit Composition

Pits: 90 percent
 Minor components: 10 percent
 Estimates are based on observations, descriptions, and transects of the mapunit.

Description of Pits

Setting

Landform: End moraines, ground moraines

Minor Components

Udorthents, loamy

Percent of map unit: 8 percent
 Hydric soil rating: No

Udorthents, clayey

Percent of map unit: 2 percent
 Hydric soil rating: No

Rs—Rossburg silt loam, occasionally flooded

Map Unit Setting

National map unit symbol: 5pg9
 Elevation: 500–700 ft
 Mean annual precipitation: 27–42 in
 Mean annual air temperature: 45°F–55°F
 Frost-free period: 140–165 d
 Farmland classification: All areas are prime farmland

Map Unit Composition

Rosburg and similar soils: 90%
 Minor components: 10%
 Estimates are based on observations, descriptions, and transects of the map unit.

Description of Rossburg

Setting

Landform: Stream terraces, flood plains
 Parent material: Alluvium

Typical profile

H1—0–21 in: silt loam
 H2—21–49 in: loam
 H3—49–60 in: stratified gravelly sandy loam to silt loam

Properties and qualities

Slope: 0%–2%
 Depth to restrictive feature: More than 80 in
 Natural drainage class: Well drained
 Runoff class: Low
 Capacity of the most limiting layer to transmit water (Ksat): Moderately high to high (0.60–2.00 in/hr)
 Depth to water table: More than 80 in
 Frequency of flooding: Occasional
 Frequency of ponding: None
 Calcium carbonate, maximum in profile: 30%
 Available water storage in profile: High (about 11.0 in)

Interpretive groups

Land capability classification (irrigated): None specified
 Land capability classification (nonirrigated): 2w
 Hydrologic Soil Group: B
 Ecological site: Moist Floodplain (F099XY008MI)
 Hydric soil rating: No

Minor Components

Shoals

Percent of map unit: 4%
 Landform: Flood plains

Very poorly drained soils

Percent of map unit: 3%
 Landform: Abandoned channels on flood plains, abandoned channels on stream terraces
 Hydric soil rating: Yes

Bedrock at 30–40 in

Percent of map unit: 3%

Sh—Shoals silt loam, 0%–2% slopes, frequently flooded

Map Unit Setting

National map unit symbol: 2t6lr
 Elevation: 340–1,000 ft
 Mean annual precipitation: 34–42 in
 Mean annual air temperature: 48°F–55°F
 Frost-free period: 140–180 d
 Farmland classification: Prime farmland if drained and either protected from flooding or not frequently flooded during the growing season

Map Unit Composition

Shoals and similar soils: 85%
 Minor components: 15%
 Estimates are based on observations, descriptions, and transects of the map unit.

Description of Shoals

Setting

Landform: Flood plains
 Landform position (three-dimensional): Dip
 Down-slope shape: Linear
 Across-slope shape: Linear
 Parent material: Loamy alluvium

Typical profile

Ap—0–10 in: silt loam
 B—10–42 in: loam

C—42–79 in: stratified sandy loam to silt loam

Properties and qualities

Slope: 0%–2%

Depth to restrictive feature: More than 80 in

Natural drainage class: Somewhat poorly drained

Runoff class: Low

Capacity of the most limiting layer to transmit water (Ksat): Moderately high to high (0.60–2.00 in/hr)

Depth to water table: About 6–18 in

Frequency of flooding: Frequent

Frequency of ponding: None

Calcium carbonate, maximum in profile: 22%

Available water storage in profile: High (about 10.0 in)

Interpretive groups

Land capability classification (irrigated): None specified

Land capability classification (nonirrigated): 2w

Hydrologic Soil Group: B/D

Hydric soil rating: No

Minor Components

Sloan

Percent of map unit: 8%

Landform: Flood plains

Landform position (three-dimensional): Dip

Down-slope shape: Linear

Across-slope shape: Linear

Hydric soil rating: Yes

Eel

Percent of map unit: 7%

Landform: Flood plains

Landform position (three-dimensional): Rise

Down-slope shape: Linear

Across-slope shape: Linear

Hydric soil rating: No

To—Toledo silty clay, 0%–1% slopes

Map Unit Setting

National map unit symbol: 2v14z

Elevation: 560–990 ft

Mean annual precipitation: 28–38 in

Mean annual air temperature: 45°F–52 °F

Frost-free period: 135–210 d

Farmland classification: Prime farmland if drained

Map Unit Composition

Toledo and similar soils: 90%

Minor components: 10%

Estimates are based on observations, descriptions, and transects of the map unit.

Description of Toledo

Setting

Landform: Lakebeds (relict)

Down-slope shape: Linear

Across-slope shape: Linear, concave

Parent material: Clayey glaciolacustrine deposits

Typical profile

Ap—0–9 in: silty clay

Bg—9–34 in: silty clay

Cg—34–80 in: silty clay

Properties and qualities

Slope: 0%–1%

Depth to restrictive feature: More than 80 in

Natural drainage class: Very poorly drained

Runoff class: Negligible

Capacity of the most limiting layer to transmit water (Ksat): Very low to low (0.00–0.01 in/hr)

Depth to water table: About 0–12 in

Frequency of flooding: None

Frequency of ponding: Frequent

Calcium carbonate, maximum in profile: 21%

Salinity, maximum in profile: Nonsaline (0.0–0.6 mmhos/cm)

Available water storage in profile: Moderate (about 7.0 in)

Interpretive groups

Land capability classification (irrigated): None specified

Land capability classification (nonirrigated): 3w

Hydrologic Soil Group: D

Ecological site: Wet Lake Plain Flats (F099XY013MI)

Hydric soil rating: Yes

Minor Components

Fulton

Percent of map unit: 6%

Landform: Lakebeds (relict)

Microfeatures of landform position: Rises

Down-slope shape: Linear

Across-slope shape: Convex, linear

Hydric soil rating: No

Lenawee

Percent of map unit: 3%

Landform: Lakebeds (relict)

Microfeatures of landform position: Open depressions

Down-slope shape: Linear

Across-slope shape: Concave, linear

Hydric soil rating: Yes

Haskins

Percent of map unit: 1%

Landform: Lakebeds (relict)

Micro-features of landform position: Rises

Down-slope shape: Linear

Across-slope shape: Convex, linear

Hydric soil rating: No

Tp—Toledo silty clay, 0%–1% slopes, flooded

Map Unit Setting

National map unit symbol: 2v14y

Elevation: 560–620 ft

Mean annual precipitation: 28–38 in

Mean annual air temperature: 45°F–52°F

Frost-free period: 135–210 d

Farmland classification: Not prime farmland

Map Unit Composition

Toledo, flooded, and similar soils: 95%

Minor components: 5%

Estimates are based on observations, descriptions, and transects of the map unit.

Description of Toledo, Flooded**Setting**

Landform: Terraces
 Landform position (three-dimensional): Tread
 Down-slope shape: Linear
 Across-slope shape: Linear, concave
 Parent material: Clayey glaciolacustrine deposits

Typical profile

Ap—0–8 in: silty clay
 Bg—8–34 in: silty clay
 Cg—34–80 in: silty clay

Properties and qualities

Slope: 0%–1%
 Depth to restrictive feature: More than 80 in
 Natural drainage class: Very poorly drained
 Runoff class: Negligible
 Capacity of the most limiting layer to transmit water (Ksat): Very low to low (0.00–0.01 in/hr)
 Depth to water table: About 0–12 in
 Frequency of flooding: Frequent
 Frequency of ponding: Frequent
 Calcium carbonate, maximum in profile: 20%
 Salinity, maximum in profile: Nonsaline (0.0–0.6 mmhos/cm)
 Available water storage in profile: Moderate (about 6.8 in)

Interpretive groups

Land capability classification (irrigated): None specified
 Land capability classification (nonirrigated): 4w
 Hydrologic Soil Group: D
 Ecological site: Wet Floodplain (F099XY009MI)
 Hydric soil rating: Yes

Minor Components**Fulton, flooded**

Percent of map unit: 5%
 Landform: Terraces
 Landform position (three-dimensional): Tread
 Microfeatures of landform position: Rises
 Down-slope shape: Linear
 Across-slope shape: Convex, linear
 Hydric soil rating: Yes

TpA—Toledo silty clay, 0%–1% slopes, flooded**Map Unit Setting**

National map unit symbol: 2v14y
 Elevation: 560–620 ft
 Mean annual precipitation: 28–38 in
 Mean annual air temperature: 45°F–52 °F
 Frost-free period: 135–210 d
 Farmland classification: Not prime farmland

Map Unit Composition

Toledo, flooded, and similar soils: 95%
 Minor components: 5%
 Estimates are based on observations, descriptions, and transects of the map unit.

Description of Toledo, Flooded**Setting**

Landform: Terraces

Landform position (three-dimensional): Tread
Down-slope shape: Linear
Across-slope shape: Linear, concave
Parent material: Clayey glaciolacustrine deposits

Typical profile

Ap—0–8 in: silty clay
Bg—8–34 in: silty clay
Cg—34–80 in: silty clay

Properties and qualities

Slope: 0%–1%
Depth to restrictive feature: More than 80 in
Natural drainage class: Very poorly drained
Runoff class: Negligible
Capacity of the most limiting layer to transmit water (Ksat): Very low to low (0.00–0.01 in/hr)
Depth to water table: About 0–12 in
Frequency of flooding: Frequent
Frequency of ponding: Frequent
Calcium carbonate, maximum in profile: 20%
Salinity, maximum in profile: Nonsaline (0.0–0.6 mmhos/cm)
Available water storage in profile: Moderate (about 6.8 in)

Interpretive groups

Land capability classification (irrigated): None specified
Land capability classification (nonirrigated): 4w
Hydrologic Soil Group: D
Ecological site: Wet Floodplain (F099XY009MI)
Hydric soil rating: Yes

Minor Components

Fulton, flooded

Percent of map unit: 5%
Landform: Terraces
Landform position (three-dimensional): Tread
Microfeatures of landform position: Rises
Down-slope shape: Linear
Across-slope shape: Linear, convex
Hydric soil rating: Yes

W—Water

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14. ABSTRACT Historical loss of wetlands coupled with excess phosphorus (P) loading at watershed scales have degraded water quality in portions of the western Lake Erie Basin (WLEB). In response, efforts are underway to restore wetlands and decrease P loading to surface waters. Because wetlands have a finite capacity to retain P, researchers have developed techniques to determine whether wetlands function as P sources or sinks. The following technical report evaluates the soil P storage capacity (SPSC) at locations under consideration for wetland restoration in collaboration with the Great Lakes Restoration Initiative (GLRI) and the H2Ohio initiative. Results indicate that the examined soils display a range of P retention capacities, reflecting historic land-use patterns and management regimes. However, the majority of study locations exhibited some capacity to sequester additional P. The analysis supports development of rankings and comparative analyses of areas within a specific land parcel, informing management through design, avoidance, removal, or remediation of potential legacy P sources. Additionally, the approaches described herein support relative comparisons between multiple potential wetland development properties. These results, in conjunction with other data sources, can be used to target, prioritize, justify, and improve decision-making for wetland management activities in the WLEB.					
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