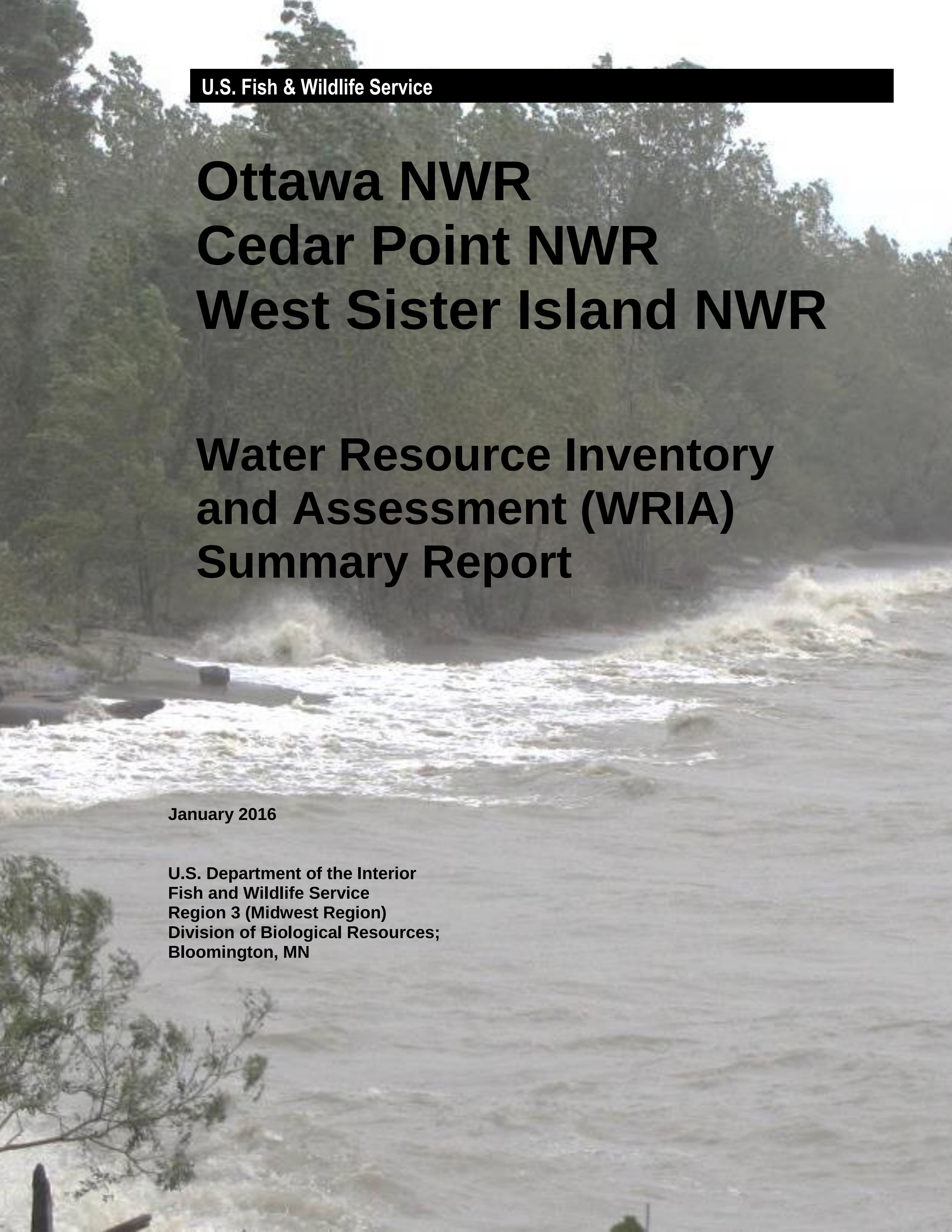

U.S. Fish & Wildlife Service

Ottawa NWR
Cedar Point NWR
West Sister Island NWR

Water Resource Inventory and Assessment (WRIA) Summary Report

January 2016

U.S. Department of the Interior
Fish and Wildlife Service
Region 3 (Midwest Region)
Division of Biological Resources;
Bloomington, MN

Cover image: Ron Huffman (USFWS). Ottawa NWR dike at Lake Erie, October 3, 2015. Strong northeast winds occurred over an unusually long period from September 30 to October 4, resulting in a peak seiche of 575.58 IGLD, with sustained lake levels above 574.0 for about 44 hours.

The mission of the U.S. Fish & Wildlife Service is working with others to conserve, protect, and enhance fish and wildlife and their habitats for the continuing benefit of the American people.

The mission of the National Wildlife Refuge System is to administer a national network of lands and waters for the conservation, management and where appropriate, restoration of the fish, wildlife and plant resources and their habitats within the United States for the benefit of present and future generations of Americans.

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Author's Note:

There are embedded links throughout this document within the table of contents. A database of the presented data, additional data, documents and the referenced studies will be available as part of a digital document library housed on the Environmental Conservation Online System (ECOS). Geospatial data layers were obtained from the U.S. Fish and Wildlife Service, USGS seamless server, the Environmental Protection Agency, and the Ohio Geographically Referenced Information Program.

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Executive Summary

The Water Resource Inventory and Assessment (WRIA) is a reconnaissance-level effort, which provides:

- Descriptions of local soils, geology, and natural setting information
- Historic, current, and projected climate information, including hydroclimate trends
- An inventory of surface water and groundwater resource features
- An inventory of relevant infrastructure and water control structures
- Summaries of historical and current water resource monitoring, including descriptions of datasets for applicable monitoring sites
- Brief water quality assessments for relevant water resources
- A summary of state water laws
- A compilation of main findings and recommendations for the future

The WRIA provides inventories and assessments of water rights, water quantity, water quality, water management, climate, and other water resource issues for each Refuge. The long-term goal of the National Wildlife Refuge System (NWRS) WRIA effort is to provide up-to-date, accurate data on Refuge System water quantity and quality in order to acquire, manage, and protect adequate supplies of water. Achieving a greater understanding of existing information related to Refuge water resources will help identify potential threats to those resources and provide a basis for recommendations to field and Regional Office staff. Through an examination of previous patterns of temperature and precipitation, and an evaluation of forward-looking climate models, the U.S. Fish and Wildlife Service (USFWS) aims to address the effects of global climate change and the potential implications on habitat and wildlife management goals for a specific Refuge.

WRIAs have been recognized as an important part of the NWRS Inventory and Monitoring (I&M) and are identified as a need by the *Strategic Plan for Inventories and Monitoring on National Wildlife Refuges: Adapting to Environmental Change* (USFWS 2010a, b). I&M is one element of the U.S. Fish and Wildlife Service's climate change strategic plan to address the potential changes and challenges associated with conserving fish, wildlife and their habitats (USFWS 2011). Water Resource Inventory and Assessments have been developed by a national team comprised of U.S. Fish and Wildlife Service water resource professionals, environmental contaminants Biologists, and other Service employees.

The WRIA summary narrative supplements existing and scheduled planning documents, by describing current hydrologic related information and providing an assessment of water resource needs and issues of concern. The WRIA will be a useful tool for Refuge management and future assessments, such as a hydro-geomorphic analysis (HGM), and can be utilized as a planning tool for the Comprehensive Conservation Plan (CCP), Habitat Management Plan (HMP) and Inventory & Monitoring Plan (IMP). The Contaminants Assessment Process (CAP) is complete for Ottawa National Wildlife Refuge Complex (Kurey 1997, Banda et al. 2015), and the HMP is under final review (USFWS 2014). Many of the findings and recommendations within the CAP and HMP are applicable to water resources and are reiterated in the WRIA summary narrative.

This Water Resource Inventory and Assessment (WRIA) Summary Report for Ottawa National Wildlife Refuge Complex (ONWRC) describes current hydrologic information, provides an assessment of water resource needs and issues of concern, and makes recommendations regarding Refuge water resources. The assessment focuses on the Ottawa and Cedar Point National Wildlife Refuges (ONWR and CPNWR). Because of West Sister Island National Wildlife Refuge's (WSINWR's) comparatively small area and lack of water features typically inventoried in the WRIAs, it is not a focus for this report. Most of this assessment applies exclusively to the ONWR and CPNWR portions of the Complex, though summaries of Lake Erie's conditions and stage trends have some relevancy to WSINWR. As part of the WRIA effort for ONWRC, water resources staff in the Division of Biological Resources (NWRS) received review comments and edits from Jason Lewis (USFWS), Ron Huffman (USFWS), and Kathy Huffman (USFWS).

This Summary Report synthesizes a compilation of water resource data contained in the national interactive online WRIA database (https://ecos.fws.gov/wria/). The information contained within this report and supporting documents will be entered into the national database for storage, online access, and consistency with future WRIAs. The database will facilitate the evaluation of water resources between regions and nationally. This report and the database are intended to be a reference for ongoing water resource management and strategy development. This is not meant to be an exhaustive nor a historical summary of water management activities at ONWRC.

Findings

ONWRC's water quality and quantity are almost entirely controlled by the conditions of Lake Erie, which lies directly adjacent to the Refuges' main tracts. Southwestern Lake Erie and drainages relevant to ONWRC suffer from a variety of water quality concerns, but the most prominent threats are interrelated and include high sediment and nutrient loads, decreased water clarity, and depleted oxygen concentrations. In particular, dissolved reactive phosphorus is higher than it has ever been in the Sandusky and Maumee Watersheds (Ohio Department of Agriculture, et. al. 2013), which presents additional pressures to the Lake Erie ecosystem. Together, high phosphorus and sediment create conditions for harmful algal blooms (HABs) which have numerous ecological implications. These issues are aggravated by other water resource threats, such as invasive zebra mussels, quagga mussels and climate change. Projected warmer and longer summers may lead to shallower Lake waters and reductions in ice cover, which when coupled with increases in nutrient and sediment loads will make the Lake more vulnerable to HABs and oxygen depletion; further threatening resources and management options on ONWRC .

HABs and the toxins they produce are serious, current threats to the Lake Erie ecosystem and Refuge Resources. Lake Erie has become increasingly more vulnerable to HABs due to high phosphorus and sediment loading, elevated water temperatures, and aging wastewater infrastructure in the region. HABs impact the ecosystem by blocking light attenuation through the water column, depleting dissolved oxygen levels as they decompose, and out-competing other organisms by consuming a large portion of the phytoplankton, zooplankton, and nutrients in the system. In addition, they produce microcystin, which is toxic to humans and the environment. Together these processes frequently cause fish kills, mortality of other organisms, direct and indirect impairment to waterfowl, and degradation of Refuge aesthetics and habitat.

ONWRC's primary water source is Lake Erie, and the Lake's water levels and quality dictate Refuge management options. Consequently, the entire Lake Erie drainage basin influences ONWRC's water resources. As water levels and quality respond to changes in land use, water use, and climate change across all of the Lake's contributing drainages, ONWRC will be especially limited in its ability to influence the quality and quantity of its own water resources; since the responsibility to manage Lake Erie is shared by many municipalities, agencies, watershed groups, and governments on a broad scale. The Lake is particularly vulnerable to urban development and the intensification of agriculture across its contributing drainages. These types of land conversions have increased over the years, a trend that is expected to continue in the future and have direct, adverse impacts on Lake Erie water supply/demand, quality, and the ecosystem.

ONWRC primarily manages its units separately and without direct hydrologic connection to Lake Erie. This approach impairs invasive species spread, protects certain units from dramatic water level fluctuations, and enables more water resource control overall, however hydrologic isolation also restricts nutrient exchange and habitat use, especially for fish. The disconnect between Refuge management units and the Lake significantly limits the functions of these coastal ecosystems, and both Lake Erie and Refuge habitats would likely benefit from future coastal Lake Erie wetland reconnection projects. The reconnection of Pool 2B with Crane Creek has shown to improve species richness (Pfaff 2012), enhance nutrient exchange, increase sediment capture, and enhance waterfowl habitat and foraging grounds. The ecosystems within isolated units across ONWRC vary greatly, however, and may all respond to reconnection in different ways (Pfaff 2012).

Many of the natural hydrologic processes, such as sediment scour and accretion dynamics, have been altered in the Lake Erie Basin as a direct result of shoreline armoring and the construction of dikes, levees, and other structures. The system now heavily relies on such structures to prevent land recession, and infrastructure and water control structures are now necessary to sustain both natural and anthropogenic resources in the region. These structures may have been planned without extensive consideration for future changes in the regional climate or Lake levels, however, and some may be outdated. More specifically, significant infrastructure limitations during high Lake levels and seiche events compromise ONWRC's water resource management abilities and contribute to erosion and habitat degradation across the Refuges (R. Huffman, personal communication, Feb. 19, 2016).

According to a relevant USGS stream gage dataset on the Sandusky River (USGS 04198000), average annual discharges and peak annual discharges have shown statistically significant increases since the 1940s, suggesting wetter conditions overall due to increases in both the frequency and magnitude of runoff events in the region as a result of climate changes and anthropogenic factors. Since the trends have leveled off, however, these patterns merely reflect a change over the long term, and continued increases in the magnitudes or frequencies of runoff events are not necessarily expected in the immediate future. The same trends have been observed in annual peak streamflow data for other relevant USGS stream gages (USGS 04195500 and USGS 04195820), supporting the idea that the flow regimes of surface water drainages near ONWRC are now different than they once were.

Recent studies suggest that ONWRC's region is relatively sensitive to climate change, and that changes have already occurred. The number of frost-free days has increased since the 1950s (USDA 2011), and fewer cool summer nights has led to increased average summer temperatures (ONCD 2010). Annual precipitation has also increased since the 1950s (MRCC 2012), and streams have responded with higher average and minimum discharges (Small et al. 2006), as well as higher peak discharges (see Hydro-Climatic Data Network Section). Warmer and drier summers coupled with wetter springs and winters are projected by several climate models, and winter is expected to become shorter in general by the end of the century (Hayhoe et al. 2010).

Lake Erie water temperatures have generally been warming, especially in the summer, and average annual evaporation has also generally increased (EPA/NOAA 2014). Water levels have recently been above long-term averages, though projections expect water supply in Lake Erie to decline (NWF 2013) due to increases in evaporation that are expected to exceed increases in average annual streamflow. Summer Lake levels will very likely experience declines, due to less precipitation and higher evapotranspiration projections in these months. This effect would be exacerbated by future development, population growth, and urban expansion in the area, and may require ONWRC to draw upon alternative water sources.

Surface water tributaries draining through the refuge suffer from typical water quality threats of agricultural streams, including chemical, sediment, and nutrient loads. Groundwater in the region may exhibit relatively high levels of strontium, aluminum, sulfate, and arsenic concentrations, as well as other water quality issues.

ONWRC has several water resource threats and needs that are common to most Field Stations in the Midwest Region, however this Complex has already addressed many of them. In doing so, they set themselves up for improved management and assessment of threats related to both water quantity and quality. For example:

- ONWRC monitors water levels of managed impoundments in a common datum (International Great Lakes Datum of 1985, IGLD85).
- The Complex uses available LiDAR data to evaluate how water levels relate to habitat management objectives and impact surrounding lands.
- Bathymetric surveys of managed and important water features have been completed for portions of the Complex, and this information is useful in determining optimal water level targets and computing overall water storage capacities to meet habitat management goals and protect water supplies.
- According to the HMP, Refuge staff establishes annual drawdown targets using bathymetry and elevation information, and water management influences are periodically assessed to incorporate additional LiDAR and bathymetry data, refine future management plans, and improve future infrastructure design.

Recommendations

The WRIA provides a collection of recommendations related to the primary findings from existing water quality and quantity information, as well as identified gaps in the water resource inventory. These recommendations are suggestions to help improve understanding of water resource quality, quantity, and related limitations for habitat management, however alternative opportunities to act on current or future threats may exist. Each water resource concern and recommendation should be thoroughly assessed prior to the implementation of management actions, and when appropriate should be incorporated into the planning process with consideration for Refuges' overall goals and priorities.

USFWS should participate in programs focused on reducing peak discharges, sediment loads, and phosphorus loads to the western Lake Erie Basin, and encourage the development of green infrastructure and best management practices across ONWRC's relevant watersheds. When possible, implement projects on Refuge lands to reduce sediment loads and encourage nutrient absorption. ONWRC's future fee title acquisitions and restoration activities offer opportunities to improve the quality and regulate the quantity of water reaching Lake Erie.

As discussed by Pfaff (2012) future reconnections of management units with Lake hydrology should be planned on an individual basis to account for the ecological variability between units. All activities should closely monitor pre- and post-project environmental conditions to improve general understanding of coastal lake wetlands' roles in nutrient exchanges and ecosystem processes.

Assess water control structures across Refuge lands, and maintain, improve, or decommission aging infrastructure that does not complement projected changes in the regional climate and Lake Erie levels. Water level considerations should also be incorporated into the designs for new structures.

ONWRC should work towards increasing vegetative cover and riparian buffer zones to help offset surface water quality threats in Lake Erie and its tributaries. All restoration plans should strongly consider climate change, and re-vegetation projects should be completed with species adapted to projected future environmental conditions. Likewise, ecosystem implications of likely climate scenarios should be thoroughly assessed with special consideration for the vulnerabilities of important species to water temperatures, lake levels, and new flow regimes, as well as potential invasive species that may favor new environmental conditions.

Conduct vulnerability assessments to determine the sensitivities of waters and important species across ONWRC. Identify specific areas that are particularly important for use by waterfowl and other important biota, which may be at risk of significant decreases in water levels and lack control structures to sustain necessary water supplies.

Investigate alternative water sources to improve water resource management if future Lake levels demand more active management approaches, especially for the summer months when Lake levels will most likely experience the most significant declines. Since many of the surface water inputs coursing through the Refuge carry pesticides, nutrients, and other chemicals with them, groundwater may be a more favorable option. However, nearby monitoring wells reveal potentially concerning groundwater quality in the region, so groundwater dynamics and quality should be thoroughly analyzed before this resource is drawn from.

The feasibility of groundwater use to sustain Complex units should also be assessed from a water quantity standpoint. The quantity needed to sustain the Refuges could easily deplete groundwater pockets within the Refuge complex.

Water quality data from the synoptic sampling that occurred in 2012-2013 should be evaluated to identify any potential water quality threats to ONWRC. Basic descriptive statistics (eg., mean, median, minimum/maximum values) of each parameter should be calculated for each unit and for tracts sharing common water sources, and values should be compared with Ohio EPA's water quality standards. These measurements should be conducted again in 2017-2018 for comparison, and to help identify any nutrient level changes over the 5-year period. This information, along with on-going water level monitoring, would provide valuable information about the health and function of ONWRC's management units.

Based on current Lake levels and pump locations, the Complex's withdrawals are most likely considered to be sourced from the Lake. However if Lake Erie levels decline in the future, withdrawal points may fall under state waters, for which stricter permitting requirements apply. Refuge management should stay informed with Ohio's Diversion/Withdrawal Regulation Program to ensure that operations continue in accordance with State regulations.

Several pumps on the Complex are currently capable of pumping 2.5 million gpd (7.7 acre-feet per day) or greater, and therefore may require permits during some years of operation, depending on the length of time operated. These include the Cedar Point, Moist Soil, Blausey, and Darby pumps. If additional pumps are purchased and installed in the future, their expected pumping rates should be considered for permitting purposes. However, any pump system predating the Compact established in December of 2008 is grandfathered in and does not require a permit. Ohio reports "grandfathered" facilities with their registration program, and facilities that register can still be added to the grandfathered list retroactively, as long as current water use is the same as it was prior to the Compact. Regardless, the refuges' pump systems must be registered with the state of Ohio because it is a requirement for any facility capable of 100,000 gpd or greater to do so. Instructions and forms can be found on the Ohio DNR Division of Water Resources website (http://water.ohiodnr.gov/water-use-planning/water-withdrawal-facilities-registration#FOR).

The following recommendations are provided as part of a project to implement adaptive strategies for water supply management by creating high resolution topographic and bathymetry maps, water depth and distribution tables, and a water budget (Credico, 2014):

> The locations and dimensions of water control structures (WCSs) and pumps should be inventoried to create a current WCS map, monitor water distribution, and enable future calculations of water inputs, outputs, and storage across ONWRC.
>
> Water level and climate data should be collected and assessed frequently to evaluate possible changes in future water supply. A climate station should be installed closer to the Refuge to improve the accuracy of these assessments, since the local climate varies greatly due to Lake effects. Optimal water levels for various management objectives may also be considered using the USGS Shoreline Management GIS tool (Snyder et al. 2012).
>
> Flow meters should be installed in Refuge pumps to monitor discharges. This information would be useful in evaluating the efficiency of the pumps, determining pumping capacities for variable speed pumps, and confirming that pumps are operating as they should.
>
> Credico (2014) offers a preliminary water budget for ONWR’s wetlands sharing common water supply sources, but this should be developed again after bathymetry data for the entire Refuge is collected to improve accuracy.

Introduction

Prior to the late 19th century, the glacially-fed Great Black Swamp once extended across roughly 1,500 square miles and encompassed portions of the Maumee and Portage River Watersheds (Figure 1 Estimated historic extent of the Great Black Swamp (Black Swamp Conservancy, http://www.blackswamp.org/main/protecting-land/)Figure 1). Drainage, deforestation, and agricultural activities, however, left very limited tracts of the productive swamp/marsh system that once inundated the region.

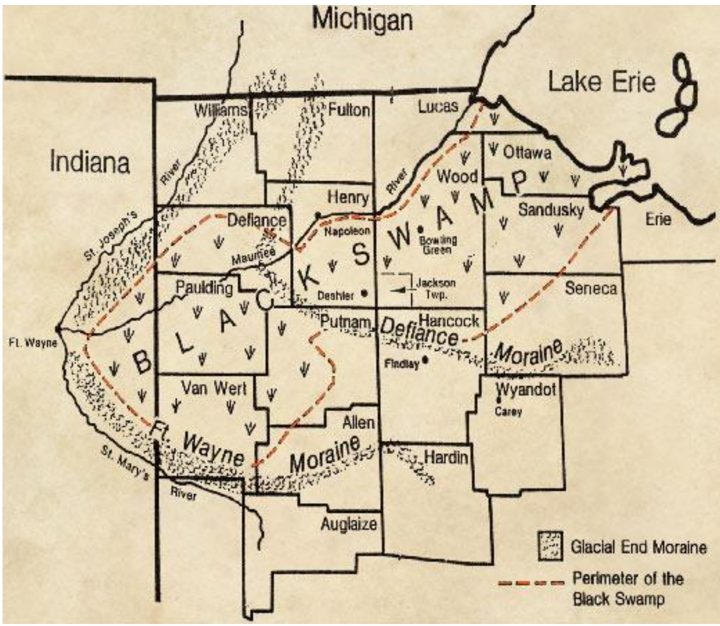


Figure 1 Estimated historic extent of the Great Black Swamp (Black Swamp Conservancy, http://www.blackswamp.org/main/protecting-land/)

Though fragmented and significantly reduced in size, the remaining wetland tracts continued to support high levels of biodiversity and provide significant habitat for waterfowl, migratory birds, and endangered and threatened species. Thus, efforts to conserve and protect remaining valuable lands commenced in the 20th century, prompting the establishment of a national research reserve, several state parks, state nature preserves/wildlife areas, private nature reserves, and the Ottawa National Wildlife Refuge Complex (ONWRC) (Figure 2).

Included in the Complex is the 6,500-acre Ottawa NWR (ONWR) off the southwestern shore of Lake Erie, which was established in 1961 *"…for use as an inviolate sanctuary, or for any other management purpose, for migratory birds,"* and to protect valuable marsh habitat adjacent to Lake Erie. Today the Refuge is managed as three main units, including the originally-acquired tract (Ottawa Unit), the area near the mouth of the Portage River (Darby Unit), and the marsh near the mouth of the Toussaint River (Navarre Unit). ONWR also comprises other smaller tracts detached from these main units, located along the riparian zones of Portage River, Toussaint River, and Turtle Creek (see Water Resource Features section for further details).

To add to these protected areas, 2,445 acres of land northwest of ONWR, including Lake Erie's largest continuous fringing marsh habitat, was donated by the owners of the Cedar Point Shooting Club in 1964, leading to the establishment of Cedar Point NWR (CPNWR) (Figure 3). CPNWR and ONWR were both founded with the same purpose and under the authority of the Migratory Bird Conservation Act (16 U.S.C. 715d). They joined the previously-established West Sister Island NWR (WSINWR), a significant nesting area for wading birds encompassing roughly 80 acres, located nearly ten miles offshore. The Island was designated *"a refuge and breeding ground for migratory birds and other wildlife…"* by President Franklin D. Roosevelt in 1937 (Executive Order 7937), and was subsequently designated the State's only Wilderness Area in 1975 (Public Law 93-632). Prior to the establishment of ONWR, the Island was an unmanaged protected area, and today it is co-owned by USFWS and the U.S. Coast Guard.

Together, the three Refuges are generally managed to "*protect, enhance, and restore habitat for threatened and endangered species, provide suitable nesting habitat for migratory birds; provide spring and fall migrational habitat for waterfowl and other migratory birds; provide habitat for native resident flora and fauna; and provide the public with wildlife-dependent recreation opportunities"* (USFWS 2000). The Complex encompasses over 9,700 acres of important habitat within the Maumee Lake Plain and Marblehead Drift/Limestone Plain Level IV ecoregion (57a, 57d; USEPA, 2013), and is part of both the Upper Midwest and Great Lakes, and Eastern Tallgrass Prairie and Big Rivers Landscape Conservation Cooperatives (LCC). Land acquisition occurs within a limited area across Ottawa, Sandusky, and Lucas Counties (USFWS 2014). The area has been designated a Globally Important Bird Area by the American Bird Conservancy, an Important Bird Area through Audubon Ohio, and a Regionally Significant Site in the Western Hemisphere Shorebird Reserve Network.

Additional details about the history, setting, establishment, and significance of the Refuges are described in the CCP and HMP (USFWS 2000, USFWS 2014).

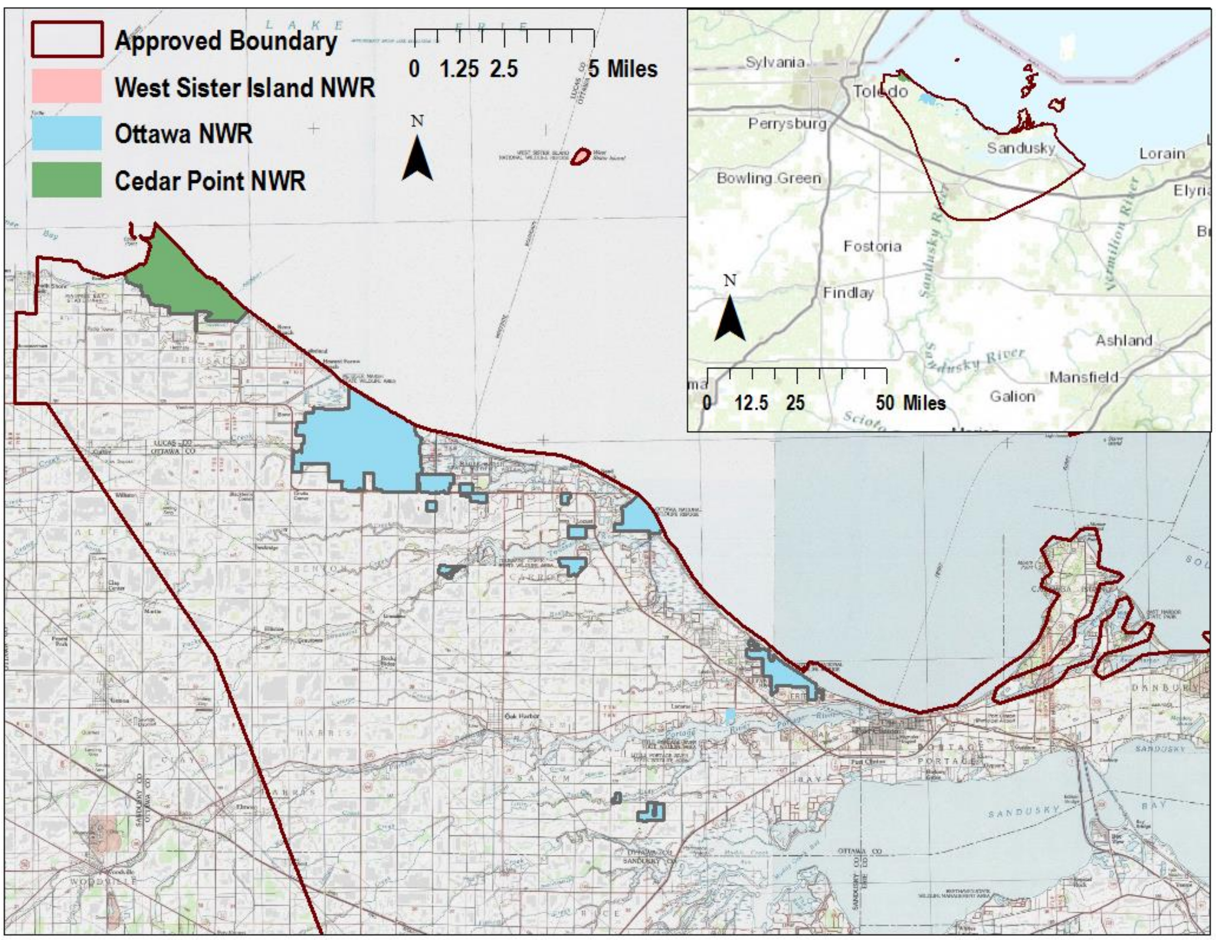


Figure 2 Reference map of ONWRC

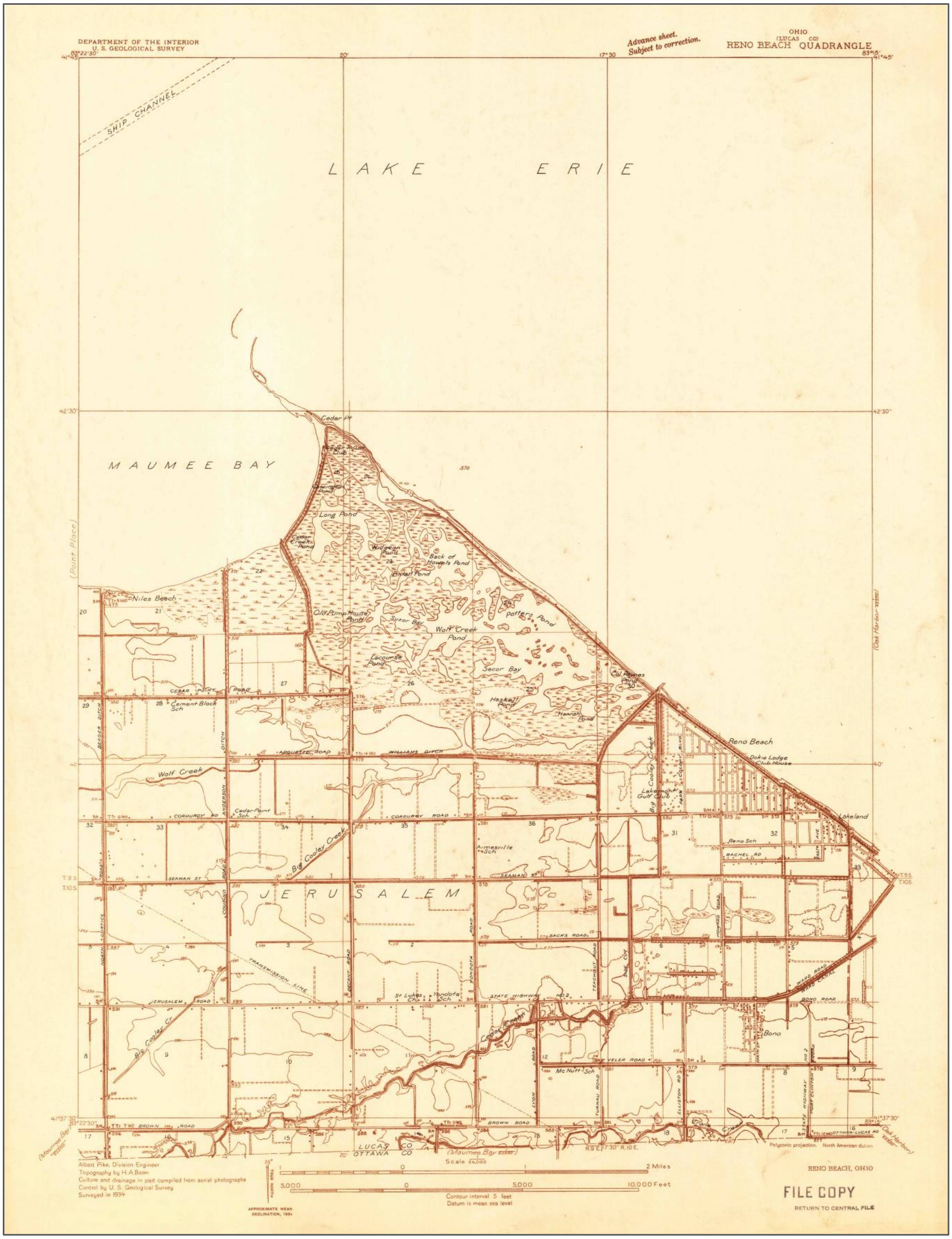


Figure 3 Historical map (1934) of Reno Beach USGS Quadrangle, including CPNWR (http://nationalmap.gov/historical/)

Natural Setting

The natural setting section describes the resources associated with the Refuges, including relevant watershed boundaries, the region's topography, geology, soils, and climate. These underlying, non-living components of an ecosystem provide the context for the form, function, and management of water resources. Many of these elements are additionally described in the CCP (USFWS 2000).

Hydrologic Unit Codes (HUCs)

Hydrologic information can be described in the context of ONWRC's designated Region of Hydrologic Influence (RHI), which is the relevant region for the collection of water quality and quantity information. For the purposes of the WRIA, Hydrologic Unit Code (HUC) boundaries, part of the USGS Watershed Boundary Dataset, are often used as a general framework to designate RHIs. HUCs are used to designate watersheds of various sizes and often represent the initial aggregate level of water quality and quantity information available from a variety of agencies. HUC boundaries are a successively smaller classification system based on drainage, adapted from Seaber et al. (1987). The 8-digit HUCs (HUC-8s) most relevant to ONWRC's authorized boundary include the Lower Maumee, Cedar-Portage, and Sandusky Drainages (Figure 4). A list of relevant HUC-10s and the smaller HUC-12 boundaries are also provided in the reference maps below (Figure 5 and Figure 6).

In this case, ONWRC's RHI is represented in part by the 10-digit Hydrologic Unit Code (HUC-10) boundaries nearby or intersecting the Complex's expansion boundary authorized by Congress. While these represent significant drainages flowing into or near the Refuges, the entire Lake Erie drainage basin should be considered as part of ONWRC's RHI, since the primary hydrologic driver (Lake Erie) lies downstream rather than upstream of these Refuges. Lake Erie's water levels and quality dictate Refuge management options, a dynamic that is rather unique for USFWS NWRS management areas in the Midwest.

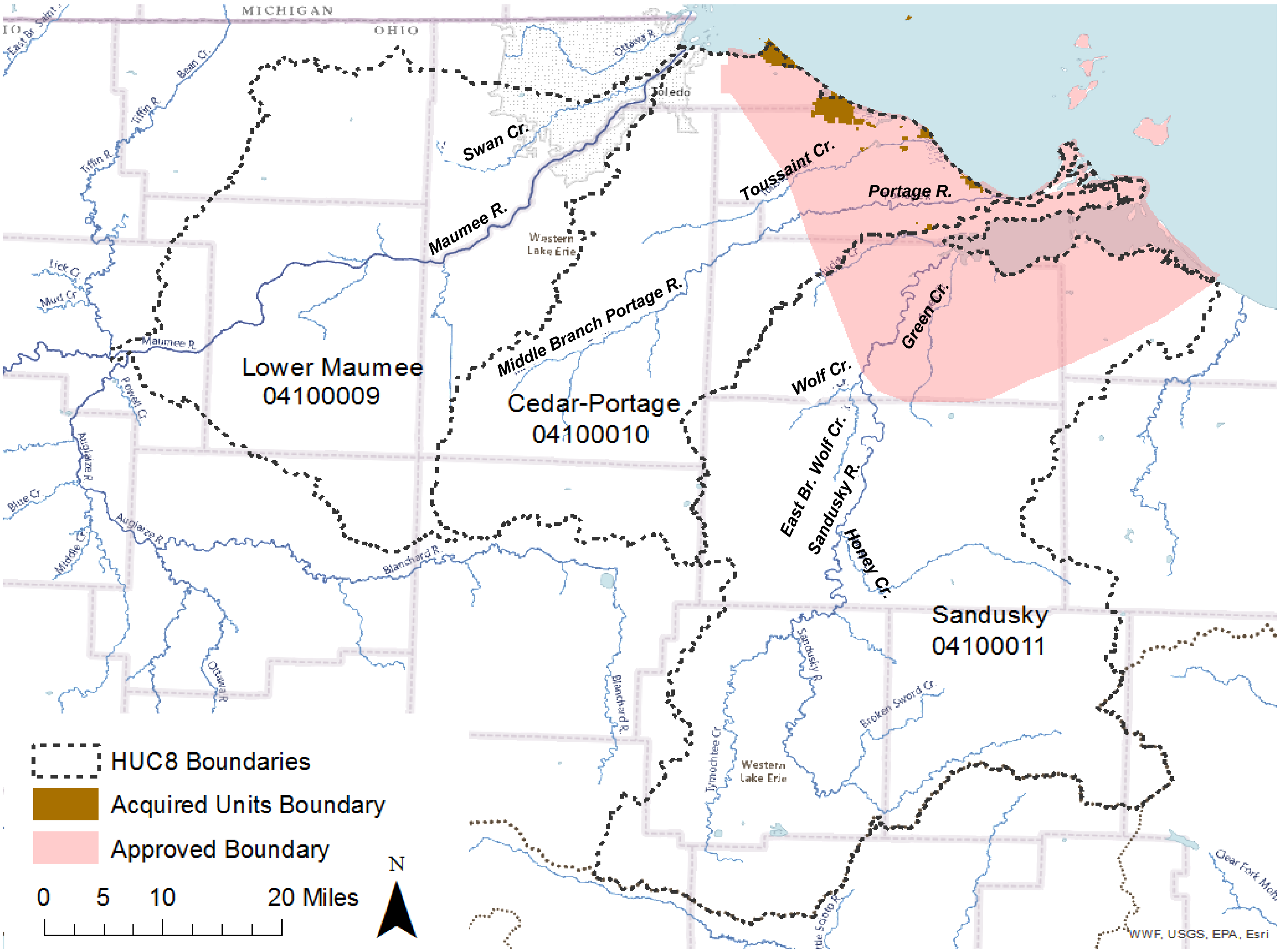
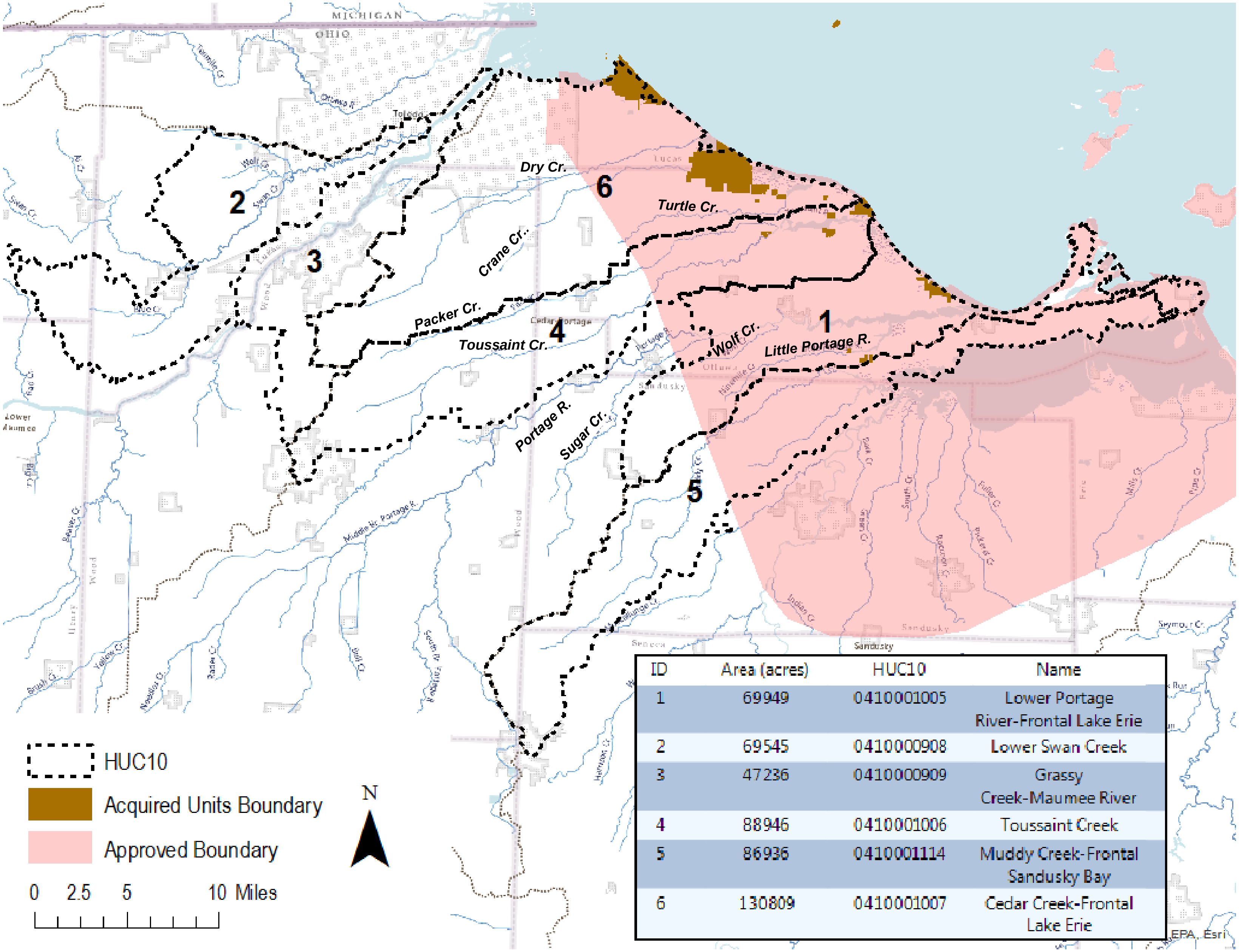
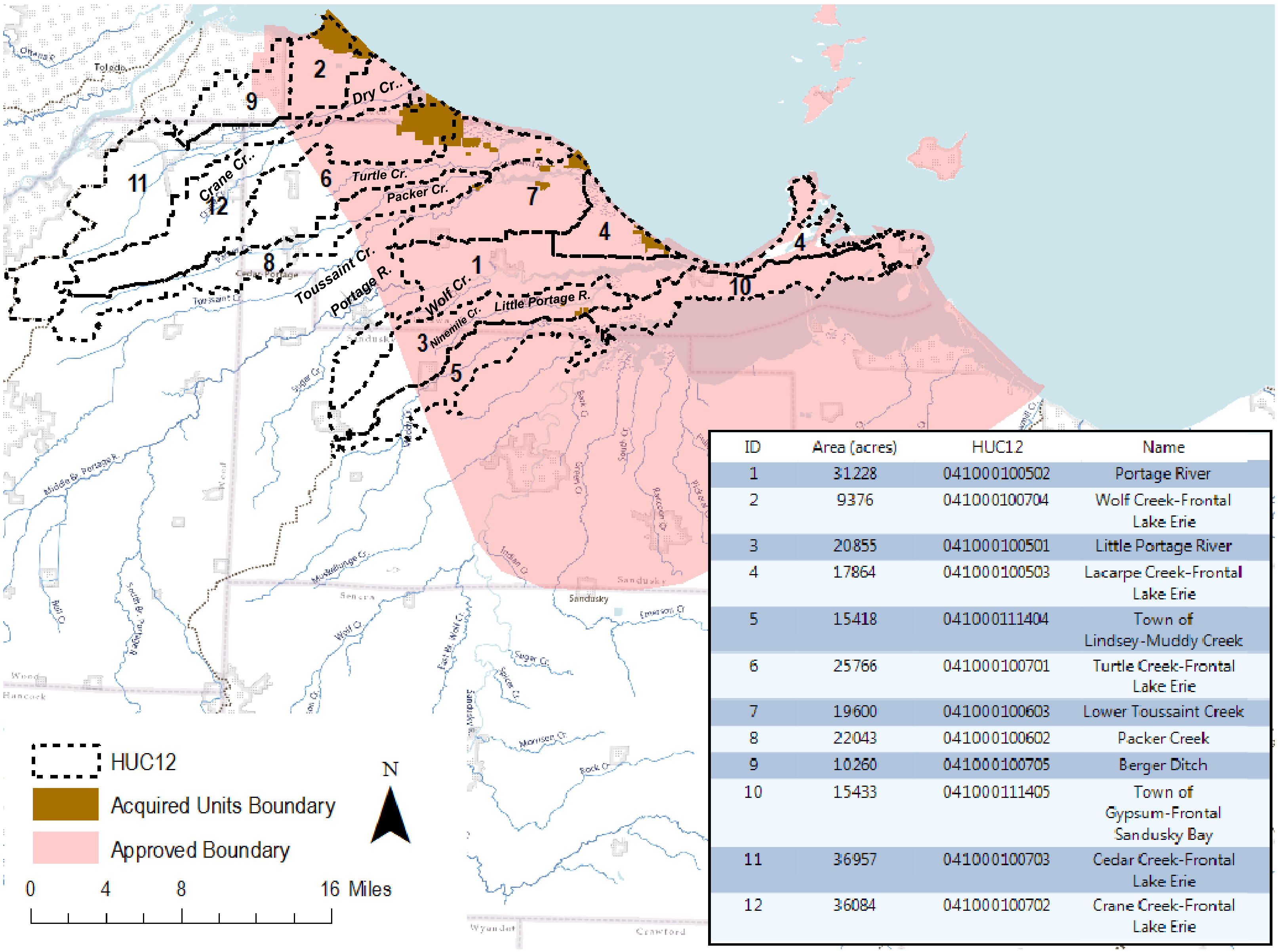


Figure 4 HUC-8s relevant to ONWRC



ID	Area (acres)	HUC10	Name
1	69949	0410001005	Lower Portage River-Frontal Lake Erie
2	69545	0410000908	Lower Swan Creek
3	47236	0410000909	Grassy Creek-Maumee River
4	88946	0410001006	Toussaint Creek
5	86936	0410001114	Muddy Creek-Frontal Sandusky Bay
6	130809	0410001007	Cedar Creek-Frontal Lake Erie

Figure 5 HUC-10-s relevant to ONWRC



ID	Area (acres)	HUC12	Name
1	31228	041000100502	Portage River
2	9376	041000100704	Wolf Creek-Frontal Lake Erie
3	20855	041000100501	Little Portage River
4	17864	041000100503	Lacarpe Creek-Frontal Lake Erie
5	15418	041000111404	Town of Lindsey-Muddy Creek
6	25766	041000100701	Turtle Creek-Frontal Lake Erie
7	19600	041000100603	Lower Toussaint Creek
8	22043	041000100602	Packer Creek
9	10260	041000100705	Berger Ditch
10	15433	041000111405	Town of Gypsum-Frontal Sandusky Bay
11	36957	041000100703	Cedar Creek-Frontal Lake Erie
12	36084	041000100702	Crane Creek-Frontal Lake Erie

Figure 6 HUC-12s relevant to ONWRC

Watershed characteristics and alterations

Understanding the constraints of water management within these drainage areas is particularly challenging, since anthropogenic impacts of Lake Erie and its tributaries are complex, far-reaching, and difficult to mitigate. ONWRC is influenced by the entire Lake Erie drainage basin, but development and agricultural impacts are severe when solely considering tributary watersheds directly draining through ONWRC lands.

According to the National Land Cover Dataset, the Toussaint/Portage drainage area is dominated by agricultural (~76%) and urban (~13%) land uses, with very limited forest (~4%), wetland (~4%), grassland (1%), and barren (1%) areas. Very similar land use statistics are reflected in the neighboring, hydrologically-influential Maumee River Basin. Both of these drainages have experienced recent (between 1992 and 2001) decreases in agricultural land cover, however have expanded in urban area at nearly the same rate, while experiencing little to no changes in forest and wetland coverage (Ohio EPA 2008). Assuming development continues at this pace, the region will face increasing ground and surface water demands, "flashier" watersheds due to higher impermeable surface cover, flood control challenges, and higher concentrations of anthropogenic-related threats to water quality. Surface water from the Great Lakes is widely used for domestic consumption, agriculture, energy production, and industry. In the last decade of the 20th century, the population of the Great Lakes watershed increased by 10% (Ohio EPA 2008), and demand for water is expected to increase with the population, even with consideration for the implementation of conservation measures (NOAA 2013).

Prior to extensive development, land cover across this part of Ohio included widespread elm-ash and beech forests, natural coastal marshes, bogs, and fens. However the landscape has since transitioned to a dominance of corn, soybean, hay, and grain production. The remaining forested areas have almost completely lost their elm and ash populations, however maple hardwoods still remain (USFWS 2014). Now these forest fragments vary significantly in composition, but common species include oaks and hickories with some cottonwoods, willows, American basswood, American beech, and black walnuts (USFWS 2014).

The sustainability of beach land cover in this area is an important habitat concern for ONWRC. These areas have been directly impacted by development activities in the area. Barrier beaches were once common offshore, naturally eroded and rebuilt in response to hydrologic and climatic processes, and separated the Lake from coastal wetland habitat, thereby providing adjacent marshland some degree of protection from Lake processes. After the widespread construction of dikes, seawalls, and other shoreline infrastructure, sediment transport dynamics were altered and the regional hydrology lost its ability to rebuild beaches, leading to further development of manmade shoreline protection. Because of this infrastructure, erosion rates have generally been described as moderate to slow along this stretch of the Lake Erie coast, but have been most significant in frontal barrier beaches (Ohio DNR 2012). CPNWR's sandspit has been particularly vulnerable, receding approximately 2,000 feet since the 1870s, though this may reflect migration of the bar rather than a permanent loss of material (Ohio DNR 2012).

With the loss of the area's natural hydrologic processes, dikes and similar structures now offer the only mechanism to continue protecting coastal wetland habitat in this area. Today, "natural" beaches across ONWRC's portion and adjacent stretches of Lake Erie are limited to areas where structures perpendicular to the coastline have allowed for deposition. The largest unarmored shoreline areas relevant to ONWRC are the barrier beach at the Toussaint Wildlife Area, and the beach areas near the Darby Division and Navarre Marsh (Ohio DNR 2012).

Topography

High resolution bare-earth Light Detection and Ranging (LiDAR) data has been processed for ONWR's acquisition boundary and limited surrounding areas (Capeder 2014) (Figure 7). Elevation data for CPNWR is presented with a 10 meter resolution by the National Elevation Dataset (Figure 8). LiDAR survey methods do not perform well in areas with dense vegetation and produce poor returns against water, so there may be inherent inaccuracies in datasets collected from wetland areas.

In order to improve the coordination of water level management of international waters, the U.S. and Canada developed the IGLD in 1955, which was revised in 1988, and will continue to be updated approximately every 30 years. This is the reference system used for ONWRC's elevation and water levels, and generally matches sea level. The North American Vertical Datum of 1988 (NAVD88) is the national standard in the U.S. and provides reference for vertical control surveying using a single, static point. Near the Complex, the difference between IGLD85 and NAVD88 is roughly 0.22 feet (i.e., IGLD85 = NAVD88 – 0.22 feet).

As shown in the datasets, the Maumee Lake Plains region of Ohio generally exhibits very flat-lying topography with low relief, except for several natural shallow depressions, sloughs, manmade ditches, and dikes. This landscape is remnant of the area's glacial past, when it served as a lake basin in front of retreating ice masses and allowed for the deposition of flat beds primarily composed of clay and silt. The area is scattered with some beach ridges, bars, dunes, deltas, low moraines, and clay flats. Together, the topography and geology of the region support a dendritic stream pattern draining into Lake Erie in a relatively gradual manner (WLEBP 2003). This contrasts the more dramatic transition commonly found east of the Columbus Escarpment, where shoreline cliffs border portions of the Lake. Across ONWRC, slopes near Lake Erie are shallowest near the CPNWR sandspit, and at the mouth of the Toussaint River.

The hydrology over this topography is unique in this region because the geology and tilting to the north facilitates drainage that does not follow a direct path downslope, and allows for differential movement of streams roughly 2.8 feet per mile (Sparling 1967).

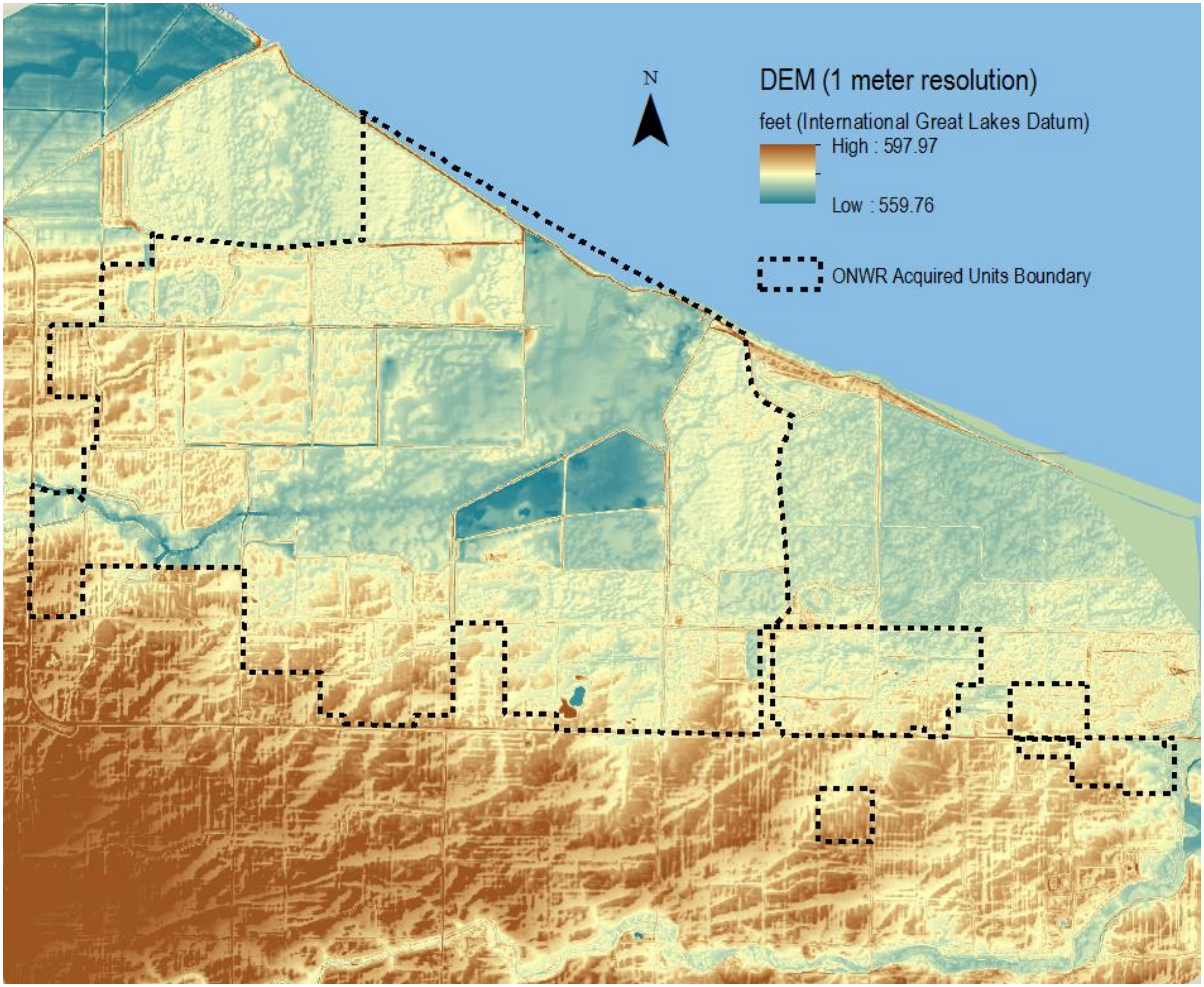


Figure 7 LiDAR data for ONWR

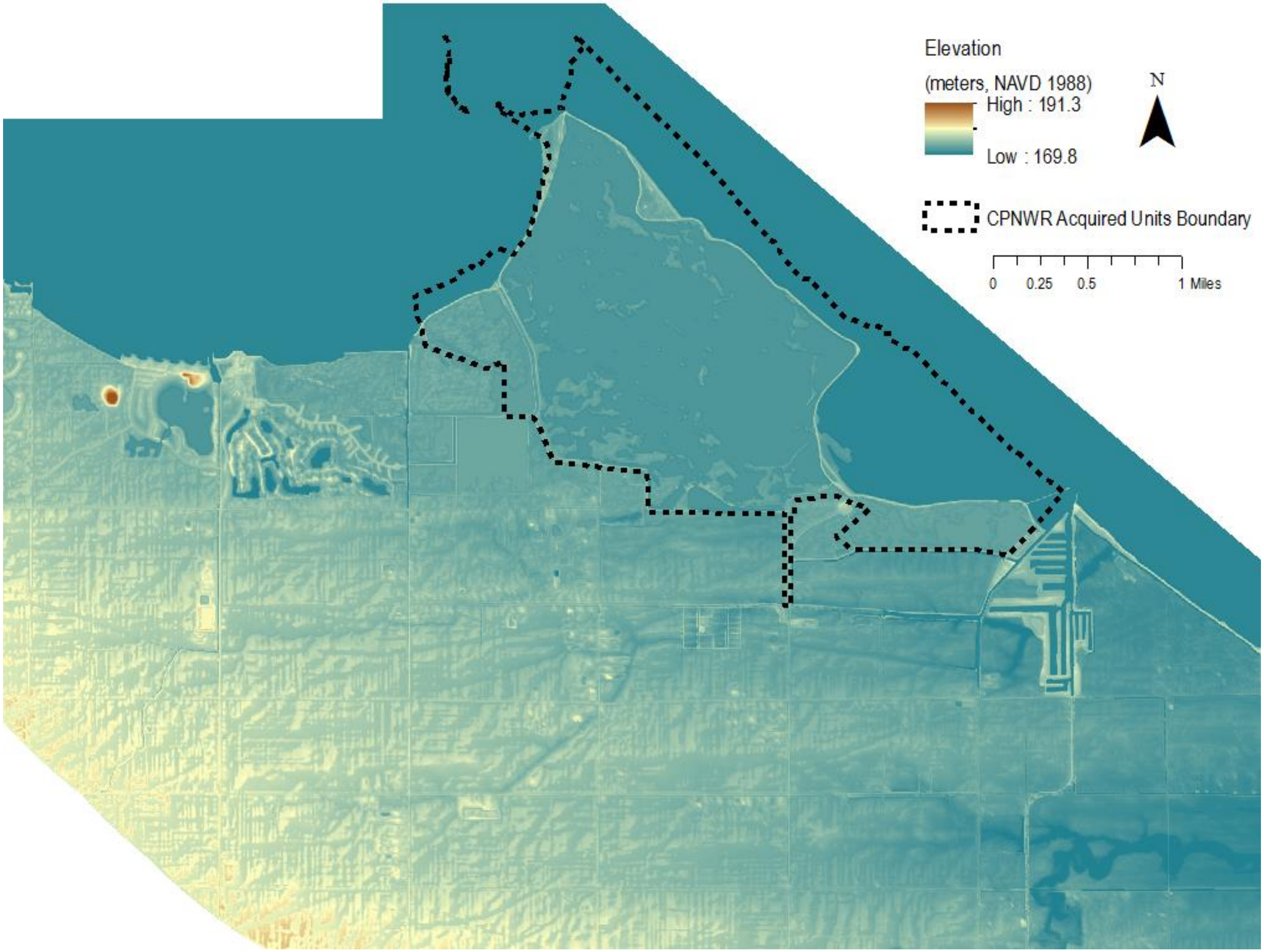


Figure 8 NED information for CPNWR

Geology

Much of northwestern Ohio's geologic makeup was shaped during the Pleistocene Period (2.5 million-11,000 years ago), when glaciers extended across the State. Glacial action during this time carved a wide, flat landscape, transported boulders, deposited silt, sand, and gravel, and packed poorly-sorted materials into a dense, impermeable layer. This set the stage for the formation of the Great Black Swamp, which occupied what was formerly the southwestern portion of the glacial 'Lake Maumee,' a Holocene era precursor to Lake Erie (Ohio DNR 1989). As the ice masses began to melt at the end of this period, meltwater and ice jams formed glacial lakes where fine sediments were deposited and large ridges were left behind. Roughly 14,000 years ago, beginning with Lake Maumee, a series of huge glacial lakes were formed in northern Ohio, ancestors to today's Lake Erie (Ohio DNR 1989). During this time water levels transitioned between approximately 12 different stages, from Lake Maumee's water level of roughly 800 feet (msl), down to approximately 470 feet (msl) for early Lake Erie (USFWS 2014). The lake area continued to grow and shrink for thousands of years before it evolved into the Great Black Swamp and modern Lake Erie, which reached its current stage, 571 feet (msl), roughly 3,500 years ago. In its wake it left sand dunes and high ridges dispersed across the marshland, some of which remain in the northwestern portion of Ohio, where the unique sandy soil supports tracts of oak savannah and grassland prairie.

In its current state, the bedrock surface topography in this part of Ohio *"depicts a glacially modified, fluvially dissected relict landscape on the rock surface,"* and ranges in elevation from 520-540 feet (msl) in areas underlying ONWR, and roughly 500-520 feet (msl) at CPNWR, over 70 feet below Lake Erie's average surface water elevation (571 feet, msl) (Shideler et al. 1996). The structure of the region's bedrock is controlled in part by the Findlay Arch, which segregates bedrock materials from the Appalachian and Michigan Basins. Outcrops of Lockport Dolomite occur here, and in several other areas near the Refuge (Sparling 1967).

ONWRC is part of the Huron-Erie Lake Plains of the Central Lowland physiographic province. In general, the geology of this area can be described as Pleistocene-aged clay, silt, and wave-planed clayey till overlying carbonate bedrock and shales from the Silurian/Devonian periods (Brockman 1998). For the most part, glacial and postglacial lake deposits of Holocene and late Wisconsin age comprise the surficial geology.

Soils

Soils evolve over time because of interactions between climate, organisms, and topography, but retain some underlying physical and chemical properties based on their original parent materials. These soil-forming factors can also be confounded by anthropogenic influences, and constantly work together to different degrees in changing the characteristics of subsurface material. The result is a complex mosaic of soils that varies on both geographic and temporal scales. There are inherent limitations, then, with classifying, delineating, and mapping such information.

According to the NRCS SSURGO database, the soils found across the ONWRC have common characteristics (Figure 9). The Toledo series is found on lake plains of the late Wisconsin glacial event, and is the primary soil type found in Refuge wetland units. This clayey soil type consists of very deep, nearly level, very poorly drained soils (Figure 10) formed in glaciolacustrine sediments, which are sediments deposited by glacial meltwater in lakes, including ice margin lakes or other types formed from glacial erosion or deposition. Sediments in the bedload and suspended load of meltwater streams are carried into lakes and deposited.

The second most prominent soil type in the Refuge Complex, the Nappanee series, consists of very deep, somewhat poorly drained soils that are moderately deep or deep to dense till. They formed on wave-worked, clayey till plains, till-floored lake plains, till plains, and moraines of the Wisconsin glacial event.

Several sandy soil types common near the Lake Erie shoreline (Algansee, Oakville, and Glendora series) are also occasionally found within wetland management units and have been documented to facilitate seepage into inadequately-diked wetlands (Adams 1994), though currently the Refuges' ability to retain water in their impoundments does not seem to be an issue. Sand deposits are greatest near CPNWR and near the Port Clinton embayment southeast of ONWR (Ohio DNR 2012).

When Refuge wetlands are inundated over long periods, the soils typically evolve into a mucky material with high organic matter content and can be consolidated through dewatering and occasional exposure. It is important to consider these substrate changes while exploring future unit-Lake reconnection projects. Though these connections will expand fish habitat, improve nutrient cycling and offer numerous other benefits to the ecosystem, they could also increase turbidity, make dewatering less convenient, and limit emergent vegetation growth. For these reasons, management on ONWRC attempts to maximize design elements to control for potential changes in Lake Erie stage levels and climate change. All reconnections have the management capacity to be closed and isolated from Lake Erie as needed to allow for substrate consolidation and reestablishment of emergent vegetation.

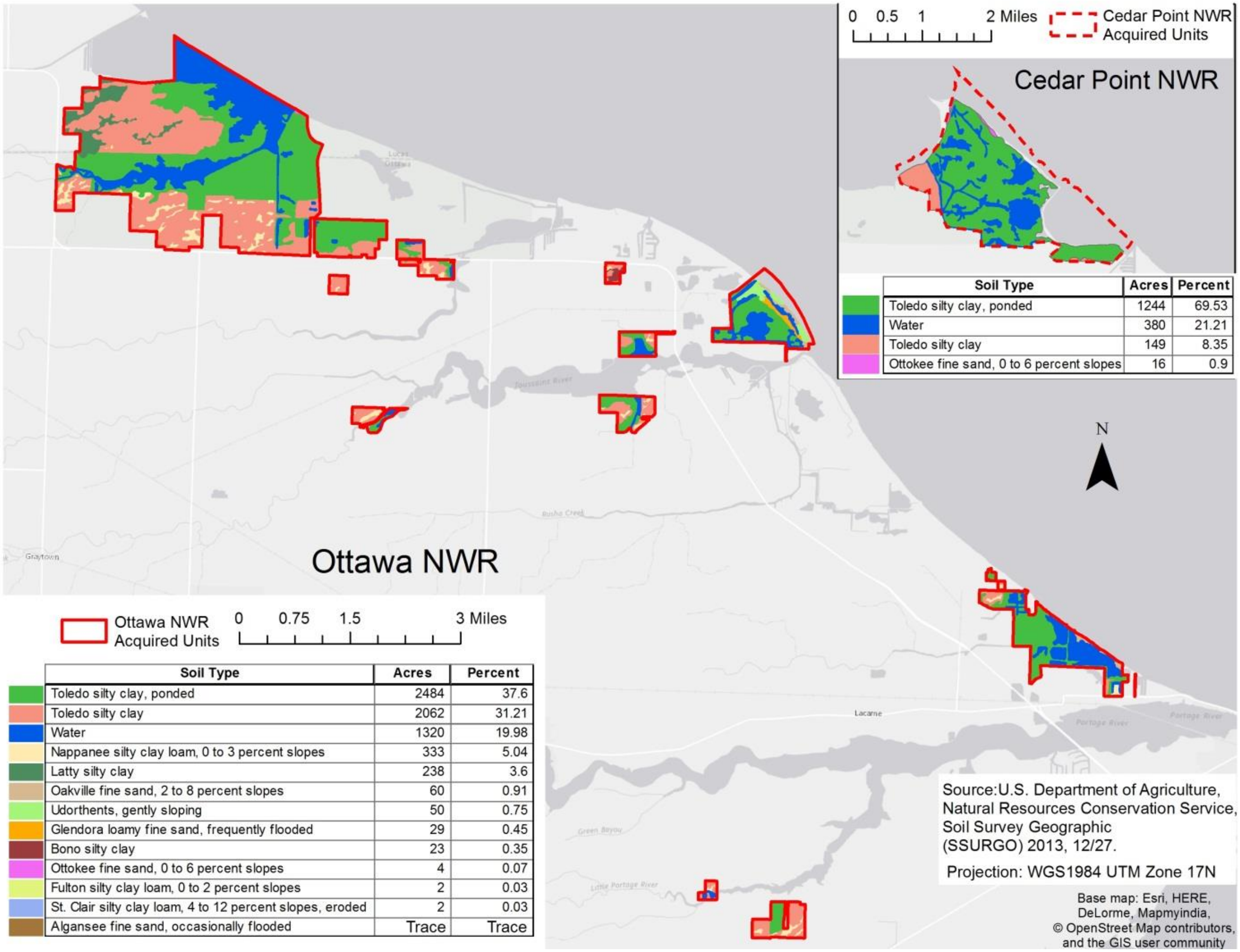


Figure 9 Soil types within ONWR's and CPNWR's acquired boundary. Note: Boundary pictured differs from actual management boundary, particularly in the Navarre Marsh area.

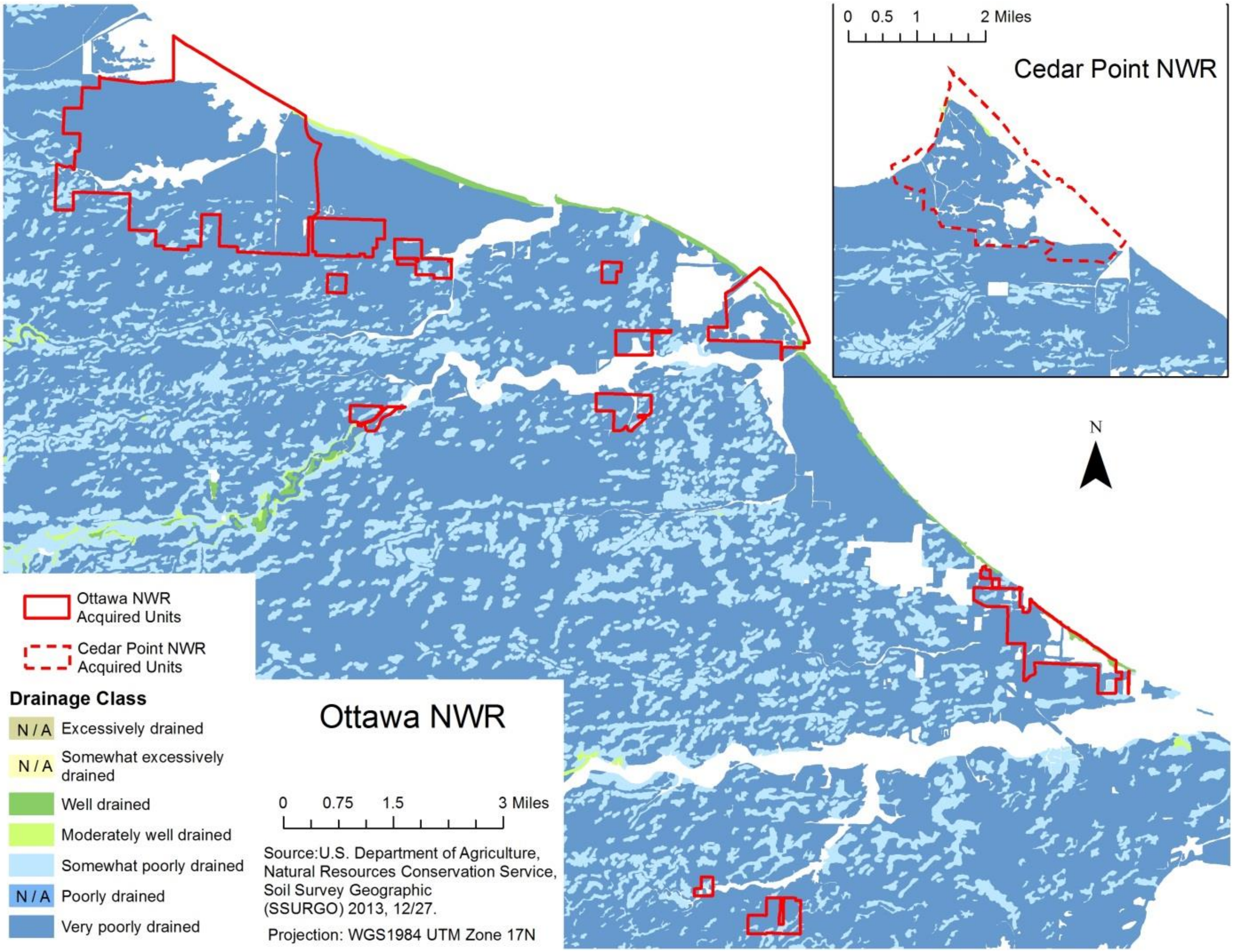


Figure 10 Soil drainage information relevant to ONWR and CPNWR. Note: Boundary pictured differs from actual management boundary, particularly in the Navarre Marsh area.

Climate

Climate is defined within the WRIA as the typical precipitation and temperature conditions over years or decades. Climate trends and patterns will affect groundwater levels, lake levels, river runoff, flooding regularity, flooding magnitude, and drought conditions. The WRIA provides a broad overview and analysis of trends and patterns in precipitation and temperature for the region of the Refuge. This section describes ONWR's current climate, specifically in the context of the HCDN, which provides a description of changes in the region's hydroclimate. PRISM and USHCN datasets offer additional details of recent climate patterns. The climate section also summarizes historic climate trends, projections for the future, climate-related changes seen in Lake Erie, and additional hydrologic implications.

There are a number of models and studies that have evaluated current and anticipated trends in the Midwest, which provide supplementary information and a more comprehensive analysis of large-scale climatic conditions (e.g. Hayhoe et al. 2010, NOAA 2013, UCS 2009, Groisman et al. 2005).

Current Climatic Conditions

In general, climate of the Great Lakes region is largely driven by temperature differentials and alternating air flows from the Gulf of Mexico, Canada, and the Northern Pacific. The water temperatures of the Great Lakes also have an effect by regulating the region's weather patterns, creating lake effect snow, and increasing local precipitation. Average high temperatures in lakeshore areas, where ONWRC is located, are approximately 1.5°F cooler than areas roughly seven miles inland, while average low temperatures are 2.9°F cooler in inland locations (USFWS 2014). ONWR typically experiences 3 or fewer extreme heat days (temperatures above 95°F) because of these temperature moderation effects of Lake Erie, while other parts of the Midwest experience more frequent hot days (NOAA 2013). This function of the Lake can, at times, delay extreme cold conditions in the winter, or cause a later spring thaw.

The climate near the southwestern basin of Lake Erie is characterized as humid continental with relatively large temperature differences between seasons, typically hot summers and at times severely cold winters. Bouts of both wetness and dryness are common, with precipitation well-distributed annually, but highly variable year-to-year (USFWS 2014). On average, the Refuge experiences 33 inches of rainfall per year, and 16 inches of snow annually (USFWS 2014).

Prism and USHCN Datasets

Weather information was obtained for ONWR (41°37'22.3"N 83°13'18.0"W) using the PRISM (Parameter-elevation Relationships on Independent Slopes Model) Data Explorer*. PRISM is an analytical tool that uses point data, a digital elevation model, and other spatial data sets to generate gridded estimates of monthly, yearly, and event-based climatic parameters, such as precipitation, temperature, snowfall, degree days, and dew point* (http://www.wcc.nrcs.usda.gov/climate/prism.html).

The PRISM interpolation method provides spatial climate information for the conterminous United States. This grid is created with temperature and precipitation datasets and accounts for potential variation with elevation. Other orographic, topographic, and atmospheric factors are also considered in this model. The PRISM information applicable to ONWR was used to compare data obtained from a station from the U.S. Historical Climatology Network ([USHCN]; Menne et al. 2012). The USHCN is a network of sites listed by the National Weather Service, which maintains standards in quality and continuity of data collection. The closest USHCN station is located in Tiffin, Ohio, roughly 40 miles south of the Refuge.

The average monthly temperatures and precipitation interpolated from the PRISM dataset are similar to those recorded at the USHCN station in Tiffin. However, the climatic variability in this region may cause some discrepancies between the stations, especially considering the USHCN station is located a significant distance to the south of Lake Erie, a major driver of the local climate. The two datasets follow the same general precipitation patterns, however precipitation at the Tiffin site is slightly more variable, with high-magnitude events more likely throughout the year, especially from May-September.

Average monthly temperatures on the Refuge range between 25.2 degrees Fahrenheit in January to 73.8 degrees Fahrenheit in July, according to the PRISM interpolation (Figure 11), and seasonal average, minimum, and maximum temperatures for autumn are apparently consistent throughout the period of record at ONWR (Figure 12).

Monthly precipitation averages generally range between 2-4 inches throughout the year near Tiffin, OH (Figure 13). May-July are usually the wettest months, while February is usually the driest, though precipitation is relatively consistent throughout the year. Monthly precipitation may total over 5 inches at any time of the year, and precipitation over 6 inches has been recorded through summer and early fall months.

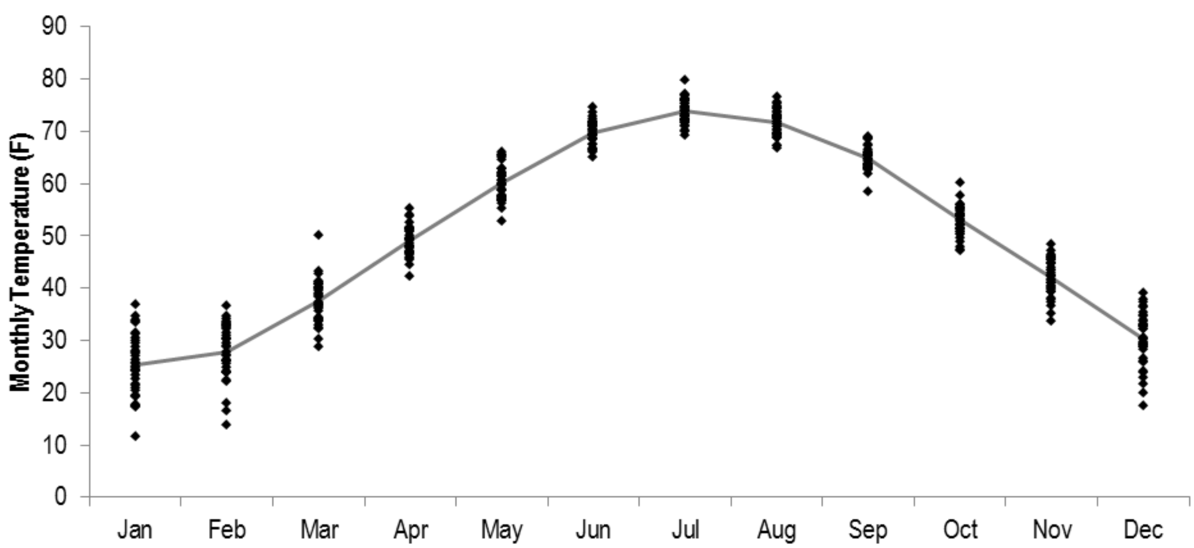


Figure 11 Monthly average mean temperatures 1975-2012 (x-coord: -83.221668 y-coord: 41.622869)

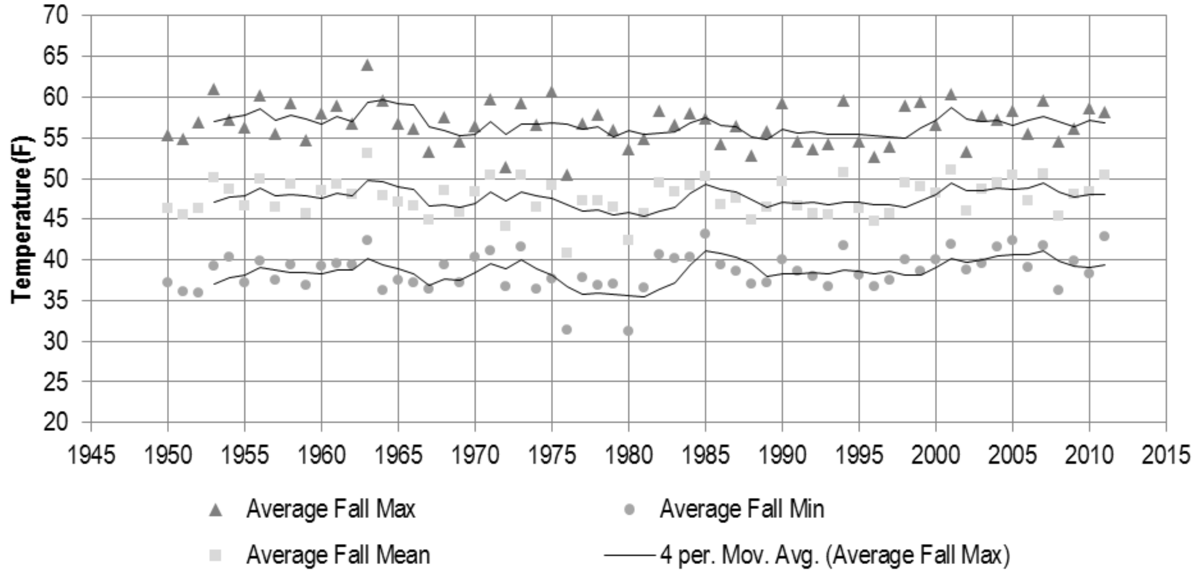


Figure 12 Seasonal average temperatures for autumn at ONWR (x-coord: -83.221668 y-coord: 41.622869)

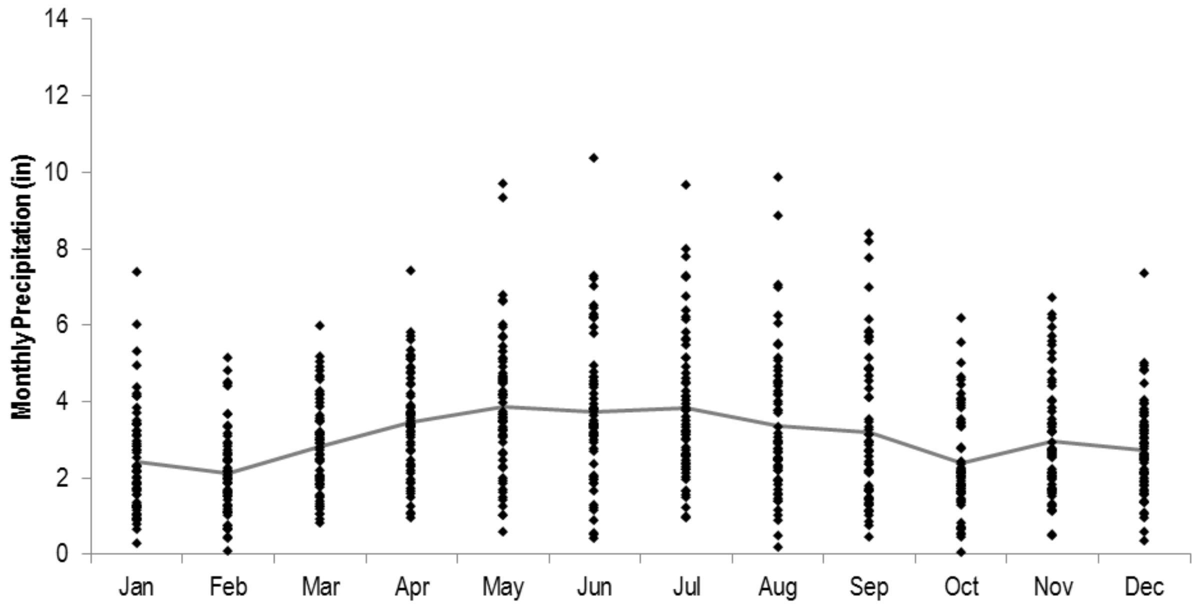


Figure 13 Monthly precipitation data site 338313, TIFFIN, Ohio from 1950-2011 (source- MJ Menne CN Williams Jr. RS Vose NOAA National Climatic Data Center Asheville NC

Hydro-Climatic Data Network (HCDN)

A reference hydrograph obtained from the Hydro-Climatic Data Network (HCDN) provides additional context for the assessment of surface water quantity patterns (see surface water quantity discussion in water monitoring section). The HCDN is a network of USGS stream gages located within relatively undisturbed watersheds, which are appropriate for evaluating trends in hydrology and climate that are affecting flow conditions (Slack et al., 1992). This network attempts to provide a look at hydrologic conditions without the confounding factors of direct water manipulation and land use changes. Peak discharge, average annual discharge, and annual monthly discharge trends were compared for this analysis.

USGS 04198000 (Sandusky River near Fremont, OH) is the closest site that meets the criteria for the HCDN and provides the most relevant comparison of surface water trends. Simple linear regression shows a statistically significant increasing trend in average annual discharge for this site (Figure 14), as well as a statistically significant increase in peak annual discharge (Figure 15). These findings suggests recent wetter conditions may be explained, at least in part, by more frequently-occurring high-magnitude events.

The increases in both the magnitude and frequency of high-magnitude events observed at this gage are likely attributed to changes in the local climate in addition to more direct influences, such as land and water use changes. Refuge waters are likely responding to similar changes in climate. However, since no significant trends exist in the most recent half of the dataset, hydrologic conditions on the Sandusky River, and other important tributaries to the Refuges and Lake Erie, currently appear to be relatively stable. At this point, these findings indicate more of a step-increase in both total and peak flow, rather than a continually increasing trend.

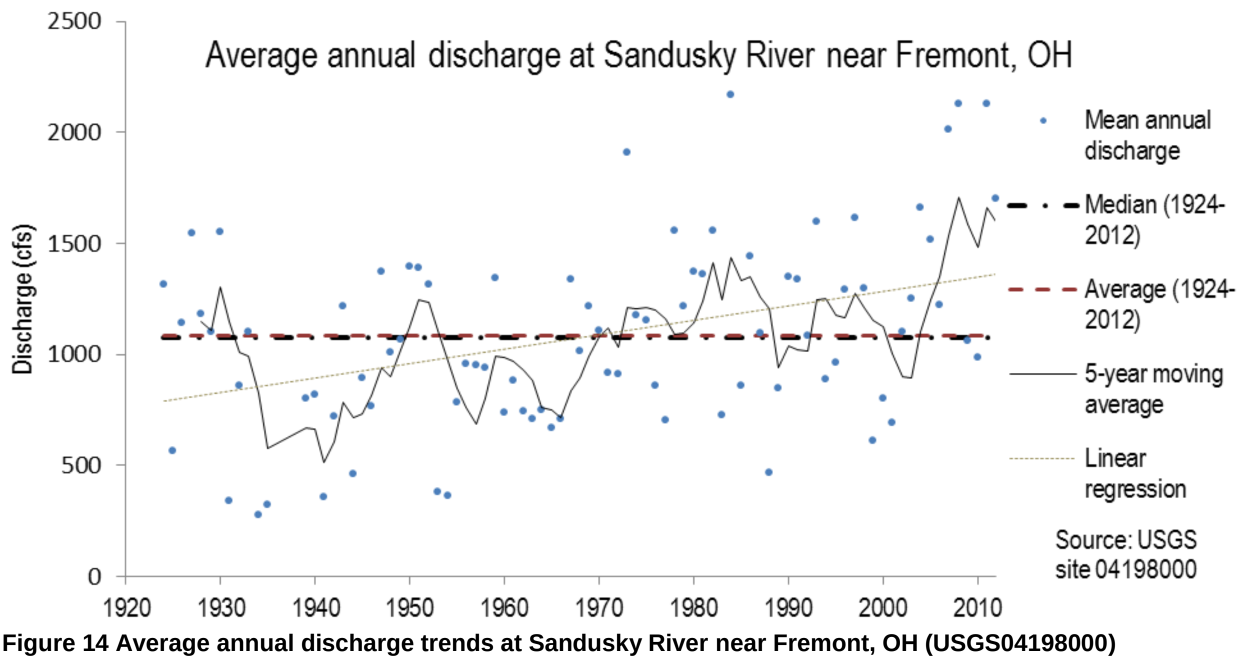


Figure 14 Average annual discharge trends at Sandusky River near Fremont, OH (USGS04198000)

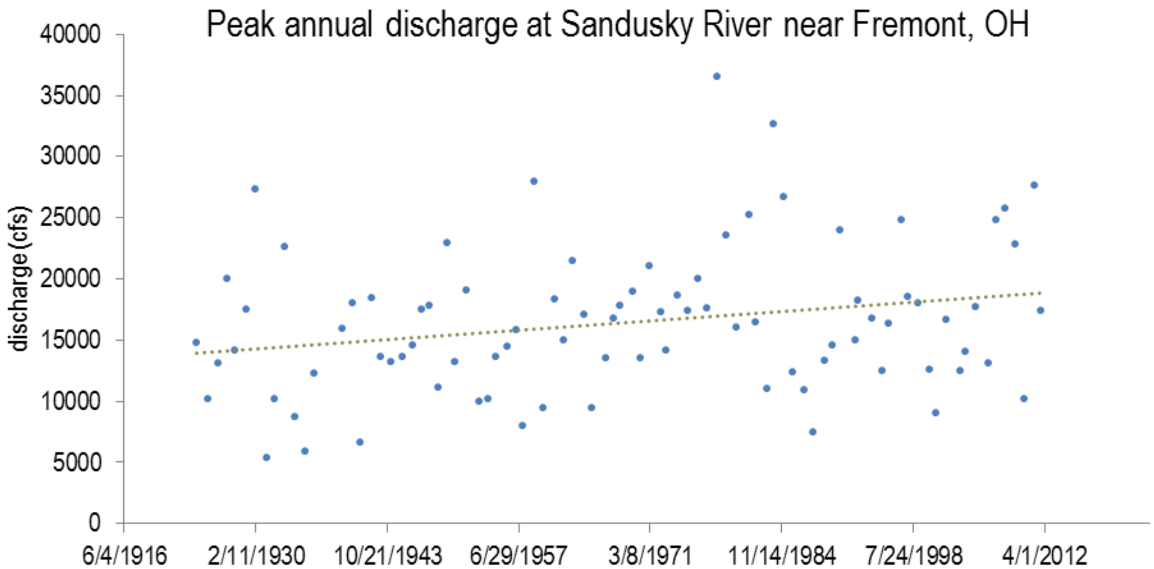


Figure 15 Peak annual discharge trends at Sandusky River near Fremont, OH (USGS04198000)

Past climate trends throughout the Great Lakes Region:

Historic records of weather and climate near Toledo, Ohio are discussed in detail by Hutter (1952). Temperature and precipitation patterns typically cycle over the long term, which creates challenges in drawing conclusions based on historical data for a given location. However, observations from regional climate reports are summarized below and provide some context for what may be expected in the immediate future. Some of these observations are outdated, and trends may have since changed.

- The number of frost-free days has increased between 1951-2010 (USDA 2011).
- Though no trend was observed in average autumn temperatures at the PRISM site (Figure 12), observations on a broader scale, in the Great Lakes Region, have shown significant increases in average fall and spring temperatures, later freeze dates, and decreases in total frozen periods (Jensen et al. 2007, Magnuson et al. 2000).
- Several recent heat waves have occurred in 1995, 1999, and 2006 (Palecki et al. 2001), and a shift from frequent to infrequent cold periods was experienced between the 80's and 90's (DeGaetano and Allen 2002).
- Average snow depth and average consecutive days with snow have both generally decreased, however lake-effect snow for areas downwind of the lakes have increased through the 20th century, likely because of higher surface water temperatures and decreased ice cover (Burnett et al. 2003). ONWR is not located in a major hotspot for lake effect snow, so this observation is not particularly relevant to the Refuge.
- Annual precipitation has increased between 1951-2010, demonstrated by an increase in the number of days with total precipitation exceeding 1.25 inches (USDA 2011).
- Climate data in Northwestern OH indicates there has been an increase in 1-2.49 inch precipitation events since 1970 (Midwestern Regional Climate Center 2012).

- Recent wetter conditions have been documented in the region by more frequent 100-year storms and an increase in the total number of rainy days (Kunkel et al. 1999), as well as increases in the 24-hr and 5-year storms since the beginning of the 20th century (Andresen et al. 2012).
- Since autumn precipitation has increased in the Great Lakes region, streams have generally responded by increased average and minimum discharges rather than higher annual peak flows (Small et al. 2006), though in northwestern Ohio specifically, significant increases in both average and peak discharges have been observed (see HCDN discussion).

Future climate predictions

By the end of the century, climate models predict the Great Lakes region will generally become warmer and drier in the summer, and winter and spring are expected to become significantly wetter than current conditions, especially in Ohio and other states south of the Great Lakes (Hayhoe et al. 2010, Winkler et al. 2012). Average summer temperatures could increase in this part of Ohio by more than 3°F by the end of the century under high emission scenarios, or by approximately 1.5°F under lower-emission conditions (UCS 2009). Spring precipitation events could become more intense, while summer precipitation rates may decline while evaporation rates increase (Magnuson et al. 1997, Lofgren et al. 2002).

Climate models using both low and high CO_2 emission scenarios predict a significant decrease in the average number of snow days per year by the end of the century (Hayhoe et al. 2010). The proportion of the year without frost is expected to continue to increase as well (USDA 2011). Similarly, some models suggest a continued increase in the proportion of the winter that is ice-free, possibly up to 61% more by 2030 (Stefan and Fang 1997), and a reduction of lake-effect snow by 50-80% by 2100 (Kunkel et al., 2002).

Lake Erie water levels and temperatures

This section provides a summary of past observations in the western basin of Lake Erie in the context of climate factors. A general description of Lake Erie water quantity and relevant monitoring locations on the Lake is provided in the Water Resource Monitoring Section (see Lake Erie Water Resources).

Just as Lake Erie is a strong controller of its surrounding microclimate, climate change will continuously influence the Lake’s ecosystem and physical structure. There are many variables at play that dictate Lake Erie’s water levels, some of which include ice cover, thermal expansion, groundwater impacts, consumption and other anthropogenic influences, sedimentation, backwater effects, and evaporation processes. The Lake is also strongly affected by seiches, which are temporary changes in lake levels driven by wind and atmospheric conditions. During a seiche, lake water can flow into tributaries, changing flow and water levels several miles upstream. Refuge water levels are clearly impacted by these events, though the effect is attenuated inland (see Water Quantity Section).

Though the various factors at play complicate attempts to isolate climate-driven impacts to Lake Erie, this section offers a brief summary of recent observed changes in the Lake’s hydrology and discusses them in the context of the region’s hydroclimate.

Lake Erie has generally been warming, especially in the summer. Surface water temperatures of the Lake were higher on average between 2005-2013 compared to temperatures between 1995-2004, especially between the months of May-August (USEPA 2014, NOAA 2014). Similar surface water temperature trends have also been documented on a longer temporal scale, since the 1970s, while average annual ice cover has reportedly decreased (NOAA GLERL 2012). The Lake's annual evaporation rate has been noted to have increased as well, especially between the late 1960s to present.

Reduced duration and extent of ice cover on lakes and rivers have been documented in this region on both local and global scales (Magnuson et al. 2000, Kling et al. 2003). Jensen et al. (2007) reports that changes in ice breakup dates and declines in ice duration within the Great Lakes Region are occurring most rapidly at lower latitudes, including areas relevant to the Refuge. This suggests that the southwestern portion of Lake Erie and inland waterbodies may be especially sensitive to changes in air temperatures, compared to waters in other locations within the Great Lakes Region.

Lake Erie's seasonal water cycle has been shifting in response to climate factors, particularly in response to changes in the timing and magnitude of runoff and precipitation in the area. Water level responses have been consistent with climate change expectations, such as increased fall evaporation rates and a larger fraction of precipitation falling as rain (Gronewold and Stow 2014). Water level fluctuations in 2011 and 2012, for example, behaved unexpectedly. The Lake's monthly average levels rose 2.6 feet between February 2011-June 2011, which is a more dramatic rise than ever before measured. Another increase of 0.6 feet occurred between November and December 2011, which is abnormally high for that season, and the longest continuous water level decline followed from December 2011-October 2012 (Gronewold and Stow 2014).

Lake Erie's water levels have been slightly above average between 1970s-2000, however recent levels have generally been consistent with the average since 1918 (NOAA, 2013) (Figure 16). The September 2014 Great Lakes Basin Hydrology report indicates that Lake Erie levels were 5 inches above the long-term average in the month of August (ACOE 2014). Surface water elevation seems to be particularly sensitive to changes in precipitation inputs, as indicated by high levels following especially wet years in long term datasets, and lower levels following years with lower-than-average precipitation.

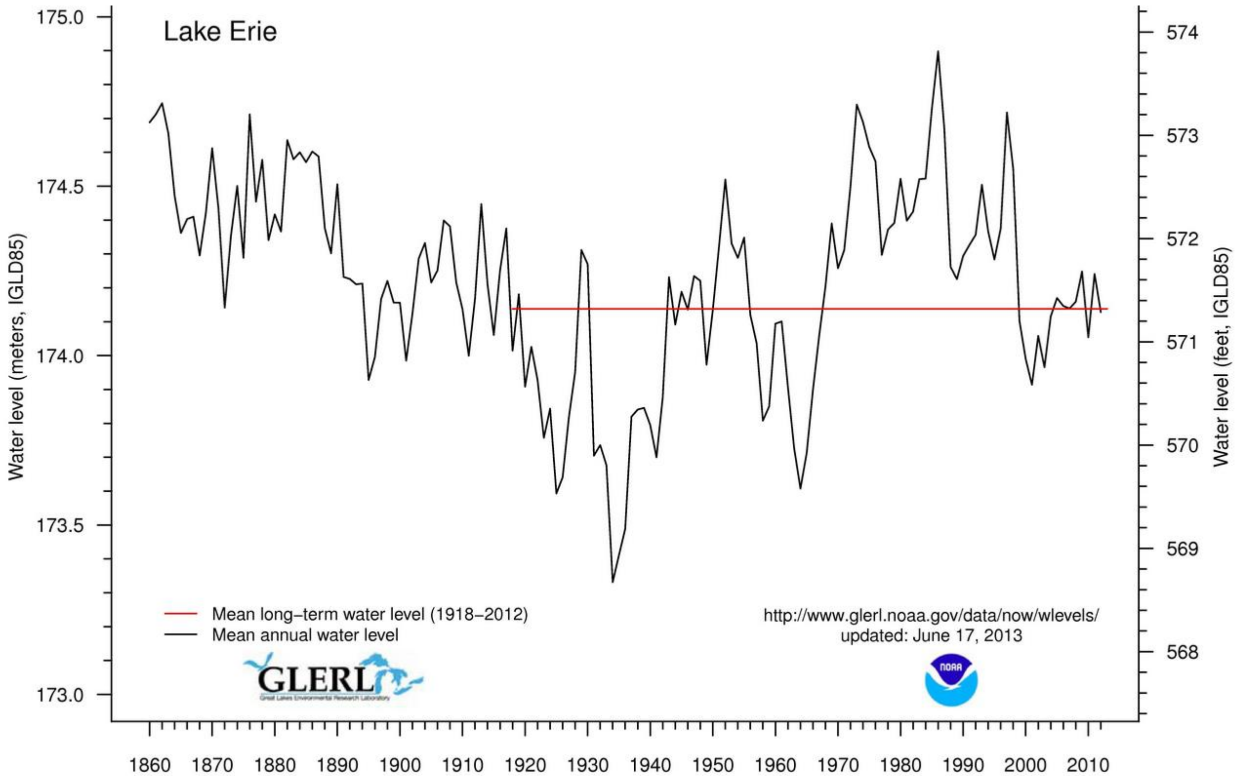


Figure 16 Average annual water level of Lake Erie at Fairport, OH (gage #9063053) (NOAA, 2013)

The NOAA NOS Lake Erie gage in Toledo, OH (#9063085, http://glakesonline.nos.noaa.gov/monitor.html) (Figure 16) offers additional information about the Lake's past trends, and ONWR staff relies heavily on this information to monitor both Lake levels relative to Refuge management units. Data trends since the 1970s provide the most valuable information related to Lake Erie's response to climate and water use changes. However, since Lake levels happened to be high in the 1970s, it is not clear if recent patterns are simply due to variations of normal, or if regional climate and water use changes are affecting the Lake. While records from 1970 (gage #9063085) indicate a statistically significant decline in average daily mean water levels for Lake Erie, levels have been relatively stable since 2001 and are consistent with historic stages (Figure 17). Longer records do not indicate any trend in lake levels, and current levels are still well-above minimum levels reached in the 1930s (less than 569.2 feet, IGLD 1983).

Water levels are projected by most models to decline (Lofgren et al. 2002), and could drop an additional 4-5 feet by the end of this century (NWF 2013). The USACOE provides monthly bulletins with six-month forecasts of water levels for each of the Lakes, as well as summaries of the basin hydrology. According to the September 2014 predictions (http://w3.lre.usace.army.mil/hh/ForecastData/MBOGLWL-erie.pdf), water levels are expected to be slightly higher than the average from historical records (1918-2013), at least through February 2015.

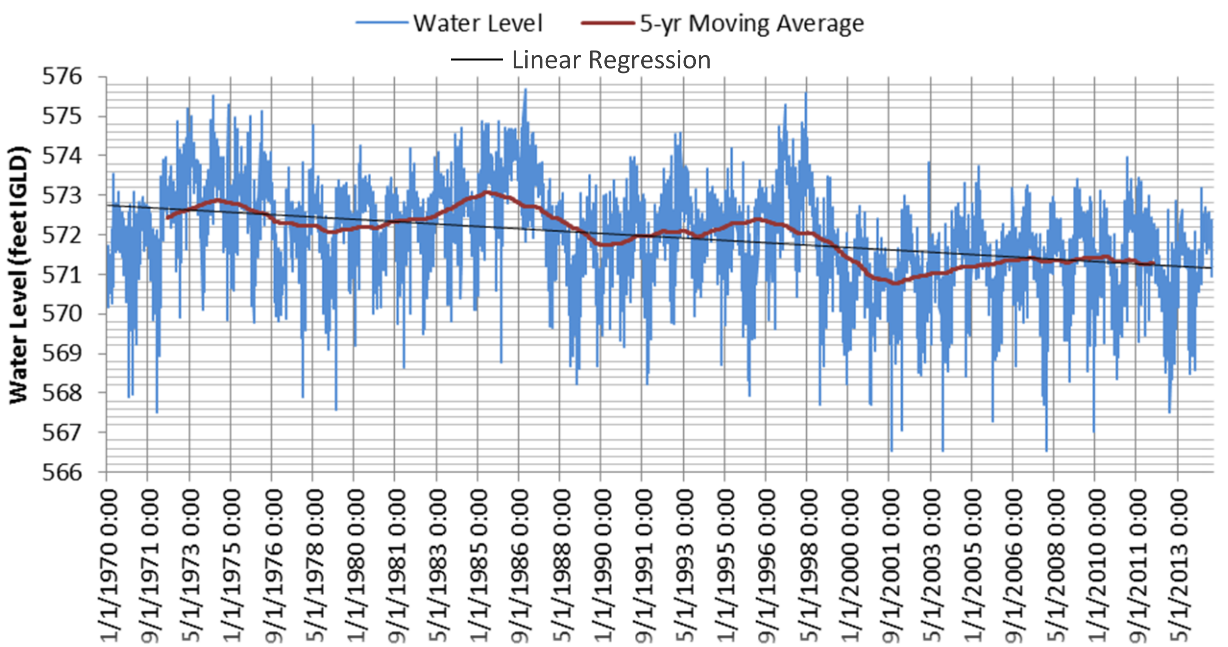


Figure 17 Daily mean water levels at Toledo OH (9063085) from 1970-2014

Lake levels have recently been elevated well-above long term averages, and there were four major seiche events in 2015, including one of extended duration from September 30-October 4 (R. Huffman, personal communication, Feb. 19, 2016). Specifically, the Toledo, OH gage reached levels between 575.58 ft and 576.1 ft (IGLD) from May 31-June1, June 27-June28, September 30-October 4, and December 28-December 29. The monthly average stage for July 2015 at the Toledo gage was 573.37 IGLD (R. Huffman, personal communication, Feb. 19, 2016). Under such extreme conditions, Refuge management is compromised, and various infrastructure limitations may need to be addressed to improve ONWRC's water management capacity when Lake levels are high (See Water Resource Management Units section for detailed observations from 2015).

Implications

Climate-specific impacts are difficult to distinguish from the many variables controlling Lake Erie's water level, and population change projections will further-confound attempts to decipher the cause of changes to the Lake's net water supply and physical characteristics. The current understanding of climate projections and their implications on Lake Erie water levels in this area is that warmer winters will result in more evapotranspiration, but spring and fall will be wetter in general, so inland runoff during these wet seasons will provide water to offset Lake losses to a degree. The evapotranspiration increases, however, are expected to eventually exceed changes in precipitation, leading to a net loss in Lake supply. However, this is not what has been seen to date. On an annual scale, increases in evapotranspiration have not resulted in water level declines, and the Lake and its tributaries have actually experienced net gains despite temperature changes. This suggests that Lake levels may be more sensitive to precipitation patterns than anticipated by climate models, and recent increases in extreme events, and consequently runoff and ground absorption, may be contributing. If projections hold true and Lake stages do experience declines, there will be serious water quantity and quality implications for ONWRC and Lake Erie.

The Lake will likely experience reductions in water clarity and increases in nutrient loads due to more intense spring precipitation events, or at least a continuation of current concentrations even with conservation measures in place. This would create favorable conditions for more frequent and longer-living algal blooms, including harmful algal blooms (HABs) of cyanobacteria, which produce microcystin (a toxin that threatens drinking and irrigation water, as well as the general ecosystem). Warmer surface water conditions, shorter winters, reduced ice cover duration, and earlier temperature stratification throughout the Lake profile will only continue to exacerbate HAB issues, and a higher concentration of decaying biomass will decrease dissolved oxygen levels and expand the Lake's hypoxic, "dead zone" area and duration (Blumberg and DiToro 1990). Of the five Great Lakes, Lake Erie is particularly sensitive to these processes (Mortsch and Quinn 1996).

Lake Erie has already demonstrated increasing susceptibility to large algal blooms between 2002-2013 (Obenour et al. 2014), and one of Lake Erie's most serious blooms in 2011 likely occurred because of high phosphorus loads delivered by abnormally-high spring precipitation, followed by a period of weak circulation and warm surface waters (Michalak et al. 2013). In general, spring phosphorus loads provide an effective metric to predict future algal bloom sizes through the following summer and fall in Lake Erie (Obenouer et al. 2014, Ohio EPA 2013, IJC 2014, Stumf et al. 2012). Invasive mussels exacerbate HAB issues to some degree as well. For example, the invasive zebra mussel is abundant in the Lake prefers to feed on non-threatening algae species (i.e., that do not produce biotoxins such as microcystin) rather than more problematic cyanobacteria, thereby reducing competition for the cyanobacteria and increasing the likelihood of uncontrollable growth of a single, threatening species (Vanderploeg et al. 2001). Conflicting studies make it unclear whether invasive mussels will benefit or be harmed by anticipated climate changes in Lake Erie.

Climate change factors have been identified as major drivers in Lake Erie HAB issues, possibly with more weight than other, more-easily managed anthropogenic factors such as infrastructure and sewage overflow issues (Michalak et al. 2013, Obenour et al. 2014). With this in mind, the Ohio Phosphorus Task Force's current recommendation—a 47% phosphorus reduction from northwestern Ohio tributaries / 37% reduction from the Maumee River—may not be enough considering the increasing sensitivity of the system with respect to climate change (Obenour et al. 2014). ONWR's water resources are particularly sensitive to these issues since the Western Basin has such a shallow depth and high nutrient loads delivered from the Maumee River; the Lake's largest tributary by area, which has more than doubled its dissolved reactive phosphorus loads since 1995 (NWF 2013).

Besides HAB concerns, impacts to wetlands present additional climate change implications to note. In general, these ecosystems may be adversely impacted by lower water levels, earlier spring thaws, hotter summers, larger floods, higher sediment infilling rates, and degraded water quality. However there also lies some potential to offset climate-related threats. The likely future decline in lake stage in this already-shallow lake will expose new littoral-zone wetland habitat that may, to some degree, replace functions of currently-existing wetlands at risk of degradation by climate change factors, and help offset the many direct current and future threats to Lake Erie itself. This includes the potential exposure of wetlands on shoreline areas that are currently developed, filled, or altered in some way. There may be future possibilities, then, to increase the proportion of Lake Erie coastline as protected wetland habitat, and possibly encourage preservation of coastal lands even outside Refuge boundaries. Unfortunately, it is highly likely these areas are vulnerable to phragmites, narrow leaved cattail, or other invasive species establishment without significant input of control efforts. If so, these wetland areas would not offset the functions of wetland areas lost in other areas of the Refuge. Currently, USFWS ownership reaches the high water mark. If the high water mark declines, ownership may extend, which could open opportunities to protect and manage these areas.

In summary, on an annual scale increases in evapotranspiration have not actually resulted in lower water levels, as would be expected, however some climate warming scenarios still anticipate decreases in Lake and tributary water levels, especially in the summer due to less precipitation and higher evapotranspiration during these months (Magnuson et al. 1997, Lofgren et al. 2002, Kling et al. 2003). Assuming these projections hold true and the Lake experiences significant declines in the long term, there will be serious water resource implications for ONWRC. Lower stages and higher Lake temperatures will aggravate the already-existing HAB, oxygen depletion, and invasive species issues. Perhaps with more direct significance to Refuge management, ONWRC may need to draw from alternative water sources, such as groundwater or additional surface water connections, to sustain the hydrology of existing management units, most of which currently do not have a direct connection with the Lake but still rely heavily on its stage.

Water Resource Features

Crane Creek

ONWR's primary tributary input is Crane Creek, an agricultural drainage which is typical of small streams in the Midwest. This drainage has a direct influence on Refuge waters and important coastal habitats on the Lake. Some of the sub-watershed's characteristics and flow statistics are summarized below for the entire drainage area (Crane Creek mouth), as well as contributing drainages to two water resource monitoring locations (Crane Creek at HWY 2 and Crane Creek at Opher Lentz Rd (Table 1). This information was derived using elevation, land cover, climate, and other datasets, rather than from monitoring activities. Additional estimated statistics, as well as the associated geospatial information (watershed polygons and pourpoints), will be uploaded to the WRIA database.

Drainage Point	Crane Creek Mouth*	Crane Creek at HWY 2*	Crane Creek at Opher Lentz Rd
Area (sq. miles)	57	44.6	39.3
Slope (feet per mile)	2.96	3.49	3.49
Streamflow variability index at outlet	0.616	0.613	0.608
Forest coverage in drainage area (%)	3.56	3.68	3.73
Wetland/water coverage in drainage area (%)	8.97	1.25	1.28
2-year discharge (cfs)	873	974	881
5-year discharge (cfs)	1170	1410	1230
10-year discharge (cfs)	1360	1700	1530
25-year discharge (cfs)	1570	2020	1830
50-year discharge (cfs)	1710	2250	2040
100-year discharge (cfs)	1850	2480	2240
500-year discharge (cfs)	2140	2950	2670

* Crane Creek Mouth and Highway 2 discharges and recurrence intervals are influenced by seiche events.

Table 1 Watershed characteristics and flow statistics for 3 points on Crane Creek

Water Management Units

Dramatic water level fluctuations of Lake Erie call for active management approaches to protect Refuge resources from sudden drawdowns and flooding. This includes use of pumps, gravity flow, extensive dike systems, and other structures to ensure the availability of water year-round. As a result of this heavy management system, many of the units have little or no connection to Lake Erie. This limits their functions for flood control, spawning habitat for fish, and nutrient cycling between the marsh and Lake ecosystems. To address these issues, several restoration and Lake Erie reconnection projects have been completed or are underway within ONWRC to improve water quality and benefit the ecology of the Lake and contributing subwatersheds. For example, portions of the Toussaint River and Crane Creek floodplains have been targeted for expansion and hydrologic reconnection to help restore natural cover, water retention capacities, and improve water quality in ONWRC. Specifically, restoration activities for Metzger Marsh, Blausey Tract, Pool 2a, Pool 2b, Ottawa Pool 1, and Cedar Point Pool 1 have incorporated actions to reconnect spawning habitat with Lake Erie hydrology.

Besides Lake Erie, alternative water sources aid water management activities to a small degree during summer months when evapotranspiration may exceed precipitation rates. These surface water inputs and ditches include Crane Creek, Tank Ditch, Lindsey-Limestone Ditch, Radar Ditch, LeCarpe Creek, Toussaint River, and West Ditch. In the vicinity of ONWRC, most of these tributaries are drowned river mouths without discernable flow, and the depth and extent of these areas are almost entirely driven by changes in Lake water levels. The small proportion of water in these areas that originates from these tributaries rather than the Lake, has primarily coursed through agricultural land and carries nutrients, pesticides, and other chemicals. This is an important consideration if future Lake water levels require water to be drawn from other sources to sustain ONWRC's management units. Other alternatives are discussed later in the WRIA (see Aquifer Characteristics).

ONWRC wetland units are generally managed to maintain productive habitats to support the natural life cycles of migrating waterfowl, wading birds, shorebirds, and other wetland species. Water level management strives to mimic cycles of open water, submerged, and emergent vegetation required by important wildlife that use the Refuge for reproduction and feeding. On a rotational basis, unit water levels are usually drawn down during the growing season to promote growth of vegetation and invertebrate populations, and raised in the fall to maximize waterfowl habitat. Each unit's management plan is modified as necessary to eradicate invasive plants, encourage habitat diversity, or stimulate vegetative growth.

ONWRC's main tracts include WSINWR, CPNWR, ONWR – main tract, ONWR – Navarre Marsh, and ONWR – Darby Unit (Figure 18). Information from the HMP about each Refuges' units and acreage are provided below, however the CCP and HMP provide additional information about wetland and Refuge management activities at ONWRC, including specifics about each impoundment (USFWS 2000, USFWS 2014). In addition, water management and moist soil unit plans for ONWRC are available through the USFWS ServCat database (reference codes 5901 and 7412).

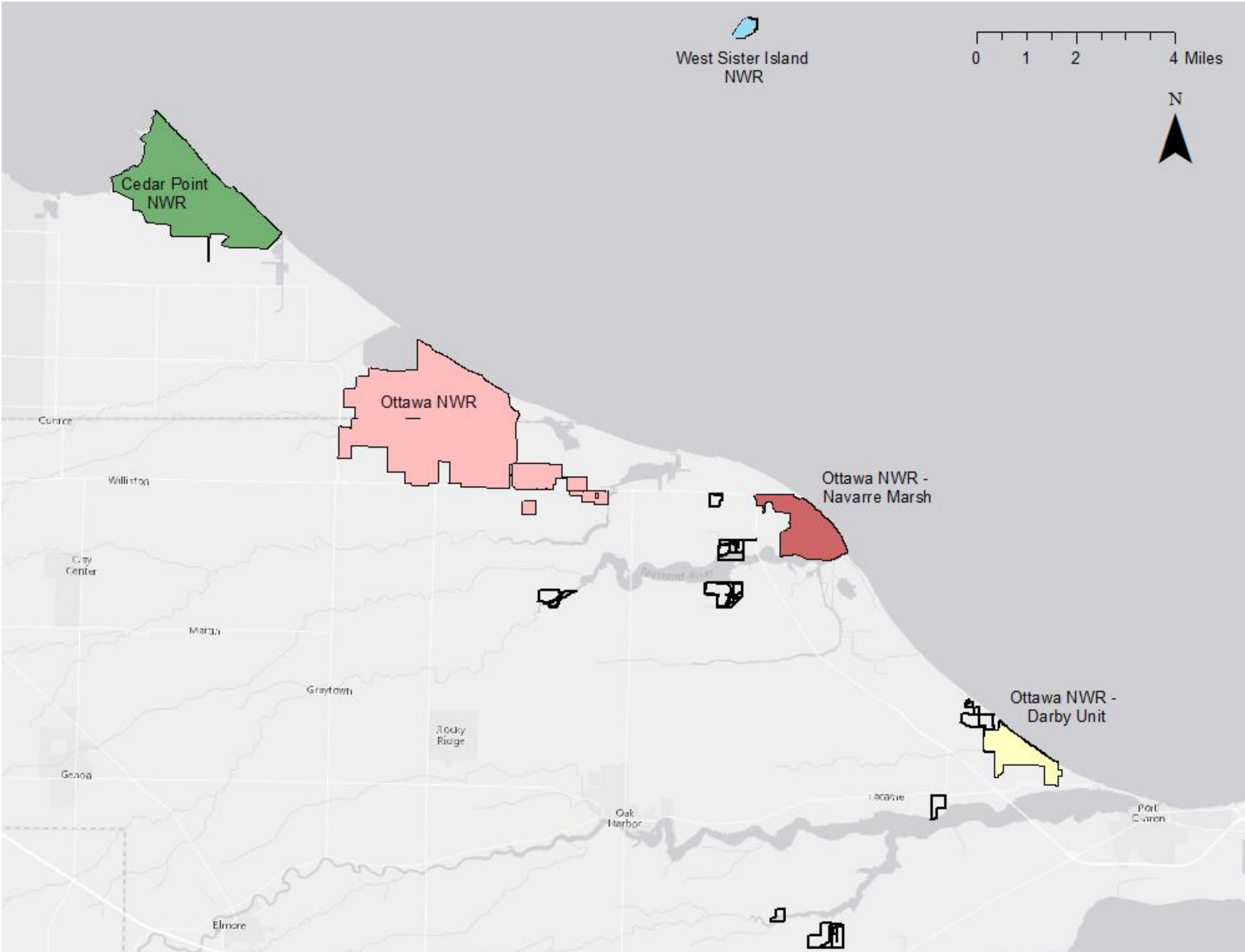


Figure 18 ONWRC's main management units

Ottawa National Wildlife Refuge

ONWR includes 26 separate wetland impoundment units, and its main tract expands across 4,902 acres. This includes the original coastline acquisition, as well as more recent property expansions including Diefenthaler, Roe, Kontz, Hemminger, and Boss units.

As described in the HMP, portions of the Crane Creek Estuary intersect the main, 4,902-acre tract (Figure 19). The Estuary provides 900 acres of habitat for important resources of concern. Its direct connection to the Lake allows for fish access, mussel habitat, and water quality benefits that are not present in other hydrologically-disconnected Refuge units (USFWS 2014).

The Navarre Unit is 635 acres in size, is managed as three different wetland pools (Figure 20), and includes one of Western Lake Erie's largest beach ridge forests. This property is co-managed with First Energy and water control is primarily passive to avoid impacts to the Davis-Besse Nuclear Power station. As a result, USFWS's ability to control vegetation and other ecosystem components is somewhat limited in this portion of ONWR (USFWS 2014).

ONWR's Darby Unit expands across 644 acres and its originally-acquired tract is separated into four management units (Figure 21). Young and Drusbacky Tracts are also part of the Darby management area. Inputs to the 4 Darby Unit from LaCarpe Creek are controlled by a ditch and pump station (USFWS 2014).

Other fragmented tracts across ONWR's limited acquisition boundary include Schneider, Helle, Gaeth/Kurdy, Blausey, Knorn, Burmeister, Price, and Adams Units totaling 693 acres and primarily located along the riparian zones of Turtle Creek, Toussaint River, Little Portage River, and Portage River (USFWS 2014). Of these, the Blausey Unit is the only area with managed wetlands, including a pump station and fish passage structure (Figure 22 and Figure 23).

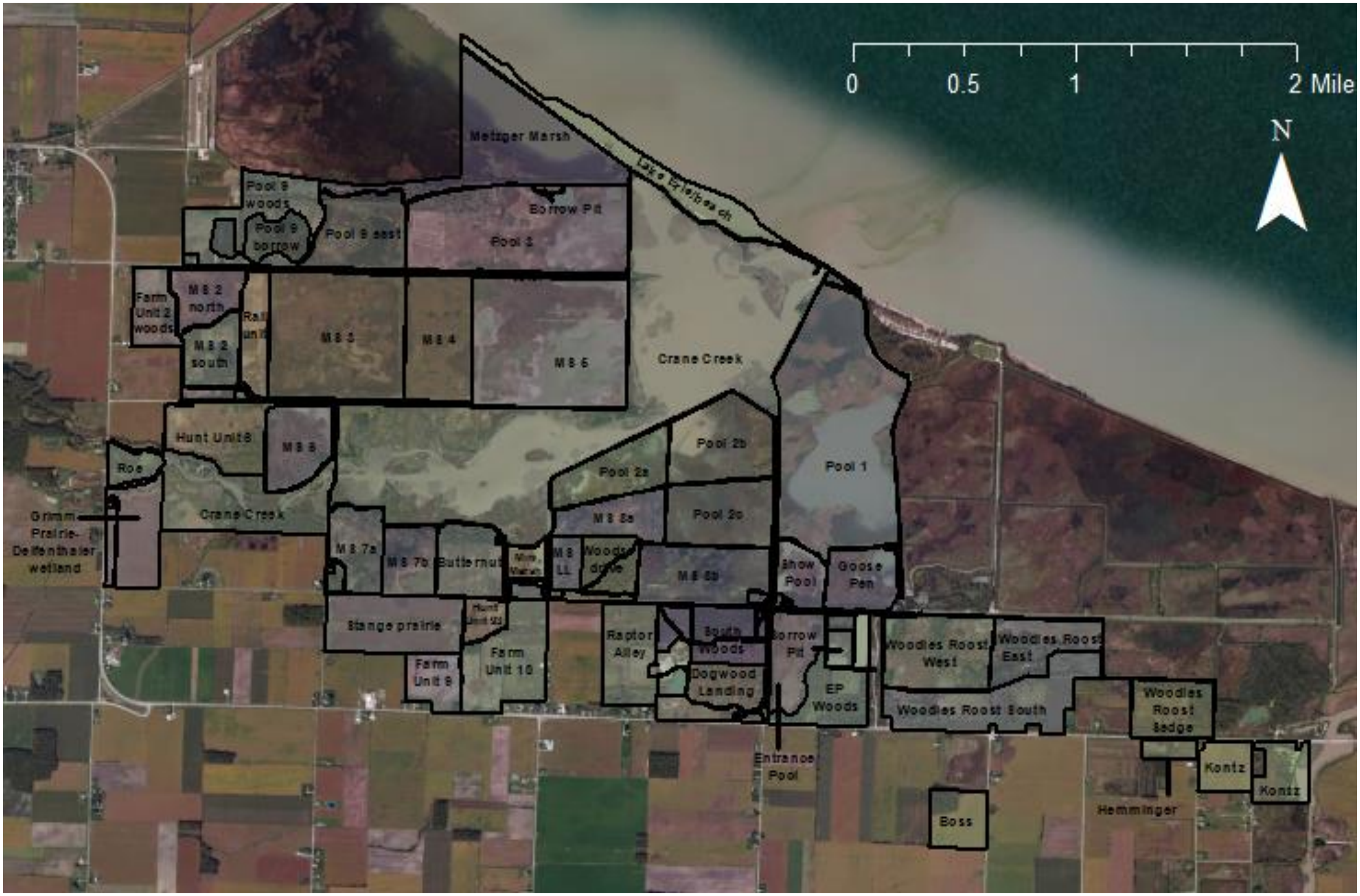


Figure 19 Properties within or near ONWR's main tract

Figure 20 Properties within or near ONWR's Navarre Marsh Unit

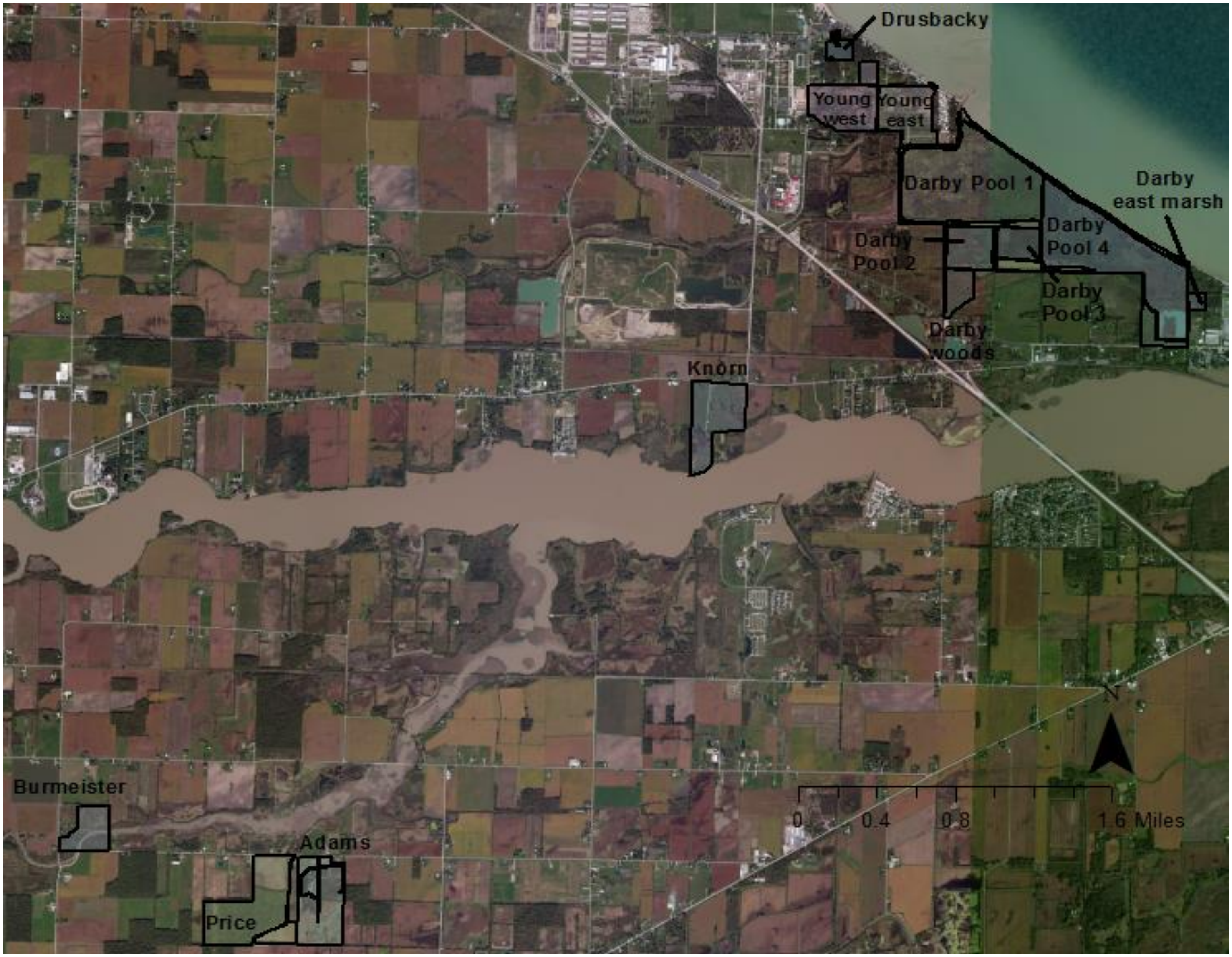


Figure 21 Properties within or near ONWR's Darby Unit

Figure 22 Ottawa NWR Complex, Blausey Unit fish passage and ladder to Toussaint River, completed 2013.

Figure 23 Ottawa NWR Complex, Blausey Unit fish ladder in operation. Stop logs allow wetland unit to be managed at a variety of water levels while maintaining connectivity for fish.

Cedar Point National Wildlife Refuge

CPNWR is currently managed as three different marsh pools totaling 2,646 acres (Figure 24). The largest of these, Pool 1, is 1,444 acres in size, representing Western Lake Erie's largest area of contiguous fringing marsh habitat and home to Ohio's largest wild rice population (USFWS 2014). This Pool contains CPNWR's only pump structure, and the Great Lakes Restoration Initiative will fund the construction of a fish passage structure in 2015 (USFWS 2014). The Potter's Pond Unit and Lake Erie open water additionally make up 777 acres of this Refuge, and Pool 2 has an expanse of roughly 155 acres.

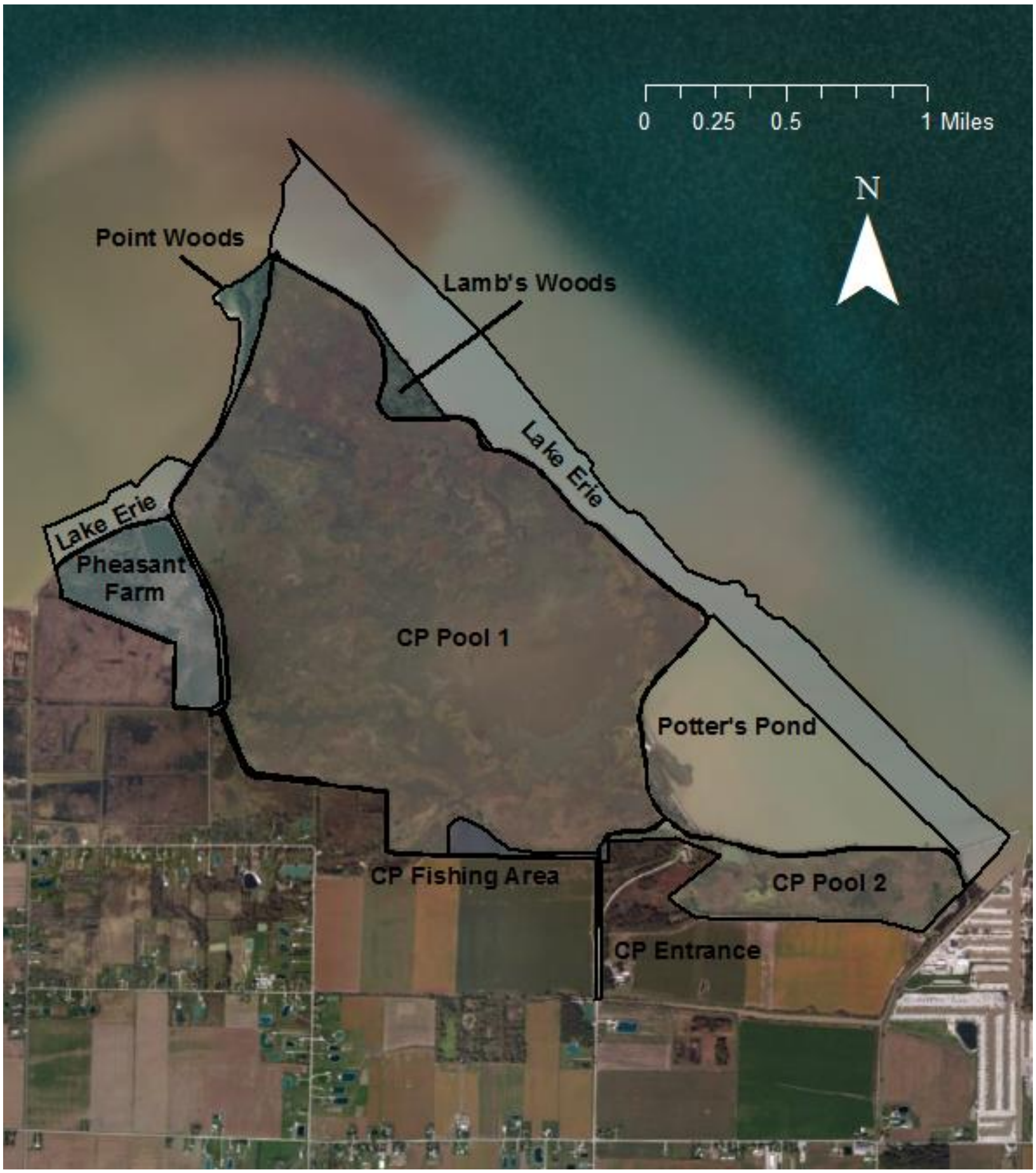


Figure 24 Management units within CPNWR

West Sister Island National Wildlife Refuge

Approximately 75 acres of the 80-acre WSINWR is owned by USFWS, and is a designated Wilderness Area. The Island provides the largest nesting grounds in the U.S. portion of the Great Lakes, and "*large numbers of great blue heron, great egret, black-crowned night heron, and double-creasted cormorants nest on the island, along with small nesting populations of herring gull, cattle egret, and snowy egret. The occasional little blue heron nest is also observed"* (USFWS 2014).

As noted in the executive summary, WSINWR lacks the water features and active management typically included in the WRIA effort. As such, it is not a focus in this report. The section describing the Lake Erie water levels and temperatures provides the most relevant information to WSINWR habitat conditions.

Infrastructure and WCSs on ONWRC

Since the construction of jetties to stabilize the canals used to drain the Great Black Swamp, infrastructure has been ever-present across western Lake Erie and its contributing watersheds. Today almost the entire shoreline has been developed with manmade structures, which have disrupted the transport of sediment, hydrology, and natural erosion/accretion processes of Lake Erie on broad scales. Now, the altered state of the Basin requires the use of dikes, levees, riprap, and other mechanisms to effectively control erosion and manage water levels. Infrastructure has in a sense replaced barrier beaches and other natural processes that were part of the Lake's natural hydrology prior to the introduction of infrastructure and other active management approaches.

On ONWRC specifically, water resource management incorporates the use of WCSs, drainage ditches, and infrastructure to manage isolated impoundments as well as pools with hydrologic connections to Lake Erie tributaries and Crane Creek. WCS types primarily include pipes, flap gates, screw gates, dual screw-flap gates, and stop log structures (USFWS 2014). Dual screw-flap gates are used in some units to facilitate a passive connection to the Lake. Eight different pump stations across the Complex are also used to pump surface water into several management units. The Great Lakes Restoration Initiative (GLRI) funds two other pumps which are utilized by ONWRC, and the pump used by ODNR to manage Metzger Marsh Wildlife Area is also used by USFWS.

Several infrastructure limitations across ONWRC were revealed during the four seiche events in 2015. For example, water backed up the Tank Ditch and overtopped Veler Road, flowing into Pool 9, Pool 9 east, and Pool 3 (R. Huffman, personal communication, Feb. 19, 2016) (Figure 25). Much of Stange Prairie and the adjacent ditch system were also flooded. Structure failure on the Lindsey-Limestone ditch allowed water to back flood around Mini-Marsh, and overtop the road, flooding the Butternut Woods and Visitor Center Woods areas. Repeated flooding occurred in the Dogwood Landing area east of the visitor center, as water flowed around the dike at the main entrance. Flooding also occurred at the Gaeth/ Kurdy refuge housing area, due to a significant hole in the coastal wetland dike. Further, significant erosion and loss of beach habitat occurred at CPNWR's Lamb's Woods beach, including loss of some trees (Figure 26). Similar effects were felt at Darby Marsh, and at Navarre Marsh, the area of sand beach ridge outside of the dike adjacent to the Toussaint River experienced significant beach erosion and loss of trees during through the seiche events of 2015 as well (R. Huffman, personal communication, Feb. 19, 2016).

Figure 25 Ottawa NWR, Lake Erie flooding over Veler Road into Pool 9 east and Pool 3, June 27, 2016. High Lake Erie water levels in 2015 in combination with strong northeast winds produced a high seiche event, peaking at 576.51 IGLD. Long term average Lake Erie water level is 571.33

Figure 26 Cedar Point NWR beach front erosion at Lamb's Woods. Natural loss of beach sand, shrubs, and trees occurred during 2015 as a result of high Lake Erie water levels and 4 major storm events. Such ecosystem disturbance processes are now largely severed from coastal habitats by armored dikes.

ONWRC manages an extensive assortment of WCSs on CPNWR and ONWR (see Appendix A), though no structures exist on WSINWR. Levees, Refuge roads, and ditches are also used across the Complex to manage water flow and levels and separate impoundment units. The inventory collected for the WRIA may be based on outdated information and requires additional review. An updated infrastructure inventory should be collected in the future and added to the WRIA database.

NWI

ONWRC's wetland tracts can be described with the National Wetlands Inventory (NWI), which is an extensive, ongoing survey by the U.S. Fish and Wildlife Service of aquatic habitats across the United States. This is a national published dataset, however its accuracy is limited, especially with respect to the classifications and acreage values. The NWI has not necessarily been verified with ground truth surveys and may be limited by the quality of the imagery used to derive the dataset. For example, the NWI information collected for ONWRC appears to overestimate riverine habitat, and may overestimate total acreage. Dominant habitat of the Complex is in reality represented by palustrine wetlands.

According to the NWI classification within ONWR's acquisition boundary, much of the mapped units are permanently-flooded riverine wetland systems, which contain slow-flowing water over low gradients or connect separate bodies of standing water (see Appendix B). A large portion of Complex habitat is classified as palustrine systems dominated by trees, shrubs, or emergent vegetation that persist through most of the growing season most years. These wetlands are semi-permanently and artificially flooded, often by dikes or manmade obstructions.

In terms of general wetland types, the NWI classified most of the acquisition boundaries for ONWR and CPNWR combined as freshwater emergent wetland. Additional information associated with wetlands relevant to the Refuges can be found in Appendix B.

NHD

The National Hydrography Dataset (NHD) is a vector geospatial dataset including information about the nation's lakes, ponds, rivers, streams, and other water features, part of the USGS's National Map. No NHD features were identified in the relatively small area retained by WSINWR. Within the acquired boundary for ONWR and CPNWR, the flowpaths identified by the NHD can be broken down based on type. The majority of the flowpaths were considered artificial paths, canal/ditch, or stream/river features, and most were too small to have been named in the dataset (see Appendix C for more details).

The NHD's inventory of "named features" is not necessarily all-inclusive, and some features may be mis-categorized. The NHD also provides an approximate representation of general water flow and does not necessarily reflect actual conditions.

A more comprehensive inventory of relevant information, including unnamed features, will be available through the WRIA database (https://ecos.fws.gov/wria/).

Aquifer characteristics

The Silurian-Devonian aquifer lies beneath ONWRC, and is primarily composed of limestone or dolomite, though some gypsum deposits are found in this region. These underlying formations were deposited between 400-450 million years ago and are covered by a layer of glacial till and lacustrine sediments. The ground moraine layer overlying the primary carbonate bedrock aquifer varies in thickness, and contains a heterogeneous mix of boulder, cobble, gravel, sand, silt, and clays. Aquifer thickness ranges roughly between 1,400ft-1,600ft near the Refuge, and there is high vertical flow in northwestern Ohio as a result of fractures in the tills, which allow flow to depths of 30ft in some areas (Bugliosi 1999). This water source generally yields water at rates between 25-500gpm (ODNR 2012). Regional groundwater movement generally flows from the southwest to the northeast and discharges into Lake Erie, with several local groundwater divides occurring locally between major drainages of ONWRC (Breen 1991).

The recharge, discharge, and transmissivity characteristics of the aquifer system in this region is relatively constant, indicated by uniform spacing between potentiometric surface contours (i.e. the imaginary "energy" surface level that illustrates the level to which water would rise if the confining unit were drilled with wells) (Breen 1991). A hydrologic connection between Lake Erie and the groundwater aquifer is also indicated by the flattening of these contours with increasing proximity to the southern shoreline to the Lake, though the Lake is not a significant groundwater recharge source based on water quality data. Instead, recharge primarily occurs from precipitation infiltration in karst areas in eastern Sandusky County, in areas where drift deposits are shallow (Breen 1991), or in areas with sand and gravel deposits. Toledo, Ohio obtains some water from the region's carbonate aquifer for municipal and other purposes, and this activity has decreased recharge to Lake Erie and drawn water from the Lake into the groundwater (USGS 2000). These withdrawals have also lowered groundwater levels in the area by as much as 35 feet below Lake levels. Since groundwater in this area is meeting municipal use standards, it may be considered for Refuge use as an alternative to surface water pumping, if future changes in Lake levels restrict gravity flows and require more active water resource management.

The quality of the regional groundwater should, however, be further investigated before this resource is drawn from. The most relevant groundwater quality sampling well is 402 feet deep in Lockport Dolomite aquifer, which is the deepest groundwater source of drinking water in the area (Figure 27). A cursory review of water quality data from this well (http://wwwapp.epa.ohio.gov/ddagw/Documents/sitesum/OTT00139ssf.pdf) reveals potentially-concerning levels of strontium, aluminum, and sulfate based on averages from 1987-2012. In addition, average total dissolved solid levels are above secondary maximum contaminant levels (causing cosmetic or aesthetic effects, such as taste). There have also been relatively high fluoride and sodium levels in nearby monitoring locations of Ohio's carbonate aquifer (Ohio EPA 2010a), as well as high arsenic concentrations (Ohio EPA 2012), so if future hydrologic conditions require ONWRC to investigate groundwater as an alternative water source, these issues, as well as the sustainability of groundwater use in this area, should be considered.

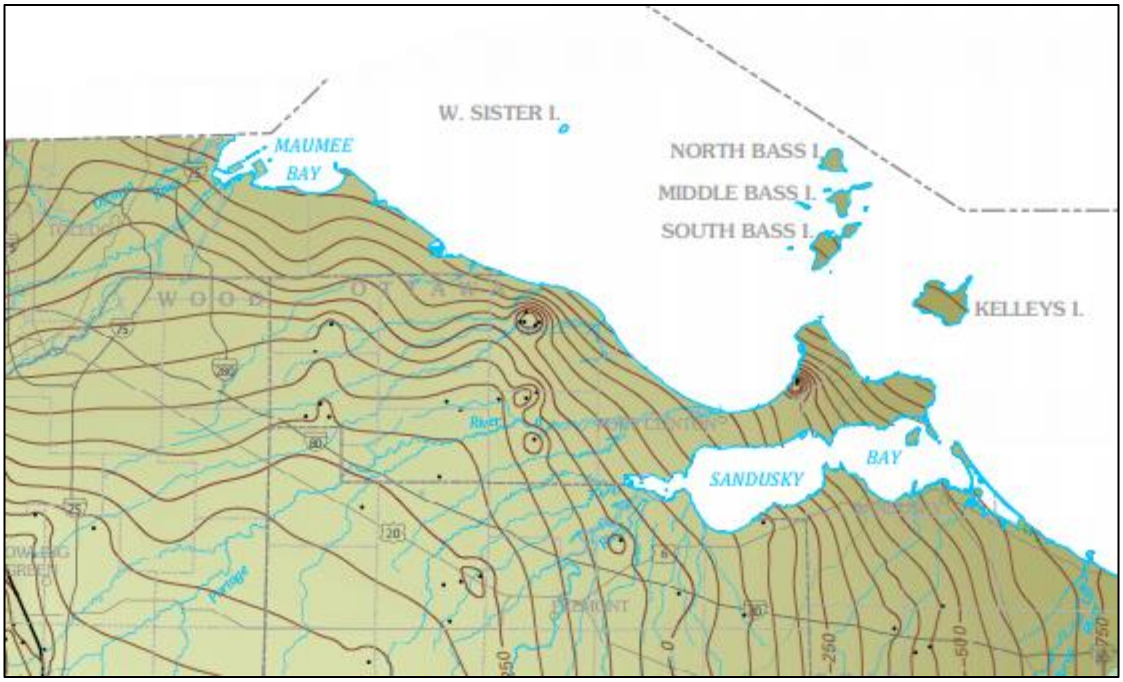


Figure 27 Elevation of the base of the region's deepest groundwater source (Lockport Dolomite aquifer) (Ohio DNR 2012, http://oilandgas.ohiodnr.gov/Portals/oilgas/pdf/EG-6_USDW.pdf)

Some consideration should also be given to the sole source aquifer (SSA) within ONWRC's 5,000-acre approval boundary. An SSA is a sensitive and/or valuable underground water supply, providing at least 50% of the drinking water for the overlying area. This designation is made by the EPA under Section 1424(e) of the Safe Drinking Water Act of 1974. The communities that rely on a SSA may lack alternative sources that could meet demands because of economic, legal, or physical constraints. The SSA relevant to ONWRC is the Bass Island Aquifer, near Catawba Island, which is relatively far from ONWR's main tract. Though ONWRC would not likely draw directly from this aquifer, future groundwater pumping activities should consider potential impacts to this resource.

Water Resource Monitoring

The WRIA identified historical and ongoing water resource related monitoring on or near the Refuges. Ground and surface water stations were considered relevant if located within the Refuge's HUC-10 and/or drainage areas adjacent to Refuge property. Relevant sites were evaluated for applicability based on location, period of record, extensiveness of data, sampling parameters, trends, and date of monitoring. Water resource datasets collected on the Refuges can be categorized as water quantity or water quality monitoring of surface or groundwater. Water quantity monitoring typically involves measurements of water level and/or volume in a surficial water body or subsurface aquifer. Water quality can include laboratory chemical analysis, deployed sensors or biotic sampling such as fish assemblages or invertebrate sampling. Biotic sampling is often used as an indicator of biological integrity, which is a measure of stream purpose attainment by state natural resources management organizations.

Potential water quality threats may be identified by comparing monitoring data with recommended standards. The EPA developed technical guidance manuals and nutrient criteria for the protection of aquatic life in various types of waters specific to different ecoregions. Those developed for rivers/streams and lakes/reservoirs for ecoregion VI are summarized below (USEPA 2000; Table 2). These criteria are relevant to individual streams and lakes identified within ONWRC's RHI, but do not apply to Refuge wetland units. Additional information related to the application of federal water quality standards and regulations to wetlands is provided by the EPA (http://water.epa.gov/lawsregs/guidance/wetlands/quality.cfm), however most states, including Ohio, have not developed specific water quality criteria for wetlands. The standards listed for lakes also may reflect different values than those established for Lake Erie.

Parameter	Lakes and Reservoirs	Rivers and Streams
TP (ug/L)	37.5	76.25
TN (mg/L)	0.78	2.18
Chl a (ug/L)	8.59	2.7
Secchi (m)	1.36	-
Turbidity (FTU/NTU)	-	6.36

Table 2 EPA Recommended criteria for lakes and reservoirs and rivers and streams in ecoregion VI (level III) (USEPA, 2000)

Ohio additionally lacks specific water quality standards for groundwater resources. Groundwater quality data may alternatively be compared to the National Primary Drinking Water Regulations "maximum contaminant level" and secondary standards for contaminants which cause aesthetic problems, rather than more direct health effects.

The EPA has compiled national recommended water quality criteria for roughly 150 pollutants (http://water.epa.gov/scitech/swguidance/standards/criteria/current/index.cfm) to provide guidance in developing state-specific standards. The development of state and federal water quality standards requires consideration for the existing and potential uses of water bodies. Different uses often require different levels of protection for specific pollutants. Water bodies may have several different uses associated with them, such as aquatic life and recreation, in which case criteria for each pollutant are determined based on the most vulnerable designated use (http://water.epa.gov/drink/contaminants/#List).

State water quality standards and the associated measurement methodology may be found in Chapter 3745-1 of the Ohio Administrative Code (http://epa.ohio.gov/dsw/rules/3745_1.aspx). These include standards specifically for Lake Erie and specific temperature criteria for the western portion of the Basin. Because the Lake is ONWRC's main source of water, the quality of Lake inputs relative to the appropriate standards is the most relevant to Refuge water resources.

Several resources offer water quality and quantity datasets relevant to the Refuge and were utilized in the creation of ONWR's water resource monitoring site inventory. For example:

- Data for historical sampling locations can be retrieved through the EPA STORET (STOrage and RETrieval; http://www.epa.gov/storet/) database. This data warehouse is a repository for water quality, biological, and physical data used by state environmental agencies, EPA and other federal agencies, universities, and private citizens.

- Water quality data for active and inactive monitoring sites can also be accessed from the USGS National Water Information System (NWIS) database (http://www.waterqualitydata.us/).

- USFWS conducted sediment and soil sampling in 2011 at units 2A, 2B, 2C, MS3, Pool 1, Blausey and Helle, and samples were analyzed for inorganics (Banda et al. 2015) (see Surface Water Quality section for summary of results).

- Data from two continuous water quality and quantity monitoring locations at ONWR (Crane Creek and Pool 2B) maintained by the USFWS (2009-2014, Pool 2B was discontinued in 2014, and only stage data has been recorded for Crane Creek as of 2014) is stored in the regional water monitoring WISKI database. Real-time data from the Pool 2B gage may be accessed online (http://amazon.nws.noaa.gov/cgi-bin/hads/interactiveDisplays/displayMetaData.pl?table=dcp&nesdis_id=FED06290). More information about these sites is detailed in the following subsections below.

- Synoptic nutrient sampling was conducted in 2012-2013 in order to collect baseline data and to evaluate the conditions of ONWRC's water resources. The datasets have been consolidated and can be found in the WRIA database.

- NOAA National Ocean Service maintains a network of 51 stations to monitor water levels, temperature, hydrology, and weather information related to the Great Lakes. Lake Erie water level station #9063085 in Toledo, OH and the current station on the Maumee River are the most relevant to Refuge resources (http://glakesonline.nos.noaa.gov/geographic.html, see Climate section for additional discussion). Station #9063053 east of ONWR in Fairport, OH provides additional relevant information.

Water Monitoring Stations and Sampling Sites

The WRIA identified 7 monitoring sites that are considered applicable to the Refuge's water resources, including 5 surface water monitoring sites and 2 groundwater monitoring stations (see Appendix D).

A list of 158 identified inactive sites that are relevant, but not necessarily directly applicable to the resources of concern, was also created and will be loaded into the ECOS WRIA application (https://ecos.fws.gov/wria).

Four USGS gages provide datasets that are especially relevant to ONWR and CPNWR water resources (Figure 28). These include three surface water gages and a groundwater monitoring station near Bellevue, OH.

ONWRC uses roughly 21 staff gages to monitor water level and/or flow at CPNWR, and ONWR's main tract, Blausey, and Darby Units (see Appendix E). All staff gages are surveyed to IGLD 1985.

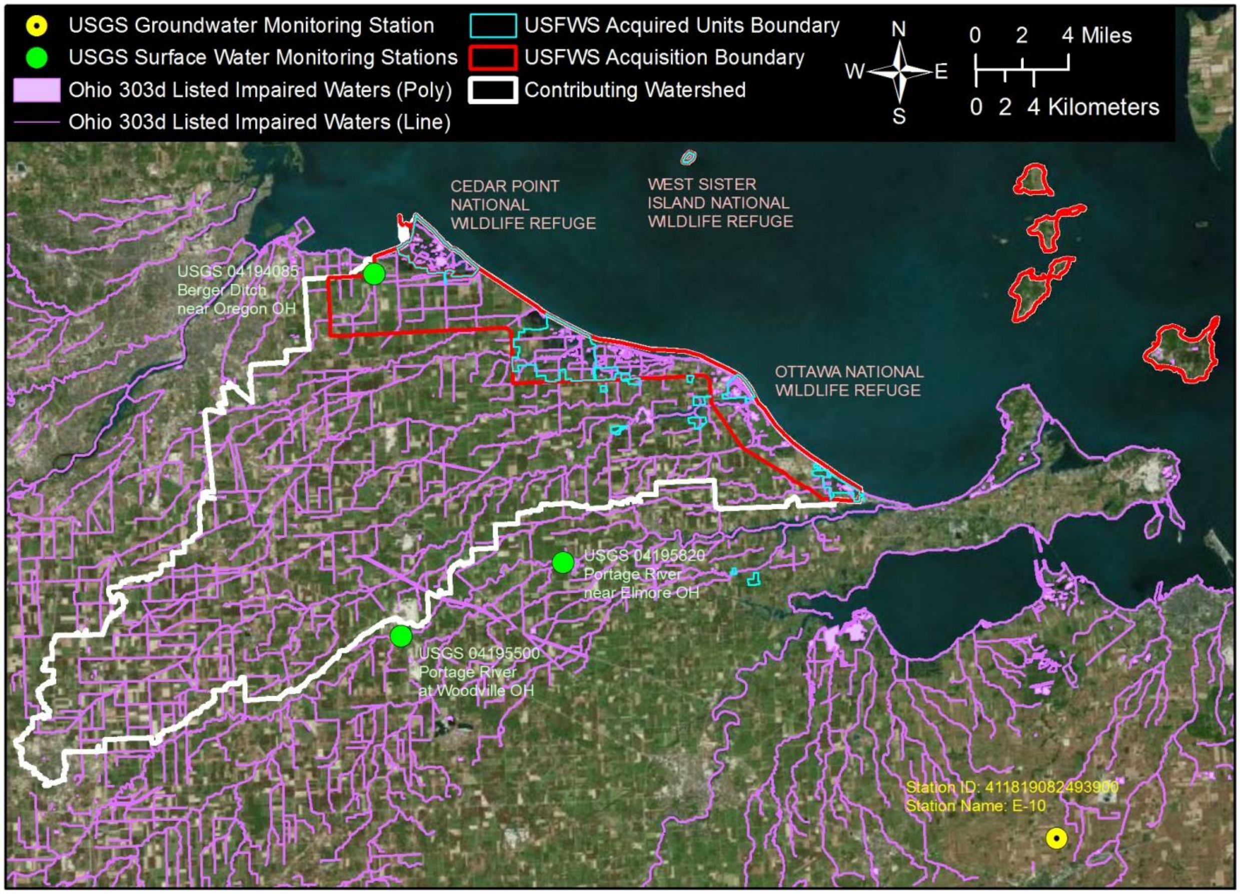


Figure 28 Locations of applicable USGS ground and surface water monitoring stations

Surface Water Quantity

ONWRC has several water quantity-related threats and needs that are common to most Field Stations in the Midwest Region, however this Complex has already addressed many of them. In doing so, they set themselves up for improved management and assessment of threats related to both water quantity and quality. For example:

- ONWRC monitors water levels of managed impoundments in a common datum (IGLD85).
- The Complex uses available LiDAR data to evaluate how water levels relate to habitat management objectives and impact surrounding lands.
- Bathymetric surveys of managed and important water features have been completed for a portion of the Complex, and this information is useful in determining optimal water level targets and computing overall water storage capacities to meet habitat management goals and protect water supplies.
- According to the HMP, Refuge staff establishes annual drawdown targets using bathymetry and elevation information, and water management influences are periodically assessed to incorporate additional LiDAR and bathymetry data, refine future management plans, and improve future infrastructure design.

Berger Ditch

Berger Ditch near Oregon, OH (USGS 04194085) represents a drainage area of 15.4 square miles, and is partially fed by Wolf Ditch upstream. The ditch drains directly through Maumee Bay State Park and into the Bay west of CPNWR. Negative flows recorded at this gage suggest this waterway is impacted by the seiche effect in Lake Erie and northern winds pushing water upstream into the Ditch (Brady, 2007).

The dataset from this site includes discharge measurements taken from 2006-2014. Flows seem to be especially low from August-November (Figure 29), while the highest average monthly flow occurs in March (Figure 30).

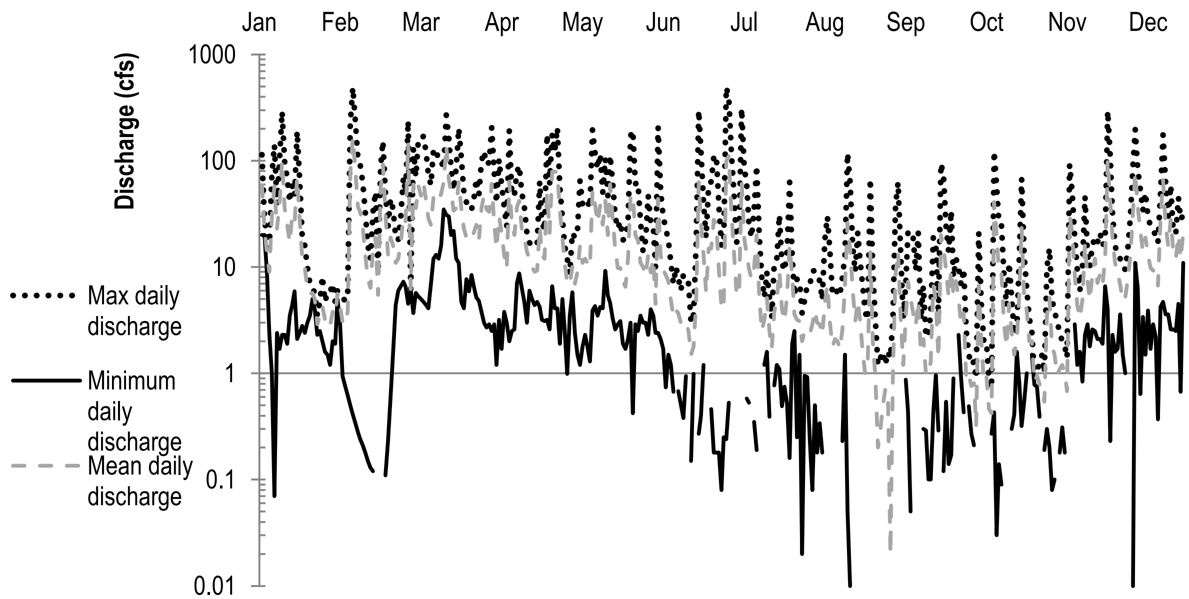


Figure 29 Graph of daily discharge stats from USGS site 04194085 (Berger Ditch near Oregon OH) 2006-2011

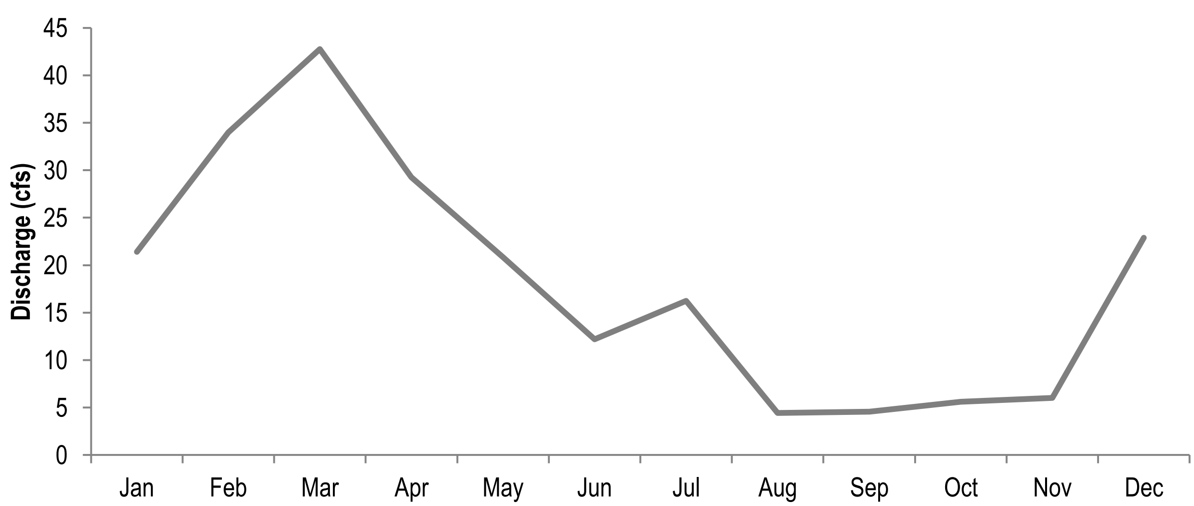


Figure 30 Monthly mean discharge at USGS site 04194085 (Berger Ditch near Oregon OH) 2006-2011

Portage River

Two USGS gage stations located on Portage River (USGS 04195500 at Woodville, OH and USGS 04195820 near Elmore, OH) provide comprehensive information about local water quantity. Portage River is a major tributary to Lake Erie and meets the Lake near Port Clinton southeast of ONWR.

The Woodville gage drains approximately 428 square miles in Sandusky County. Discharge data from 1929-2012 shows relatively consistent maximum and average daily discharges throughout the year (Figure 31), with average monthly discharges highest in March and lowest in August-October (Figure 32). High discharges even through summer months are not uncommon, and flow seems to be the most variable through December-February. According to peak annual discharge data at this gage site, peak flow events have apparently increased in frequency as indicated by a positive linear relationship over the period of the record (Figure 33), however the trend is not statistically significant.

Storms within the Portage River drainage tend to be more localized during the summer compared to winter and spring events, which are more widespread (WLEBP, 2009). This drainage is also more prone to flooding during winter months because of ice jams. The River represents the flattest drainage basin in Ohio, with an average slope of less than three feet per mile, excluding headwater areas (USACOE, 2008). Since the gradients of adjacent lands are so low, the Portage River floodplain is quite wide and lacks clear boundaries, and flood risks extend over a large area during high discharge and precipitation events. The River is also very responsive to Lake Erie water levels, especially seiche events.

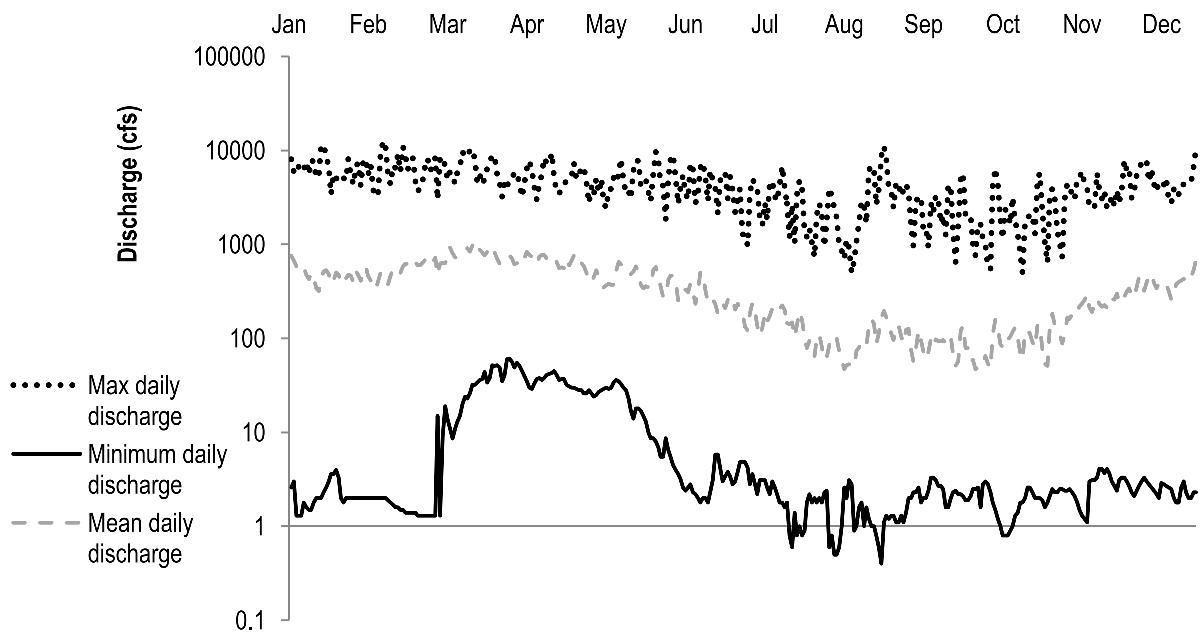


Figure 31 Graph of daily discharge stats from USGS site 04195500 (Portage River at Woodville, OH) 1929-2012

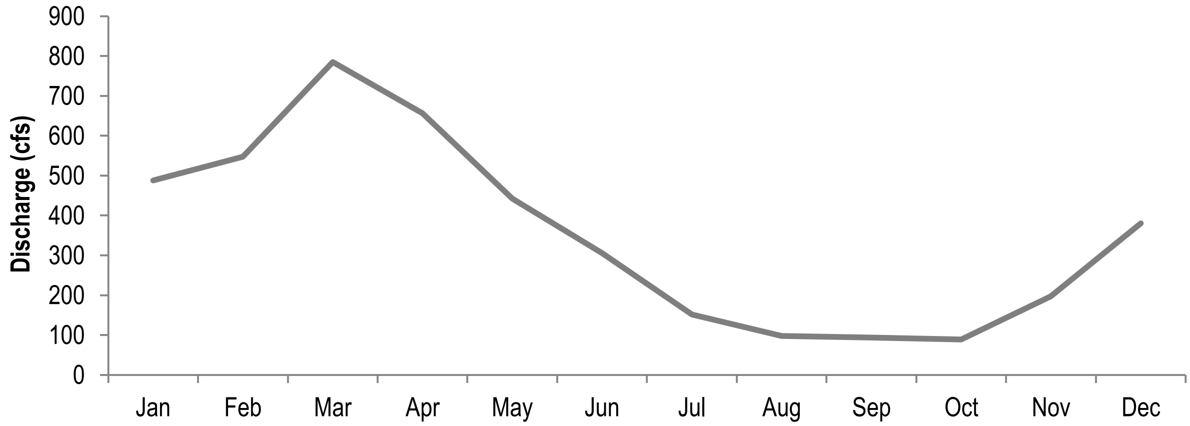


Figure 32 Monthly mean discharge at USGS site 04195500 (Portage River at Woodville OH) 1928-2011

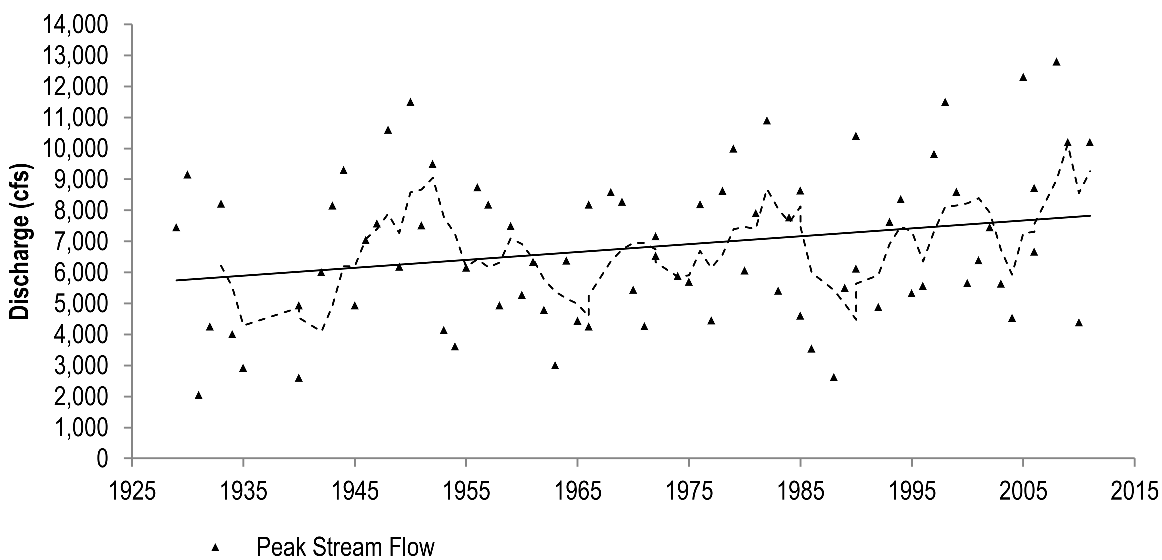


Figure 33 Annual peak streamflow data from USGS site 04195500 (Portage River at Woodville OH) 1929-2011

The USGS gage near Elmore (USGS 04195820), OH offers a dataset more relevant to ONWR's water resources than USGS 04195500 because of its closer proximity to the Refuge. This gage measures stage and streamflow from a 494 square mile drainage area on the Portage River in Ottawa County. This is a smaller dataset than the upstream gage at Woodville, with monitoring information from 1998-present.

At this site the highest variability in daily discharge highs and lows occurs in December-February, and average and minimum daily flows are lowest August-October (Figure 34). Average monthly discharge is highest in March and lowest in September or October (Figure 35). The most recent and largest floods recorded by this gage occurred in 2005, 2008, and 2011 (13100 cfs, 13500 cfs, and 14100 cfs, respectively). While the magnitude of annual peak flows appears to be increasing (Figure 36), the dataset is too small to determine if this condition is different from earlier flow patterns. Given this information and the increasing peak discharge trend recorded at the Woodville gage, Crane Creek may be demonstrating similar patterns, in which case surface flow through ONWR may be experiencing higher-magnitude peak discharge events. This does not, however, indicate an increase in surface water inputs overall (average annual discharge).

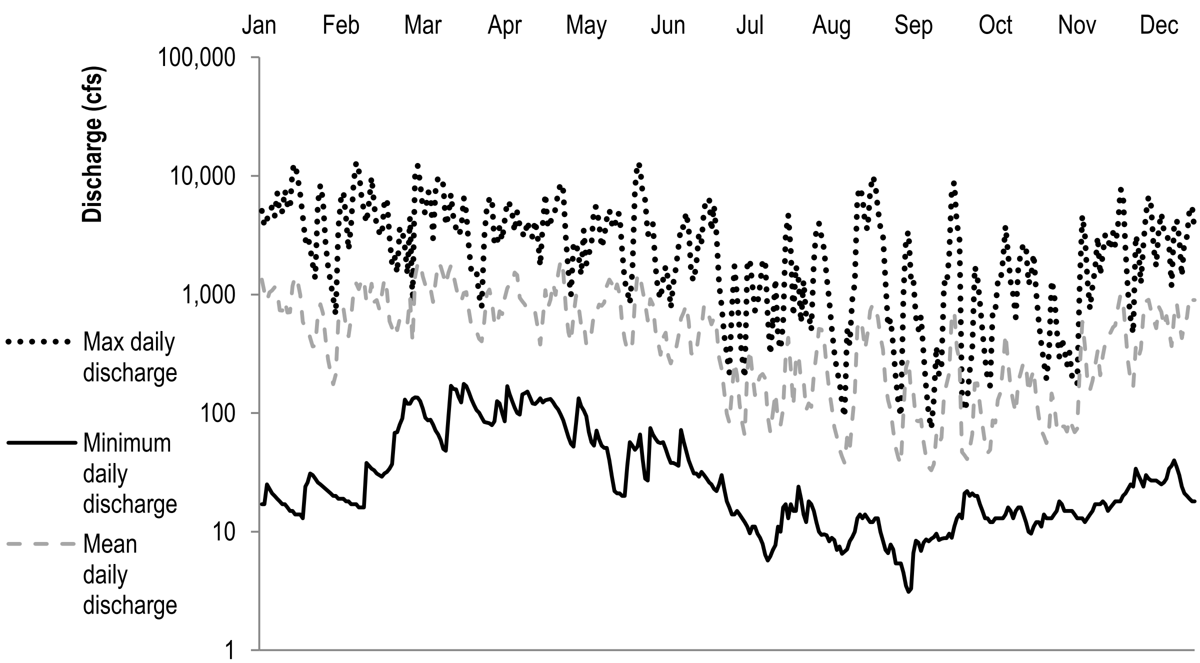


Figure 34 Graph of daily discharge stats from USGS site 04195820 Portage River near Elmore OH, 1998-2011

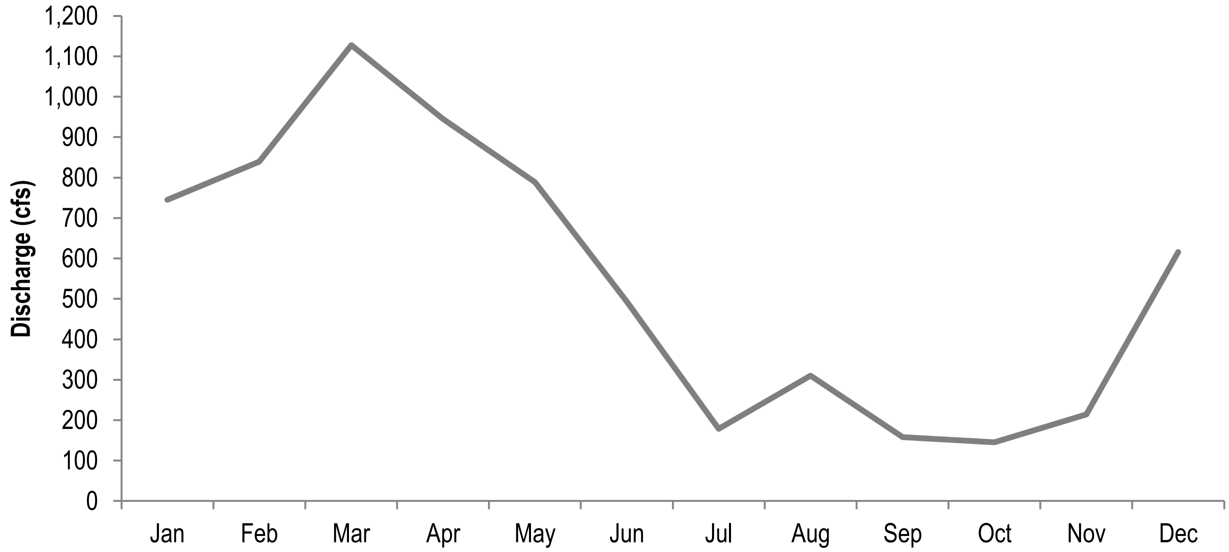


Figure 35 Monthly mean discharge at USGS site 04195820 Portage River near Elmore OH, 1998-2011

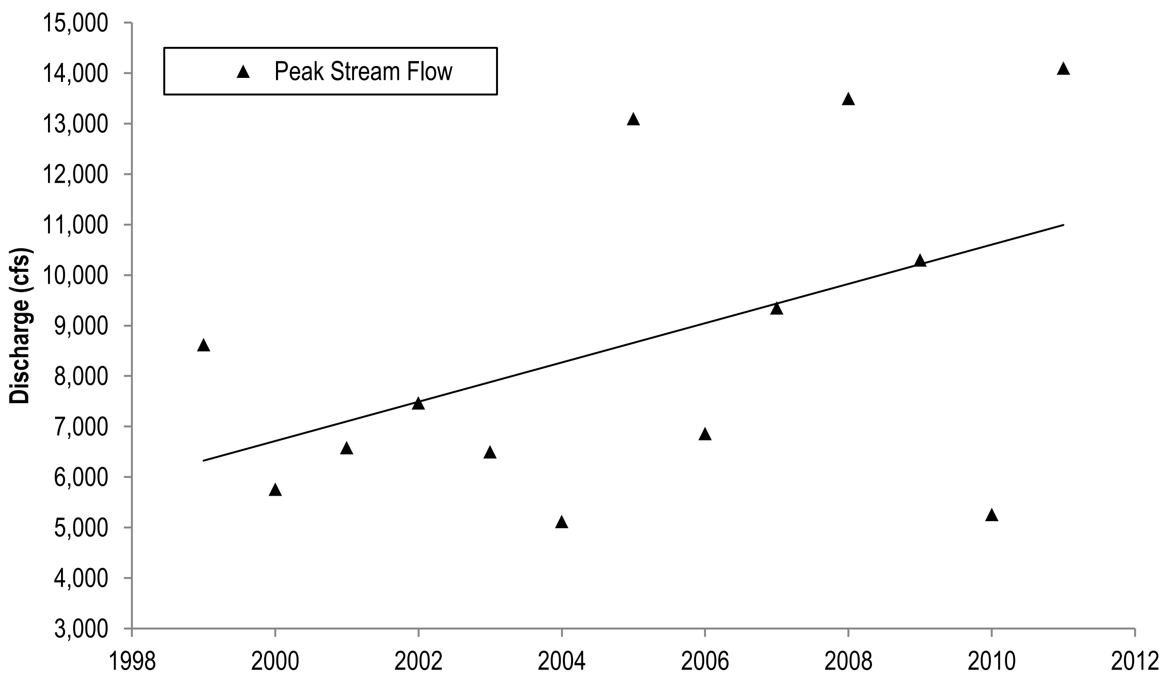


Figure 36 Peak streamflow data from USGS site 04195820 Portage River near Elmore OH, 1999-2011

Groundwater Resources

The 135-ft monitoring well located near Bellevue, OH (USGS 411819082493900) provides the most comprehensive groundwater data and is representative of ONWR's water resources. This site represents Columbus Limestone of the Silurian-Devonian aquifer system, and is located at a ground surface elevation of 712 feet (NAVD of 1988). The aquifer is visible at Seneca Caverns in Bellevue, and groundwater quality at that location is of potable quality. It has been suggested that subsurface flow in the area may follow the regional direction and discharged directly into Lake Erie, or alternatively may follow a path to an artesian spring to the north known as the "Blue Hole" of Castalia. Attempts to identify a groundwater connection between the two locations has been inconclusive in the past, however, due to drought conditions (Ruedisili et al. 1990).

The monthly mean water depth at USGS 411819082493900 (Figure 37) demonstrates the local water table's seasonal trends, with the average elevation of the water table typically at its highest in the spring or early summer. There has been an apparent decrease in both the average and median depth to water table over the period of the record, meaning the water table has been rising over time. The highest recorded water level in this area was 2.23 feet below the surface on June 1, 2011, and the lowest was 64.53 feet below the surface on Feb 21, 2010, indicating a highly dynamic aquifer that responds rapidly to changes on the surface.

Strong surface and groundwater connections are evident in this region, since aquifer response is typically consistent with surface water behavior. This connection is apparent during the floods of 2008 and 2011; events which were caused by excessive snowfall and rainfall. Groundwater levels following 2011, which was a particularly wet year, were sustained above past levels through the dry season. This may have influenced the period of stable, high groundwater levels observed earlier than usual in 2012. The lack of a stable hydrograph at this site suggests groundwater may be somewhat disconnected from Lake Erie.

Surficial flood events have in the past been intensified in the area of Bellevue as the result of sinkhole blockage by sediment and vegetation and the upwelling of groundwater in other areas (Pavey et al., 2008). The geology underlying this area of ONWR's RHI has many sinkholes and other karst features, which allow extremely rapid recharge to the aquifer. These complex geologic characteristics make groundwater and flooding activity for ONWR's RHI generally hard to predict. For example, the water table elevations for some local aquifers have been found to increase dramatically, sometimes up to 50 feet within several days, but may require weeks to decline to pre-flood levels (Pavey et al., 2008). The changing and erratic behavior of climate through all seasons further-cofound understanding of flood patterns and connections between surface and groundwater in this lake-influenced region.

While high recharge rates, such as those exhibited at this well site, secure large volumes of groundwater resources for long-term use, they also pose a contamination risk because shorter travel times through the subsurface sometimes prevent adequate filtration. The Salina and Bass Islands Dolomite bedrocks northwest of this well do not have many karst formations, however, so other areas of the Refuge's RHI may not exhibit the same recharge behavior. Additional information about specific aquifers in the region is discussed in the Water Resource Features section (see Aquifer Characteristics).

Since much of the area does not have karst formations and is overlain with glacial lake plain deposits, pollution potential is relatively low. Areas of sand dunes, beaches, beach ridges, and wetlands along the coast, however, are most vulnerable to groundwater contamination (Smith 1994). The most significant groundwater impacts in Ottawa County have reportedly been from landfill sites, above ground storage tanks, surface impoundments, and spills (Ohio EPA 2010).

Several springs exist in the region, particularly near the Sandusky Bay area. Cold Creek, for example, is fed by the Blue Hole of Castalia. Groundwater quality in this area exhibits very low dissolved oxygen, but the Castalia State Fish Hatchery aerates the water to support sport fisheries in the area (Ohio EPA 2010b). Further, Green Creek is influenced by Beaver Creek Spring, which contributes high concentrations of total dissolved solids, and there is a strong groundwater contribution at the confluence of this Creek and Beaver Creek, affecting fish species composition (Ohio EPA 2010b). Little Pickerel Creek, and Pickerel Creek are also spring fed streams feeding Sandusky Bay. Ohio DNR conducted groundwater monitoring in 2008-2009 in this area, at Rockwell Springs Trout Club, and determined that spring discharges here are strongly responsive to heavy precipitation (ODNR 2009).

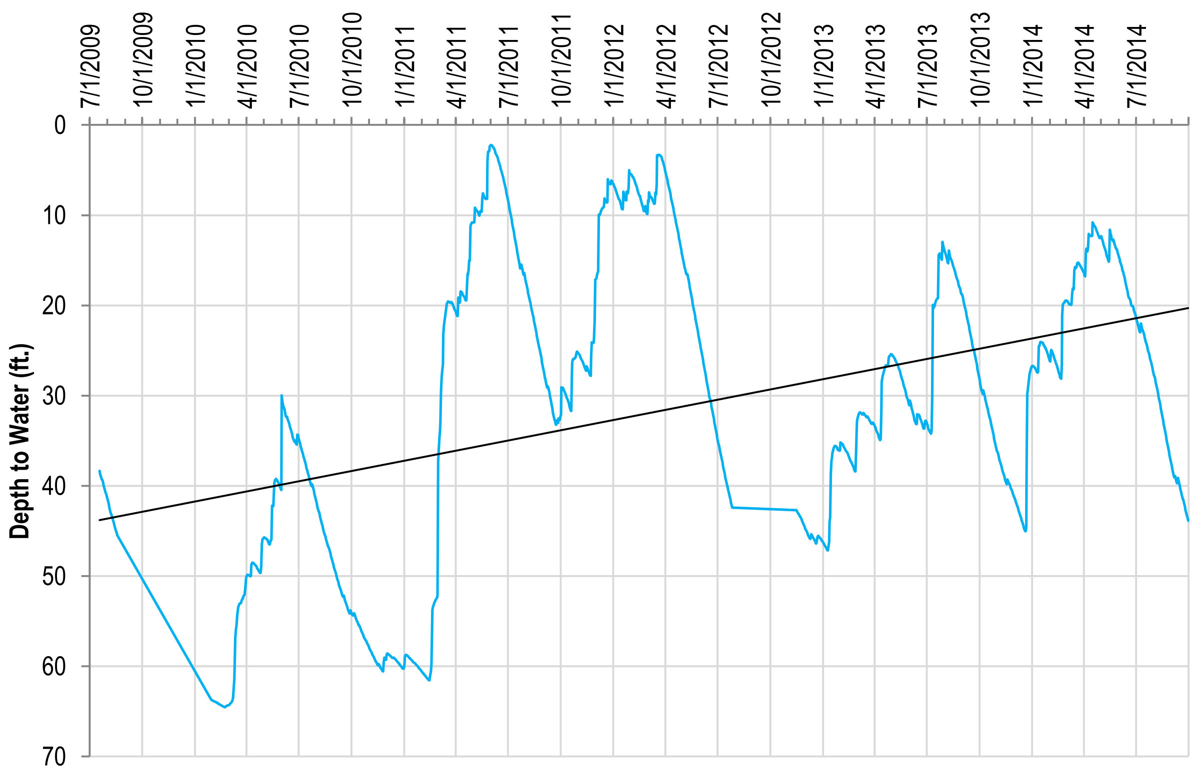


Figure 37 Depth to water at USGS 411819082493900, E-10, 2009-2014

Lake Erie Water Resources

This section provides a general description of Lake Erie's net supply and typical stage patterns. For more details about climate-related changes to Lake Erie's resources and stage plots from relevant monitoring stations, refer to the Climate Section (see Lake Erie water levels and temperatures).

Lake Erie water level is a strong controller of tributary flow dynamics and water quality for the Refuge units over seasonal and long term scales. The primary inputs to the Lake include flow from the Detroit River, other tributaries, groundwater inputs, and precipitation, while outflows include discharge to Lake Ontario, evaporation, and withdrawals or diversions. The Lake has an average water level elevation of 571 feet (MSL) over the period of record, a surface area of roughly 9,910 square miles, and a shoreline length of 871 miles. Water that flows into the Basin experiences a relatively short residence time, approximately 2.6 years, and the Lake has an average depth of 62 feet with a maximum depth of 210 feet. The western 20% of the Lake, where ONWR is located, is particularly shallow, with an average depth of only 24 feet.

Typically, water levels remain low through the winter, stages rise in the spring, and decline through the late summer and early fall. On an annual scale, the difference between high early summer (typically June-July) levels and low levels in winter (typically January-February) is approximately 14 inches (ODNR 2013). Lake currents along the Refuge's coast tend to flow to the southeast and currents here are strongest during the months of January, October, and December (Michalak et al., 2013). Low lake circulation throughout the year facilitates algal growth and often results in degraded water quality. Some areas of the Lake also exhibit diverging currents, such as the patterns along CPNWR which formed the sand spit (ODNR 2012).

Though gravitational forces influence water levels to some degree, changes are minor and are undetectable compared to other factors driving water elevations, so the Lake is considered to be non-tidal. Seiche and storm surge events have significant impacts on short-term fluctuations of Lake water level. Periods of strong, consistent winds to the northeast, for example, often cause low Lake levels in waters relevant to the Refuge and raise levels on the other side of the Lake. Then in the event of a rapid decline or shift in wind magnitude or direction, water levels in the entire basin oscillate. These seiches usually last 12-14 hours, and are typically strongest in the summer (Kasat, 2006). Storm events and dramatic changes in atmospheric pressure can increase the frequency and magnitude of seiches, and some have changed water levels by up to 6.5 feet in one day on Lake Erie.

Winds from the northeast associated with tropical storms or fading hurricanes have been known to pile water in the Western Lake Erie Basin and cause flooding in the area (ODNR 2012). This sometimes happens concurrently with high-stage events in Lake Erie, exacerbating the flooding.

Surface Water Quality

Many of the water quality monitoring sites identified through the EPA STORET database house no data, house limited datasets, or are not from a location considered relevant by USFWS hydrologists. In addition to water chemistry data obtained from EPA and USGS databases, water quality information found in several reports and peer-reviewed journal articles were reviewed for applicability to Refuge water resource management. Summaries of available information for individual water features are provided in the subsections below based on relevant monitoring datasets, literature, and 303(b)/303(d) reports/assessments. The findings from the CAP (Kurey et al. 1997, Banda et al. 2015, Banda et al. 2014) are additionally summarized in this section.

Maumee Area of Concern and monitoring across the region

ONWRC is part of the 775 square mile Maumee Area of Concern (Figure 38). “Areas of Concern” (AOCs) are designated “geographic areas that fail to meet the general or specific objectives of the Great Lakes Water Quality Agreement where such failure has caused or is likely to cause impairment of beneficial use of the area’s ability to support aquatic life.”

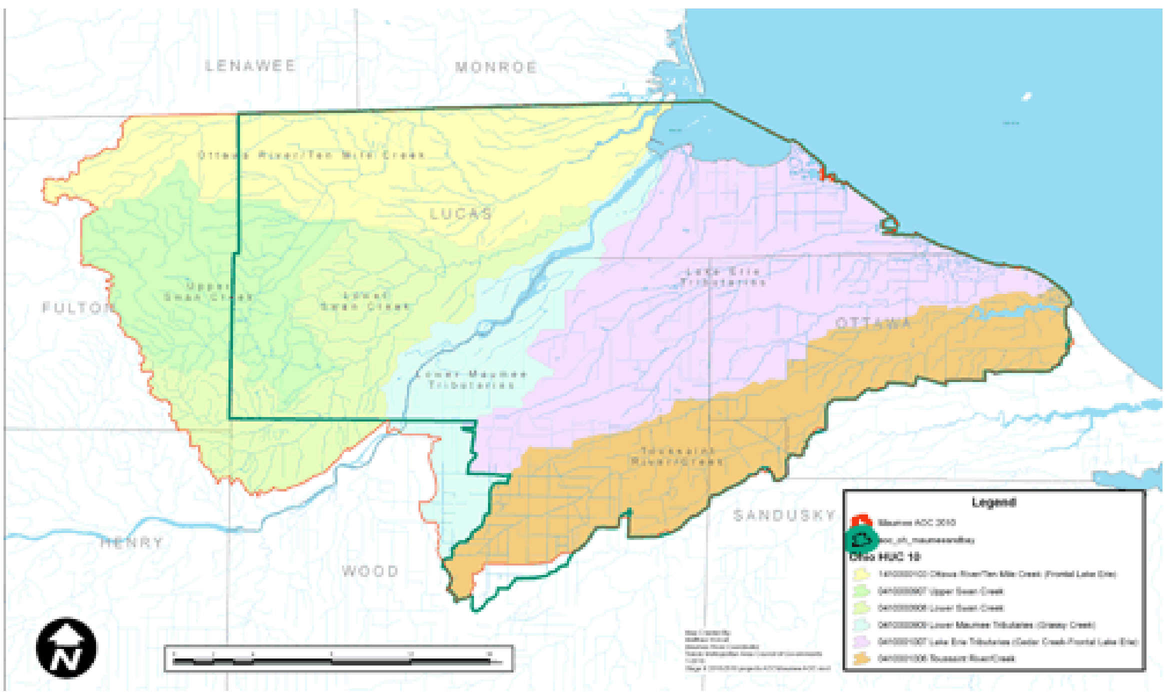


Figure 38 Maumee Area of Concern (partnersforcleanstreams.org)

AOCs are designated based on 14 types of impairments related to both ecological and human impacts. Beneficial uses for which the Maumee AOC has an impaired status for (i.e., impaired anywhere within the Maumee AOC boundaries) are listed below (Table 3).

Beneficial Use Impairment
Restrictions on fish consumption
Restrictions on wildlife consumption
Degradation of fish populations
Fish tumors or other deformities
Degradation of benthos
Restrictions on dredging activities
Eutrophication or undesirable algae
Beach closings (recreational contact)
Degradation of aesthetics
Added costs to agriculture or industry
Loss of fish habitat
Loss of wildlife habitat

Table 3 Maumee Area of Concern Beneficial Use Impairments (http://www.epa.gov/greatlakes/aoc/maumee/index.html)

Across these drainages, the most prominent water quality concerns are interrelated and involve high sediment and nutrient loads combined with invasive species spread, decreased water clarity, and depleted oxygen concentrations. Though the Lake has demonstrated general improvements in water quality since the 1960s, it has exhibited declines again in recent years (Sallee et al. 2013). In particular, dissolved reactive phosphorus is higher than it has ever been in the Sandusky and Maumee watersheds (Ohio EPA 2013).

A Remedial Action Plan has been developed to address these issues, guide restoration actions, identify sources, and work toward the delisting of the Maumee Area of Concern. Some of the associated water quality restoration actions have directly involved ONWRC waters. For example, the Toussaint River Improvement Program developed incentives to help reduce sediment and nutrient loads to the Toussaint River and Lake Erie from 1997-2000. This project implemented conservation practices, a streambank stabilization project, installed 27 miles of filter strips, and set aside 233 acres of floodplain as buffer area along the River to improve water quality (http://www.partnersforcleanstreams.org/).

Additional water quality monitoring activities have been part of other programs and projects implemented in the region. For example, the Maumee Bay Bacteria Study was conducted from 2003-2005 by the University of Toledo Lake Erie Center, the USGS, and the Toledo Metropolitan Area Council of Governments to measure the survival and sources of E. coli to Maumee Bay and Lake Erie. Similarly, Black and Veatch conducted a Stream and Septic System Monitoring Study within the Maumee Area of Concern (AOC) for the USACOE in 2004 as part of the Maumee River AOC Remedial Action Plan. The Ohio Department of Health and Ohio DNR also have current data available on the contamination levels of recreational waters, as part of the Bathing Beach Monitoring Program (http://publicapps.odh.ohio.gov/BeachGuardPublic/Default.aspx).

Extensive water quantity and water quality data associated with the USACOE's Lake Erie Wastewater Management Study (1974), which evolved into the National Center for Water Quality Research (NCWQR), are available for download on the Heidelberg University website (http://www.heidelberg.edu/academiclife/distinctive/ncwqr/data/data). These data include several years' worth of daily water quality data, typically from USGS sampling locations, including discharge, suspended solids, phosphorus, nitrogen, chloride, sulfate, silica, and conductivity.

The Heidelberg University Water Quality Laboratory is also responsible for the Honey Creek/Sandusky River Targeted Watershed Project, a joint effort with the Sandusky River Watershed Coalition and funded by the USEPA (http://sanduskyriver.org/node/65). This project involved the sampling of invertebrates, nitrates, phosphorus, and discharge in the Sandusky River Basin from 2008-2011 to guide BMPs.

Pool 2B and Crane Creek Water Quality & Quantity Monitoring

Miscellaneous measurements were made on Crane Creek between fall of 2009 and spring of 2011 in order to improve the general understanding of the Creek's hydrology and water quality parameters. The monitoring site was located upstream of ONWRC near Williston (at Opfer Lentz Road). Measurements of streamflow ranged from 0.39 cfs to an estimate of 350 cfs, while pH was found to remain neutral (7.29 – 7.87) and specific conductance (0.691 mS/cm), dissolved oxygen concentrations (7.36-14.7 mg/L), and turbidity (4.3-88.9 NTU) fluctuated with changes in seasons and streamflow (Table 4).

Although local reports state that this site will experience backwater conditions during high lake levels and/or seiche events, all visits over this period observed the stream to be free flowing, and none occurred during times of especially high lake levels.

Date	Time	Streamflow	Water Temperature	pH	Specific Conductivity	Dissolved Oxygen mg/l	Dissolved Oxygen % Saturation	Turbidity
10/5/2009	1745	1.69	13.2	7.87	0.692	8.96	85.7	4.3
4/21/2010	1815	4.91	16.6	7.84	0.88	14.7	150.5	4.6
5/4/2010	1652	55.6	17.2	7.29	0.665	7.36	76.7	88.9
6/10/2010	1330	26.7	20	7.83	0.691	7.79	85.9	39.1
7/10/2010		0.39						
8/18/2010	1330	2.97						
10/15/2010	1300	2.29						
3/30/2011	1228	8.96	4.1	7.63	0.847	12.63	97	7.2
4/28/2011		est ~350						

Table 4 Water quality and streamflow measurements at Crane Creek (2009-2011)

USFWS's water quality and quantity monitoring stations are located on the primary surface water input for ONWR, Crane Creek (413723083123801), and at Pool 2B (413721083124001) (Figure 39). The sites measure stage and water quality parameters as part of a Great Lakes Restoration Initiative project led by the USGS to study the benefits of direct reconnection of coastal wetlands (Pool 2B) with the Great Lakes (via Crane Creek). Continuous data collection has been conducted at these locations from 2009-2014 for stage, specific conductance, water temperature, dissolved oxygen, pH, and turbidity. Annual water quality data reports are available on the ServCat application of the ECOS website (https://ecos.fws.gov/servcat; ServCat reference for 2013 Crane Creek report: 28525; ServCat reference for 2013 Pool 2B report: 28526). At the conclusion of the USGS project in the spring of 2015, the Pool 2B gage will be removed and monitoring at the Crane Creek gage will be limited to stage data. The Crane Creek gage will be maintained as a long term monitoring site to record trends and inform water management activities.

In addition to continuous water quality measurements collected by the USFWS, the USGS has collected water quality samples and point measurements from these sites and other locations over the same period. In addition, the USGS installed an acoustic Doppler profiler in 2013 in the Pool 2B reconnection structure to continuously record velocities, flow direction and real-time streamflow through the structure (Figure 40 and Figure 41). All data collected as part of this project will be released in a forthcoming USGS interpretive report.

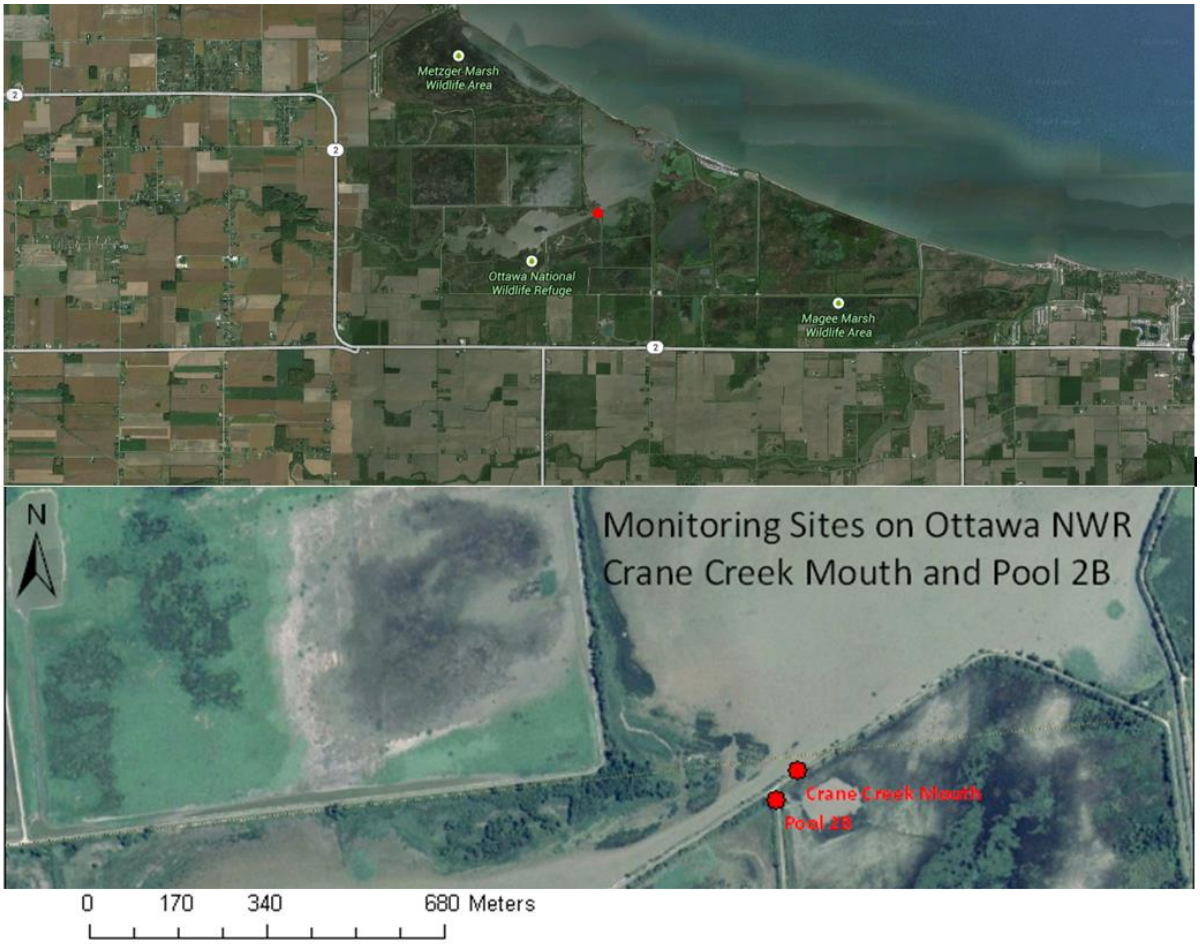


Figure 39 USFWS monitoring sites at Crane Creek and Pool 2B

Figure 40 Ottawa NWR Complex, fish passage to Crane Creek completed 2011 restoring hydrological connectivity to Lake Erie. Significant improvement to water quality and fish populations have been documented through a USGS research project.

Figure 41 Ottawa NWR Complex, fish passage to Crane Creek, water flowing out of unit during seiche. Improvement to water quality through reduced turbidity visible as water mixes with Crane Creek water.

Below are stage and water quality figures from USFWS monitoring sites at Crane Creek and Pool 2B (Gruetzman et al. 2014). The comparison between Crane Creek and Lake Erie stage data show that Refuge waters closely follow Lake patterns, and ONWR is affected by seiche events just as frequently, though to a lesser degree (lower-magnitude peaks and troughs) as Lake Erie at the Toledo, OH gage (Figure 42). The data suggest that seiche events are attenuated from Lake Erie to Crane Creek, and from Crane Creek to Pool 2B.

In the context of the USGS's project to study the impacts of the hydrologic reconnection of Pool 2B with the Crane Creek Estuary, the datasets clearly show that water levels of Crane Creek and Pool 2B have more-closely paralleled each other since the 2011 reconnection, and it appears as though Pool 2B stages have increased overall, now experiencing higher-magnitude peaks (Figure 43). These hydrologic changes are expected to result in ecological shifts that are being examined as part of the USGS project. Findings suggest that the reconnection benefited invertebrate populations and bird feeding habitats, while also providing more variable fish habitat (Pfaff 2012). Fish species richness is also now more similar between Crane Creek and Pool 2B post-connection, and vegetation has shown an unexpected positive response as well, demonstrated by increased richness in Pool 2B (USGS 2012). While this impoundment responded positively to hydrologic reconnection, it is cautioned that management units across ONWRC vary significantly ecologically, and future reconnection proposals should be evaluated on a case-by-case basis and monitored extensively if possible (Pfaff 2012).

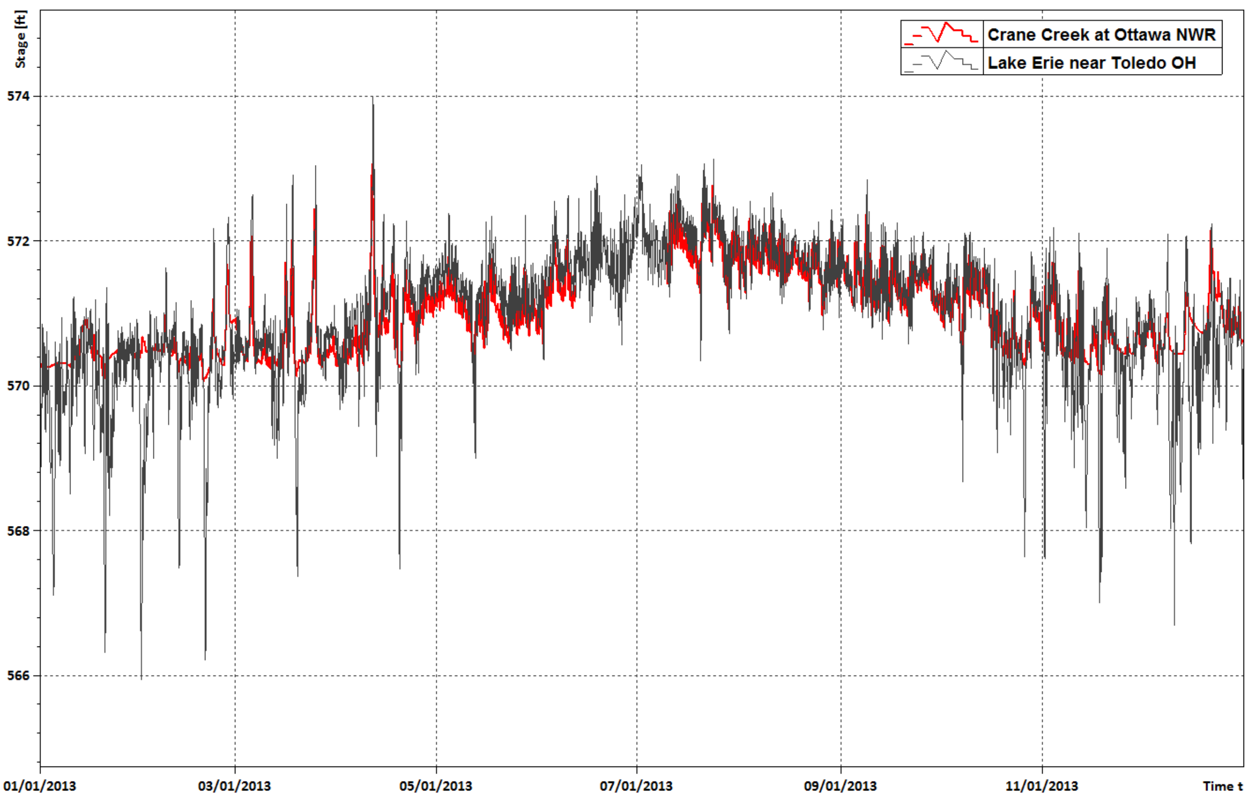


Figure 42 Stage data (2013) for Crane Creek and Lake Erie near Toledo, OH

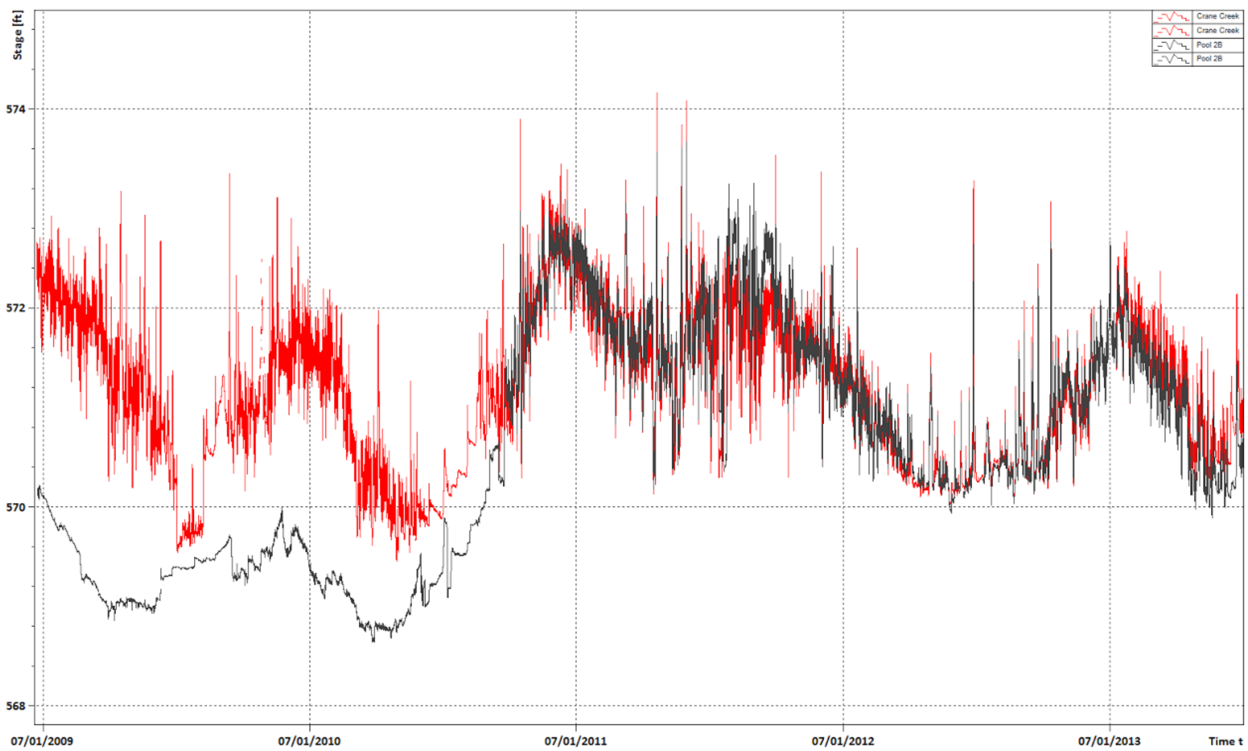


Figure 43 Stage data (2009-2013) for Crane Creek and Pool 2B

An additional water quality dataset from these monitoring sites is provided below. Pool 2B seems to closer-emulate specific conductivity patterns of Crane Creek since the reconnection project (Figure 44), and demonstrates higher minimums and somewhat less variability compared to specific conductivity datasets from 2009-2010, when stages were lower.

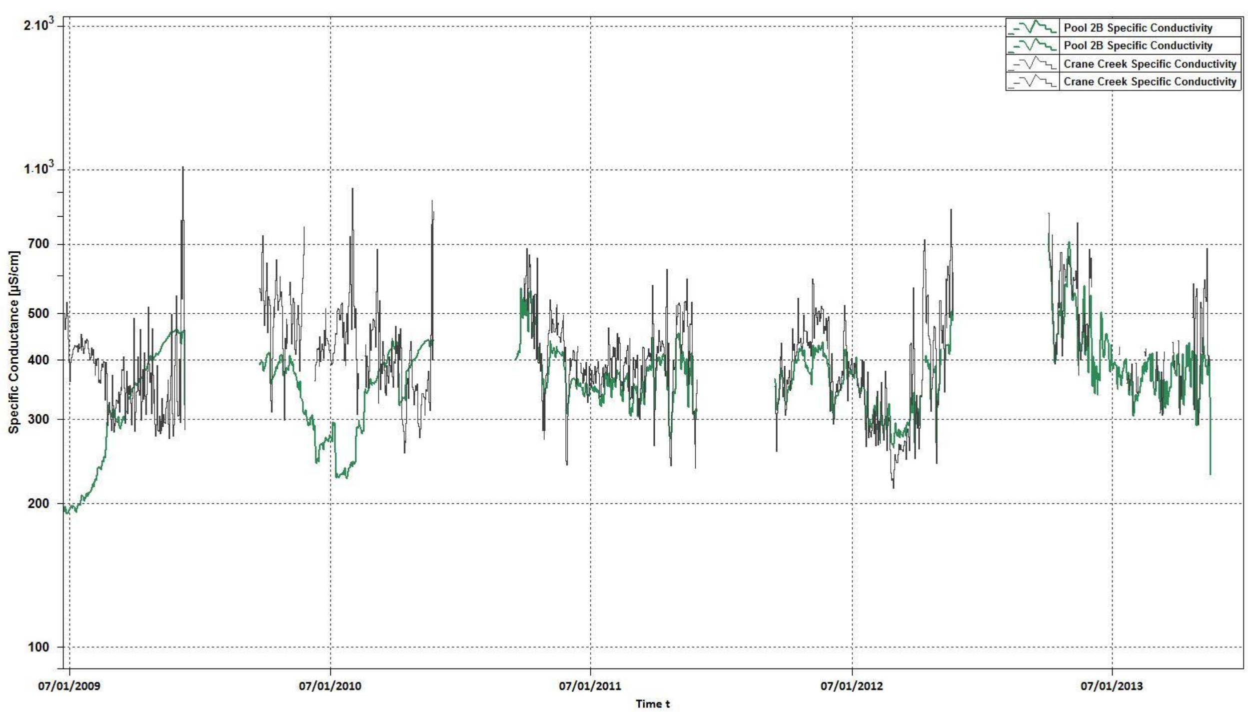


Figure 44 Specific conductivity data (2009-2013) for Pool 2B and Crane Creek

Contaminants Assessment Process (CAP)

Bill Kurey (USFWS) completed the contaminants assessment process (CAP) for ONWR in 1997. This evaluation involved the identification of contaminant sources and pathways for ONWR, which served as a basis for future water management practice recommendations. Another CAP, led by Jo Banda (USFWS), has been completed for the complex in February 2015. Some of the hydrologically-significant points from both evaluations include:

- Several surface water pathways threaten water resource quality of the Refuge, including Cedar Creek, Crane Creek, Lacarpe Creek, Lake Erie, Reno Side Cut Ditch, Rusha Creek, Toussaint River, Turtle Creek, and Ward Canal (Banda et al. 2015).
- First Energy Davis-Besse Nuclear Power Station, southeast of the Refuge, may threaten Refuge waters (Lake Erie) in the form of nutrients, thermal pollution, and other water quality parameters (Banda et al. 2015).
- Herbicides and pesticides, such as rotenone, Rodeo, 2, 4-D, Scepter, Prowl, Basagran, Dicamba, and Roundup, threaten wetland and adjacent waterbody resources. Amphibians, reptiles, and fish may especially be threatened (Banda et al. 2015).
- Possible areas subject to spills include areas of Lake Erie adjacent to the Refuge, ditches and streams that flow adjacent to or through the Refuge, and areas near Route 2, which may be a source of accidental spills (Banda et al. 2015).
- Potential contaminant transport pathways for CPNWR include Cedar Creek, Lake Erie, the Maumee River, Reno Side Cut Ditch, Sautter Ditch, Williams Ditch, and Wolf Creek (Banda et al. 2015).
- Waterfowl and other wildlife are adversely impacted by consuming PCB/DDE-contaminated fish (Kurey 1997).
- Air deposition of metals threatens Lake Erie water quality, and diving ducks may be adversely affected by selenium (Kurey 1997).
- Sediment and soil samples taken across the Complex reveal arsenic and nickel contamination at sites 2A and 2B; arsenic, cadmium, copper, and nickel issues at the Blausey Unit; and nickel contamination at the Crane Creek, Helle, and Pool 1 Units (Table 5. Inorganic element ranges and values (for those above sediment criteria) from sediment samples at sites at ONWR. Only sites with values exceeding sediment criteria are reported (Banda et al. 2015).)(Banda et al. 2015).

			Sample Sites										
Substance	Range (ppm DW)	Sediment Criteria	2A-B	2B-B	2C-001	Blau-001	Blau-003*	Blau-004	Blau-005*	CC-001	CC-Seiche	Helle-002	Pool 1-001
Al	4840-16600												
As	2.99-7.93	5.9[a]; 9.79[b]	7.89					7.24	6.37				
B	2.78-9.42												
Ba	37.7-124												
Be	0.557-1.14												
Ca	3650-28300												
Cd	0.19-0.676	0.6[a]; 0.99[b]						0.676					
Co	6.17-14.6												
Cr	9.39-26.1	37.3[a]; 43.4[b]											
Cu	13.5-33.6	35.7[a]; 31.6[b]					33.6						
Fe	11500-29900												
Hg	0.017-0.066	0.17[a]; 0.18[b]											
Mg	2920-10200												
Mn	144-476												
Mo	0.688-2.25												
Na	0-0												
Ni	14.7-36.7	22.7[b]	31.2	24.3	27.4	32.35	28.2		34.6	31	28.5	36	24
Pb	9.33-21.6	35[a]; 35.8[b]											
Se	0.414-1.65	2[c]											
Sr	34.6-226												
Tl	0.126-0.283												
V	18.4-34.5												
Zn	37.9-118	123[a]; 121[b]											

Table 5. Inorganic element ranges and values (for those above sediment criteria) from sediment samples at sites at ONWR. Only sites with values exceeding sediment criteria are reported (Banda et al. 2015).

303(b) Reporting and 303(d) assessments

Section 303(d) of the Clean Water Act requires that each state identify water bodies where water quality standards are not met based on designated usage.

According to the Ohio EPA's most recent Integrated Water Quality Monitoring and Assessment Report (2012), several streams and rivers relevant to the Refuge's RHI suffer from impairments. For example, Portage River, Indian Creek, and Lower Toussaint Creek were not supporting the designated use for human health since PCB levels exceed Ohio's water quality standard as of 2012. Sandusky River (Wolf Creek to Sandusky Bay) was also listed as impaired for its designated use for public drinking water supply due to high nitrate levels. Northwestern Ohio waters suffer from elevated atrazine due to agricultural land use in the region, and several sites in this region are on the watch list (Ohio EPA 2012). The Maumee River and Sandusky River (Fremont) have TMDLs for total phosphorus, ammonia, nitrate plus nitrite, total suspended solids, and E. coli (Ohio EPA 2012).

Based on Ohio EPA's 2008 assessment, 20 water features relevant to Refuge water resources are included in the 303(d) list and are summarized below (Table 6, Figure 45) (http://www.epa.gov/waters/enviromapper/).

Ohio EPA's 303(d) List (2008 Assessment)				
HUC10	Water Feature Name	Cause for Listing	Length Mile	Area (sq. km)
0410001006	Portage River (Downstream North Branch to Downstream Sugar Creek)	Organic enrichment/low Dissolved Oxygen	157.3633	59.1942
0410001006	Portage River (Downstream North Branch to Downstream Sugar Creek)	PCB(s) in fish tissue	157.3633	59.1942
0410001006	Portage River (Downstream North Branch to Downstream Sugar Creek)	Siltation	157.3633	59.1942
0410001007	Portage River (Downstream Sugar Creek to Mouth); Lake Erie Tributaries West of Marblehead	Organic enrichment/low Dissolved Oxygen	165.021023	594.4646952
0410001007	Portage River (Downstream Sugar Creek to Mouth); Lake Erie Tributaries West of Marblehead	PCB(s) in fish tissue	165.021023	594.4646952
0410001007	Portage River (Downstream Sugar Creek to Mouth); Lake Erie Tributaries West of Marblehead	Siltation	165.021023	594.4646952
0410001004	Middle Branch Portage River (Downstream Rocky Ford Creek to Downstream South Branch)	Habitat Alterations	273.0557	277.3593
0410001004	Middle Branch Portage River (Downstream Rocky Ford Creek to Downstream South Branch)	Organic enrichment/low Dissolved Oxygen	273.0557	277.3593
0410001004	Middle Branch Portage River (Downstream Rocky Ford Creek to Downstream South Branch)	Flow Alteration(s)	273.0557	277.3593
0410001004	Middle Branch Portage River (Downstream Rocky Ford Creek to Downstream South Branch)	Siltation	273.0557	277.3593
0410001005	Portage River (Downstream South/Middle Branches to Downstream North Branch)	PCB(s) in fish tissue	142.6930	89.5703
0410001113	Lake Erie Tributaries (East of Green Creek to West of Mills Creek)	Organic enrichment/low Dissolved Oxygen	186.8483	1264.2854
0410001113	Lake Erie Tributaries (East of Green Creek to West of Mills Creek)	Pathogens	186.8483	1264.2854
0410001113	Lake Erie Tributaries (East of Green Creek to West of Mills Creek)	Habitat Alterations	186.8483	1264.2854
0410001114	Lake Erie Tributaries (West of Mills Creek to East of Sawmill Creek)	Nutrients	116.2847	262.8201
0410001114	Lake Erie Tributaries (West of Mills Creek to East of Sawmill Creek)	Pathogens	116.2847	262.8201
0410001114	Lake Erie Tributaries (West of Mills Creek to East of Sawmill Creek)	Siltation	116.2847	262.8201
0410001102	Sandusky River (Headwaters to Upstream Broken Sword Creek)	PCB(s) in fish tissue	160.1344	208.4485

Table 6 Ohio EPA's 303(d) listing (2008 assessment)

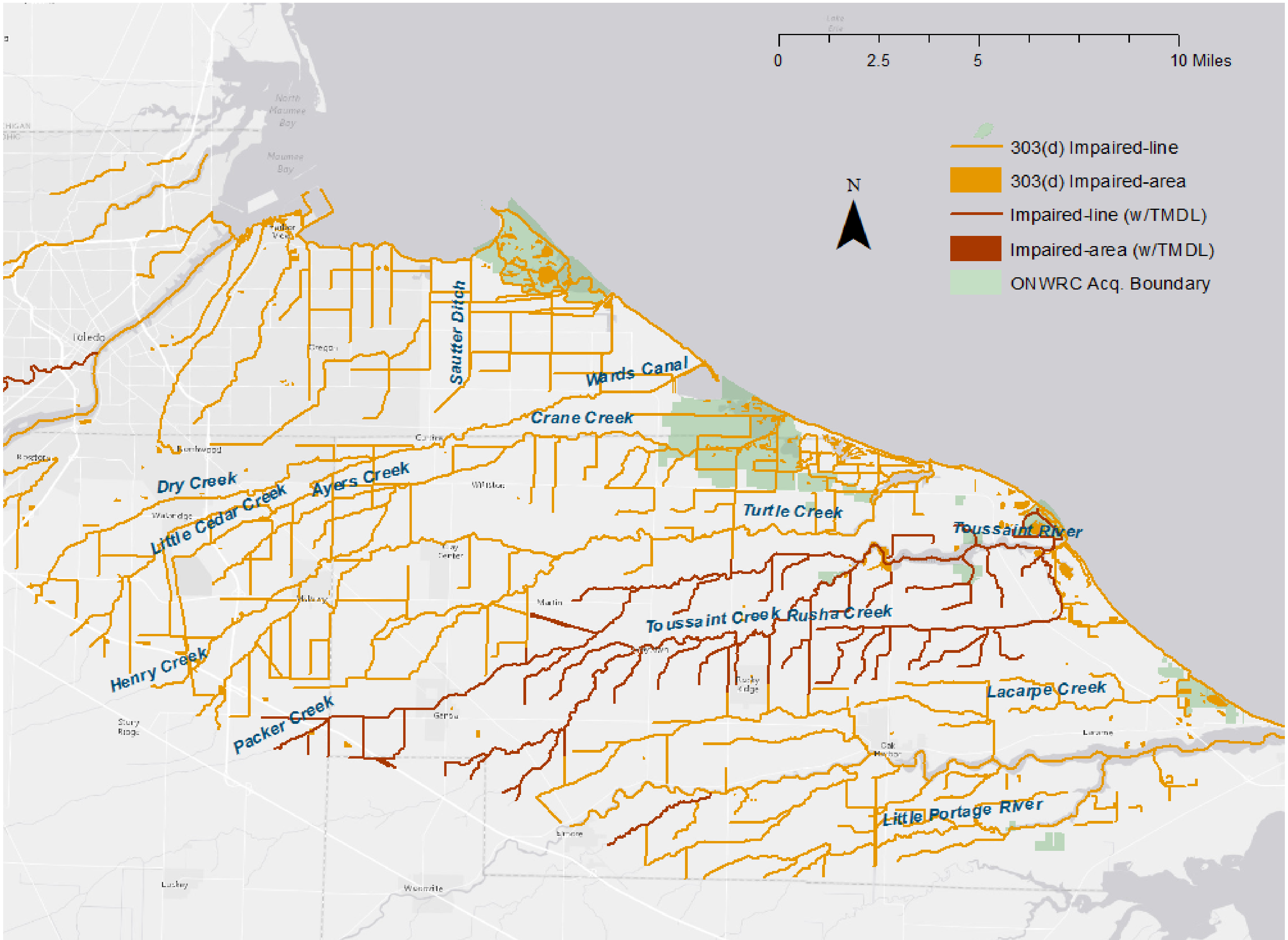


Figure 45 303(d) impaired waters near ONWRC

In addition, several fish advisories have been noted in water bodies relevant to ONWR and are listed in the table below (Table 7). Several important water features with no associated advisories have not been sampled for fish recently, however. The conditions of these water features may have changed since the last sampling. Contaminants covered by these advisories include PCBs, dioxin, and mercury.

Water Feature(s)	Most recent year sampled	Counties
Lake Erie	2012	Ashtabula, Cuyahoga, Erie, Lake, Lorain, Lucas, Ottawa, Sandusky
Lake Erie Tributaries	2008	Ashtabula, Cuyahoga, Erie, Lake, Lorain, Lucas, Ottawa, Sandusky
Maumee River	2012	Defiance, Henry, Lucas, Paulding, Wood
Ottawa River	2011	Lucas
Ottawa River	2009	Allen, Putnam
Swan Creek	2012	Lucas
Toussaint Creek	2008	Ottawa, Sandusky
Portage River	2008	Ottawa
Sandusky River	2009	Crawford, Sandusky, Seneca, Wyandot

Table 7 Past fish advisories relevant to ONWRC

As discussed earlier (see Climate section), HABs and the toxins they produce are serious, current threats to the Lake Erie ecosystem and Refuge Resources. Lake Erie has become increasingly more vulnerable to HABs due to high phosphorus and sediment loading, elevated water temperatures, and aging wastewater infrastructure in the region. Harmful algal blooms themselves impact the ecosystem by blocking light attenuation through the water column, depleting dissolved oxygen levels as they decompose, and out-competing other organisms by consuming most of the phytoplankton, zooplankton, and nutrients also required by other consumers. These processes frequently cause fish kills and mortality of other organisms, including waterfowl, impact Refuge aesthetics, and degrade feeding habitats. HABs in Lake Erie also primarily produce the toxin microcystin, was responsible for threatening Toledo, Ohio’s water supply in summer of 2014. Currently there is no national standard for this contaminant, though the EPA is working to develop one.

Water Law

In states that apply the riparian rights doctrine, landowners of property with naturally flowing surface water running through or adjacent to their property have rights to reasonable use of the surface water associated with the property itself. The "reasonable use" standard protects downstream users by ensuring that one landowner's use does not unreasonably impair the equal riparian rights of others along the same watercourse. Additionally, the law limits riparian rights to those rights "intimately associated" with the water; uses falling outside of this definition are usually considered unreasonable uses.[1]

An important corollary to the riparian rights doctrine is that, generally, states classify their navigable[2] *surface waters as public, whether through statute or through the common law public trust doctrine.*[3] *This is important because on public waters, the riparian landowners' rights are subject to public rights of, at a minimum, navigation. For this reason, states regulate waters for the purpose of putting the water to "beneficial use," a term defined differently amongst the states.*

The state of Ohio follows a traditional common law riparian rights scheme, complemented by permit programs for large water users and a registration and water resource inventory system. Unfortunately, FWS can do very little to assert rights to instream water use, but many of the regulations strive to maintain a sustainable surface water quantity.

In Ohio, a riparian state, the legislature has defined the factors state courts should consider when determining whether a water use is reasonable. At a minimum, the court must evaluate:

- *(1) The purpose of the use;*
- *(2) The suitability of the use to the watercourse, lake, or aquifer;*
- *(3) The economic value of the use;*
- *(4) The social value of the use;*
- *(5) The extent and amount of the harm it causes;*
- *(6) The practicality of avoiding the harm by adjusting the use or method of use of one person or the other;*
- *(7) The practicality of adjusting the quantity of water used by each person;*
- *(8) The protection of existing values of water uses, land, investments, and enterprises;*
- *(9) The justice of requiring the user causing harm to bear the loss.*[4]

[1] John W. Johnson, United States Water Law: An Introduction 38 (CRC Press, 2009).

[2] "Navigable," in this context, is a legal term of art that varies from state to state, separating public waters from those that are private. As a general notion, "navigable" means navigable in fact, which, historically, has been tested by whether or not a log or canoe could float on the water. *See, e.g.*, Paul G. Kent & Tamara A. Dudiak, *Wisconsin Water Law: A Guide to Water Rights and Regulations* 4 (University of Wisconsin-Extension, 2d ed., 2001).

[3] The public trust doctrine, in most states, refers to the concept that state, as trustee to the public, preserves navigable waters "for public use in navigation, fishing and recreation." Black's Law Dictionary 1232 (6th ed. 1990). This prohibits the state from selling the beds to private parties.

[4] Ohio Rev. Code § 1521.17. The Ohio Legislature adopted the factors put forth in the Restatement (Second) of Torts published by the American Law Institute.

This replaced the simplified reasonable-use rule that prevailed in Ohio common law, which defined water uses as reasonable unless it caused "real, material, and substantial" damage to other riparian owners' rights.[5] Public waters in Ohio consist of all navigable waters, and riparian rights are subject to public rights of navigation[6] and fishing[7] thereon.

The state has instituted separate permit programs for large diversions and withdrawals from Ohio waters, explicitly noting that permit programs would not impact common law riparian rights.[8] The permit program for large-scale diversions focuses on two areas: the Lake Erie and Ohio River basins. The Ohio Department of Natural Resources (DNR) requires persons diverting more than 100,000 gallons-per-day to apply for a permit.[9] DNR may hold a hearing and will issue a permit if: (1) the water is not needed for other uses within the basin; (2) the diversion will not endanger public health, safety and welfare; (3) the diversion is a reasonable and beneficial use of the water; (4) "efforts have been made to develop and conserve water resources;" (5) the diversion is consistent with state and local water resource plans; and (6) the diversion will not have "significant adverse impact on in-stream uses or on economic or ecological aspects of water levels."[10] Once issued, the permittee must annually report to DNR, and the agency may revoke the permit if the authorized allotment is exceeded.

For the withdrawal program, water users withdrawing two million gallons-per-day on average in a 30-day period must receive a permit from DNR, exempting public water systems that were in existence prior to 1984, which only must comply with registration requirements.[11] This permit program applies to all state water sources and requires permittees to comply with more stringent standards. Permits must: (1) not adversely affect public water rights in navigable waters; (2) incorporate "maximum feasible conservation practices," considering available technology and the economics of alternatives; (3) reasonably promote the protection of the public health, safety, and welfare of the public; (4) not have a significant detrimental effect on water quantity or quality; (5) be consistent with regional or state water resources plans; and (6) have sufficient water available for withdrawal and other existing legal water uses.[12] Procedurally, withdrawal permittees have the same hearing, reporting and revocation rights as the diversion permittees.

As a result of the Great Lakes Basin Compact and subsequent Ohio law, DNR must notify state governors and Canadian premiers of Compact member states and provinces of any diversion over 100,000 gallons-per-day or withdrawals over five million gallons-per-day (averaged over a 30-day period) in the Lake Erie basin. If any objections are raised, the state must consult with the Compact members and seek a mutually agreeable recommendation for the water use.[13] Ohio has taken some steps to inventory state water resources and plan for the future. DNR collects and maintains detailed information regarding the type and location of water sources and the consumptive and divertive uses for the purpose of "interpretation, storage, retrieval,

[5] *McElroy v. Goble*, 6 Ohio St. 187, 188–89 (1856).
[6] *State* ex rel. *Andersons v. Masheter*, 1 Ohio St. 2d 11, 13 (1964).
[7] *Sloan* v. *Biemiller*, 34 Ohio St. 492, 514 (1879).
[8] Ohio Rev. Stat. § 1501.31.
[9] Ohio Rev. Stat. § 1501.32(A).
[10] *Id.* at (B).
[11] Ohio Rev. Stat. § 1501.33.
[12] Ohio Rev. Stat. § 1501.34.
[13] Ohio Rev. Stat. §§ 1501.32(C), 1501.35.

exchange and dissemination" of the inventory.[14] *In order to assist DNR in its inventory, any facility that has the capacity to withdraw from more than 100,000 gallons-per-day must register with the state and report annually its average daily withdrawal and return flow to the water source.*[15] *This requirement only applies to surface water, unless a groundwater withdrawal (1) occurs in an area DNR designated a "ground water stress area," and (2) the threshold capacity of the source in that stress area has been reached.*[16]

Using the water inventory and other scientific resources as guidance, the Water Advisory Council may make policy and legislation recommendations regarding water management and conservation that "promote economic, industrial, and social development . . . while minimizing threats to the state's natural environment."[17] *They also serve to make water management recommendations for any type of state plan or project, and coordinate water management between agencies.*[18] *Any state policy changes FWS would like to see added or amended would likely start with the Water Advisory Council. Overall, most programs in Ohio are state-run, rather than delegated to local units as other states in Region 3 have done.*

[14] Ohio Rev. Stat. § 1521.15
[15] Ohio Rev. Stat. § 1521.16.
[16] *Id.* at (B).
[17] Ohio Rev. Stat. § 1521.031.
[18] Id.

Permit Requirements

In the context of ONWRC water resource management, Ohio's withdrawal, diversion, and consumptive use permit programs may become especially relevant if Lake Erie levels decline and active water management practices increase. In terms of the "reasonable use" standard, any use is considered a withdrawal, and there are currently no provisions for mitigating factors, such as being the most downstream water user in the Basin, as ONWRC is. In addition to withdrawal permit requirements outlined in ORC §1501.33, water use permits are also required under the Great Lakes-St. Lawrence River Basin Water Resources Compact (ORC §1522.01). Because CPNWR utilizes water resources directly from Lake Erie, withdrawal regulations outlined in the Compact are relevant. Water usage from the Lake below the threshold quantity of 2.5 million gallons (7.7 acre-feet per day) per day (90-day average; equal to 693 acre-feet) is exempt from permit requirements (ORC §1522.14). This threshold also applies to recognized Lake Erie navigation channels, meaning direct tributaries of Lake Erie, extending bank to bank, that are state or federally maintained navigation channels. In addition to Lake withdrawals or consumptive uses over this amount, the Compact requires permits for those equal to or exceeding 1 million gallons per day from any river, stream, or groundwater resource within the Lake Erie Watershed, and a lower threshold (100,000 gpd) applies if the river or stream is a "high quality water."

Based on current Lake levels and pump locations, the Complex's withdrawals are most likely considered to be sourced from the Lake. However if Lake Erie levels decline in the future, withdrawal points may fall under state waters, for which the stricter permitting requirements apply. Refuge management should stay informed with Ohio's Diversion/Withdrawal Regulation Program to ensure that operations continue in accordance with State regulations.

Several pumps on the Complex are currently capable of pumping 2.5 million gpd (7.7 acre-feet per day) or greater, and therefore may require permits during some years of operation, depending on the length of time operated. These include the Cedar Point, Moist Soil, Blausey, and Darby pumps. If additional pumps are purchased and installed in the future, their expected pumping rates should be considered for permitting purposes. However, any pump system predating the Compact established in December of 2008 is grandfathered in and does not require a permit. Ohio reports "grandfathered" facilities with their registration program, and facilities that register can still be added to the grandfathered list retroactively, as long as current water use is the same as it was prior to the Compact.

Regardless, the Refuges' pump systems must be registered with the state of Ohio because it is a requirement, strictly for inventory purposes, for any facility capable of 100,000 gpd or greater to do so. Instructions and forms can be found on the Ohio DNR Division of Water Resources website (http://water.ohiodnr.gov/water-use-planning/water-withdrawal-facilities-registration#FOR).

Geospatial Data Sources

HUC polygons are available from the EPA as part of the Watershed Boundary Dataset (http://www.ncgc.nrcs.usda.gov/wps/portal/nrcs/main/national/ngmc). These boundaries were delineated in cooperation with the USGS using methodology adapted from Seaber et al (1987)

High resolution LiDAR data (1 m cell size) was processed and merged for the Refuge by Vince Capeder (USFWS, 2014)

Multiple types of geospatial layers are available from the USGS National Atlas website (http://nationalatlas.gov/maplayers.html)

The National Wetland Inventory- U. S. Fish and Wildlife Service. 1985-1986. National Wetlands Inventory website. U.S. Department of the Interior, Fish and Wildlife Service, Washington, D.C. http://www.fws.gov/wetlands/

The National Hydrologic Dataset (NHD) is produced as a cooperative effort by the Environmental Protection Agency (EPA), the U.S. Geological Survey (USGS), and other federal and state agencies.

DEM, LiDAR, bathymetry, and NAIP imagery data were compiled by Credico (2014).

Literature Cited

Adams (1994). Ottawa National Wildlife Refuge Complex Marsh, Water, Moist Soil Management Plan. U.S. Fish & Wildlife Service National Wildlife Refuge System. 60 p.

Andresen, J., S. Hilberg, K. Kunkel, 2012: Historical Climate and Climate Trends in the Midwestern USA. In: U.S. National Climate Assessment Midwest Technical Input Report. J. Winkler, J. Andresen, J. Hatfield, D. Bidwell, and D. Brown, coordinators. Available from the Great Lakes Integrated Sciences and Assessments (GLISA) Center, <http://glisa.msu.edu/docs/NCA/MTIT_Historical.pdf>.

Banda, J.A. (2012). Ottawa National Wildlife Refuge Contaminants Assessment Process. Accessible online: <https://ecos.fws.gov/cap>.

Banda, J.A. (2014). Ottawa National Wildlife Refuge Contaminants Assessment Process. Accessbile online: <https://ecos.fws.gov/cap>.

Blumberg, A. F. and Di Toro, D. M. (1990). Effects of Climate Warming on Dissolved Oxygen Concentrations in Lake Erie. Transactions of the American Fisheries Society 119:210-223.

Brady, A.M.G. (2007). Escherichia coli and suspended sediment in Berger Ditch at Maumee Bay State Park, Oregon, Ohio, 2006. USGS Open-File Report 2007-1244.

Breen, K.G., and Dumouchelle, D.H. (1991). Geohydrology and quality of water in aquifers in Lucas, Sandusky, and Wood Counties, Northwestern Ohio. USGS Water-resources investigations report 91-4024. 234 p. <http://pubs.usgs.gov/wri/1991/4024/report.pdf>

Brockman, C.S. (1998). Physiographic Regions of Ohio. Ohio Department of Natural Resources. < http://www.people.iup.edu/kpatrick/Great%20Lakes/Ohio%20Physiography.pdf>.

Bugliosi, E.F. (1999). The Midwestern Basins and Arches Regional Aquifer System in Parts of Indiana, Ohio, Michigan, and Illinois: summary, Issue 1423 Part I. 46p.

Burnett, A.W., Kirby M.E., Mullins H.T., Patterson W.P. (2003). Increasing Great Lake–Effect Snowfall during the Twentieth Century: A Regional Response to Global Warming?. J. Climate, Vol. 16, 3535–3542.

Cowardin, L.M, V. Carter, F.C. Golet, & E.T. LaRoe. (1979). Classification of wetlands and deepwater habitats of the United States. Department of the Interior. U.S. Fish and Wildlife Service, Washington*, D.C.* 131 p.

Credico, J. (2014). Ottawa National Wildlife Refuge wetland bathymetric and water resource assessment (draft report). 116p.

DeGaetano, A. T., and R. J. Allen (2002), Trends in twentieth century temperature extremes across the United States, J. Clim., 15, 3188–3205

Gronewold, A.D., and Stow, C.A. (2014). Unprecedented seasonal water level dynamics on one of the Earth's largest lakes. *Bulletin of the American Meteorological Society* 95:15-17 (DOI:10.1175/BAMS-D-12-00194.1) <http://www.glerl.noaa.gov/pubs/fulltext/2014/20140011.pdf>

Groisman, P.Y., Knight, R.W., Hegerl, G.C., and Razuvaev, V.N. (2005). Trends in intense precipitation in the climate record. Journal of Climate, Volume 18: 1326-1350.

Hayhoe, K., J. Vandorn, V. Naik and D. Wuebbles. (2010). Climate change in the Midwest prokections of future temperature and precipitation trends. 28 pp.

Hutter, H.K. (1952). Eighty years of weather and climate at Toledo, Ohio. The Ohio Journal of Science. V. 52 I. 2, 62-75. <http://hdl.handle.net/1811/3906>.

Jensen, O.P., Benson, B.J., Magnuson, J.J., Card, V.M., Futter, M.N., Soranno, P.A., Stewart, K.M. (2007). Spatial analysis of ice phenology trends across the Laurentian Great Lakes region during a recent warming period. Limnol. Oceanogr., 52(5), 2013-2026.

Kasat, R. (2006). Nutrient dynamics in a small agricultural Lake Erie tributary. < http://deepblue.lib.umich.edu/handle/2027.42/35336>

Kling, G.W., K. Hayhoe, L.B. Johnson, J.J. Magnuson, S. Polasky, S.K. Robinson, B.J. Shuter, M.M. Wander, D.J. Wuebbles, D.R. Zak, R.L. Lindroth, S.C. Moser, and M.L. Wilson. (2003). *Confronting Climate Change in the Great Lakes Region: Impacts on our Communities and Ecosystems*. Union of Concerned Scientists, Cambridge, Massachusetts, and Ecological Society of America, Washington, DC.

Kurey. B. (1997). Ottawa National Wildlife Refuge Contaminants Assessment Process. Accessbile online: <https://ecos.fws.gov/cap>.

Kunkel, K. E., Andsager, K., and Easterling, D. R. (1999). Long-term trends in extreme precipitation events over the conterminous United States and Canada, J. Climate 12, 2515–1527.

Kunkel, K. E., Westcott, N. E., & Kristovich, D. A.R. (2002). Special Section on the Potential Impacts of Climate Change in the Great Lakes Region, Assessment of potential effects of climate change on heavy lake-effect snowstorms near Lake Erie. Journal of Great Lakes Research, 28, 4, 521.

Lofgren, B.M., Quinn, F.H., Clites, A.H., Assel, R.A., Eberhardt, A.J., and Luukkonen, C.L. (2002). Evaluation of potential impacts on Great Lakes Water Resources based on climate scenarios of two GCMs. J. Great Lakes Res. 28(4):537-554.

Magnuson, J.J., Webster, K.E., Assel, R.A., Bowser, C.J., Dillion, P.J., Eaton, J.G., Evans, H.E., Fee, E.J., Hall, R.I., Mortsch, L.R., Schindler, D.W., and Quinn, F.H. (1997). Potential effects of climate changes on aquatic systems: Laurentian Great Lakes and Precambrian Shield Region.

Magnuson, J.J., Robertson D.M., Benson B.J., Wynne R.H., Livingstone D.M., Arai T., Assel R.A., Barry R.G., Card V., Kuusisto E., Granin N.G., Prowse T.D., Stewart K.M. & Vuglinski V.S. (2000). Historical trends in lake and river ice cover in the northern hemisphere. Science 289: 1743-1746.

Menne, M.J., Durre, I., Vose, R.S. , Gleason, B.E., and Houston, T.G. (2012) “An overview of the Global Historical Climatology Network-Daily database.” *Journal of Atmospheric and Oceanic Technology*, 29, 897–910,doi:10.1175/JTECH-D-11-00103.1

Midwestern Regional Climate Center. (2012). Climate trends in the western Lake Erie Basin.

Mortsch, L.D., and F.H. Quinn. 1996. Climate change scenarios for Great Lakes Basin ecosystem studies. *Limnology and Oceanography* 401:903-911.

National Oceanic and Atmospheric Administration Great Lakes Environmental Research Laboratory. (2012). Innovative Research for the Freshwater Seas: Strategic Plan 2012. U.S. Department of Commerce.

National Oceanic and Atmospheric Administration Great Lakes Environmental Research Laboratory. (2013). Great Lakes Water Level Observations. < http://www.glerl.noaa.gov/data/now/wlevels/>

National Oceanic and Atmospheric Administration. (2014). Great Lakes water level observations. <www.glerl.noaa.gov/data/now/wlevels/levels.html>

National Wildlife Federation. (2013). Taken by storm: how heavy rain is worsening algal blooms in Lake Erie, with a focus on the Maumee River in Ohio. 23 p. Retreived from: < http://www.nwf.org/~/media/PDFs/Water/Taken_By_Storm_NWF_2013.ashx>

National Wildlife Federation. (2014). Restoring the Great Lakes’ Coastal Future. Technical Guidance for the Design and Implementation of Climate-Smart Restoration Projects. 105 p. < http://www.habitat.noaa.gov/pdf/restoring_the_greatLakes_coastal_future_design_implementation_and_case_studies.pdf>.

Obenour, D.R., Gronewold, A.D., Stow, C.A., Scavia, D., (2014).Using a Bayesian hierarchical model to improve Lake Erie cyanobacteria bloom forecasts. *Water Resour. Res.* 50.

Ohio Department of Natural Resources. (2008). Ground water induced flooding in the Bellevue Ohio area, Spring and Summer 2008. ODNR Division of Water Technical Report of Investigation 2009-1. < http://soilandwater.ohiodnr.gov/portals/soilwater/pdf/groundwater/Bellevue_Final_Report.pdf>

Ohio Environmental Protection Agency. (2010)a. An overview of ground water quality in Ohio. Ohio 2010 Integrated Report. 29 p.

Ohio Environmental Protection Agency. (2010)b. Biological and Water Quality Survey of the Sandusky Bay Tributaries 2009. Erie, Sandusky, and Seneca Counties, Ohio. OEPA Report DSW/EAS 2010-4-6. < http://www.epa.ohio.gov/portals/47/citizen/clyde/SBTTSDJune092010.pdf>

Ohio Environmental Protection Agency (2012). An overview of water quality in Ohio. Ohio 2012 Integrated Report. 33 p. <http://www.epa.state.oh.us/portals/35/tmdl/2012IntReport/IR12SectionMfinal.pdf>

Ohio Environmental Protection Agency (2013), Ohio Lake Erie Phosphorus Task Force II, Final report, Ohio Environmental Protection Agency, Columbus, Ohio.

Ohio Department of Agriculture, Ohio Department of Natural Resources, Ohio Environmental Protection Agency, Ohio Lake Erie Commission. (2013). Ohio Lake Erie Phosphorus Task Force II Final Report. <https://www.motherjones.com/files/task_force_report_october_2013.pdf>

Ohio Department of Natural Resources. (1989). Division of Geological Survey, Ohio Geology Newsletter: The history of Lake Erie. <http://www2.ohiodnr.com/portals/geosurvey/PDFs/newsletter/Fall89.pdf>.

Ohio Department of Natural Resources. (2012). Region Description: Cedar Point National Wildlife Refuge (Lucas County) to Rock Ledge (Ottawa County). Lake Erie Shore Erosion Management Plan, Western Basin Region Introduction. 10p.

Ohio Environmental Protection Agency. (2008). Evaluation of land use/land cover characteristics in Ohio drainages to Lake Erie. Ohio Phosphorus Task Force. <http://www.epa.state.oh.us/portals/35/lakeerie/ptaskforce/OPTF_Landuse_20081001_hres.pdf >

Palecki, M. A., S. A. Changnon, and K. E. Kunkel (2001). The nature and impacts of the July 1999 heat wave in the Midwestern United States: Learning from the lessons of 1995. Bulletin of the American Meteorological Society, 82, 1353-1368, doi:10.1175/1520-0477(2001)082<1353:TNAIOT>2.3.CO;2.

Pavey, R.R., Angle, M.P., Donovan, M.P., and Swinford, E.M. Karst Flooding in Bellevue, Ohio, and vicinity, 2008. < http://geosurvey.ohiodnr.gov/portals/geosurvey/PDFs/Karst/BellevueKarst2008.pdf>

Pfaff, J.M. (2012). Spatial and seasonal variability in Crane Creek, a diked freshwater estuary complex tributary to Western Lake Erie. 57p. < http://deepblue.lib.umich.edu/bitstream/handle/2027.42/92462/Pfaff_Thesis_Final.pdf?sequence=1>

Ruedisili, L.C., Kihn, G.E., and Bell, R.C. (1990). Geology of Seneca Caverns, Seneca County, Ohio. The Ohio Journal of Science. v90, n4, 106-111 http://hdl.handle.net/1811/23402

Sallee, R., Hesse, G., and Kosek-Sills, S. (2013). Lake Erie Protection & Restoration Plan. Ohio Lake Erie Commission.

Seaber, P.R., Kapinos, F.P., and Knapp, G.L.. (1987). Hydrologic Unit Maps: U.S. Geological Survey Water-Supply Paper 2294, 63 p.

Shideler, G.L., Stone, B.D., and Larsen, G.E. (1996). Map showing bedrock surface topography of the Toledo area, northwestern Ohio and southeastern Michigan. USGS Miscellaneous Field Studies Map MF-2309. Map scale, 1:100,000. <http://ngmdb.usgs.gov/Prodesc/proddesc_5928.htm>

Slack, J.R. and J.M. Landwehr, Hydro-Climatic Data Network (HCDN): A U.S. Geological Survey Streamflow Data Set for the United States for the Study of Climate Variations, 1874-1988, U.S. Geological Survey Open-File Report 92-129.

Small D, Islam S, Vogel RM, (2006). Trends in precipitation and streamflow in the eastern US: Paradox or perception? Geophys Res Lett 33.

Smith. (1994). Ground water pollution potential of Ottawa County, Ohio. Ground Water Pollution Potential Report No. 20. ODNR Division of Water. <http://soilandwater.ohiodnr.gov/portals/soilwater/pdf/maps/groundwater%20pollution/Preprinted/Ottawa_GWPP_wMap.pdf>.

Snyder, D., Haluska, T., & Respini-Irwin, D. (2012). The Shoreline Management Tool- An ArcMap tool for Analyzing Water Depth, Inundated Area, Volume, and Selected Habitats, with an Example for the Lower Wood River Valley, Oregon. *USGS,* 1-68. Retrieved from http://pubs.usgs.gov/of/2012/1247/pdf/ofr20121247.pdf

Sparling, D.R. Anomalous drainage pattern and crustal tilting in Ottawa County and Vicinity, Ohio. Ohio Journal of Science: Volume 67, Issue 6, 378-381. <http://hdl.handle.net/1811/5347>

Stefan, H. G., and Fang, X. (1997).Simulated climate change effects on ice and snow covers on lakes in a temperate region, Cold Regions Sci. Technol., 25, 137–152, 1997.

Stumpf, R. P., T. T. Wynne, D. B. Baker, and G. L. Fahnenstiel (2012), Interannual variability of cyanobacterial blooms in Lake Erie, PLOS ONE, 7, e42444.

Union of Concerned Scientists (UCS). (2009). “Confronting climate change in the U.S. Midwest - Ohio.” Cambridge, MA: UCS Publications. < http://www.ucsusa.org/sites/default/files/legacy/assets/documents/global_warming/climate-change-ohio.pdf>

United States Army Corps of Engineers. Monthly Bulletin of Great Lakes Water Levels, six-month forecast bulletins. <http://www.lre.usace.army.mil/Missions/GreatLakesInformation/GreatLakesWaterLevels/WaterLevelForecast/MonthlyBulletinofGreatLakesWaterLevels.aspx>

United States Department of Agriculture. (2011). Cropping Systems Coordinated Agricultural Project: Climate Change, Mitigation, and Adaptation in Corn-based Cropping Systems. No. 2011-68002-30190

United States Environmental Protection Agency. (2000). Ambient Water Quality Criteria Recommendations: Information supporting the development of state and tribal nutrient criteria, rivers and streams in nutrient ecoregion VI. Washington, D.C.

United States Environmental Protection Agency, 2013, Level III and IV ecoregions of the continental United States: Corvallis, Oregon, U.S. EPA, National Health and Environmental Effects Research Laboratory, map scale 1:3,000,000 <http://www.epa.gov/wed/pages/ecoregions/level_iii_iv.htm.>

United States Environmental Protection Agency. (2014). Climate Change Indicators in the United States: Great Lakes Water Levels and Temperatures.

United States Fish and Wildlife Service. (2000). Comprehensive Conservation Plan. < http://www.fws.gov/midwest/Planning/ottawa/index.html>.

United States Fish and Wildlife Service. (2010a). Operational Blueprint for Inventory and Monitoring on National Wildlife Refuges: Adapting to Environmental Change. 45 pp.

United States Fish and Wildlife Service. (2010b). Strategic Plan for Inventories and Monitoring on National Wildlife Refuges: Adapting to Environmental Change. 56 pp.

United States Fish and Wildlife Service. (2011). Rising to the urgent challenge: strategic plan for responding to accelerating climate change. 36 pp.

United States Fish and Wildlife Service. (2014). DRAFT Habitat Management Plan.

United States Geological Survey. (2000). The importance of ground water in the great lakes region. Water resources investigations report 00-4008. 14p. <http://water.usgs.gov/ogw/pubs/WRI004008/WRIR_00-4008.pdf>

United States Geological Survey. (2012). New Strategies for Restoring Coastal Wetland Function: Summary Annual Report – 2011. Annual report to U.S. Fish and 57 Wildlife Service Ottawa National Wildlife Refuge, Oak Harbor, Ohio. 58 p.

United States National Oceanic and Atmospheric Administration (NOAA). (2013). Regional Climate Trends and Scenarios for the U.S. National Climate Assessment. Part 3. Climate of the Midwest U.S. by Kunkel, K.E, L.E. Stevens, S.E. Stevens, L. Sun, E. Janssen, D. Wuebbles, S.D. Hilberg, M.S. Timlin, L. Stoecker, N.E. Westcott, and J.G. Dobson. NOAA Technical Report NESDIS 142-3, 95 p.

Vanderploeg, H. A., J. R. Liebig, W. W. Carmichael, M. A. Agy, T. H. Johengen, G. L. Fahnenstiel, and T. F. Nalepa (2001), Zebra mussel (Dreissena polymorpha) selective filtration promoted toxic Microcystis blooms in Saginaw Bay (Lake Huron) and Lake Erie, Canadian Journal of Fisheries and Aquatic Sciences, 58(6), 1208-1221.

Winkler, J.A., Arritt, R.W., Pryor, S.C. (2012). Climate Projections for the Midwest: Availability, Interpretation and Synthesis. In: U.S. National Climate Assessment Midwest Technical Input Report. Available from the Great Lakes Integrated Sciences and Assessment Center < http://glisa.umich.edu/media/files/NCA/MTIT_Future.pdf>.

Western Lake Erie Basin Partnership. (2003). Western Lake Erie Basin Revised Expanded Reconnaissance Study Section 905(b) Analysis (WRDA 86). 82p. <http://www.wleb.org/documents/reconstudyreport.pdf>

Western Lake Erie Basin Partnership. (2008). Western Lake Erie Basin Study Portage Watershed Assessment, Final Draft. USACOE. Buffalo, NY. 159 p. < http://www.tmacog.org/Environment/Portage/WLEBPortage.pdf>

Appendix A: Water Control Structures

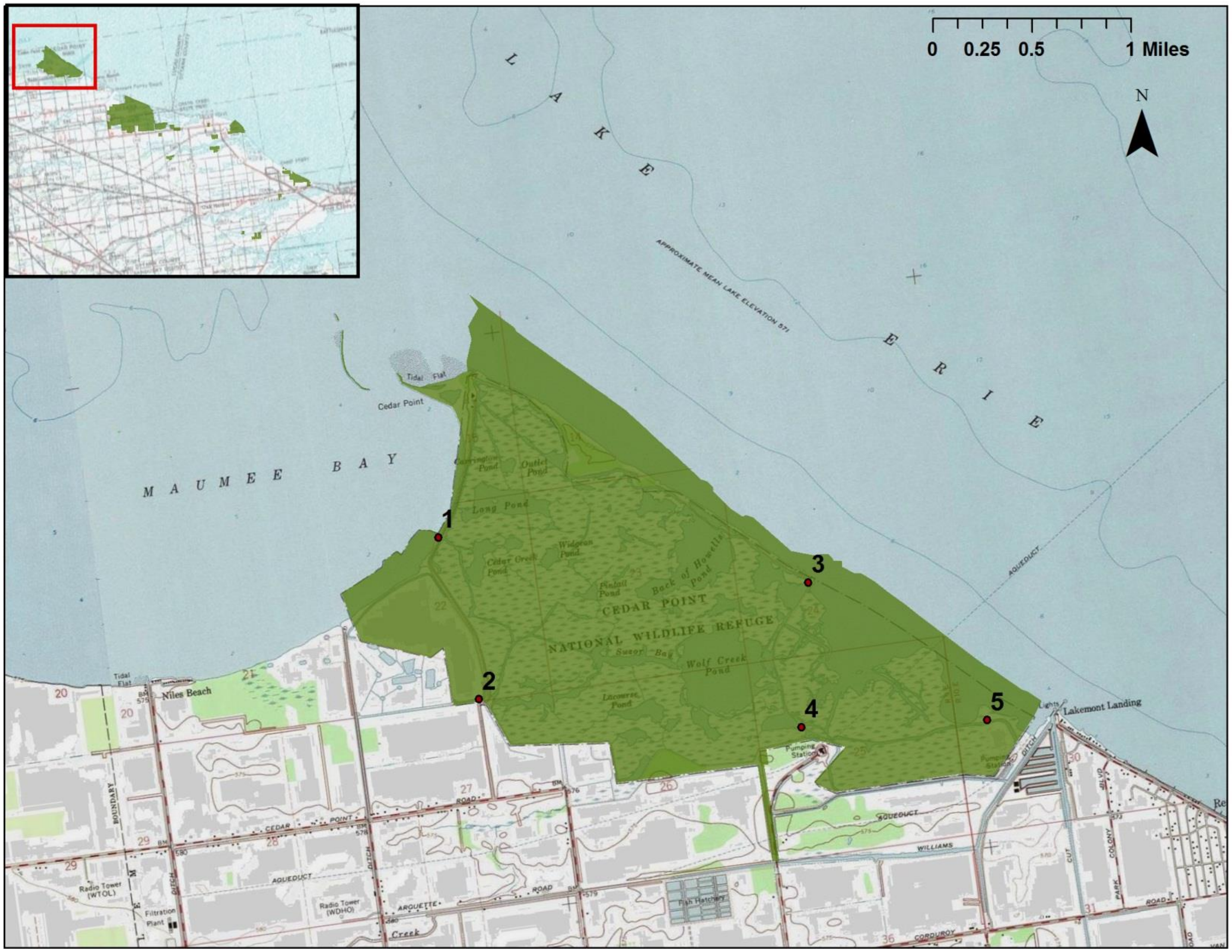


Figure 46 WCSs at CPNWR

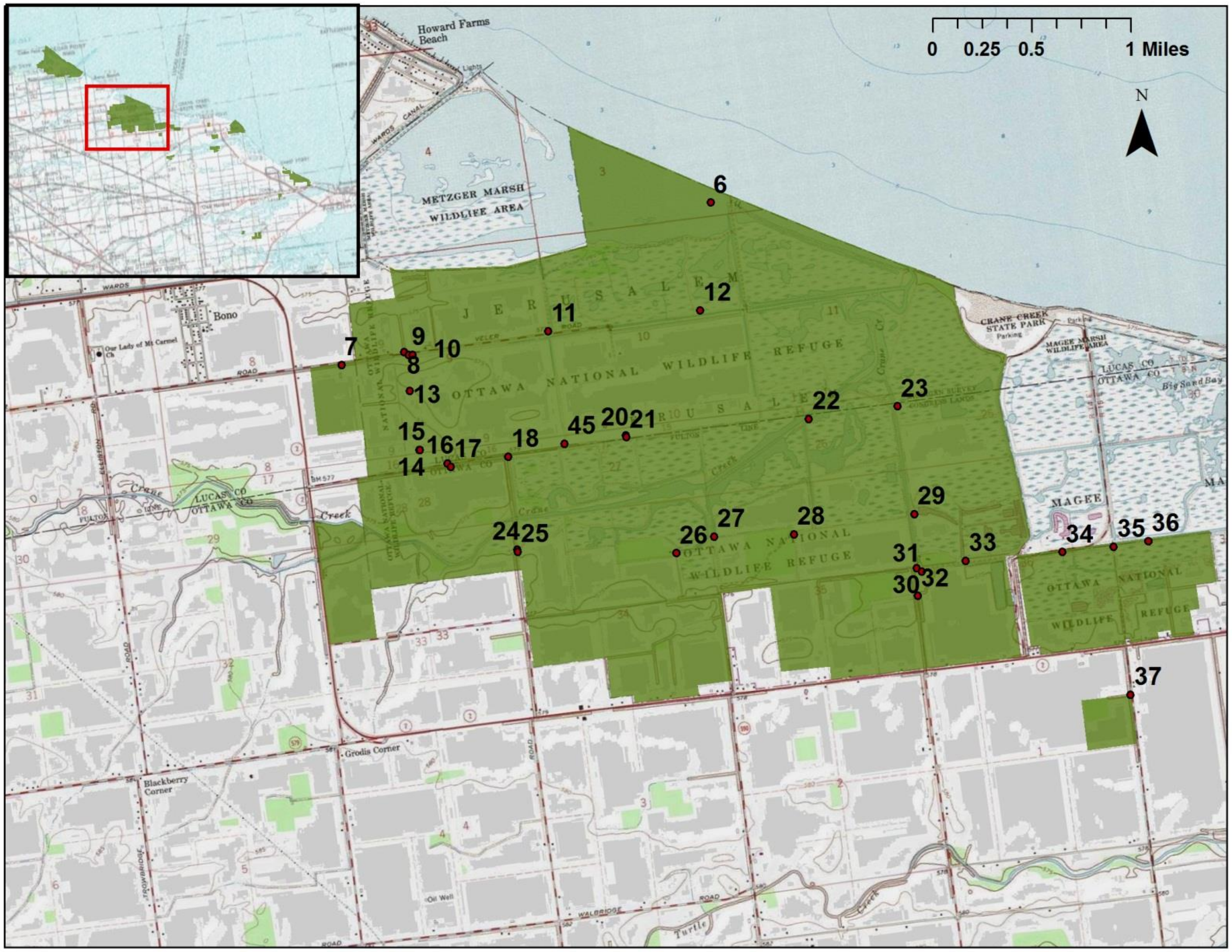


Figure 47 WCSs at ONWR (main tracts - west)

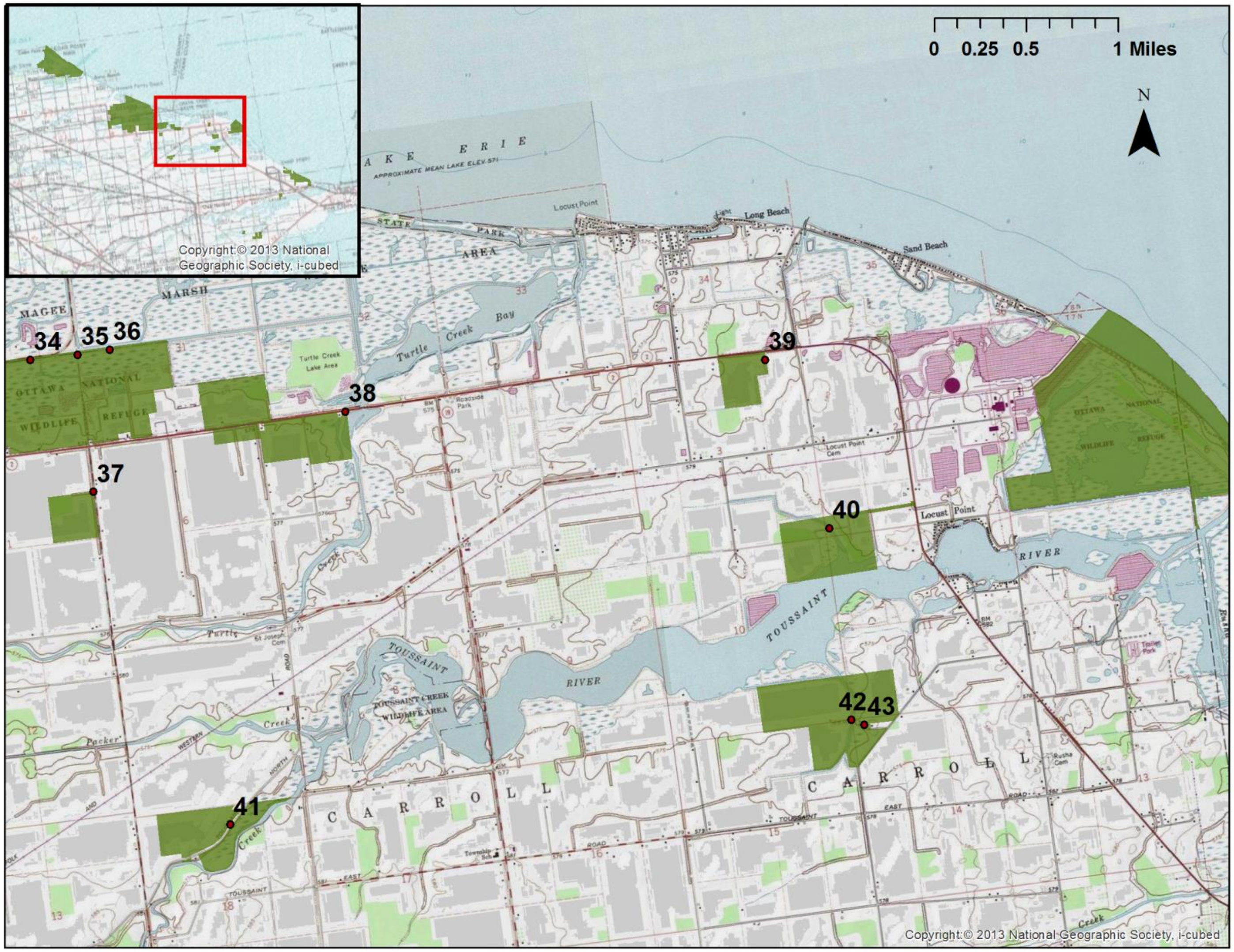


Figure 48 WCSs at ONWR (main tracts – east)

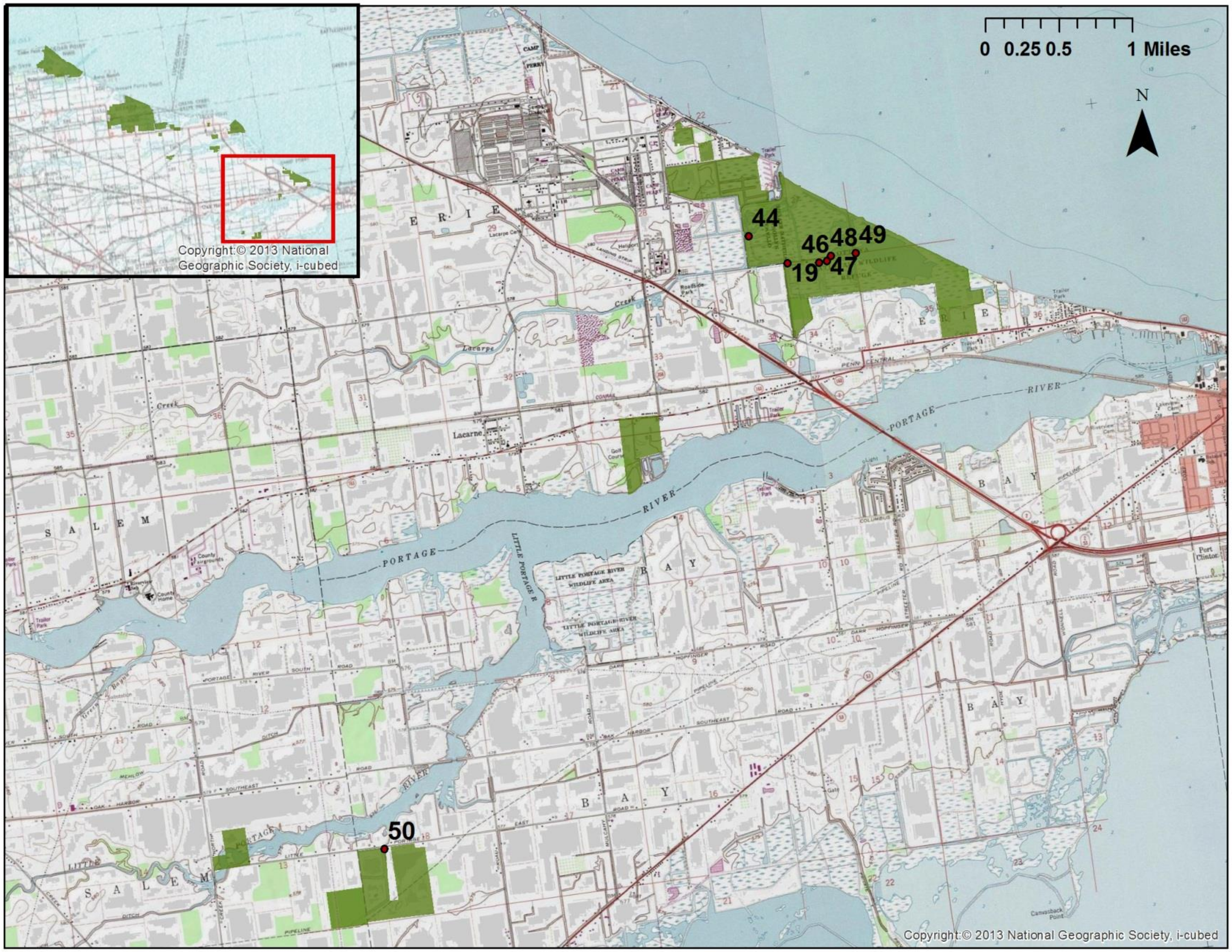


Figure 49 Water control structures at ONWR (Darby Unit)

ID	ft	NGLD	Structure	Notes	Flow
1	578.4	578.2	CP Pool 1 west WCS		
2	575.3	575.1	CP Pheasant Farm WCS		
3	0.0	0.0	CP Pool 1 pump	Pumping Station	Inflow
4	579.0	578.8	CP Pool 1/Pool 2/Potters Pond WCS		
5	579.7	579.4	CP Pool 2/Potters Pond WCS		
6	576.6	576.4	Metger's Marsh WCS/Pump: Not on Refuge lands, Fish Research	Lift Gate	Inflow/Outflow
7	578.9	578.6	OTW Farm Unit 2 WCS		
8	0.0	0.0	OTW Pool 9 WCS/pump, Borrow, Veler Rd	Pumping Station	Inflow/Outflow
9	578.3	578.1	OTW Moist Soil 2 pump	Pumping Station	Inflow/Outflow
10	577.7	577.4	OTW Rail Unit WCS		
11	576.4	576.2	OTW Pool 9 southeast WCS		
12	576.5	576.2	OTW Pool 3 WCS		
13	578.9	578.7	OTW Moist Soil 2 north WCS		
14	578.0	577.8	OTW Moist Soil 2 south WCS-1		
15	578.0	577.8	OTW Moist Soil 2 south WCS-2		
16	0.0	0.0	OTW Hunt Unit 2 WCS/pump	Pumping Station	Outflow
17	579.3	579.0	OTW Hunt Unit 6/Hunt Unit 6 WCS		
18	578.0	577.7	OTW Moist Soil 3 pump	Pumping Station	Inflow/Outflow
19	578.9	578.7	OTW Darby pump/WCS	Pumping Station	Inflow/Outflow
20	577.5	577.3	OTW Moist Soil 4 WCS		
21	576.9	576.7	OTW Moist Soil 4 WCS (agridrain)		
22	580.0	579.8	OTW Pool 2b WCS		
23	0.0	0.0	OTW Pool 1 Pump	Pumping Station	Inflow
24	0.0	0.0	OTW Moist Soil 7a pump	Pumping Station	Inflow/Outflow
25	577.8	577.6	OTW Moist Soil 7a WCS		
26	578.2	578.0	OTW MiniMarsh pump	Pumping Station	Inflow/Outflow
27	578.7	578.5	OTW Moist Soil-8a/Crane Creek pump	Pumping Station	Inflow/Outflow
28	577.6	577.4	OTW Moist Soil 8b/Woods WCS		
29	577.1	576.9	OTW Showpool WCS		

30	0.0	0.0	OTW MS 8b pump	Pumping Station	Inflow/Outflow
31	576.4	576.2	OTW Entrance Pool WCS		
32	0.0	0.0	OTW South Woods Unit 12 pump	Pumping Station	Outflow
33	574.2	574.0	OTW Goosepen WCS		
34	577.9	577.7	OTW West Woodys Roost WCS		
35	578.8	578.6	OTW East Woodys Roost/West Woodys Roost WCS		
36	579.1	578.9	OTW East Woodys Roost WCS		
37	577.2	576.9	OTW Boss WCS		
38	0.0	0.0	OTW Kontz pump	Pumping Station	Outflow
39	574.4	574.1	OTW Schneider WCS		
40	0.0	0.0	OTW Gaeth-Kurdy pump	Pumping Station	Outflow
41	574.2	574.0	OTW Helle WCS		
42	0.0	0.0	OTW Blausey west pump	Pumping Station	Outflow
43	0.0	0.0	OTW Blausey east pump (old farm pumps/distribution box)	Pumping Station	Outflow
44	576.2	576.5	OTW Darby Pool 1 west WCS		
45	578.9	578.7	OTW Moist Soil 3 WCS		
46	578.1	577.8	OTW Darby Pool 2 WCS		
47	578.2	578.0	OTW Darby Pool 3 WCS		
48	576.0	575.8	OTW Darby Pool 1 south WCS		
49	576.0	575.8	OTW Darby Pool 4 WCS		
50	0.0	0.0	OTW Price pump	Pumping Station	Outflow

Table 8 ONWRC water control structures

Appendix B: NWI Information

The NWI is based on interpretation of aerial photographs rather than ground surveys, and its criteria differ from those used in jurisdictional wetlands delineations for permitting by the USACE under Section 404 of the Clean Water Act.

This inventory includes a Cowardin classification (1979) codes for each wetland unit. The highest level of this hierarchical classification is the system, with five divisions: marine, estuarine, riverine, lacustrine, and palustrine. The second level is subsystems, which characterize structure and inundation regime. The third level is classes, which characterize substrate material and vegetation type. Classes are further divided into finer categories of substrate or vegetation type in the fourth level of classification. A habitat may also be categorized by any of 47 modifiers, including various water regimes, water chemistry parameters, soil parameters, and human modifications.

As with most remotely-sensed data, maps and statistics derived from the NWI have inherent errors and limitations, particularly for wetland type classifications and acreage. The accuracy of baseline inventories and classifications for data related to wetlands is limited by the quality of imagery, may be subject to errors of the imagery analysts' interpretations, and may not have been verified with ground truth surveys. Wetlands are also dynamic in nature, while the imagery used for the inventory represents a snapshot in time. Landscape and climate changes may have altered the composition and/or extent of the wetlands since the dataset was created.

Wetland Type	Total acreage in FWS Interest Bndry (ONWR)	%	Total acreage in FWS Interest Bndry (CPNWR)	%
Lake	744.3	15.0	757.5	29.7
Freshwater Pond	272.0	5.5	15.0	0.6
Freshwater Emergent Wetland	3241.6	65.1	1726.2	67.7
Freshwater Forested/Shrub Wetland	510.9	10.3	40.7	1.6
Riverine	209.1	4.2	8.7	0.3
Totals	4977.9	100	2548.0	100

Table 9 NWI wetland types identified within CPNWR and ONWR acquired boundaries

Wetland Code	Total Acreage (ONWR)	%
L2UBHx	0.053921	0.001083
PEM1KAh	0.20529	0.004124
PFO1Ax	0.380932	0.007652
L2USA	1.092654	0.02195
PSS1Fh	1.299068	0.026097
PEM1Ah	1.422304	0.028572
PSS1F	2.204811	0.044292
R2EM2/UBH	2.733048	0.054904
L1UBH	3.424764	0.068799
PSS1/EM1Fh	4.178375	0.083938
PSS1Kh	7.044405	0.141513
PEM1Fd	7.338181	0.147415
PFO1A	8.448849	0.169727
PFO1F	8.636626	0.173499
PFO1Ad	9.16573	0.184128
PEM1Cd	9.597772	0.192807
PSS1KFh	9.776849	0.196405
PEM1B	11.87469	0.238548
PSS1/EM1C	12.14922	0.244063
R2UBHx	14.97587	0.300846
L2ABGh	16.04489	0.322322
R2EM2H	16.301	0.327467
PABFh	18.17355	0.365084
PFO1/EM1A	18.54252	0.372496
PFO1Fh	20.63864	0.414604
PEM1Kh	21.82894	0.438516
PSS1KCh	24.54704	0.493119
PFO1KCh	25.59535	0.514179
PSS1/EM1A	36.76804	0.738624
PFO1/SS1C	41.49003	0.833483
PEM1Fx	41.67988	0.837297
PSS1C	46.22198	0.928542
PUBG	50.54872	1.015461
PSS1/EM1Ch	62.41014	1.253742
PFO1Ch	78.28345	1.572617
PEM1Ch	83.48967	1.677203
PFO1C	93.14529	1.871172
PUBGx	93.7353	1.883025
PEM1Fh	95.88419	1.926193
PEM1A	100.0983	2.01085

PABKGh	109.5348	2.200418
PEM1KCh	166.2024	3.338799
R2UBH	175.1079	3.517698
L2UBH	177.0215	3.55614
PEM1C	209.7345	4.213303
PEM1F	307.1994	6.171251
L2UBHh	546.6209	10.98093
PEM1KFh	2185.059	43.8951
Totals	4977.911	100

Table 10 Wetland codes for wetlands of ONWR. Note: Application for code interpretation available at http://107.20.228.18/decoders/wetlands.aspx.

Wetland Code	Total acreage within CPNWR	%
PEM1KFh Total	1436.3	56.4
L2UBH Total	756.2	29.7
PEM1KCh Total	271.6	10.7
PFO1C Total	26.2	1.0
PAB3G Total	15.0	0.6
PEM1F Total	11.0	0.4
PFO1/EM1C Total	8.6	0.3
R2UBG Total	5.8	0.2
PEM1C Total	5.4	0.2
PFO1/EM1Ch Total	3.4	0.1
R2UBGx Total	2.9	0.1
PFO1KCh Total	1.9	0.1
PEM1Fh Total	1.9	0.1
L2USJ Total	1.3	0.1
PSS1/EM1Ch Total	0.6	0.0
Totals	2548.0	100

Table 11 Wetland codes for wetlands of CPNWR. Application for code interpretation available at http://107.20.228.18/decoders/wetlands.aspx.

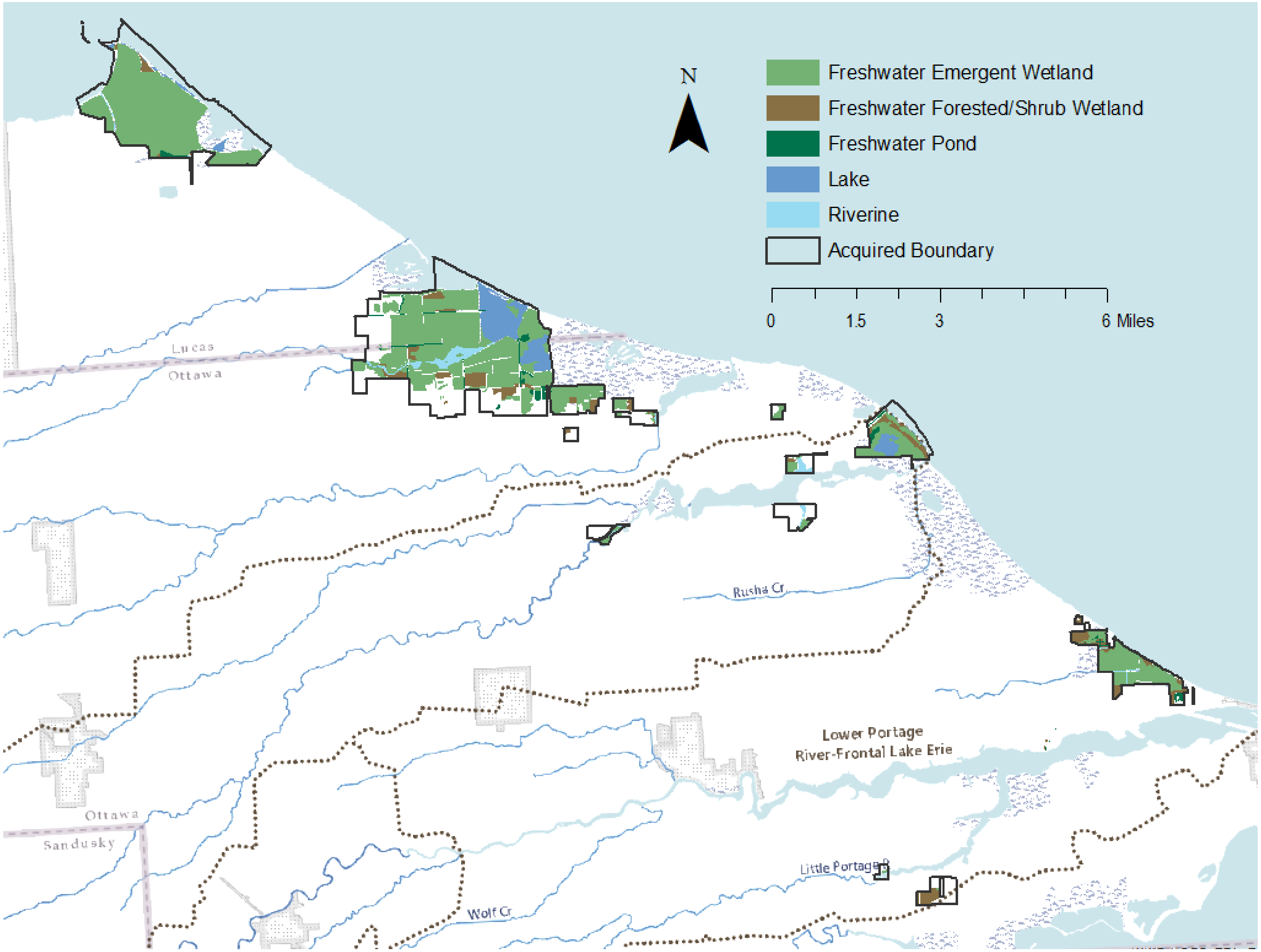


Figure 50 NWI wetland types for CPNWR and ONWR

Appendix C: NHD Information

Feature Type	Miles within ONWRC Acquired Boundary	%
Canal/Ditch	42.6	40.5
Pipeline	0.8	0.8
Stream/River - Intermittent	1.2	1.2
Stream/River - Perennial	7.8	7.4
Artificial Path	36.4	34.6
Coastline	16.4	15.6
Total:	105.2	100

Table 12 NHD information for ONWRC

Named Feature	Total Miles within Approved Boundary
Bark Creek Total	13.6
Boos Ditch Total	1.6
Buck Creek Total	5.7
Cedar Creek Total	6.7
Cold Creek Total	4.9
Cottonwood Swale Total	3.5
Crane Creek Total	10.5
Dahs Ditch Total	2.4
Dildine Ditch Total	1.4
Druckenmiller Ditch Total	1.3
Ferguson Ditch Total	5.0
Fishing Creek Total	7.3
Flag Run Total	3.2
Fuller Creek Total	5.4
Green Bayou Total	2.3
Green Creek Total	19.0
Greesman Ditch Total	2.3
Hemming Ditch Total	2.9
Indian Creek Total	9.7
Lacarpe Creek Total	5.7
Liles Ditch Total	2.4
Lindsley Ditch Total	1.4
Little Bark Creek Total	3.1
Little Pickerel Creek Total	6.4
Little Portage River Total	9.6

Little Raccoon Creek Total	7.3
Meadow Brook Total	2.4
Mehlow Ditch Total	1.0
Mills Creek Total	12.4
Minnow Creek Total	2.6
Muddy Creek Total	17.7
Muskellunge Creek Total	8.4
Ninemile Creek Total	5.5
North Branch Turtle Creek	2.1
Packer Creek Total	9.6
Pickerel Creek Total	13.8
Pipe Creek Total	10.0
Plum Brook Total	4.6
Portage River Total	21.3
Raccoon Creek Total	17.4
Reno Side Cut Total	1.6
Rusha Creek Total	8.0
Sandusky River Total	22.3
Sautter Ditch Total	0.9
Scherz Ditch Total	0.8
Schmardebeck Ditch Total	1.1
Snyders Ditch Total	1.1
South Branch Turtle Creek Total	1.9
South Creek Total	15.6
Strong Creek Total	7.6
Sucker Run Creek Total	1.3
Sugar Creek Total	2.9
Sulphur Brook Total	3.0
Taylor Ditch Total	4.5
Toussaint Creek Total	11.1
Toussaint River Total	6.5
Turtle Creek Total	12.3
Wards Canal Total	2.0
Williams Ditch Total	0.4
Wolf Creek Total	7.3
Yauch Ditch Total	2.7
Yellow Swale Total	6.6
Total	394.6

Table 13 NHD named flowlines for ONWRC

Name	Area (square miles)
The Bogs	0.537
Blue Hole	0.000
Lacourse Pond	0.016
Wolf Creek Pond	0.282
Pintail Pond	0.005
Carrington Pond	0.006
Widgeon Pond	0.007
Hannah Pond (historical)	0.016
Aldrich Pond	0.052
Cedar Creek Pond	0.022
Wolf Creek Pond	0.047
Raccoon Creek Reservoir	0.053
Back of Howells Pond	0.099
Outlet Pond	0.007
Eisenhour Marsh	0.059
Douglas Marsh	0.218
Continental Marsh	0.068
France Marsh	0.019
Searles Marsh	0.241
Ritter Marsh	0.088
Magee Marsh	0.058
Cedar Point Marsh	0.771
Hunter Marsh	0.015
Pintail Marsh	0.174
Willow Point Marsh	0.166
Metzger Marsh	0.281
Darby Marsh	0.103
Toussaint Marsh	1.590
Sand Beach Marsh	0.186
Total	5.188

Table 14 NHD named waterbodies for ONWRC

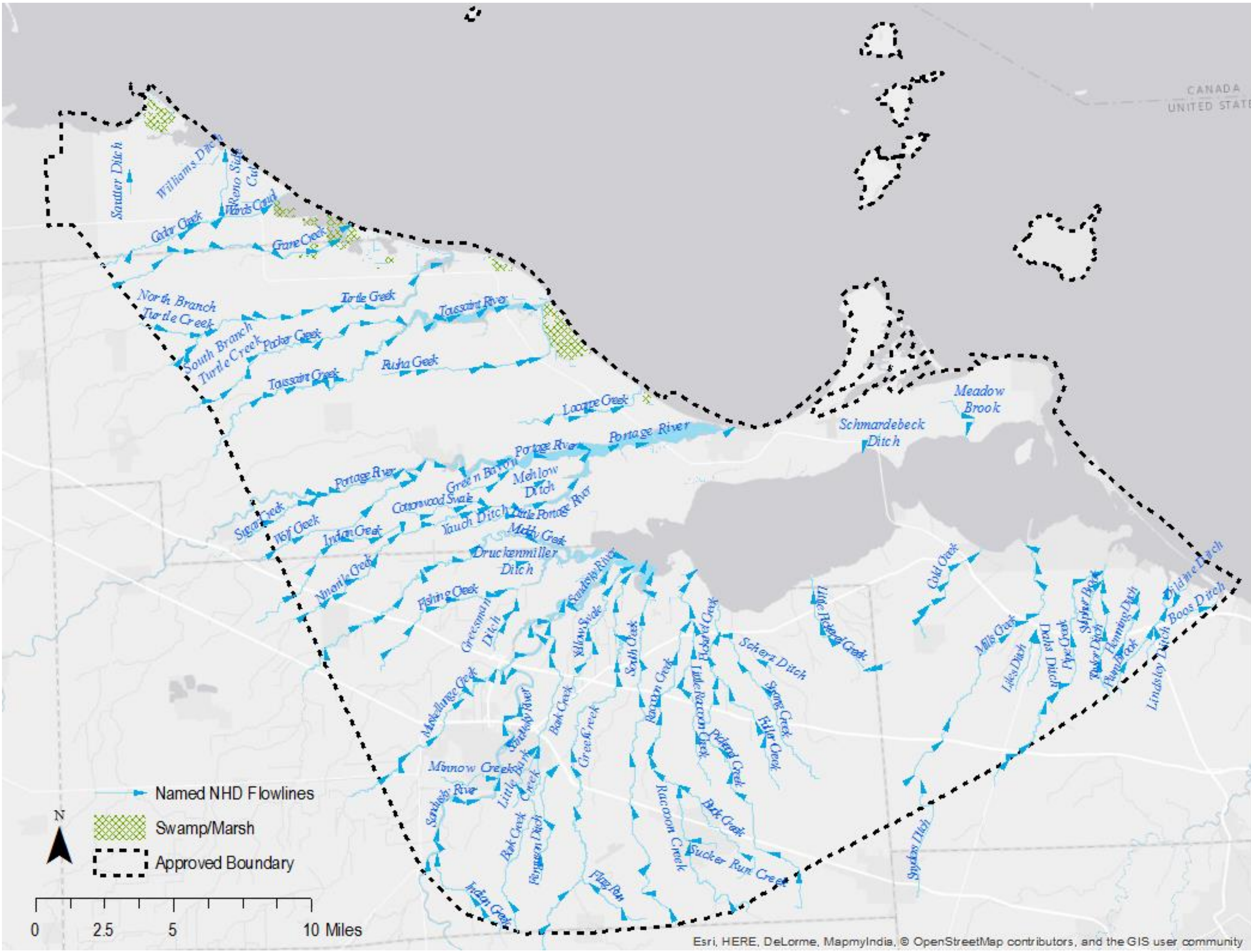


Figure 51 Named NHD flowlines within ONWRC's approved boundary

Appendix D: Water Monitoring Information

Site Name	ID (Link)	Alternate ID (Link)	Responsible Organization (s)	Data Available	Comments	HUC10	Start date	End date
Portage River at Woodville OH	USGS 04195500	21OHIO-500510	USGS Ohio Water Science Center	Daily flow and sediment data, extensive data on water quality, nutrients, metals, pollutants	Gage 614 ft above NAVD88, drainage area of 428 square miles	410001004	1928	Present
Portage River at Railroad Bridge at Woodville OH	USGS-04195600	N/A	USGS Ohio Water Science Center	Daily flow and chemistry data	Historic data, but just downstream of USGS 04195500, and extensive dataset.	410001004	1968	1980
S-2	USGS 412703083213600	N/A	USGS Ohio Water Science Center	Daily depth to water data, 1 sampling event for metals/WQ (1997)	Near sites USGS-04195600 and USGS 04195500	410001004	1978	2007
O-2 W Williams NR Port Clinton OH	USGS 413434082494000	N/A	USGS Ohio Water Science Center	Daily depth to water data, 1 sampling event for metals/WQ (1997)	Well depth of 62 feet in Silurian local aquifer system	410001005	1988	2012
Berger Ditch near Oregon OH	USGS 04194085	N/A	USGS Ohio Water Science Center	Daily flow data, 2006-2013; E. coli and sediment data, 2006	Drainage area of 15.4 square miles, gage 570 feet above NAVD88	410001007	2006	Present
Sandusky River near Fremont OH	USGS 04198000	21OHIO_WQX-500820	USGS Ohio Water Science Center	Daily flow/sediment data, extensive WQ data, additional WQ/metal readings in STORET	Drainage area of 15251 square miles, gage 626 feet above COE1912. Part of the HCDN	410001113	1923	Present

Sandusky River below Fremont OH	USGS 04198005	N/A	USGS Ohio Water Science Center	244 water chem samples	There is similar extensive data at many other USGS sites as well	410001113	1966	1980
S-3 H Keiser Cole Rd SE of Fremont OH	USGS 411914083045 300	N/A	USGS Ohio Water Science Center	Daily depth to water data, 1 water chem sampling event (1978)	Well depth: 121 feet in Salina Formation local aquifer system (Silurian-Devlonian)	410001112	1978	2012
Portage River near Elmore, OH	USGS 04195820	N/A	Ohio Water Science Center	Daily discharge data, 1998-present	Drainage area of 494 square miles, datum 572.96 above NAVD88	4100010	1998	Present
E-10	USGS 411819082493 900	N/A	Ohio USGS Water Science Center	Daily depth data, 2008-present	Well depth: 135 ft, Silurian-Devonian aquifers, Columbus Limestone local aquifer	4100011	2008	Present
Crane Creek	4.14E+14	N/A	USFWS	Stage, specific conductance, water temperature, dissolved oxygen, pH, and turbidity	Additional water level monitoring was conducted upstream of this gage for one year, however the data has not been processed. Annual reports available on servcat (2013 reference: 28525)	410001112	2009	Present
Crane Creek	N/A	N/A	USFWS	9 sampling events for streamflow, temperature, pH, specific conductance, dissolved oxygen, turbidity	No backwater conditions experienced at this site from high Lake Erie water levels during sampling times. See WRIA narrative for monitoring results (Surface Water Quality section)	410001112	2009	2011
Pool 2B	4.14E+14	N/A	USFWS	Stage, specific conductance, water temperature, dissolved oxygen, pH, and turbidity	Annual reports available on servcat (2013 reference: 28526)	410001112	2009	2014

Lake Erie (Fairport, OH)	#9063053	N/A	NOAA NOS	Comprehensive weather and water level data. Master gage for Lake Erie monitoring.	578.6 ft (MSL)		1976	Present
Lake Erie (Toledo, OH)	9063085	N/A	NOAA NOS	Comprehensive weather and water level data	569.2 feet (IGLD85 LWD). Data has not been subjected to the National Ocean Service's quality control or quality assurance procedures and do not meet the criteria and standards of official National Ocean Service data.		1877	Present

Table 15 Applicable groundwater and surface water monitoring stations within ONWR's RHI

Appendix E: Staff Gages

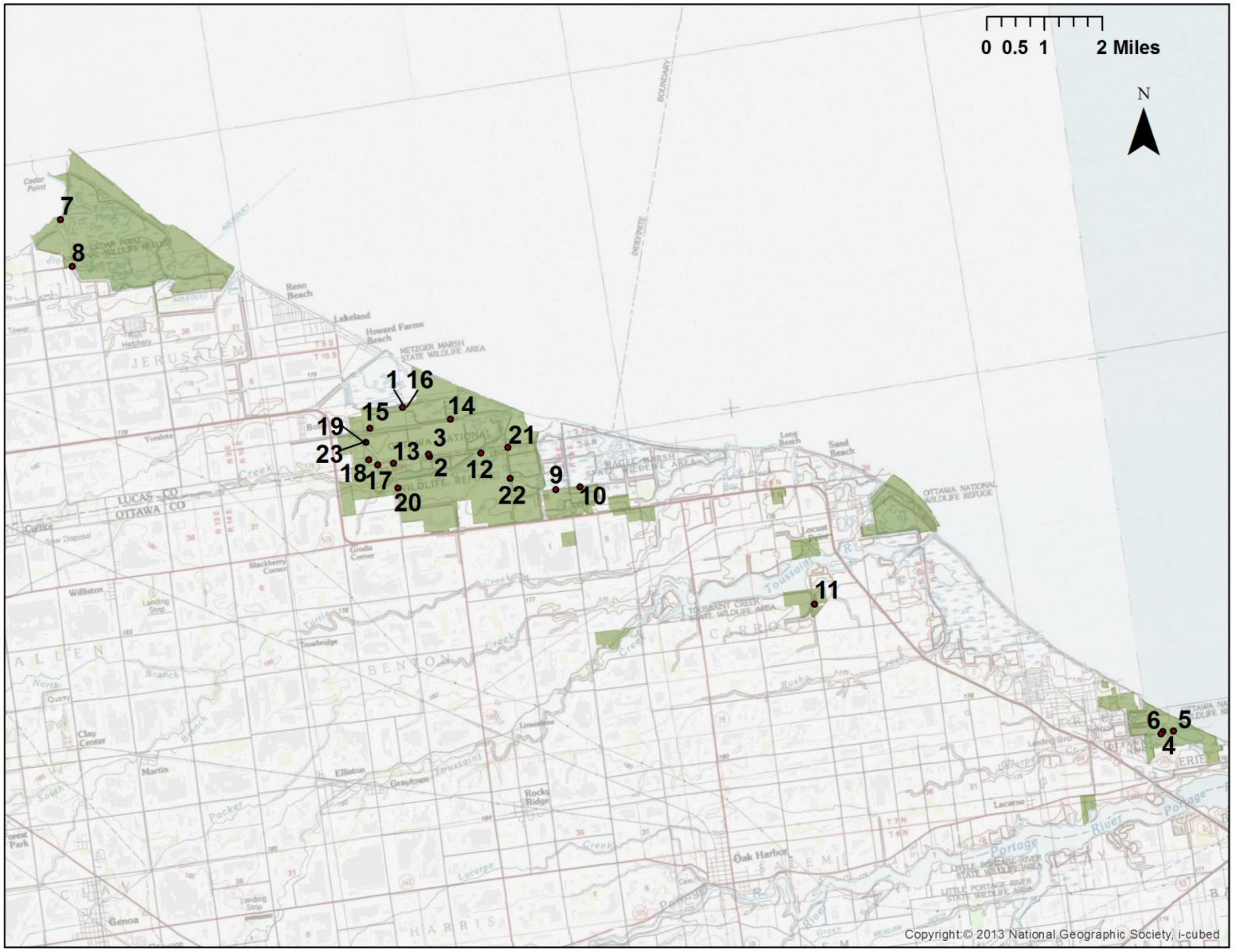


Figure 52 Staff gages at ONWRC

ID	IGLD (ft)	Description
1	577.2	pool 9 e plate top post
2	576.0	ms5 plate top round post
3	577.4	ms4 plate top metal post
4	573.6	darby pool 1 top plate board
5	577.6	darby pool 4 top plate pole
6	573.5	darby pool 3 plate top board
7	576.8	pool 1 top post wl gauge
8	575.0	cp pf wl gauge top metal post
9	575.5	woodys roost west wl gauge top post
10	574.1	woodys roost east wl gauge top post
11	575.2	blausey se wl gauge top post
12	572.4	2boss
13	577.8	ms6oss
14	576.2	pool3osspost
15	575.4	pool9barrowoss
16	577.3	pool9oss
17	578.1	fu6oss
18	578.2	ms2soss
19	578.5	ms2noss
20	576.7	7aoss
21	578.4	pool 1
22	573.8	pool 2c staff
23	578.5	ms2 n plate top post

Table 16 Staff gages at ONWRC