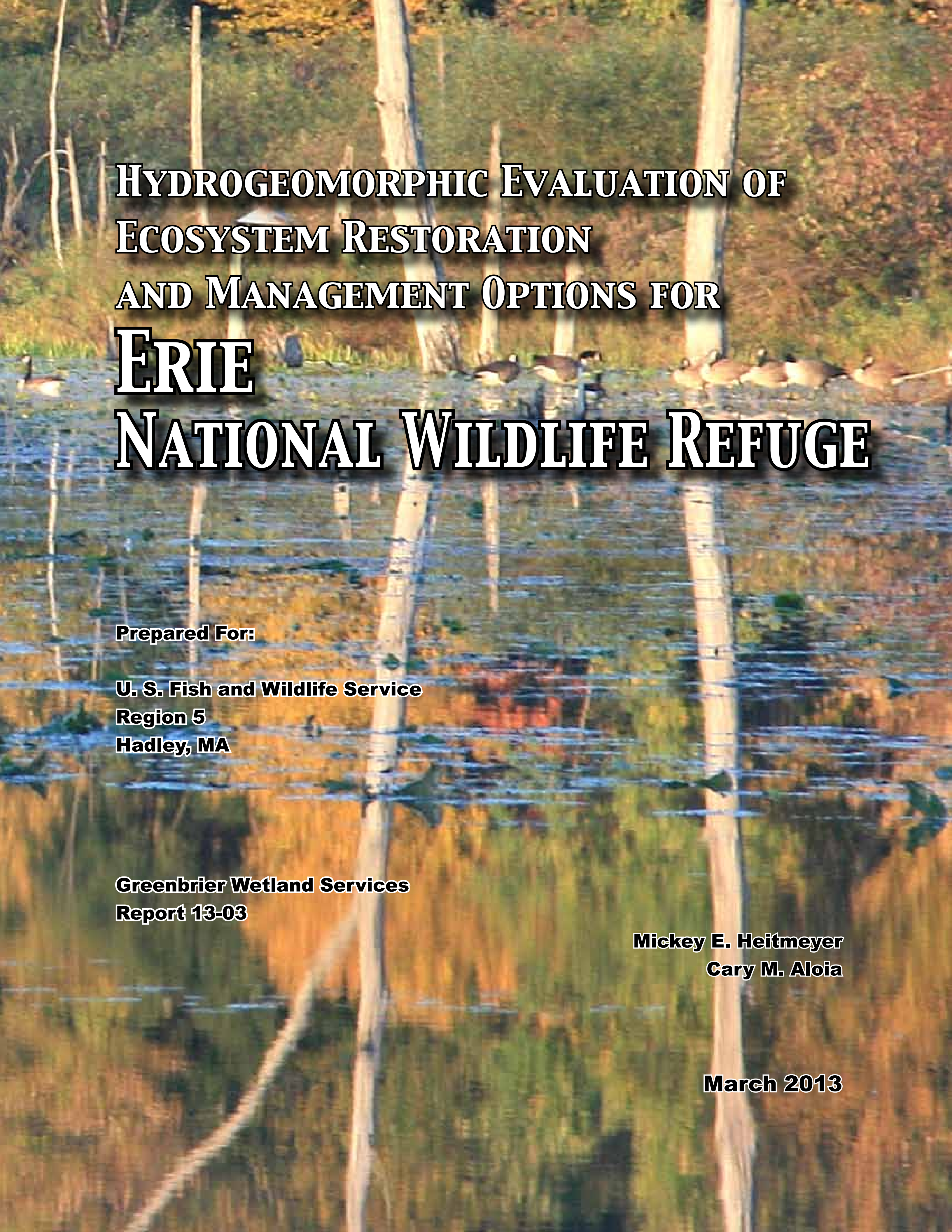

Hydrogeomorphic Evaluation of Ecosystem Restoration and Management Options for Erie National Wildlife Refuge

Prepared For:

U. S. Fish and Wildlife Service
Region 5
Hadley, MA

Greenbrier Wetland Services
Report 13-03

Mickey E. Heitmeyer
Cary M. Aloia

March 2013

HYDROGEOMORPHIC EVALUATION OF ECOSYSTEM RESTORATION AND MANAGEMENT OPTIONS FOR ERIE NATIONAL WILDLIFE REFUGE

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March 2013

Greenbrier Wetland Services
Report No. 13-03

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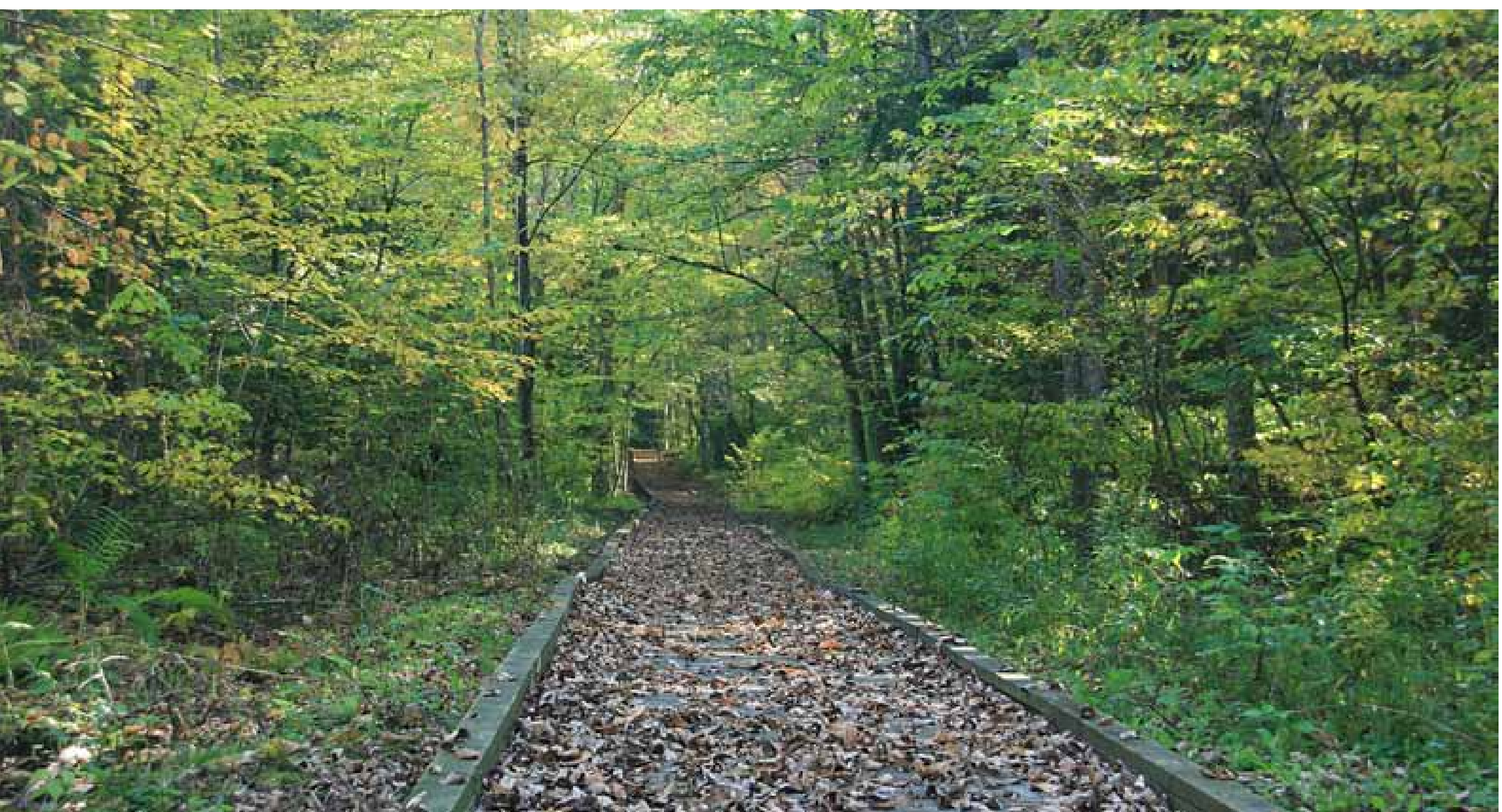


EXECUTIVE SUMMARY

This report provides a hydrogeomorphic (HGM) evaluation of ecosystem restoration options to assist future management of the Erie National Wildlife Refuge (NWR) in northwestern Pennsylvania. Erie NWR contains two divisions, Sugar Lake (5,229 acres) and Seneca (3,571 acres). Both divisions include glaciated upland hills that grade to creek floodplains within the French Creek watershed, one of the most biologically diverse creek systems in Pennsylvania. These refuge lands are among the few public landholdings in the watershed and support several endangered and threatened habitats and species.

In 2008, a Comprehensive Conservation Plan (CCP) and Environmental Assessment were initiated for Erie NWR. The current HGM evaluation assists the CCP process and obtains and collates historical and current information about: 1) geology and geomorphology, 2) soils, 3) topography and elevation, 4) hydrology, 5) aerial photographs and maps, 6) plant and animal communities, and 7) physical anthropogenic features of the Erie NWR regions with the following objectives:

1. Describe the pre-European settlement (hereafter Presettlement) ecosystem condition and ecological processes in the Erie NWR region.
2. Document changes in the Erie NWR ecosystem from the Presettlement period.
3. Identify restoration and management options incorporating ecological attributes needed to restore specific habitats and conditions.

Erie NWR is located in the Northwestern Glaciated Plateau Section of the Appalachian Plateaus Province of Pennsylvania. The geology of this region was created by continental glacial events and glacial deposits mantle upland hills and partly fill the many creek valleys that drain the area into French Creek and then to the Allegheny River to the south. Glacial drift deposits in the area average about 25 feet over sandstone, siltstone, and shale. Bedrock underlying the area includes strata from Devonian to Pennsylvanian-age rocks. About 42 distinct soil types are present on the refuge and the distribution of soils is closely linked to pre-glacial topography, glacial deposits and creek fluvial dynamics. Venango-Frenchtown-Cambridge association soils occupy uplands and side slopes while Holly-Red Hook-Chenango soils occur in creek and valley bottoms. The Holly soil type specifically characterizes recent stream deposits and floodplains that are commonly flooded.

The topography of the refuge divisions reflects glacial history and the bisected creeks of the region. The Seneca Division is marked by the Muddy Creek drainage, which flows north into French Creek and has a floodplain of about 5,000 feet wide. The Muddy Creek drainage has a relatively flat gradient with tight looping creek channels and oxbows/cutoffs. The northern part of the Sugar Lake Division is drained by Woodcock Creek, a northwestern-flowing tributary of French Creek, while the southern part of the Division is drained by Lake Creek. Topographic relief in the Woodcock Creek Valley varies by 100 to 300 feet and is relatively narrow. In contrast, the Lake Creek Valley is wider and contains more floodplain depressions and natural wetland features.

The climate of the Erie NWR region is humid continental and the area receives an average of 44 inches of rain and 53 inches of snow per year. Precipitation is mostly from March through September and the area is within a snow-belt south of the Great Lakes. Long-term precipitation data from Franklin, Pennsylvania suggest alternating wetter vs. drier precipitation patterns across years, while precipitation has generally increased from 1925 to the present. Historically, the Erie NWR ecosystem received surface water directly from creek runoff and onsite precipitation. Creek discharges follow a classic snowmelt runoff pattern with highest flows in spring, declining flow and drying of wetlands during summer to a low in August, and then slightly rising hydrographs in fall and winter depending on regional rain and snow amounts. A surficial aquifer system composed of glacial drift underlies Erie and depth to groundwater varies up to 12 feet below the surface. One groundwater seep area discharges into a fen site on the Seneca Division.

Generally, plant communities at Erie NWR are arrayed along topographic gradients in relationship to glacial hills and creek drainages. Erie NWR is within a Low Lime Drift Plain Ecoregion (EPA Ecoregion IV designation), which was historically characterized by hardwood forest on well-drained upland hills; palustrine-type eastern hemlock (*Tsuga canadensis*)-American beech (*Fagus grandifolia*)-yellow birch (*Betula alleghaniensis*)-white ash (*Fraxinus Americana*) “swamp forest” on wetter poorly drained edges of creek floodplains; and scattered small shrub/scrub (S/S) wetlands, beaver ponds, and a narrow early succession “riverfront forest” assemblage along creek drainages. The transitional area from upland hills and floodplains contained species from both upland and floodplain assemblages and has been termed “transitional forest.” One unique fen occurs on the Seneca Division.

A hydrogeomorphic matrix of relationships of the major plant communities on Erie NWR to geomorphic surface, soil type, general topographic position, and hydrology was developed using available geospatial data, botanical literature and correlation, land cover maps, historical information, and state-of-the-art understanding of southern Great Lakes vegetation communities. This matrix enabled a map of potential vegetation community distribution present prior to major European alteration to be produced. The map of potential historical vegetation represents general community distribution and is constrained by the gross scale of available elevation mapping and site-specific historical hydrology information, but nonetheless provides a model of Presettlement distribution that can be used to compare current and future desired community presence and restoration on the refuge.

Diverse animal species were historically present at Erie NWR and contained species associated with, and adapted to, upland hardwood forests, floodplain forests and swamps, small S/S and beaver pond wetlands, and creeks. Resource provision in these habitats was markedly seasonal, following the strong pulse of spring water inputs, summer drying, and cold snow and ice-covered conditions from fall through early spring. Consequently, the most abundant species were migrant birds with several resident mammals, amphibians, reptiles, fish, and birds also present.

Native people first occupied the Erie NWR region about 11,000 years before the present (BP). Numbers of people increased throughout the Archaic Period to 3,000 BP and by the Late Archaic Period some cultivation of local plants and strongly seasonal camp sites began to increase. Subsistence-settlement patterns continued into the Early Historic Period when increasing populations caused conflicts among tribes. and the redistribution of people. The local warfare between the Iroquois and Erie tribes forced the Erie from the area. The Treaty of Fort Stanwix in 1768 opened regional lands to settlers and pushed Native Americans west and north. In the late-1700s and early-1800s, European settlers increased throughout the Erie NWR region and caused extensive cutting of local forests, some oil exploration, and agricultural developments. Local timber harvest was extensive and caused erosion of hill slopes, sediment runoff and deposition in creek valleys and wetlands. Agriculture at the time was primarily wheat and livestock production, including many dairies. Land clearing, agriculture, and settlements also brought road, ditch, and dam construction across creeks and floodplains altering regional surface-water flow patterns and distribution. Historically, beaver were abundant in local creek systems and floodplains and created many small temporary beaver ponds; the increase in human populations and fur markets greatly reduced or even extirpated beaver populations by the early-1900s. Farming began to decline in the Erie NWR region in the early-1900s and economies shifted to industrial production and trade. Crawford County, where Erie NWR is located has had a declining population since the 1940s.

Erie NWR was established in 1959 with original refuge lands of about 5,150 acres in the Sugar Lake Division. The Seneca Division was authorized in 1967 and about 3,027 acres were purchased by 1973. The currently approved acquisition boundary for the refuge is 9,567 with the balance between current and authorized USFWS ownership being within the Seneca Division. Immediately prior to establishment, the Sugar Lake Division contained about 1,200 acres of cropland and 1,050 acres of pasture and hay lands. Forested lands in the Division were communities of various states of composition including second-growth hardwood and hemlock stands, abandoned orchards, and brush land. A 160-acre forest tract that had not been harvested for the previous 50+ years was designated as the Jacob Guy Research Natural Area (RNA).

Four man-made ponds were present on the Sugar Lake Division when it was established and the original Master Development Plan sought to create many additional impoundments to promote waterfowl habitat. Eventually, 16 impoundments were created including the large Pools 4 (Beuchat Pond) and 9 (Deer Run Pond). These impoundments effectively dammed many small and large drainages; Pools 4 and 9 being the largest dams on Lake Creek. All impoundments had water-control infrastructure to provide management capability. Nesting islands were built in many impoundments. No impoundments were ever constructed or developed on the Seneca Division.

Early management of impoundments was relatively static among years as water was captured and held during spring, some drawdown occurred in most impoundments during summer, reflooding occurred in fall if water was available, and then levels were lowered in winter. Pools 4 and 9 typically were not lowered in summer because sport fish were introduced and managed for a recreational fishery in these pools. Starting in the mid-1980s, water management was changed to include nearly complete drainage of smaller impoundments in summer and early fall to encourage moist-soil herbaceous wetland plants and associated invertebrates consumed by migrating waterfowl. In the late-1990s to 2000 impoundment drawdowns were timed to coincide with waterfowl and shorebird migration events. However, beginning in 2001, impoundments were again filled to capacity in spring and water levels were held high through summer and fall. In this management, water levels fluctuated with seasonal patterns of precipitation at set stop-log structure levels. This more static and permanent water regime management continued through 2006, when changes were made again to mimic a more natural hydrological regime of spring flooding and summer drainage.

Over time, larger impoundments with more permanent water regimes have shifted to more perennial or emergent wetland plant assemblages, often creating dense monocultures of species like cattail (*Typha* spp.) and yellow pond lily

(*Nuphar lutea*). Many wetlands also now are invaded with reed canarygrass (*Phalaris arundinacea*), giant reed (*Phragmites* spp.), sesbania (*Sesbania* spp.), alligator weed (*Alternanthera philoxeroides*), water primrose (*Ludwigia palustris*), and giant cutgrass (*Zizaniopsis milliacea*).

Forest and grassland management on Erie NWR has included physical manipulation of vegetation through timber harvests, grazing, burning, plantings, and chemical treatments. Forest management has historically occurred on several areas on the refuge, but timber stand improvements, harvest cuts, and other treatments with fertilizers and chemicals have not occurred in recent years. Intensive agricultural cropland and livestock production has declined gradually over time in the Erie NWR region. Beginning in the 1940s many former crop and pasture fields were abandoned and mostly natural succession brush species expanded to these sites. Management at Erie has maintained some abandoned field with brush or tree succession, while others were planted to select grasses such as warm- and cool-season species and trees. Currently only 277 acres of cropland on the Sugar Lake Division are cooperatively farmed.

Ecosystem changes at Erie NWR over time include many alterations. Native upland and transition forest communities were cleared, converted to crop or hay/pasture, have changed tree and shrub species assemblages, and decreased fire occurrence compared to Presettlement periods. Swamp forests also have been cut-over, converted to other land uses; impounded or have altered hydrology because of site-specific or regional developments such as roads, ditches, levees, and water-control structures; and often are converted to more water tolerant communities such as S/S or aquatic states in impoundments. Floodplain wetlands at Erie NWR have been destroyed or drained, impounded, have altered hydrology, and have altered plant communities with shifts toward more water tolerant and invasive species. Creeks have been channelized, ditched, dammed, have reduced water quality, and have altered hydrological regimes.

The following general recommendations are suggested to improve ecosystem restoration and management at Erie NWR:

1. Manage Erie NWR to help maintain and restore the physical and hydrological character of lands within the biologically rich French Creek watershed.

2. Restore and maintain the diversity, composition, distribution, and regenerating mechanisms of native vegetation communities in relationship to topographic and geomorphic landscape position.

3. Emulate a more natural seasonally- and annually-dynamic water regime in creek corridors and associated floodplain wetlands.

Specific recommendations are provided for each of the above general goals. For Goal #1, these recommendations include:

- Protect rare community/habitat types and remnant patches of relatively unaltered community types such as fens, old-growth stands of all forest types, creek buffers and corridors, and increasing USFWS participation with regional conservation land protection and management outside of Erie NWR.
- Manage regenerating communities to attain mature and sustainable community composition and distribution specifically by evaluating all regenerating forest stands, abandoned former fields and croplands, and creek/floodplain sites relative to HGM attributes that suggest appropriate future community distribution.
- Restore ecological processes and functional patches of all native community sites including delineating, and targeting soil and water conservation measures to, sub-basins in the French Creek watershed that contribute the most sediment, nutrient, and surface water runoff to Erie NWR Divisions; restoring natural drainage corridors; and evaluating use of fire in community management.

Specific recommendations for Goal #2 include:

- Restore appropriate forest communities throughout much of the Sugar Lake Division and upland areas on the Seneca Division by promoting upland hardwood forest on hills and slopes, transition forest on toe-slopes of hills and higher edges of creek floodplains, and swamp forest in seasonally flooded floodplain sites.

- Restore S/S and seasonal herbaceous wetlands along Muddy, Dead, Lake and Woodcock Creeks.

Specific recommendations for Goal #3 include:

- Restore natural topography and water flow patterns in Woodcock and Lake Creeks and their small tributary drainages including evaluating, and removing/modifying if necessary all water-control infrastructure to determine structures that are not critical or that are impeding water management and flow; evaluating water storage and spillway operations in Pools 4 and 9; improving water flow through and across roads; and removing impoundments in higher elevation former forest sites.
- Protect and restore ground and surface water resources and manage for natural hydroperiods including managing small impoundments for short duration seasonal flooding in spring followed by drawdowns in summer and fall; managing larger impoundments, especially Pools 4 and 9 for more natural semipermanent water regimes of summer and fall drawdown and with intentional interannual dynamics of occasional periods of both drought and higher flooding,;and monitoring Muddy and Dead Creeks to remove channel obstructions/alterations that could cause more permanent water regimes from impoundment or water diversion.

Future management of Erie NWR should include key monitoring and select studies based on refuge objectives and adaptive management of above recommendations. Areas where future monitoring and additional information will be needed include ground and surface water quantity and quality, LiDAR elevation surveys, water flow and regimes, and long-term changes in vegetation and animal communities.

INTRODUCTION

Erie National Wildlife Refuge (NWR) contains 8,800 acres in the northwestern portion of Pennsylvania in Crawford County (Fig. 1). The approved acquisition boundary for the refuge includes 9,567 acres; currently the refuge encompasses glacial hill uplands and creek drainages in two separate land divisions about 10 miles apart including lands in the Muddy and Dead Creek drainages in the Seneca Division (3,571 acres) and lands in the Woodcock and Lake Creek drainages in the Sugar Lake Division (5,229 acres). Erie NWR was established in 1959 under the Migratory Bird Treaty Act and the authorizing purpose of the refuge was "*…for use as an inviolate sanctuary, or for any other management purpose, for migratory birds*". The refuge is named after the extinct Erie Indian tribe. This small tribe resided along the shores of what is now Lake Erie. In the mid-1600s, the Seneca Indians defeated the Erie tribe and the Erie people ceased to exist as a distinct group.

Erie NWR is located in the Northwestern Glaciated Plateau Section of the Appalachian Plateaus Province (Sevon 2000) and historically contained a Southern Great Lakes oak-maple hardwood forest on broad rounded uplands, transitional maple-beech-hemlock forests where hills joined floodplains, and scattered shrub wetlands and palustrine forests in the relatively narrow steep-sided valleys and creek floodplains that bisected the forests (NatureServe1 2007). The region was occupied by various groups of Native Americans and then by European settlers who harvested and cleared the forests for agriculture uses, specifically for cultivated crops and dairies. When acquired, lands on both Divisions of Erie NWR contained forest, wetlands, creeks, cropland, hay and pasture lands, and some previously cleared forest areas had also been abandoned. Immediately after the refuge was estab-

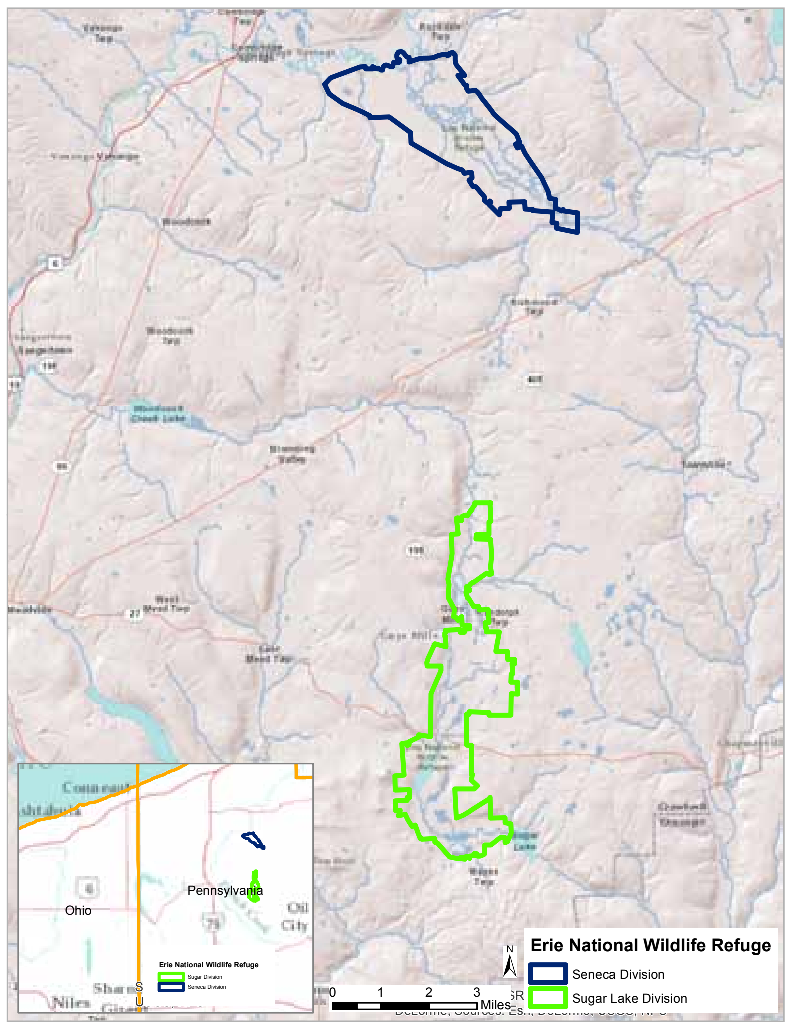


Figure 1. General location of Erie National Wildlife Refuge, Pennsylvania.

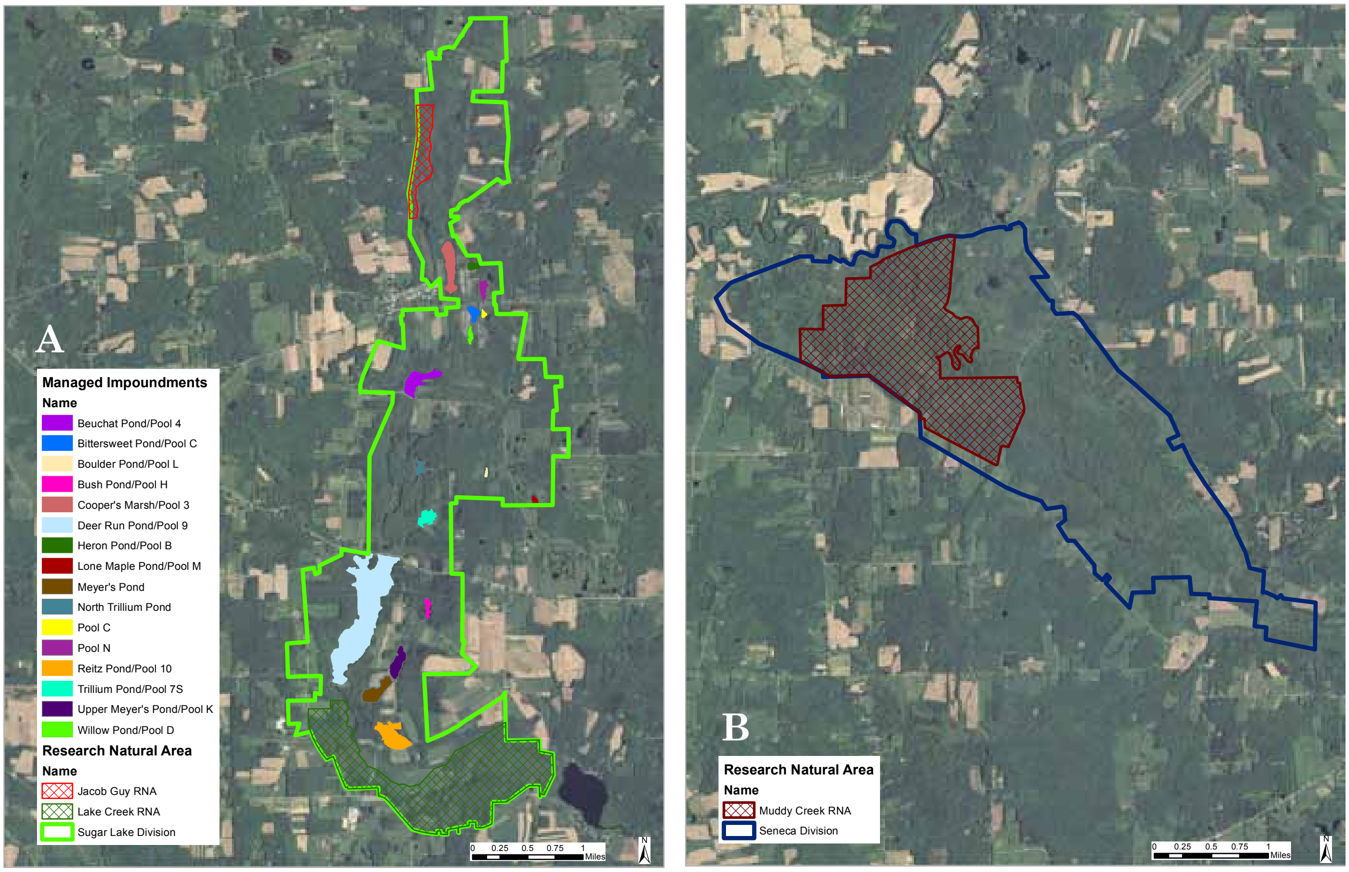


Figure 2. a) wetland impoundments and natural areas on the Sugar Lake Division and b) natural areas on Seneca Division of Erie National Wildlife Refuge.

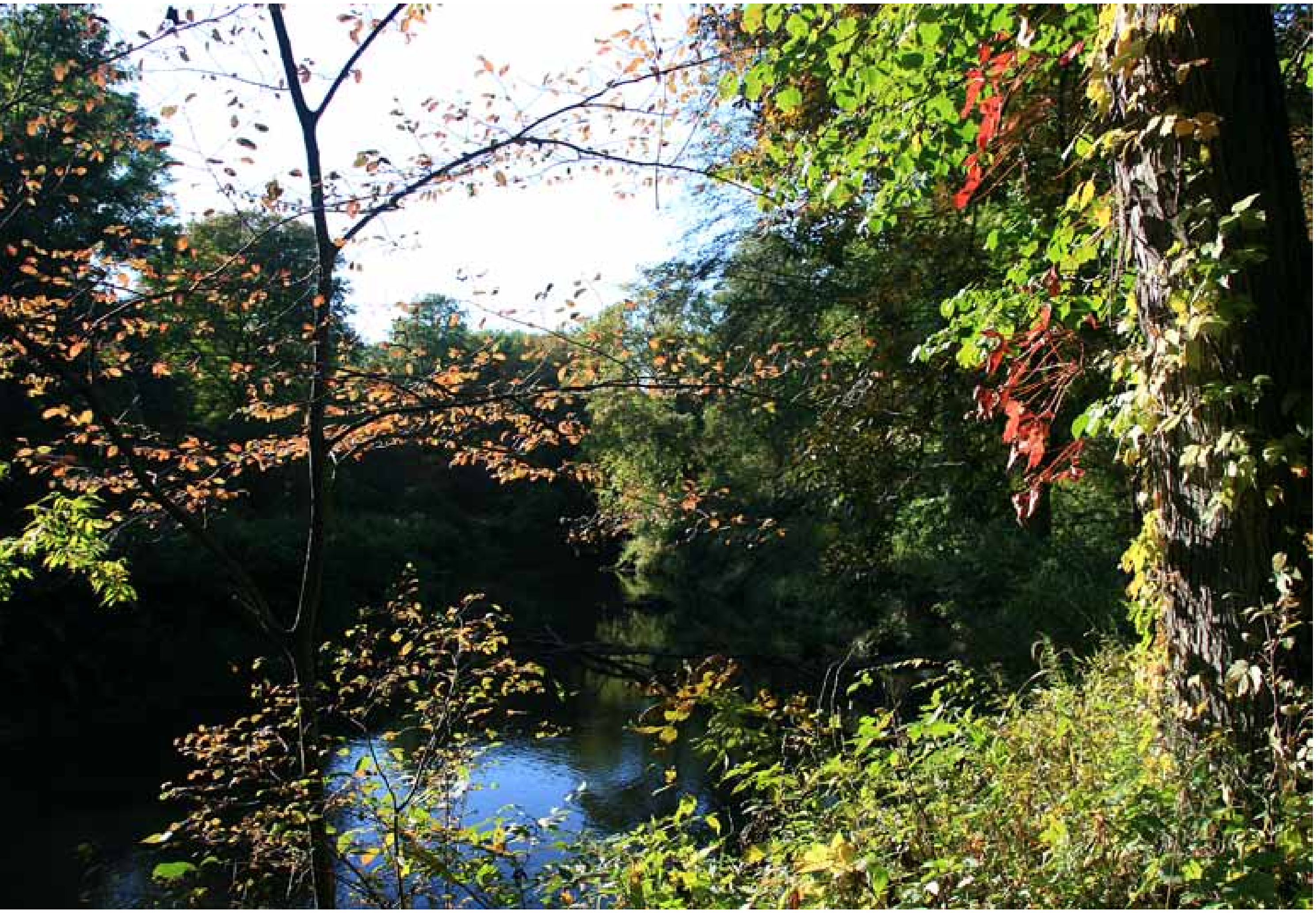
lished, management largely continued production of hay, pasture, and some row crops. Beginning in the mid-1960s, ditches, levees, and water-control structures were constructed to create a series of wetland impoundments on the Sugar Lake Division to increase waterfowl habitat (USFWS 1966). The largest impoundment, "Pool 9" (also known as Deer Run Pond) flooded about 135 acres behind Dam No. 9 on Lake Creek (Fig. 2a). Grazing and cooperative farming began to be phased out on the refuge in the 1970s; currently only 277 acres on the Sugar Lake Division are cooperatively farmed. Some fields on both divisions have been planted and managed as grassland. Forest management on the refuge has been limited to some afforestation of abandoned fields and select harvests and thinning.

Erie NWR is located within the French Creek watershed, which is one of the most biologically diverse creek systems in the state of Pennsylvania hosting several endangered and threatened species of plants and animals, especially rare stream fishes and freshwater mussels (Western Pennsylvania Conservancy 2001, 2002). Refuge lands are among the few public conservation land holdings in the watershed and protect important habitats and resources critical to the integrity of the watershed. The Seneca Division supports a variety of endangered and threatened habitats and species, specifically a presumably virgin hardwood forest stand and a unique shrub fen (Bissell and Danielson 1995, Grund 2006). Several of these areas on the Seneca Division, along with select native habitats on the Sugar Lake Division, have been designated as "Research Natural Areas (RNA's) (Deets 1994) (Fig. 2a,b). Erie NWR also is recognized as an Audubon Important Bird Area (IBA) because of its significance to various biological communities in the state (Tautin 2004, U.S. Fish and Wildlife Service (USFWS) 2006).

In 2001, Erie NWR was incorporated into the Iroquois NWR Complex. A Comprehensive Conservation Plan (CCP) and Environmental Assessment (EA) were initiated for the Erie NWR in 2008 to identify habitat and public use goals within a 15-year management horizon. Recently, Hydrogeomorphic Methodology (HGM) has been used to evaluate ecosystem restoration and management options on many NWR's and have assisted development and implementation of CCPs (e.g., Heitmeyer et al. 2009, Heitmeyer et al. 2010, Heitmeyer et al. 2012a,b). HGM evaluations obtain and collate historical and current information about: 1) geology and geomorphology, 2) soils, 3) topography and elevation, 4) hydrology, 5) aerial photographs and maps, 6) land cover and plant/animal communities, and 7) physical anthropogenic features of ecosystems (Heitmeyer 2007, Klimas et al. 2009, Theiling et al. 2012, Heitmeyer et al. 2013). This information provides a context to understand the physical and biological formation, features, and ecological processes of lands within a NWR and surrounding region. Specifically, the historical assessment provides a foundation, or baseline condition, to determine what changes have occurred in the abiotic and biotic attributes of the ecosystem and how these changes have affected ecosystem structure and function. Ultimately, this information helps define the capability of the area to provide key ecosystem functions and values and identifies options that can help to restore and sustain fundamental ecological processes and resources.

This report provides HGM evaluation of Erie NWR with the following objectives:

- Describe the pre-European settlement (hereafter Presettlement) ecosystem condition and ecological processes in the Erie NWR region.
- Document changes in the Erie NWR ecosystem from the Presettlement period with specific reference to alterations in hydrology, vegetation community structure and distribution, and resource availability to key fish and wildlife species.
- Identify restoration and management options incorporating ecological attributes needed to restore specific habitats and conditions.



THE HISTORICAL ERIE ECOSYSTEM

GEOLOGY AND GEOMORPHOLOGY

The geology and surficial geomorphology of Erie NWR was created by continental glacial events in the Appalachian Plateau Physiographic Province of Pennsylvania (Sevon 2000, Fig. 3). Glacial deposits mantle the uplands of the region and partly fill the many creek valleys that drain the glacial hills. The bedrock underlying the extensive glacial till is shale, siltstone, and sandstone. Northwestern Pennsylvania south of Lake Erie was covered by glacial ice multiple times during the Pleistocene period, most recently during the Wisconsin Age (Shepps et al. 1959, Clark et al. 2009). Ice moved down the Erie Basin as a major lobe known as the Erie Lobe, and spread out into northwestern Pennsylvania twice during the Illinoian Age and five times during the Wisconsin Age (Dreimanis and Goldthwait 1973, Fig. 4). Only three ice sheets apparently advanced south as far as Erie NWR. The first was the Illinoian, the second was the Second Illinoian, and the third was the Kent ice sheet of the Wisconsin period. The Wisconsinan

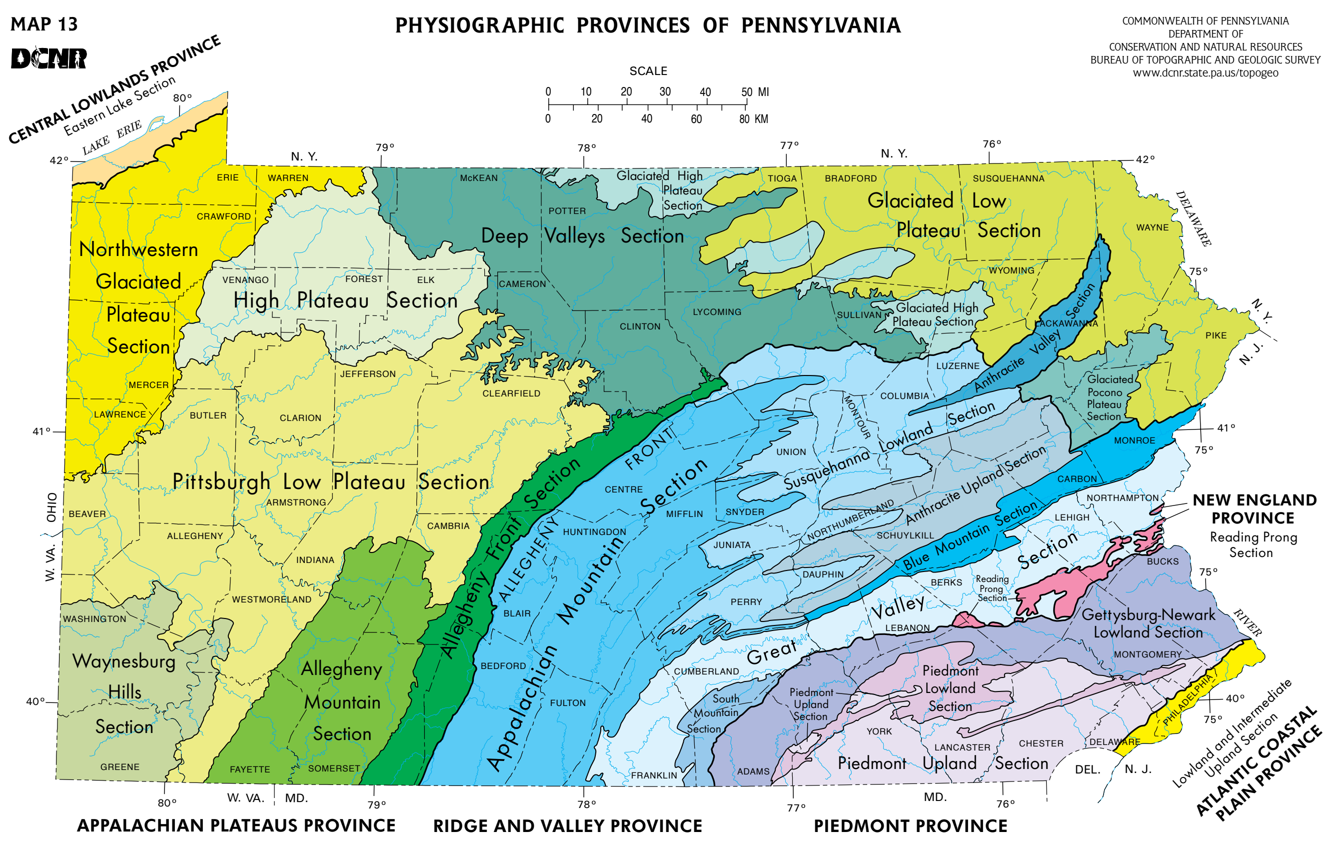


Figure 3. Physiographic provinces of Pennsylvania (from Sevon 2000, www.dcnr.state.pa.us/topogeo).

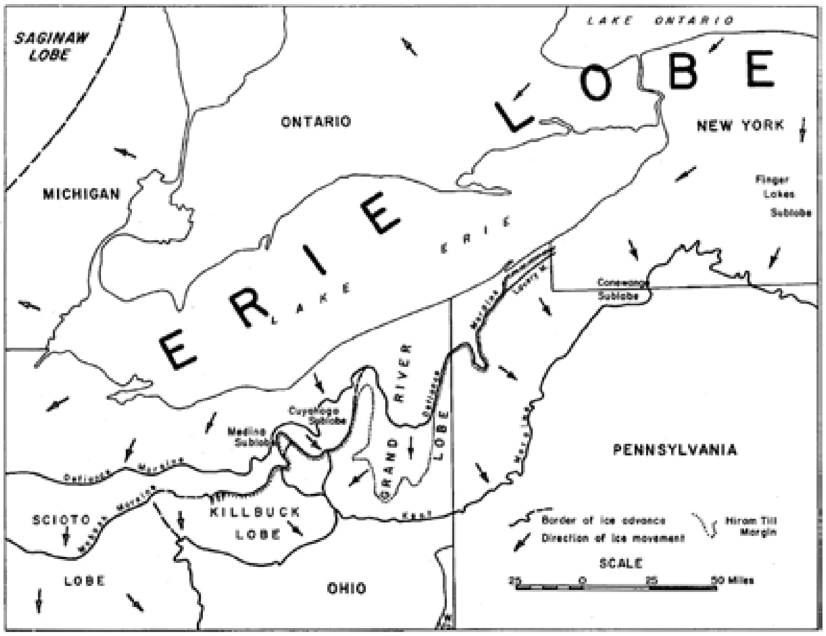


Figure 4. Glacial geology of northwestern Pennslyvania (from Schepps et al. 1959).

glacial till is comprised mostly of Kent ground and end moraine that generally is described as thick, gray, and clayey to silty and sandy strata. Erie NWR lies near the southern limit of the Wisconsin-age glacial extent. The last ice to cover this region is described as the Ashtabula Morainic System, which occurred during the Cary-Age of the Wisconsin period (Straffin and Grote 2010). The advance of this glacial ice deposited glacial till composed of silt (about 43%) with continuous end moraine (mound) and glacio-fluvial gravel outwash (Sevon and Braun 2000). The Kent terminal moraine trends from Warren County through Crawford County just south of Erie NWR. As glacial ice sheets retreated the region was covered by glacial meltwater lake deposits. The composition of the glacial tills at Erie NWR originated from the local environment and from areas to the northeast (Bacon et al. 1954). Some material may have originated from meltwater as it flowed under the ice, through fissures, or at the leading edge of the ice sheet. These types of materials consist of sands, silts, clays, and gravels described as different types of kames, eskers, or valley trains (Straffin and Grote 2010). The distribution of glacial drift throughout the area is depicted in Fig. 5 showing the location of the Erie NWR within the Kent Till ground moraine. Glacial deposits vary in depth from 0 to 500 feet with greater depths generally occurring from north to south. The average depth of glacial till overlying sandstone, siltstone, and shale bedrock near Erie NWR is 25 feet (Wurster 2012). In contrast, the erosional alluvial sediments in creek valley deposits are over 150 feet deep in some locations.

The bedrock underlying the Appalachian Plateau includes strata from Devonian to Pennsylvanian-age rocks (Fleeger 2005). Exposure of bedrock on the surface is rare (Yaworski et al. 1979). The oldest Devonian-age rocks include gray shale, siltstones, and sandstones and underlie the younger Mississippian and Pennsylvanian rocks. Mississippian period rocks are sandstones, conglomerates and shales with a thin layer of Pennsylvanian age shales and sandstones capping Mississippian rocks. Devonian rocks underlie the Seneca Division while Mississippian rocks underlie the Sugar Lake Division on Erie NWR (Fig. 6). Rocks within this region are predominantly sedimentary in nature. These sediment layers were deposited in ancient seas during the Devonian and Mississippian epochs 320 to 420 million years before the present (BP) and these sedimentary rocks subsequently were lifted and folded by tectonic processes (Schiner and Gallaher 1979, Wells et al. 2011). Although some bituminous coal beds exist within this area, the majority of coal beds lie to the south outside of the glaciated region (White et al. 1969).

The pre-glacial environment across the Appalachian Plateau in northwestern Pennsylvania was highly dissected with drainages flowing to the north towards the St. Lawrence Valley (Clark and Ciolkosz 1988). Regional drainage patterns were altered after multiple ice sheets deposited till throughout existing river bottoms and pushed water over rocks between cirques, thus re-routing and uniting drainages to flow towards the south. Many of the current drainages occur on top of glacial till depositions above and within much older glacial meltwater drainages. A few creeks continue to flow to the north into Lake Erie, however, the majority of regional creeks flow to the south as part of the greater Ohio River system. Erie NWR is within the French Creek Watershed, which flows into the Allegheny River to the south. Creeks (and other small drainages locally called “runs”) within the French Creek Watershed vary in size and gradient as many tributaries originate within ridges and descend upon steep to gently sloping valley sides.

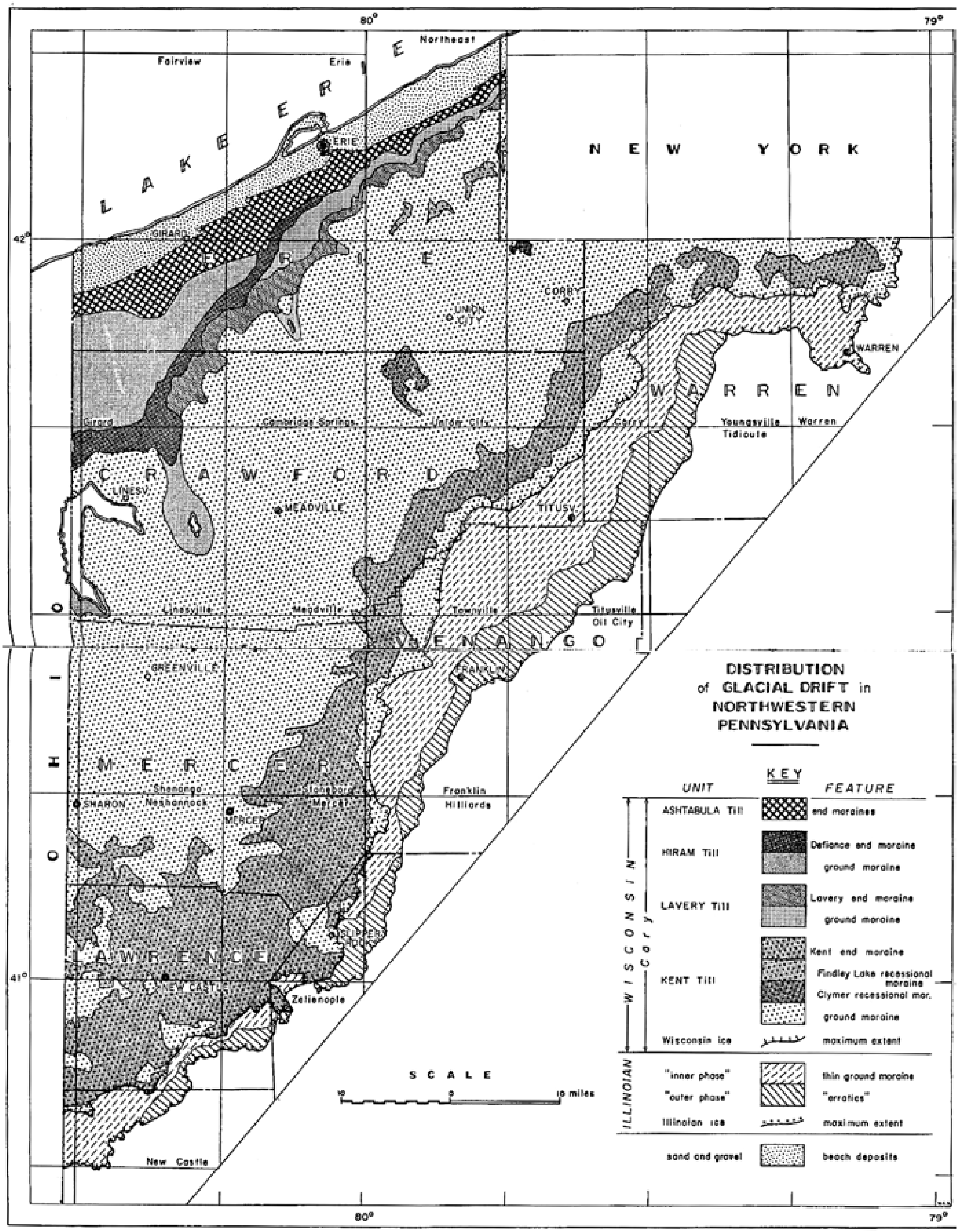


Figure 5. Distribution of glacial drift in northwestern Pennsylvania (from Schepps et al. 1959).

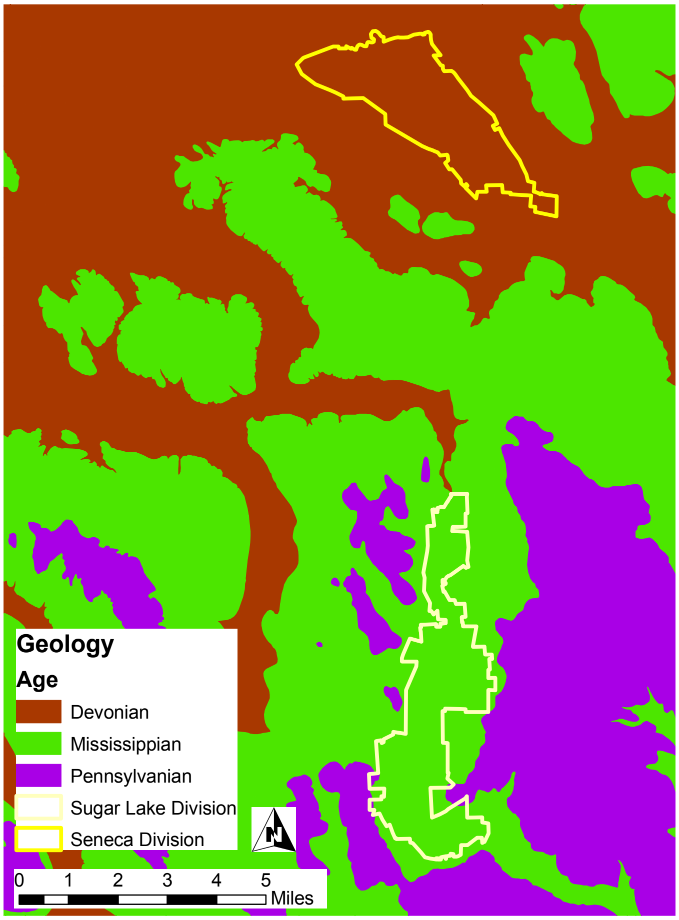


Figure 6. Bedrock geology of the Erie National Wildlife Refuge region (from Schiner and Gallaher 1979).

SOILS

About 42 distinct soil types are present on Erie NWR (Fig. 7). The distribution of soil types at Erie NWR is closely linked to pre-glacial topography, glacial deposits, and fluvial dynamics (Yaworski et al. 1979). Uplands and side slope areas within the Erie NWR are generally described as the Venango-Frenchtown-Cambridge association (VFC) while the creek and valley bottoms are described as the Holly-Red Hook-Chenango association (HRC) (Yaworski et al. 1979). The VFC association is characterized by deep and nearly level to moderately steep soils that range from well to poorly drained materials derived from the glacial Kent Till. Soil series mapped on refuge areas in the VFC association generally are dominated by silt loams formed in material from glacial till deposited on side slopes, upland knobs, and terraces. Venango soils are sloping to nearly level and are somewhat poorly drained. Frenchtown soils are nearly level and are poorly drained. Cambridge soils are mostly gently sloping to sloping and are moderately well drained. Other characteristic soils of the VFC association include Valois and Alden soil, which are deep well drained soils formed in material weathered from glacial stream deposits and are often found on outwash plains or terraces. The HRC soil-land association is typically characterized by deep and nearly level to gently sloping soils that vary from very well to somewhat excessively drained and are formed in materials weathered from stream deposits and glacial outwash. Holly silty clay loam is the dominant soil series mapped on both refuge divisions within this association and landform. The Holly soil series is characterized by deep, poorly drained soils formed in weathered material from recent stream deposits on floodplains adjacent to streams that are commonly flooded. Most of these areas contain a surface layer composed of silty clay loam. Red Hook soils occur on terraces and are somewhat poorly drained. Chenango soils are well drained and occur on outwash plains and terraces (Yaworski et al. 1979). Minor soils in the HRC association include Wyoming, Carlisle, Haven, Pope, Philo, and Halsey types. Soil distribution across the refuge reflects glacial deposition and scouring as well as the deposition and movement of sediments as the creeks and floodwaters advance and recede.

TOPOGRAPHY

Elevations on Erie NWR range from about 1,100 to 1,350 feet above mean sea level (amsl) (Fig. 8). Erie NWR is characterized by a "masked erosional topography" (Schepps et al. 1959) of rolling glacial-derived hills and creek/run valleys. Topographic features such as moraines and drumlins may be apparent throughout this region. Remnant natural glacial lakes, such as Sugar Lake located immediately south of the Sugar Lake Division, occur throughout the French Creek Watershed and were created by Wisconsin-age glacial scouring and deposition. A remnant glacial terrace approximately 20 miles south and paralleling Lake Erie currently acts as a divide between northern- vs. southern-flowing drainage basins in northwestern Pennsylvania. The French Creek Watershed, that contains both divisions of Erie NWR, lies to the south of this terrace divide and flows toward the Allegheny River. In general, the elevation gradient and relief increases to the south and east with approximate changes of 100 feet between creek bottoms and ridges. Erie NWR contains both broad rounded uplands and several steep-sided creek valleys that range from 500 to 5,000 feet wide.

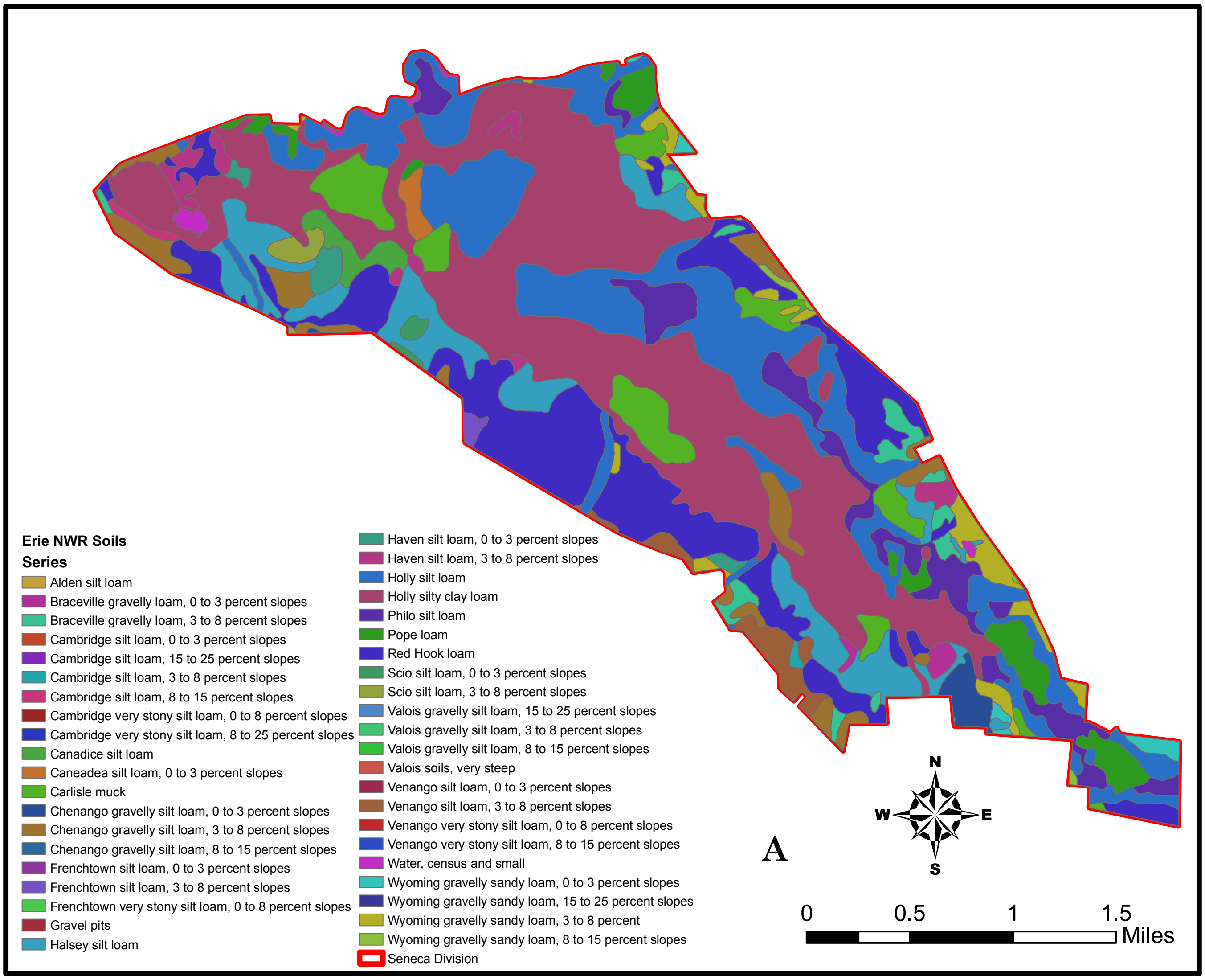


Figure 7. Soils on: a) Seneca Division and b) Sugar Lake Division of Erie National Wildlife Refuge (from USDA Soil Data Mart SSURGO).

The Seneca Division is marked by the Muddy Creek drainage, which flows north into French Creek. The widest creek bottom in the valley floor is Muddy Creek, which is about 5,000 feet wide. Muddy Creek has meandered within the central portion of the valley in tight looping bends with some oxbows and cutoff loops present. This channel pattern reflects the fine texture floodplain sediments and soils (Fig. 7) and suggests a formerly low sediment loading in the stream (Selby 1985). Local relief on the Seneca Division varies by about 150 to 300 feet and ridges are rounded and broad while valleys are of moderate slope on the east side and relatively gentle slope on the west side. Most of the proposed acquisition boundary and existing fee-title lands on Seneca Division are relatively flat valley-floor wetland type with few higher elevation uplands.

The northern half of the Sugar Lake Division is drained by Woodcock Creek, a northwestern-flowing tributary of French Creek, while the southern half of the Division is drained by Lake Creek, which also joins French Creek to the south. The drainage divide between Woodcock and Lake creeks is along state highway 198 east of the town of Guy Mills. Relief in the Woodcock Creek valley varies by 100 to 310 feet and valley margins are moderately sloping on the east side, but quite steep on the west side. The Lake Creek valley is wider and contains more floodplain depressions and wetlands than the Woodcock Creek Valley. The broader low elevation creek valleys on Erie NWR are bounded by gently rolling to steep hills containing numerous creeks (Fig. 9). The historic floodplains of Muddy, Dead, Woodcock, and Lake Creeks contain relict scour and deposition surfaces related to fluvial

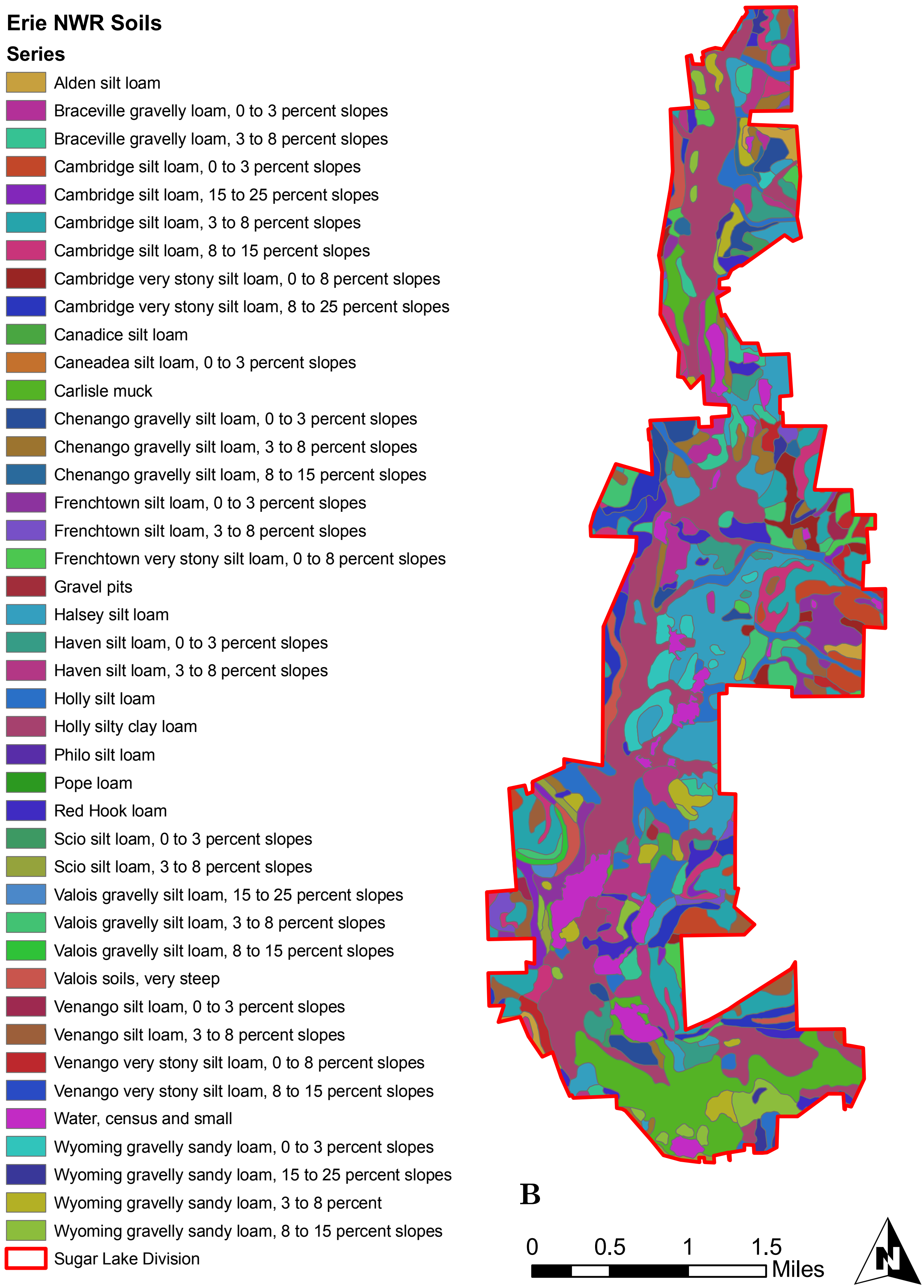


Figure 7, (continued). Soils on: a) Seneca Division and b) Sugar Lake Division of Erie National Wildlife Refuge (from USDA Soil Data Mart SSURGO).

dynamics (Grote et al. 2008). Detailed topographic maps at < 5-foot contour intervals currently are not available for all of Erie NWR.

CLIMATE AND HYDROLOGY

The climate of the Erie NWR region in northwestern Pennsylvania is characterized as humid continental (Bacon et al. 1954). Erie NWR area receives an average of 44 inches of rain and 53 inches of snow per year (Table 1) with a majority of this precipitation occurring March through September. This area lies within a snow belt region created by polar air masses moving across the Great Lakes, producing cold and cloudy conditions with snow throughout winter. Long term precipitation data from Franklin, Pennsylvania suggest that alternating wetter vs. drier precipitation patterns occur across years (U.S. Historical Climatology Network (USHCN), provided by Fred Wurster, USFWS). Since the 1920s, dry conditions existed from about 1930 to 1950 and again from 1960 to 1980; since the 1980s wetter conditions have been present (Fig. 10). Generally, water year precipitation in the region has increased over the period of record from 1925 to the present (Fig. 11). Severe weather conditions are common in northwestern Pennsylvania, producing hail, high winds, flash flooding, and sometimes tornados. Large rainfall events may create flash flooding especially in steep gradient streams. Prevailing winds are most commonly from the southwest. Mean annual temperature is approximately 47° Fahrenheit (Table 2) with an increasing warming trend since the 1920s. The average growing season is approximately 140 days, May through September.

Historically, the Erie NWR ecosystem received surface water inputs directly from runoff in the many creeks of the French Creek Watershed and from onsite precipitation (Fig. 9). The French Creek Watershed consists of ten sub-basins (Fig. 12) including the Woodcock, Sugar, and Muddy Creek sub-basins. The Muddy Creek sub-basin contains Muddy and Dead Creeks, located in the Seneca Division, which flow to the northwest to join with French Creek. The Woodcock Creek sub-basin contains several creeks within the Sugar Lake Division on the Erie NWR. Woodcock Creek flows to the northwest to join French Creek while Lake Creek flows to the south joining Sugar Creek and then ultimately French Creek. Headwaters and tributaries of these creeks originate in local hills and have relatively steep gradients and high velocities. Creek discharges during the year at Erie NWR follow a classic snowmelt runoff pattern with highest flows in early spring. For example, high peak flows in creeks within the French Creek Watershed occur in March and April as snow melts and rainfall adds to peak stream flows. The French Creek hydrograph then falls steeply to a low in August when stream flow again begins to climb. Flash floods may

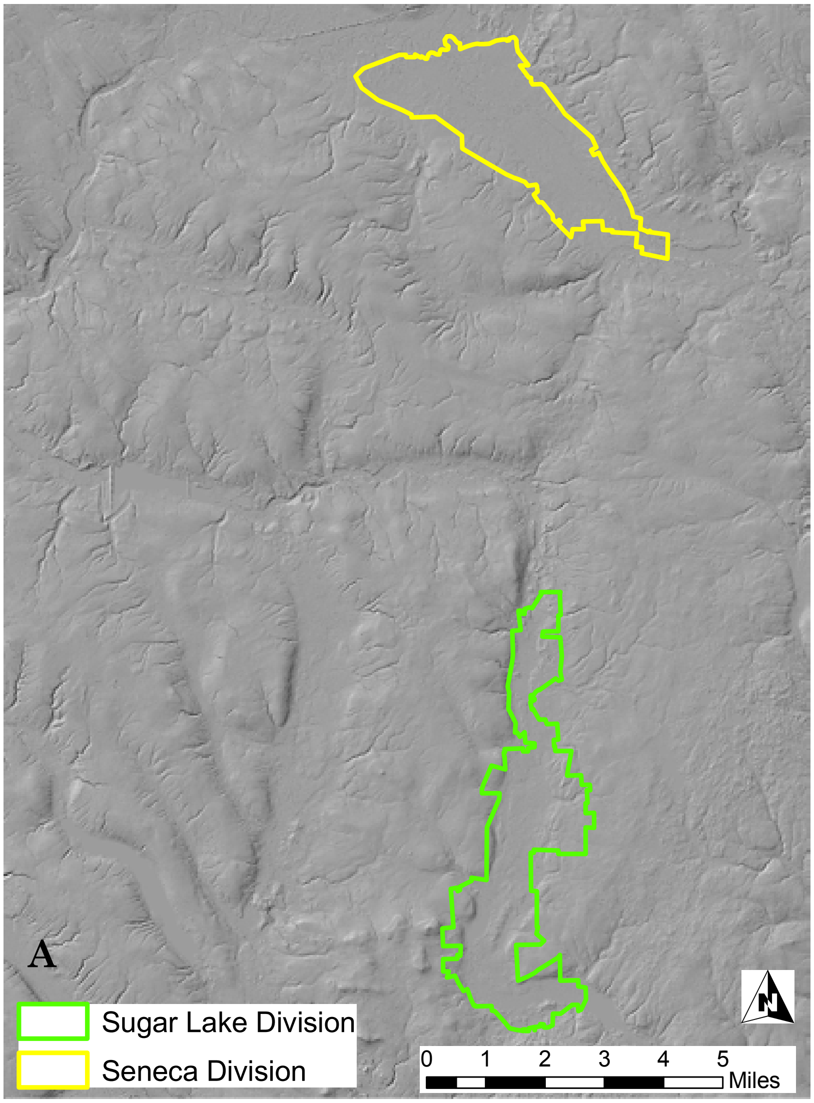


Figure 8. Elevation data available are: a) 10 meter digital elevation model (DEM) topography and b) U. S. Geological Survey 7.5-minute quadrangle topographic map of Erie National Wildlife Refuge.

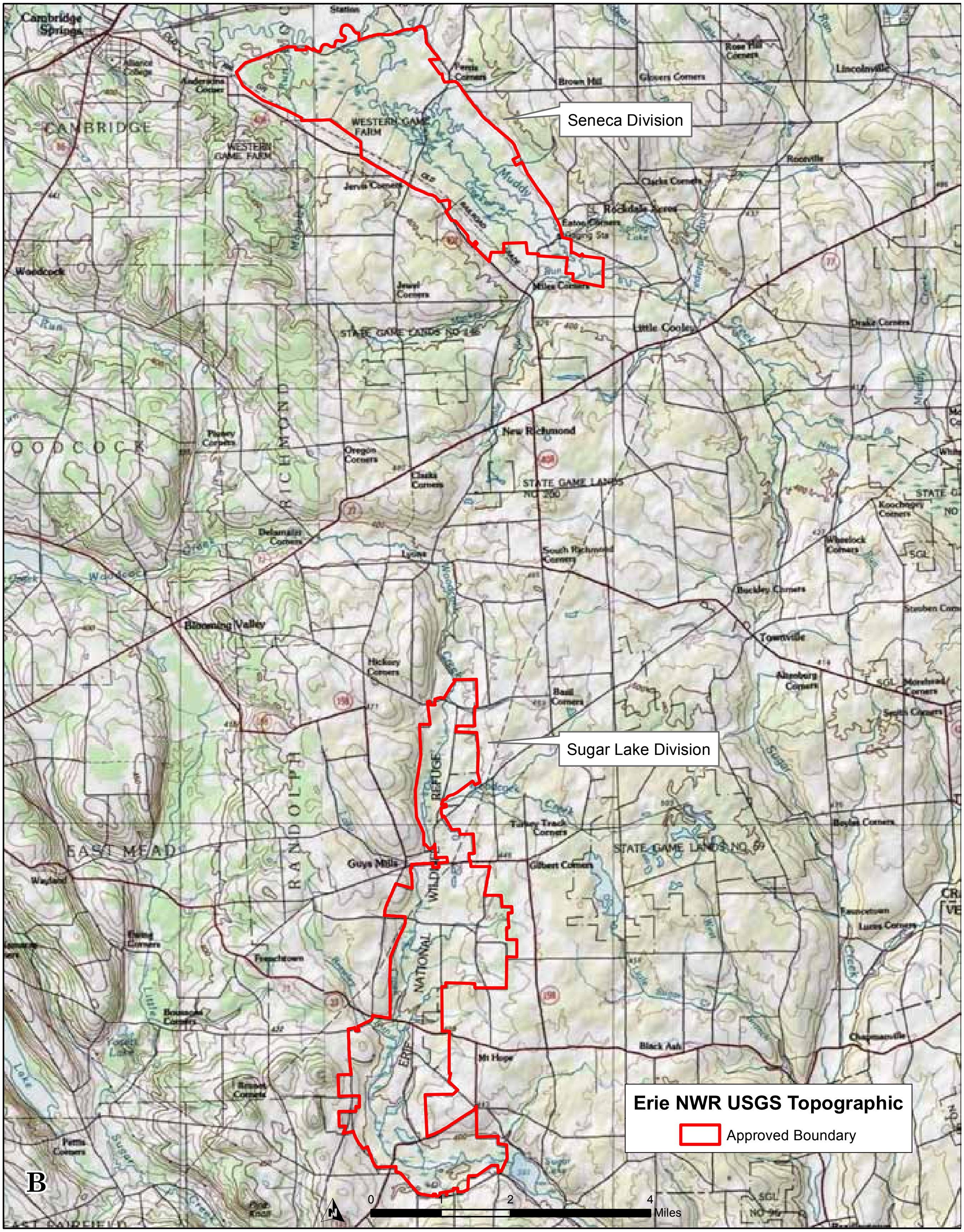


Figure 8, (continued). Elevation data available are: a) 10 meter digital elevation model (DEM) topography and b) U.S. Geological Survey 7.5-minute quadrangle topographic map of Erie National Wildlife Refuge.

occur at any time during and following large rainfall events. Ice dams also may occur in the spring during snowmelt and creates local flooding of areas. The closest hydro-climatic data network (HCDN) stream flow gauge near Erie NWR is located on Oil Creek near Rouseville, Pennsylvania . Discharge from Oil Creek at this location from 1932 to 2010 averaged between lows of 176 and highs of 1,090 cubic-feet/second (cfs) (Table 3). Gauge stations on local creeks within the refuge cover shorter periods of time but show similar hydrographs with peaks in March, trending towards lower stream flows in the summer and gradually increasing discharge in the fall.

Historic climate data predictions for the northeastern part of the U.S., including the Erie NWR region, suggest that air temperatures will increase and represent a continuation of trends observed since the 1970s (Hayhoe et al. 2007). In the last 40 years winter snowpack in the region has been decreasing, the onset of peak stream flow has occurred earlier in the year, the duration of ice cover on lakes and wetlands has decreased, and the length of the growing season has increased. Under current greenhouse gas emission scenarios winter precipitation is predicted to increase 10-15% and summer precipitation is predicted to not change or to decrease (Mack 2008).

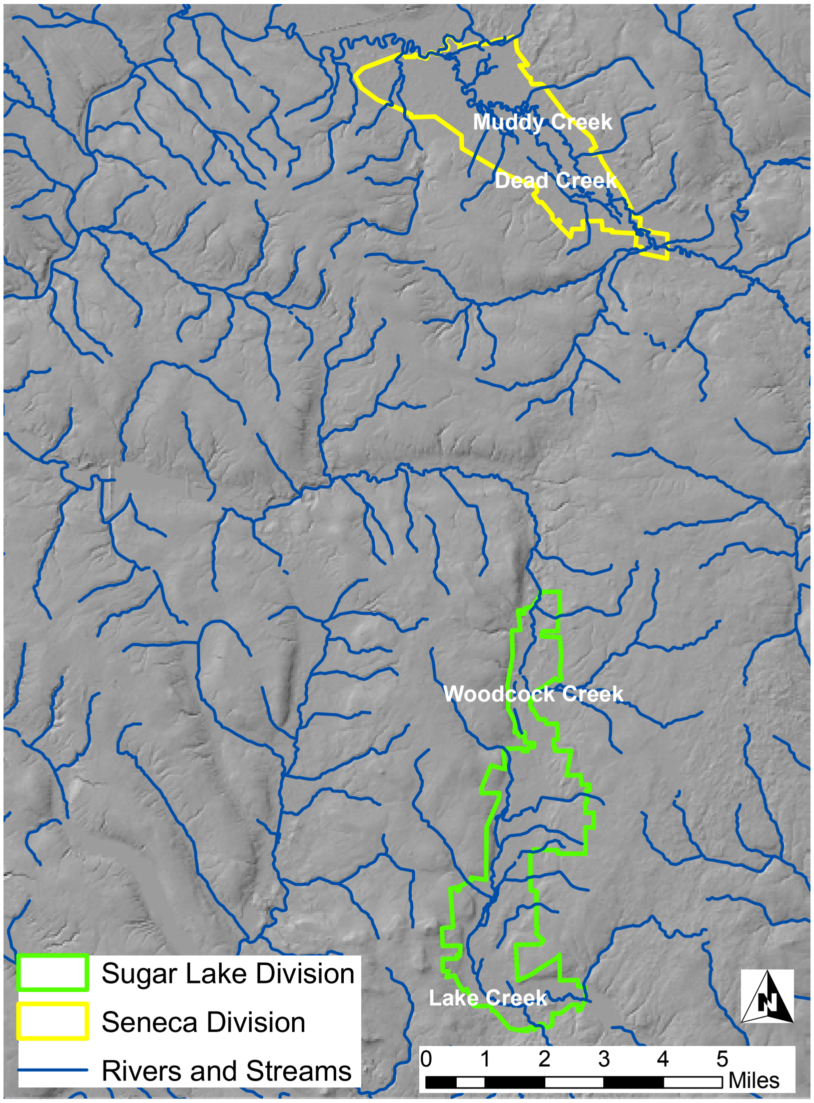


Figure 9. Major creeks on Erie National Wildlife Refuge.

A surficial aquifer system composed of glacial drift material underlies Erie NWR to various depths, from 0 to 150 meters (Schiner and Gallaher 1979, Richards et al. 1987, Trapp and Horn 1997). Water holding capacity of this aquifer is dependent upon the glacial process that deposited material throughout this area such that unsorted glacial outwash versus sorted meltwater materials are highly different. Depth to groundwater within the refuge varies from 0 to 12 feet below the surface. Bedrock comprises the second and deeper Appalachian Plateaus Aquifer System which exists in some places near the refuge at 25 feet below the ground surface (Trapp and Horn 1997). The most productive aquifers occur in glacial outwash deposits that are found at the confluences of historic glacial meltwater streams (Schiner and Gallaher 1979). Water quality and chemical characteristics of the aquifer vary dependent on the age of the bedrock and its origin. Ancient seawater, or connate, may be contained within the bedrock which includes high concentrations of salt. A majority of the recharge to the surficial aquifer occurs from precipitation and snowmelt with a very small proportion coming from hydrologic connectivity to the underlying bedrock. Recharge from bedrock to the alluvium is dependent upon joints or fracture zones within the different types of rocks (Fig. 13)

CHARACTERISTICS OF HISTORICAL PLANT COMMUNITIES

Since the Wisconsin glaciers receded from northwestern Pennsylvania about 14,000 BP, the terres-

Table 1. Precipitation data from 1971-2000 at Franklin, PA (from National Climatic Data Center, www.ncdc.noaa.gov).

Precipitation (inches)																								
	Precipitation Totals									Mean Number of Days (3)				Precipitation Probabilities (1) Probability that the monthly/annual precipitation will be equal to or less than the indicated amount										
	Means/ Medians(1)		Extremes							Daily Precipitation				Monthly/Annual Precipitation vs Probability Levels These values were determined from the incomplete gamma distribution										
Month	Mean	Med-ian	Highest Daily(2)	Year	Day	Highest Monthly(1)	Year	Lowest Monthly(1)	Year	>= 0.01	>= 0.10	>= 0.50	>= 1.00	.05	.10	.20	.30	.40	.50	.60	.70	.80	.90	.95
Jan	2.60	2.56	2.12	1937	25	5.47	1999	1.09	1981	15.8	7.4	1.3	.2	1.12	1.36	1.68	1.95	2.20	2.46	2.73	3.04	3.44	4.04	4.58
Feb	2.34	2.14	1.79	1959	10	5.53	1990	.37	1978	12.6	6.5	1.2	.2	.73	.95	1.28	1.57	1.84	2.13	2.44	2.81	3.28	4.02	4.70
Mar	3.29	3.37	1.72	1985	29	6.72	1985	.88	2000	13.8	8.2	2.0	.4	1.22	1.53	1.97	2.34	2.69	3.05	3.44	3.89	4.46	5.34	6.15
Apr	3.58	3.56	2.15	1937	26	6.17	1998	1.03	1971	13.5	8.6	2.3	.6	1.83	2.12	2.53	2.85	3.14	3.44	3.75	4.10	4.54	5.21	5.80
May	3.87	3.67	3.00	1928	18	7.89	1984	1.11	1993	12.9	8.9	2.5	.6	1.32	1.68	2.22	2.67	3.10	3.55	4.04	4.60	5.33	6.46	7.50
Jun	4.94	4.54	4.50	1981	9	10.47	1989	.93	1991	12.9	8.5	3.6	1.2	1.39	1.86	2.57	3.19	3.79	4.43	5.12	5.95	7.02	8.70	10.27
Jul	4.99	4.27	4.92	1996	19	11.29	1980	.97	1998	11.3	7.9	3.4	1.4	1.58	2.05	2.75	3.35	3.93	4.53	5.19	5.96	6.96	8.51	9.94
Aug	4.15	3.91	5.30	1994	14	7.92	1994	1.41	1995	11.0	7.7	2.8	1.1	2.05	2.40	2.88	3.27	3.62	3.98	4.35	4.78	5.31	6.12	6.84
Sep	4.31	4.25	3.05	1977	14	8.15	1996	.96	1995	11.4	8.1	3.2	1.0	1.84	2.23	2.78	3.23	3.64	4.07	4.52	5.05	5.71	6.72	7.63
Oct	3.04	3.05	4.00	1954	16	5.42	1978	1.15	1994	12.2	7.3	1.9	.4	1.35	1.62	2.00	2.31	2.59	2.88	3.19	3.54	3.99	4.66	5.27
Nov	3.53	3.42	2.20	1999	3	10.99	1985	.72	1976	14.3	8.1	2.2	.5	1.16	1.50	1.99	2.41	2.81	3.23	3.68	4.22	4.90	5.97	6.95
Dec	3.17	2.95	2.00	1968	28	7.23	1971	1.53	1976	16.7	8.3	1.7	.3	1.33	1.62	2.02	2.36	2.67	2.99	3.33	3.72	4.21	4.97	5.66
Ann	43.81	44.54	5.30	Aug 1994	14	11.29	Jul 1980	.37	Feb 1978	158.4	95.5	28.1	7.9	34.19	36.12	38.56	40.38	41.99	43.53	45.10	46.83	48.90	51.88	54.42

Snow (inches)																							
Snow Totals															Mean Number of Days (1)								
Means/Medians (1)					Extremes (2)										Snow Fall >= Thresholds					Snow Depth >= Thresholds			
Month	Snow Fall Mean	Snow Fall Median	Snow Depth Mean	Snow Depth Median	Highest Daily Snow Fall	Year	Day	Highest Monthly Snow Fall	Year	Highest Daily Snow Depth	Year	Day	Highest Monthly Mean Snow Depth	Year	0.1	1.0	3.0	5.0	10.0	1	3	5	10
Jan	14.9	12.5	4	3	11.0	1971	27	52.0	1999	39	1977	31	23	1977	8.1	7.0	1.9	.6	.1	18.6	10.8	6.5	2.7
Feb	11.0	9.1	3	2	8.0	1972	20	29.1	1972	40	1977	1	15	1977	5.6	4.9	1.3	.3	.0	14.4	9.5	5.5	1.3
Mar	9.9	10.0	1	1	16.0	1993	14	26.0	1971	16	1993	14	5	1984	3.7	3.4	1.2	.5	.1	6.1	3.1	1.3	.2
Apr	1.3	.0	#	#	6.0	1987	4	8.0	1987	6	1987	4	#+	2000	.7	.6	.1	.1	.0	.6	.2	.1	.0
May	#	.0	#	0	#	1977	9	#	1977	#	1977	9	#	1977	.0	.0	.0	.0	.0	.0	.0	.0	.0
Jun	.0	.0	0	0	.0	0	0	.0	0	0	0	0	0	0	.0	.0	.0	.0	.0	.0	.0	.0	.0
Jul	.0	.0	0	0	.0	0	0	.0	0	0	0	0	0	0	.0	.0	.0	.0	.0	.0	.0	.0	.0
Aug	.0	.0	0	0	.0	0	0	.0	0	0	0	0	0	0	.0	.0	.0	.0	.0	.0	.0	.0	.0
Sep	.0	.0	0	0	.0	0	0	.0	0	0	0	0	0	0	.0	.0	.0	.0	.0	.0	.0	.0	.0
Oct	#	.0	#	0	#	1997	23	#+	1997	#+	1997	23	#+	1997	.0	.0	.0	.0	.0	.0	.0	.0	.0
Nov	2.9	2.0	#	#	5.0	1987	21	9.0	1997	5+	2000	22	1+	2000	2.0	1.4	.3	.1	.0	2.1	.6	.1	.0
Dec	13.3	10.2	2	1	12.5	1992	11	26.0	2000	17	1977	10	5	1995	6.1	4.5	1.7	.4	.1	10.5	5.8	3.6	1.1
Ann	53.3	43.8	N/A	N/A	16.0	Mar 1993	14	52.0	Jan 1999	40	Feb 1977	1	23	Jan 1977	26.2	21.8	6.5	2.0	.3	52.3	30.0	17.1	5.3

trial ecosystem near Erie NWR evolved in response to changing climatic conditions from a late-Wisconsinian tundra to a forested landscape by the early Holocene period (Walker and Hartman 1960, Miller and Futyma 2003, Webb et al. 2003, Gorham et al. 2007). After the ice sheets melted, glacial sediments were exposed and alluvial fans developed as debris and sediment eroded from hill slopes into drainage valleys. When forest cover became established on the deposited glacial till and erosional sediments, the basic topography of the Erie NWR was stabilized and the complex of upland forests, wet-mesic forested creek valleys, alluvial valley wetlands and depressions, and creek corridors became established. Thick organic sediments accumulated in depths of up to 36 feet in many valley locations (Straffin and Grote 2010) and their presence in certain contemporary soil layers denote longer-term presence of wetlands (Yaworski et al. 1979).

Generally, contemporary ecoregions in the north and west portions of Pennsylvania follow the boundaries of glacial till deposition, terminal moraines,

Table 2. Temperature data from 1971-2000 at Franklin, PA (from National Climatic Data Center, www.ncdc.noaa.gov).

Temperature (°F)																					
Mean (1)				Extremes										Degree Days (1) Base Temp 65		Mean Number of Days (3)					
Month	Daily Max	Daily Min	Mean	Highest Daily(2)	Year	Day	Highest Month(1) Mean	Year	Lowest Daily(2)	Year	Day	Lowest Month(1) Mean	Year	Heating	Cooling	Max >= 100	Max >= 90	Max >= 50	Max <= 32	Min <= 32	Min <= 0
Jan	34.5	16.1	25.3	73	1950	26	34.1	1990	-23	1963	29	12.9	1977	1232	0	.0	.0	2.4	13.7	28.6	3.1
Feb	37.1	17.0	27.1	72+	1997	22	36.5	1998	-27	1963	27	14.2	1979	1064	0	.0	.0	3.6	10.7	24.9	2.7
Mar	47.1	24.3	35.7	81+	1938	23	43.6	1973	-22	1934	1	28.1	1984	908	0	.0	.0	11.8	3.9	24.6	.7
Apr	59.5	33.9	46.7	90	1976	19	51.3	1985	10	1964	2	42.4	1975	549	0	.0	@	22.2	.4	13.9	.0
May	70.9	43.8	57.4	94	1936	11	65.0	1991	20	1966	10	51.1	1997	268	32	.0	.2	30.3	.0	2.5	.0
Jun	79.4	53.3	66.4	101	1934	29	69.8+	1973	32+	1929	3	61.8	1972	58	99	.0	1.6	30.0	.0	.0	.0
Jul	83.5	57.8	70.7	106+	1936	10	73.5	1999	36	1971	15	67.2	2000	6	181	.0	4.0	31.0	.0	.0	.0
Aug	81.7	56.9	69.3	101+	1933	1	73.8	1980	34	1969	12	65.6	1982	23	156	.0	2.1	31.0	.0	.0	.0
Sep	74.0	50.3	62.2	100+	1932	1	66.7	1971	27	1957	27	59.4	1975	115	29	.0	.5	30.0	.0	.1	.0
Oct	62.3	39.2	50.8	88+	1927	2	58.1	1971	15	1965	29	45.9	1987	445	3	.0	.0	27.0	.0	5.9	.0
Nov	50.0	31.6	40.8	81+	1950	2	47.9	1975	1	1929	30	35.1	1996	726	0	.0	.0	13.5	1.0	16.6	.0
Dec	39.1	22.2	30.7	74	1982	4	37.6	1982	-14+	1950	27	17.7	1989	1064	0	.0	.0	4.4	8.8	25.8	1.0
Ann	59.9	37.2	48.6	106+	Jul 1936	10	73.8	Aug 1980	-27	Feb 1963	27	12.9	Jan 1977	6458	500	.0	8.4	237.2	38.5	142.9	7.5

uplifted hills and slopes, and other geologic events which mark the transition between topographic and biological communities (Fig. 14). Erie NWR lies within the Low Lime Drift Plain (EPA Ecoregion IV designation), which historically was characterized by terrestrial northern hardwood forest dominated by northern red oak (*Quercus rubra*), black oak (*Quercus velutina*), sugar maple (*Acer saccharum*), and hickory (*Carya* spp.) on well drained upland hill sites; palustrine-type eastern hemlock (*Tsuga canadensis*)-American beech (*Fagus grandifolia*)-yellow birch (*Betula alleghaniensis*)-maple-white ash (*Fraxinus americana)* hardwood forests on the wetter poorly drained edges of creek floodplains; and scattered small shrub/scrub (S/S) wetlands and beaver ponds along creek drainages (Ferguson 1968, Ruby 1968, Smith 1991, Fike 1999, Woods et al. 1999, Lundgren 2001, NatureServe1 2007). A few unique shrub fens also occurred where groundwater seeped from glacial hill slopes. Early European explorer accounts document trees of five and six feet in width and generally state that northwestern Pennsylvania was forested "as far as the eye could see." Their notes also state that the many small creek valleys in the region would provide good pastureland, but as a whole the region was heavily forested and dissected by many small creeks and chains of ridges with broken terrain that would be difficult to cultivate. The first soil surveys in Crawford County stated that "before settlement by white men the county was covered with forest, except for a few patches of grassland along French and Oil Creeks…" (Bacon et al. 1954). It was further noted that "the original forest consisted of oak, maple, American chestnut (*Castanea dentata*), black walnut (*Juglans nigra*), hickory, black cherry (*Prunus serotina*), black locust (*Robinia pseudo-acacia*), tuliptree (also known as yellow poplar, *Liriodendron tulipifera*)), ash (*Fraxinus* spp.), butternut (*Juglans cinerea*), ironwood (*Carpinus caroliniana*), mountain-laurel (*Kalmia latifolia*), pine (*Pinus* spp.),

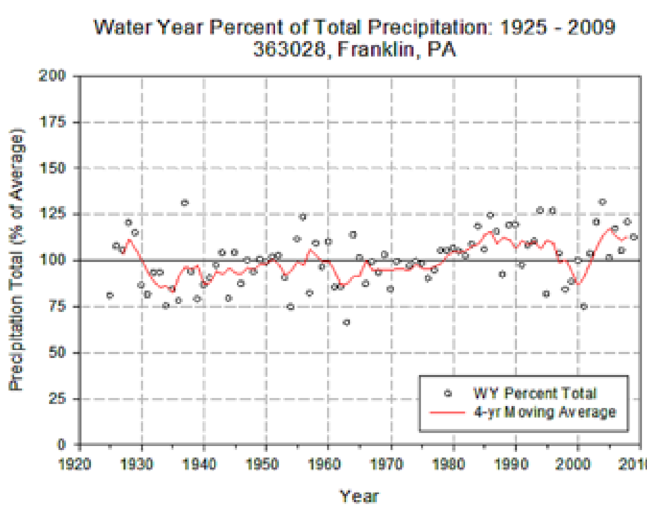


Figure 10. Water year total precipitation (percent of long-term average) at Franklin, Pennsylvania (from data in the Carbon Dioxide Information Analysis Center (CDIAC, http://cdiac.ornl.gov).

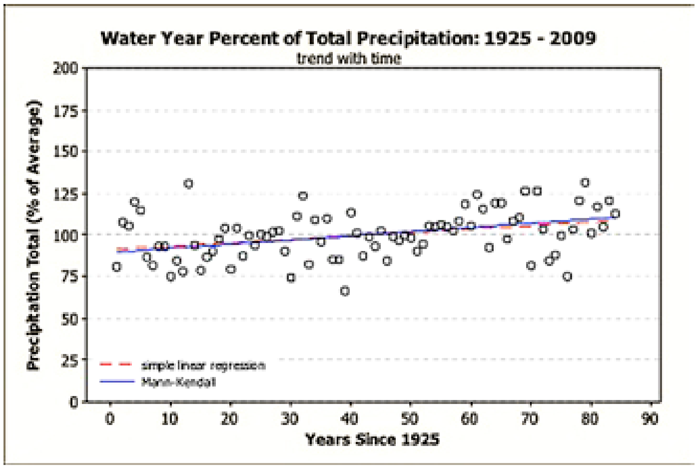


Figure 11. Trend in water year total precipitation at Franklin, Pennsylvania, 1925-2009 (from data in the Carbon Dioxide Information Analysis Center (CDIAC, http://cdiac.ornl.gov).

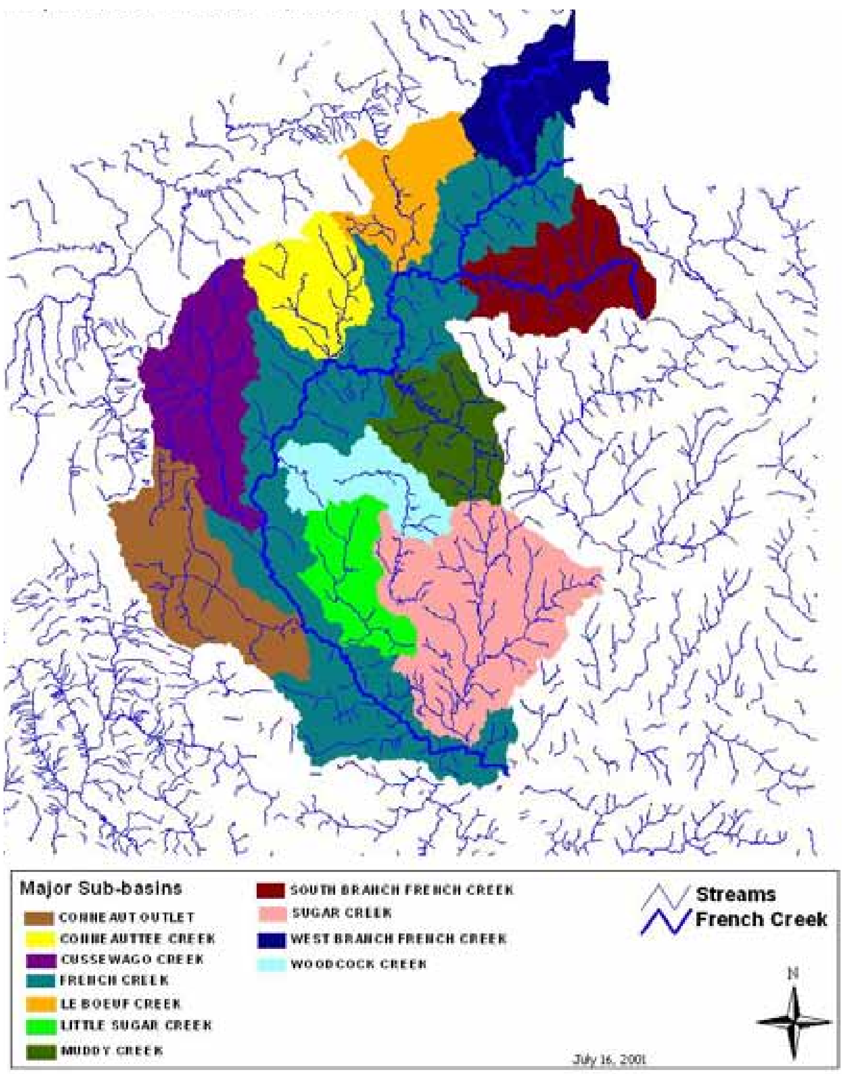


Figure 12. Sub-basins of the French Creek Watershed (from Western Pennsylvania Conservancy 2002).

eastern hemlock, and spruce (*Picea* spp.). The forest floor was open and comparatively free from underbrush…" (Bacon et al. 1954), implying a mature closed canopy condition.

Creek, Floodplain Wetland, and Riverfront Forest Communities

Generally, plant communities at Erie NWR are arrayed along topographic gradients in relationship to glacial hills and creek drainages (Smith 1991, Fig. 15). At the lowest elevations creeks bisect the glacial hills of the region and the larger creek channels contain water year round. Narrow natural levees often bound the creek channels and support early succession "riverfront-type" forest communities comprised mainly of willow, red maple, numerous shrubs such as dogwood (*Cornus* spp.) buttonbush (*Cephalanthus occidentalis*), and a few other occasional shrubs and tree species. The relatively narrow floodplains along the extant creeks on Erie NWR contain relict creek channels and depressions (such as creek oxbows) along with streamside wetlands that historically were semipermanently to seasonally flooded from increased creek discharges in spring following snowmelt. Historically, beaver often constructed dams in and along creek drainages including former channel sites (McCoy 1982; USFWS 1988). These "beaver ponds" temporarily impounded drainages in many floodplain locations and contained relatively permanent water regimes, at least during wet years, while beaver were present (Collins 1974, Dennis et al. 1989, Merendino and Ankney 1994). The average "life span" of beaver ponds in the Erie NWR region is unknown, but if they were similar to other Great Lakes regions, then beaver probably occupied and maintained dams, for 10-20 years (, Novak 1987, Naiman et al. 1988, Derby and Prince 1996).

In more permanently to semipermanently flooded sites on Erie NWR, such as natural creek oxbows and beaver ponds, aquatic bed and non-persistent emergent marsh veg-

Table 3. Mean of Monthly Discharge (cubic-feet/second) at four different locations on creeks near the Erie NWR..

Stream	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
Mean of Monthly Discharge Oil Creek 1932-2010	697	734	1,090	909	591	377	242	176	214	265	507	703
Mean of Monthly Discharge French Creek 1921-1939	1,850	1,650	2,310	1,730	871	424	235	163	288	528	1,140	1,450
Mean of Monthly Discharge Wood Creek 1974-1995	104	122	146	96	71	61	39	37	45	82	105	137
Mean of Monthly Discharge Wood Creek dam 1974-2011	58	89	100	79	42	37	25	24	27	35	67	81

etation becomes established in the deeper centers of the ponds, while S/S-type vegetation surrounds the edges of the ponds. Common aquatic plants in these wetlands includes pondweed (*Potamogeton* spp.), coontail (*Ceratophyllum demersum*), spatterdock (also known as yellow cow-lily, *Nuphar lutea*), and duckweeds (mixtures of *Lemna, Spirodela, Wolfia, Wolfiella*) (Erdman 1975). Emergent plants include rice cutgrass (*Leersia oryzoides*), lizard's tail (*Saururus cernus*), burreed (*Sparganium* spp.), cattail (*Typha* spp.), and various rushes (*Juncus* spp.) and sedges (*Carex* spp.) (Decker 1955, Deets 1994). Shallow edges of wetland depressions and creek channels that dry during summer contain narrow bands of herbaceous "moist-soil" type wetland assemblages that grade sharply into S/S communities and then to swamp forest communities (Smith 1983, NatureServe1 2007). S/S habitats contain often dense stands of buttonbush, alder (*Alnus* spp.), black willow (*Salix nigra*), black ash (*Fraxinus nigra*), and dogwood. The Muddy-Dead Creek channel-floodplain complex on the Seneca Division apparently has been dominated by an extensive S/S community for a long time and another area that likely contained extensive S/S communities over time was the Lake Creek floodplain above Sugar Lake (Deets 1994, Bissell and Danielson 1995, NatureServe1 2007).

Swamp Forest

Swamp forest communities occur in temporarily flooded or saturated (throughout the growing season) soil lowlands on Erie NWR and historically contained the unique eastern hemlock-yellow birch species assemblage with slightly higher ridges and knolls containing American beech, white pine (*Pinus strobes*), yellow birch, black ash, and red maple (*Acer rubrum*) (USFWS 1981, Smith 1983, Golet et al. 1993, Deets 1994). Soils in swamp forest areas vary from saturated "muck" to imperfectly drained mineral soils and often are acidic. Microtopography in these swamp areas is often characterized by mounds and depressions caused by uprooted trees. Canopy closure is often nearly complete in hemlock-dominated swamps and shrubs generally are sparse (Black and Mack 1976). Some sedges, ferns, and

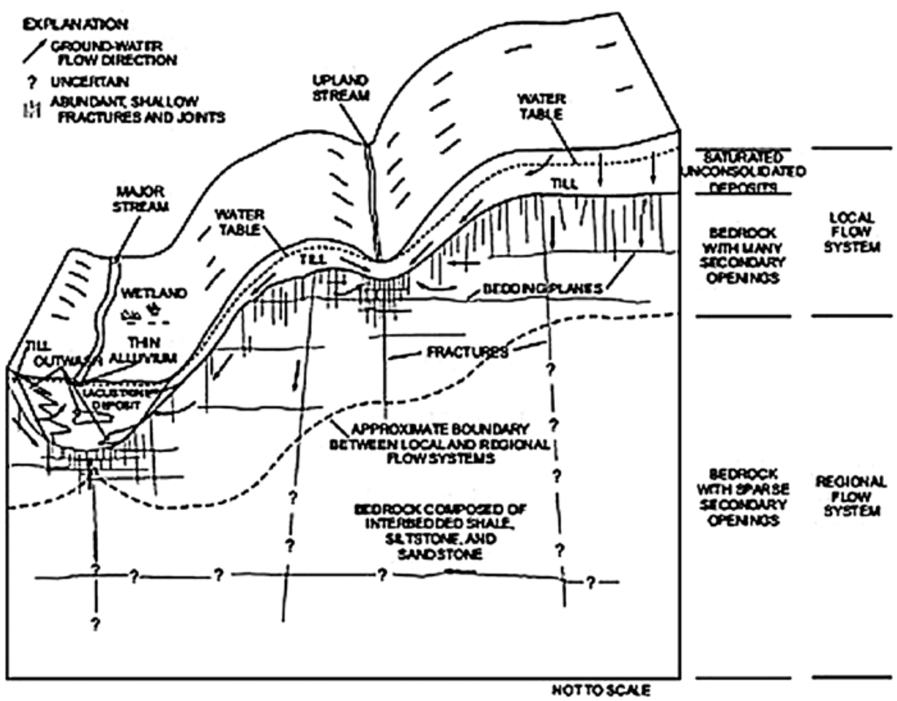


Figure 13. Conceptual model of groundwater aquifers and groundwater flow in the Appalachian Plateau near Erie National Wildlife Refuge (from Buckwater and Moore 2007).

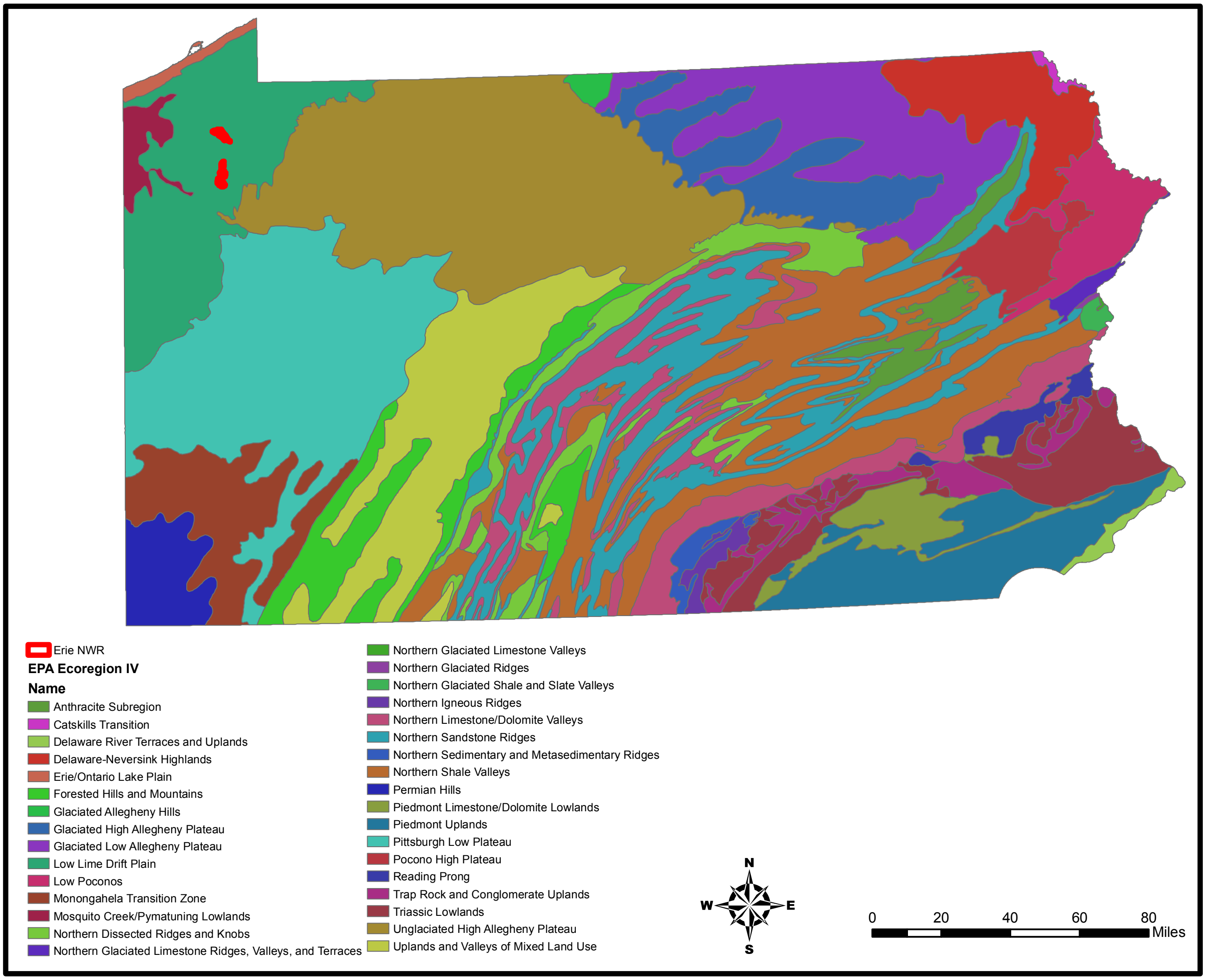
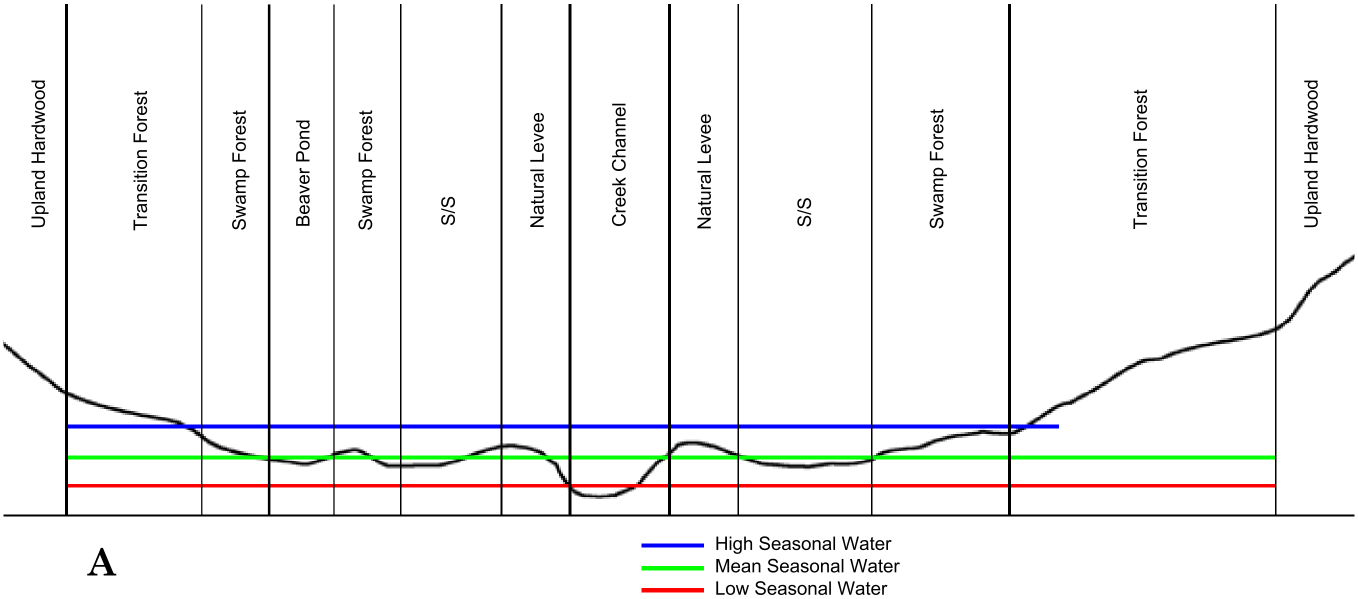


Figure 14. Environmental Protection Agency Ecoregion Level IV of Pennsylvania (from Woods et al. 1999).

gooseberry (*Ribes* spp.) occur in the understory and as ground cover. Fringed orchids (*Hebenaria psycodes*) sometimes are found in more sun-lit areas. Examples of swamp forest occur on the Lake Creek RNA in the Sugar Lake Division and in the Muddy Creek RNA and the Ferris Corners area in the northwestern corner of the Seneca Division (Deets 1994, Bissell and Danielson 1995, Grund 2006). A unique shrub fen is located in the Mohawk Valley in the northwestern portion of the Seneca Division (this fen is also known as the "Pheasant Farm Fen") (Bissel and Danielson 1995, Grund 2006). The Mohawk fen is a calcareous glacial fen fed by groundwater seeps from a recharge area to the south and east and is dominated by wetland herbaceous and shrub species. Dominant species in the shrub zone of the fen includes willow, spikerush (*Eleocharis* spp.), winterberry holly (*Ilex verticillata*), sedges, cattail, rice cutgrass, and poison sumac (*Rhus vernix*). Numerous other moist-soil herbaceous species also are present.

Transition Forest and Upland Hills

As topography transitions from low creek bottoms to upland hills on Erie NWR a "transition forest" community type occurs and contains interesting mixes of sugar maple, red maple, American beech, yellow birch, hemlock, American hornbeam (ironwood), American elm (*Ulmus americana*) and slippery elm (*Ulmus rubra*), black cherry, northern red oak, and other upland species (Deets 1994). The understory of transitional forests includes varied American beech, ironwood, black cherry, serviceberry (*Amelanchier* spp.), hawthorn (*Crataegus* spp.), and witchhazel (*Hamamelis virginiana*). Ground cover in transitional forest communities usually



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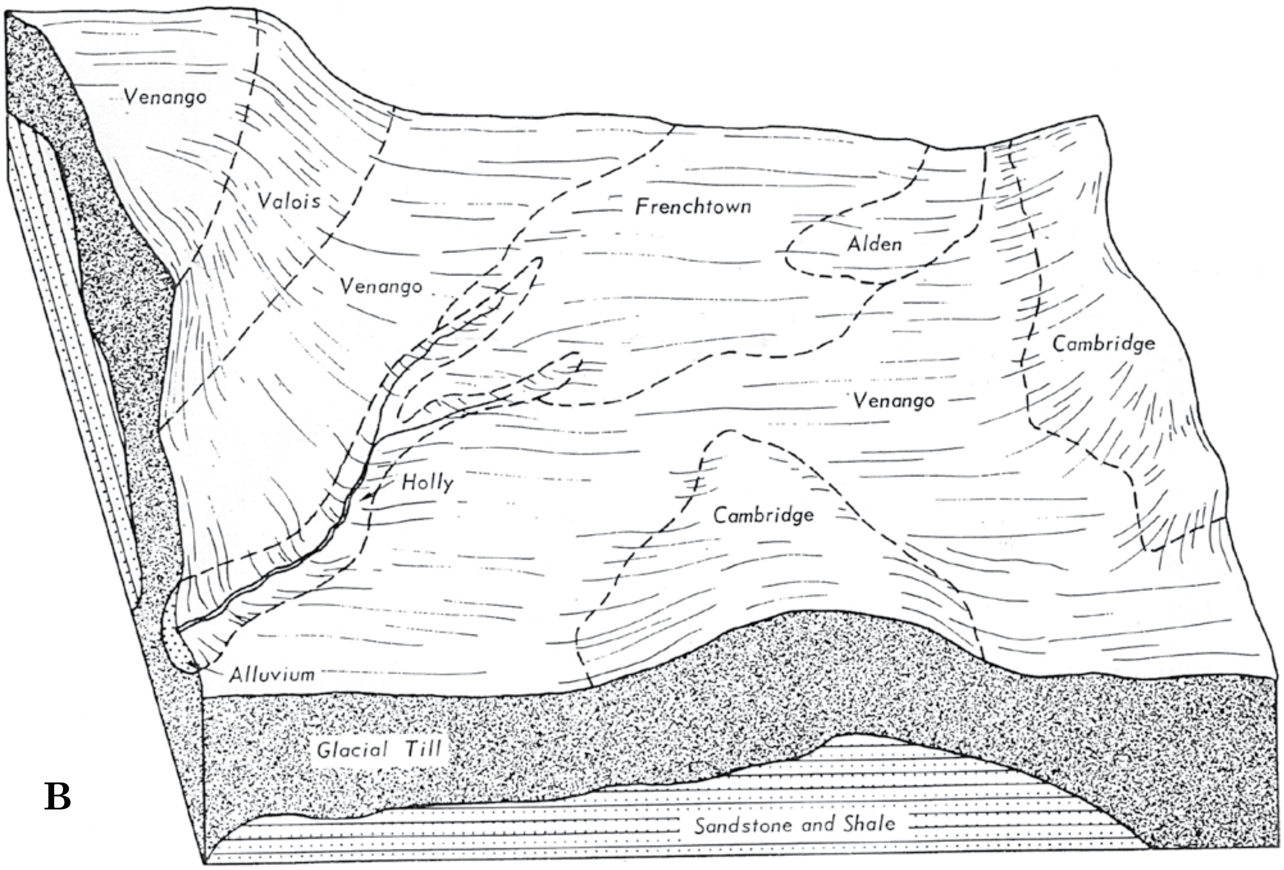

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Figure 15. a) Cross-sectional diagram of the distribution of major natural community types at Erie National Wildlife Refuge and b) schematic of the distribution of major soils in the Venango-Frenchtown-Cambridge association to demonstrate the landscape positions of soils and communities (from Yaworski et al. 1979). Dominant plant species present in the various communities are identified in the text. Natural levee sites contain early succession "riverfront" species assemblages including willow, maple, and various shrubs. The relationship of communities to soils and topography/geomorphic surface is provided in Table 4.

contains wild garlic (*Allium canadense*), may apple (*Podophylum peltatum*), helleborine (*Epipactis helleborine*), and ferns. An example of a remnant transitional forest on Erie NWR is represented on the Jacob Guy RNA (Deets 1994).

A true northern deciduous hardwood forest community occupies uplands throughout the Allegheny Plateau including Erie NWR and historically was comprised of northern red, black, and white oaks *(Quercus* alba) along with hickory, sassafras (*Sassafras albidum*), cucumbertree (*Magnolia acuminate*), sugar maple and many other typical upland tree, shrub, and understory species (Smith 1983, Fike 1999, NatureServe1 2007). A representative late succession (older growth) mixed hardwood remnant of this forest type is present on the Sugar Lake Division on Allen Road in Wayne Township and another presumably "virgin" stand of northern hardwood forest exists within the Muddy Creek RNA (Deets 1994).

Table 4. Hydrogeomorphic (HGM) matrix of historical distribution of major vegetation communities/habitat types at Erie National Wildlife Refuge in relationship to geomorphic surface, soils, and hydrological regime. Relationships were determined from vegetation species distribution in reference sites on the refuge (Deets 1994, Bissell and Danielson 1995, Grund 2006); soil maps (Fig. 7), region-specific hydrology data (Table 3 and Wurster 2012), and various botanical accounts and literature (e.g., Black and Mack 1976, Smith 1983, Fike 1999, Lundgren 2001, NatureServe1 2007).

Habitat Type	Geomorphic position	Soils	Hydrological regime[a]
Floodplain shrub wetland[b]			
Open water-aquatic	Creek channel, oxbow, beaver pond	Holly, Carlilse	P
Seasonal herbaceous	Edges of oxbows, beaver ponds, floodplain Depressions	Holly, Carlilse	P to S
Shrub/scrub	Edges of creek channels, beaver ponds, floodplains	Carlilse, Holly,	SP
Swamp forest	Creek floodplains	Philo, Pope	S
Transition forest	Edges of upland hills	Canadice, Wyoming Haven, Halsey, Red Hook, Chenago	OS-S
Upland hardwood forest	Hill slopes and ridges	Alden, Valois Cambridge, Venango, Frenchtown	OS-D

[a] P – permanent, SP – semipermanent, S – seasonal, OS-S – onsite seasonally saturated, OS-D – onsite well drained.
[b] Floodplain Shrub Wetland includes open water-aquatic, seasonal herbaceous, and shrub/scrub habitat types

DISTRIBUTION OF HISTORICAL VEGETATION COMMUNITIES

An HGM matrix of relationships of the above major plant communities to geomorphic surface, soil type, general topographic position, and hydrology was developed (Table 4) to prepare a map model of potential distribution of historical (Presettlement) vegetation communities on Erie NWR (Fig. 16). The HGM matrix of understanding, and prediction of, potential historical vegetation communities uses plant associations described in published literature, vegetation community reference sites (such as the Natural Area communities – see above), and state-of-the-art understanding of plant species relationships (NatureServe 2007 and the many references contained in the report for specific community types). These plant-abiotic correlations are in effect the basis of plant biogeography and physiography whereby information is sought on where plant species, and community assemblages, occur throughout the world relative to geology and geomorphic setting, soils, topography and aspect position, and hydrology (e.g., Barbour and Billings 1991, Bailey 1996). The hydrogeomorphic matrix provides a way to map the potential historical vegetation communities at Erie NWR in an objective manner based on the botanical correlations that identify community type and distribution, juxtaposition, and major ecological processes that created and "drive" community formation and sustainability. Obviously, the predictions of type and historical distribution of communities are only as accurate as the understanding and documentation of plant-abiotic relationships and the geospatial data for the abiotic variables for a location and period of interest.

At Erie NWR a major weakness in geospatial data available to prepare the HGM community matrix and historical map is topography/elevation information such as LiDAR that

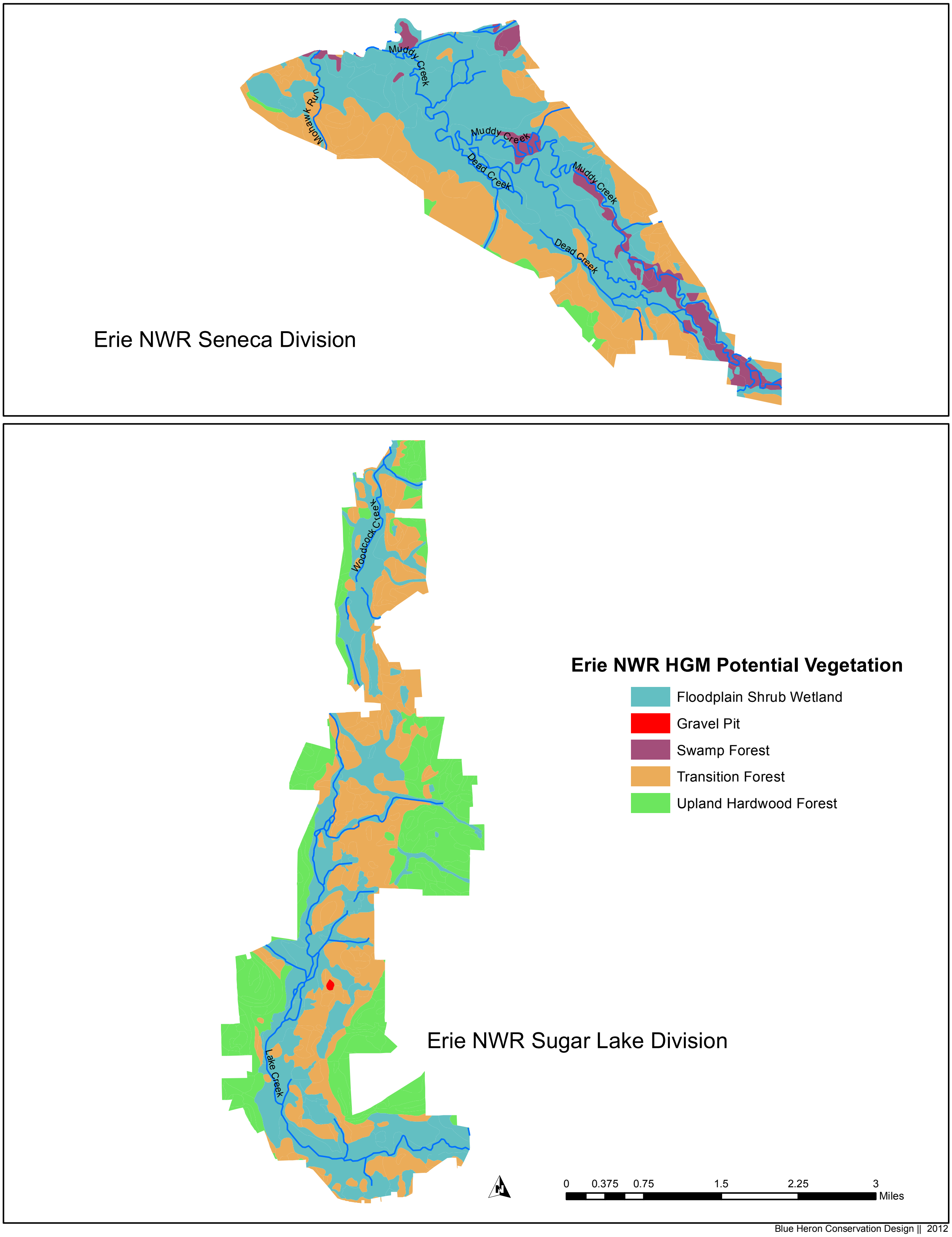

Figure 16. Potential historical vegetation community map of Erie National Wildlife Refuge. Mapping of communities was based on relationships of communities to soils, topography, hydrology, and geomorphology provided in Table 4. The “gravel pit” polygon identified on the Sugar Lake Division is within an area generally mapped as transition forest and likely was that habitat type prior to excavation and mining.

could map elevations to a one-foot or less contour interval. This lack of detailed topographic information precludes mapping hydrological regimes on the refuge because even relatively subtle changes in elevation can alter flooding periodicity and duration that separate seasonal, semipermanent, and even permanent flooding categories. Consequently, while relationships of communities to hydrological regimes are known (Table 4), the mapping of potential historical wetland types necessarily must combine open water-aquatic, seasonal herbaceous and S/S habitats under the more generic "floodplain shrub wetland" community category (Fig. 16). Because of the lack of refined elevation and hydrology mapping data, the potential historical vegetation map relies heavily on vegetation-soil associations. Another complicating factor in definitively separating vegetation communities at Erie NWR is that various botanical studies have chosen to categorize communities differently in northwestern Pennsylvania. For example, the NatureServe1 (2007) vegetation categories often mix and combine hardwood trees and hemlock in several relatively similar categories, while other ecoregion reports and classifications (e.g., Smith 1991, Bissel and Danielson 1995, Woods et al. 1999, Edinger et al. 2002) generally discuss forest settings relative to species-specific associations. Undoubtedly, future botanical inventories and research along with obtaining more refined elevation data will improve the potential historical vegetation model maps provided in this report.

KEY ANIMAL SPECIES

Erie NWR and the Allegheny Plateau region of northwestern Pennsylvania historically supported populations of many diverse animal species (e.g., Woods et al. 1999). Aquatic species within the French Creek Watershed are representative of those found in the St. Lawrence and Ohio River systems (Woods et al. 1999, Western Pennsylvania Conservancy 2001, USFWS 2006). The high animal biodiversity that currently exists within the French Creek watershed is a result of the mixing of species from these two regions since the Pleistocene when pre-glacial north flowing streams were rerouted to the south. Animal communities historically present at Erie NWR were dominated by species adapted to hardwood forests and narrow creek- riparian systems (Decker 1955, Smith 1983, Golet et al. 1993, Northern Appalachian Ecology Working Group 2000, Edminger et al. 2002). Buffalo (*Bison bison*), elk (*Cervus canadensis*), white-tailed deer (*Odocoileus virginanus*), black bear (*Ursus americanus*), and beaver (*Castor canadensis*) were documented as having been numerous throughout the region. Although few historical accounts exist and mention waterfowl or waterbirds at Erie NWR, the regional creeks and scattered floodplain wetlands undoubtedly attracted migrant and breeding waterfowl and some other waterbirds such as wading birds during spring and early summer (Brauning 1992). As wetlands dried during summer, prey resources likely provided important food for locally produced young and early fall migrant species. In wet years, some wetlands remained flooded through fall and likely were heavily used by fall migrant species. In dry years, wetland habitat, other than creek channels and deeper floodplain oxbows and beaver ponds, likely was limited during summer, fall, and winter. Among waterfowl, the locally breeding species included Canada goose (*Branta canadensis*), wood duck (*Aix sponsa*), black duck (*Anas americana*), hooded merganser (*Mergus cucullatus*) and some mallard (*Anas platyrhynchos*) (USFWS 1964, Bellrose 1980). Wetland habitats at Erie NWR also provided resources for a variety of Neotropical birds, aquatic mammals, fish, and herptiles (Roblee 2006, Rebar and Ropski 1999, Western Pennsylvania Conservancy 2001, Campbell 2011). The extensive forested and shrub habitats on the refuge were used by many migrant, wintering, and breeding bird species; mammals, amphibians, and reptiles.

CHANGES IN THE ERIE ECOSYSTEM

SETTLEMENT AND EARLY LAND USE CHANGES

A detailed history of human occupation in the Erie NWR region and their lifestyles and influences on local landscapes is provided in Glenn et al (2010) and the extensive references within this document. A brief summary of this information is provided below. Native people first occupied northwestern Pennsylvania around 11,000 years BP (Adovasio et al. 1978). These people had a highly mobile lifestyle that depended on foraging with some big game hunting as evidenced by Eastern Clovis style points found with mammoth bones in the region (Lantz 1985). Native populations increased throughout the Early, Middle, and Late Archaic Periods (10,000 to 3,000 BP), visiting the same area within the Seneca Division of Erie NWR over thousands of years (Johnson et al. 1978, Carr 1998, Stewart and Katzer 1988). Over time native people began building base camps near water resources, extraction sites near food resources, and improving and diversifying weapons and tools (Cowin 1991). Plant foods began to be more important with movements becoming more seasonal in nature. By the Late Archaic Period, native people were cultivating plants, becoming more logistical in camp locations, and beginning to participate in mortuary ceremonialism. In the Early Woodland Period 2,100 to 3,000 BP the subsistence base of local people was primarily hunting and gathering (Ballweber 1989) and horticulture began assuming a greater importance in the subsistence of people (Adovasio and Johnson 1981). Middle Woodland Period settlement patterns in the Allegheny Valley consisted of large, multi-seasonal base camps located on higher elevation terraces above major streams and creeks and smaller seasonal camps located in uplands. By the Late Woodland Period (1,100 to 350 BP/AD 850 to 1,550) native people began building fortified villages, storing foods, and burning surrounding areas to improve agriculture within the French Creek Watershed (Burkett and Cunningham 1997). Despite some local alteration of native vegetation for camp and agriculture sites, it is generally believed that native people had relatively little influence on ecological processes or communities and that the balance of valley creeks and wetlands adjoined by swamp and then upland forests was unchanged (Glenn et al. 2010).

The Early Historic Period continued the Late Woodland subsistence-settlement patterns but eventually became disrupted by increasing populations and conflicts among tribes. In the first part of the Early Historic Period the Iroquois occupied areas north of Erie NWR, the Shawnee were south, the Delaware and Erie were to the west, and the Erie occupied the refuge area and locations to the northwest (Callender 1978, Downes 1940, Goodard 1978, McConnel 1992). The fur trade with European settlers brought the Iroquois Nation to the region culminating in a war involving the Iroquois (Seneca people) who defeated the Erie in 1655 and caused the Erie to abandon the French Creek Valley (Salisbury 1996). Early expeditions up the Hudson River by the Swedes in 1637 and Dutch in 1655 established settlements in various locations throughout the region, however, these establishments were seized by the English for the Duke of York in 1664. The land of Pennsylvania was granted to a Quaker from England, William Penn, Jr., in 1671 by King Charles II. Although Penn and his family had been granted the land, he worked throughout the late-1700s to buy ownership of the land from the various tribes inhabiting the area. The Delaware tribe, or Lenape, were pushed west due to European settlement in the early-1700s and built their settlement, Cussewago, in the French Creek Watershed (Burkett and Cunningham

1997). Native American settlements throughout the area remained sparse partly due to European diseases and continued conflicts. The official Treaty of Fort Stanwix of 1768 opened lands to settlers and pushed the Native Americans to the west and north. Lands within Crawford county were broken up and given to the Population Company, Holland Land Company, and as Donation Lands by an act passed in 1783 (Buck and Buck 1968). Approximately 700,000 acres of Donation Lands were set aside for veterans of the Revolutionary War as payment for services. Lands were surveyed into 200 to 500 acre lots and drawn by lottery. The Erie NWR contains areas of Donation and Holland Land Company Lands.

In the late-1700s and early-1800s as European settlements increased throughout the Erie NWR region, large areas of local forests were cleared for timber harvest, oil exploration, subsistence farming, and agriculture (Coggeshall 1965). Sawmills were established throughout Crawford County and timber was transported down creeks to the Allegheny River and on to Pittsburgh. Impacts from timber removal included increased rates of soil erosion from cleared hill slopes, which caused heavy sedimentation in creek valleys and into Sugar Lake by 1885. Oil was first discovered by Europeans in 1857 along Oil Creek in Titusville. Naturally occurring oil had been known to the Native Americans along this creek for centuries as it bubbled up out of the ground and could be seen on the water's surface. The first oil well drilled in Crawford County was done in 1860 at 112 feet in southeast Titusville. Wheat was one of the first grain crops introduced to the region, however other crops such as buckwheat, rye, potatoes, and corn became important economically as well. Over time farming shifted to raising cattle, sheep, and horses as soils were well suited to producing grasses that provided good forage for stock. Dairies became increasingly important with the first cheese factory built in 1849. By 1870 Crawford County was ranked as the leading producer of cheese throughout Pennsylvania. With the increase in agriculture, many lakes within Crawford County were ditched in order to provide irrigation to farmlands, thus drying up many wetlands and converting vegetation communities. Other alterations occurred through the creation of dams across numerous creeks and rivers throughout northwestern Pennsylvania beginning in the 1930's. Beavers were historically very active throughout this region, creating many natural dams and wetlands (Novak 1987). The European fur trade and settlements along with increased agriculture almost extirpated the beaver and removed one of the naturally occurring processes which helped create many of the wetland complexes in this region (Dolin 2010). By the late-1800s the farming population began a steady and slow decline as mechanical farming tools reduced labor and industrial growth increased in the cities. Farming continued to decline through the 1900s with many farmlands being abandoned. Crawford County generally paralleled the U.S. national trend during the first part of the 20th Century as economies shifted from agriculture to industrial production and trade and the county population declined through the 1940s.

CONTEMPORARY HYDROLOGIC AND VEGETATION COMMUNITY CHANGES

Refuge Development and Water Management Structures

Erie NWR was established in 1959 with original refuge lands confined to about 5,150 acres in the Sugar Lake Division (USFWS 1964). The initial land acquisitions for the Sugar Lake Division encompassed about 90 individual farm holdings, many of which contained abandoned crop, hay, pasture, and orchard lands. The Seneca Division was approved by the Migratory Bird Commission in 1967. Nineteen tracts totaling 3,027 acres were purchased for the Seneca Division by 1973 with an additional 567 acres purchased to date. The currently approved acquisition boundary for the entire Erie NWR is 9,567 acres, with the balance between current and approved acreage being almost entirely within the Seneca Division. Immediately prior to establishment the Sugar Lake Division contained about 300 acres of creek, wetland, and man-made ponds; about 1,200 acres of agricultural crops; about 2,600 acres of forest and abandoned fields that were reverting back to woody cover; and 1,050 acres of active and abandoned pasture and hay fields (USFWS 1964). The forested lands at Sugar Lake Division included tracts in various states of tree species composition including second-growth hardwood and hemlock stands, abandoned orchards, small remnant Christmas tree plantations, and alder-dominated brush lands (USFWS 1964). A 160-acre forested tract that had not been harvested for the previous 50+ years was designated as the Jacob Guy RNA.

Four man-made impoundments (called "ponds") were present on the Sugar Lake Division when it was purchased by the USFWS; these were Pool 10 (now called Reitz Pond -(ca. 30 acres), Long Pond (one acre), Meyer's Pond (18 acres), and Upper Meyer's Pond (now called Pool K - 5 acres) (Fig. 17). Aerial photos indicate that Reitz Pond originally was part of a larger wetland complex associated with Lake Creek and that water was diverted from the wetland to the newly constructed impoundment in 1959, thus altering this complex. The Master Development Plan for the Sugar Lake Division sought to create a number of wetland impoundments to promote the creation of breeding, nesting, and brood rearing habitat for waterfowl (USFWS 1966). Six major impoundments were proposed to be built including Pools #1 (110 acres), # 2 (30 acres), #3 (now called Cooper's Marsh - 30 acres), #7 (60 acres), # 9 (also known as Deer Run Pond, 135 acres), and #11 (275 acres). Smaller impoundments proposed to be built included Pools B, C, D, F, M, and L along with Petersen, Heath, and Upper Meyer's ponds, which collectively totaled 37 acres.

The chronology and eventual construction of wetland impoundments on the Sugar Lake Division of Erie NWR is presented in Table 5. The largest impoundments that eventually were constructed included Erie Dam No. 4 (Pool 4 – also known as Beuchat Pond) constructed across Lake Creek in 1981, Erie Dam No. 9 (Pool 9 – also known as Deer Run Pond) in the east branch of Lake Creek in 1968, and a dam placed in Woodcock Creek in 1974 just outside the refuge boundaries. The originally proposed large Pools 1 and 11 were never constructed. A total of 16 impoundments comprising 315 acres eventually were developed in the Sugar lake Division, with a majority of them being constructed in the 1970s (Fig. 17; Table 5). Sixteen water-control structures are associated with providing water to all of the managed impoundments directly or indirectly (Fig 17). Most of the impoundments have relatively short and low levees and include small (< 18 inch diameter pipes) water-control structures that are stop-logs installed into corrugated metal riser pipes. The larger Pools 4 and 9 have more lengthy and high levees with engineered spillways and larger water-control structures designed to allow high waters to flow through the Lake Creek drainage. Pool 9 was originally constructed with a 100 foot concrete spillway and a large gated water-control structure designed to provide a maximum outflow capacity of about 200 cfs. The Pool 4 dam is about 960 feet long and 11.7 feet high and includes a 360-foot wide concrete control section along the upstream slope of the dam that acts as a spillway. Waterfowl nesting islands were constructed in many impoundments by excavating areas to provide island spoil mounds (refuge annual narratives). No impoundments were ever constructed or developed on the Seneca Division of Erie NWR.

Annual management of the developed impoundments on the Sugar Lake Division was fairly static through the early 1980s (refuge annual narratives and McCoy 1982). Typically most impoundments were managed to capture and hold water from local runoff of creeks in early spring, then water levels were partly drawn down in summer, reflooded when possible during fall migration, and then partly drawn down again during winter. A constraining issue for drawdown management on the larger impoundments (Pools 4 and 9) was the establishment of a sport fishery in the impoundments, which created conflict between maintaining fish populations vs. waterfowl food production (McCoy 1982). Starting in the mid-1980s, water management was changed to include nearly complete drainage of some smaller impoundments during summer and early fall to encourage moist-soil vegetation and associated invertebrate growth (e.g., Ver Hague 2003, USFWS 1996). In the late-1990s to 2000 impoundment draw downs coincided with waterfowl and shorebird migration events (Anderson et al. 2001, Green et al. 2009). However, beginning in 2001, impoundments were again filled to capacity in spring and water levels were held high throughout summer and fall. During this period, water-control structures were set to hold water (via stop-log placement) at set levels (mostly full-pool designations) and not moved during the year. In this management, water levels fluctuated up or down with seasonal patterns of precipitation, runoff, and evapotranspiration. This more static and permanent water regime management continued through 2006 when changes were again made to mimic a more natural hydrograph of spring and fall flooding and summer draw downs (Green et al. 2009).

The Pool 4 Dam on Erie NWR is considered a low-hazard class and the Pool 9 Dam is considered a significant-hazard class structure that could affect downstream flows and potential property damage upstream of Sugar Lake (USFWS 2003a, 2005). The emergency spillway control section of the Pool 4 dam failed in spring 1990 due to flotation and uplift of the stop-log-controlled service spillway inlet structure (W.W. Wheeler and Associates 2007). This failed section was reconstructed between 1990 and 1993 (USFWS 2005). Analyses of hazard classification and inflow design flood for the Pool 4 Dam was conducted and the primary downstream

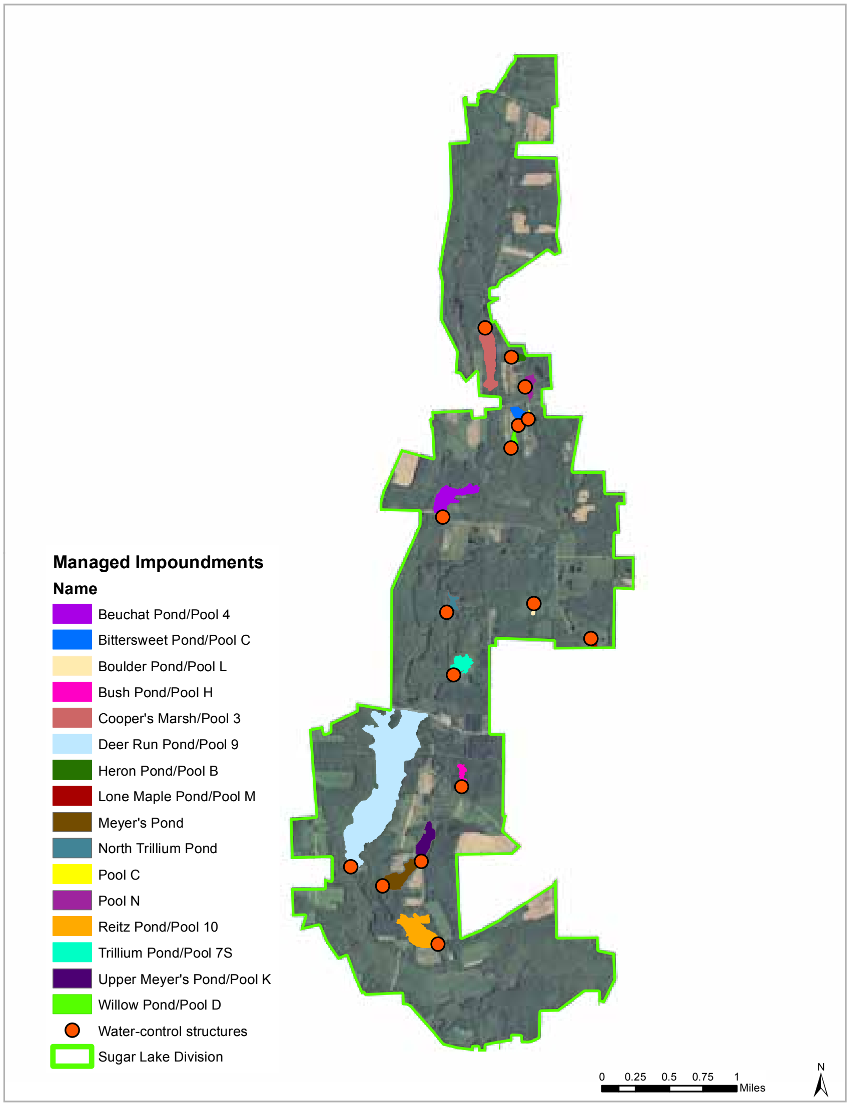

Figure 17. Location of water-control structures in relationship to wetland impoundments on Erie National Wildlife Refuge.

hazard is potential overtopping of State Highway 27, with the incremental effects associated with the failure of the Pool 4 Dam resulting in less than 0.5 feet of overtopping. Both the Pool 4 and Pool 9 Dam spillways have been reconstructed and designed in accordance with USFWS dam safety policy to accommodate a 100-year flood. For Pool 4, this level is a peak inflow of about 6,230 cfs and a 24-hour volume of about 870 acre-feet. Historically, water management at Erie NWR has attempted to release water when possible from both Pools 4 and 9 when predictions of heavy precipitation and creek flows are anticipated to reduce potential dam hazard conditions and to mediate potential pulses of high discharge levels that could cause more extensive downstream flooding. The significant-hazard class Pool 9 Dam has an approved emergency action plan that identifies roles and responsibilities should a dam failure occur.

Most surface water available for wetland management on Erie NWR comes from local and regional precipitation (rain and snow) and runoff through the various creeks in and around the refuge (refuge annual narratives). A few groundwater "seeps" also are present such as at the Pheasant Farm fen site on the Seneca Division. Currently, Erie NWR has 3 groundwater wells on the Sugar Lake Division (Fig. 18). In contrast, 76 wells are located on private property within a mile of the refuge; all but two wells are for domestic and residential use and flow at an average of less than 15 gallons/minute. These private wells have all been drilled into bedrock aquifers at an average of 25 feet beneath the surface.

Water Quality

Water quality of the Erie NWR is influenced by upstream farming activities, materials distributed over roads such as salt to melt ice, and potential contamination from oil and gas wells in the region (Patnode 2007, Fred Wurster, USFWS personal communication). Recent contaminant assessment has not identified any acute water quality issues at Erie NWR but did identify potential areas of concern (Patnode 2007). Turbidity throughout many of the creeks flowing into and through the refuge has increased over time as documented by water quality monitoring of Muddy Creek and its tributaries. One tributary of Muddy Creek has been listed as impaired by the EPA due to sediment load. Increased sediment is a result of farming and grazing practices upstream. Other inputs such as salt and brine applied to country roads may negatively impact surface water and infiltrate the soil, thus impacting plant growth, and or the quality of water and sediments in wetland impoundments. Sediments within Sugar Lake have already been negatively impacted by the accumulation of mercury from atmospheric sources. Continued oil drilling in the northwestern Pennsylvania region could potentially affect regional stream flows because

Table 5. Summary of water developments and management of Erie NWR 1959-2001, taken from refuge annual narratives and conversations with refuge staff.

Year	Location	Development Activities
1959	Lake Creek Wetland Complex	Area ditched to provide water for farmlands and Reitz
1963	Pool D (Willow Pond and C)	Created impoundment and installed structures
	Pool B (Heron pond and K)	Created impoundment
	Pool C (Bittersweet Pond and B)	Created impoundment
1964	3 small upland ponds	Created impoundments and installed structures
1965	Pools B, C, D	Water level gauges installed
	Pool 1	Initiated construction of impoundment
1966	Pool L (Boulder Pond)	Created impoundment
	Pool M (Lone Maple Pond)	Created impoundment
1967	Pool 7N (N. Trillium pond and Flattail Pond)	Created impoundment
	Pool 7S (Trillium pond and Flattail Pond)	Created impoundment
	Lower K Pond (Meyer's Pond)	Created impoundment
1968	Pool 9 (Deer Run Pond and Black Duck	Created Erie dam No. 9 and impoundment
	Meyer's Ponds	Spillway constructed
1969	Beaver Ponds	Beavers created three new ponds
1971	Cooper's Marsh (Pool 3)	Created impoundment
	Pool K (Upper Meyer's Pond) and Pool J	Created impoundments
1972	Reitz Pond (Pool 10)	Installed new concrete water-control structure
1975	Pool H (Brush Pond)	Created impoundment
	Pool N (Pipeline Pond and Gravel Pit Pond)	Created impoundment
	Peterson's Pond (Orchard Pond)	Created impoundment
	Grapevine Pond	Created impoundment
	North Pasture Pond	Created impoundment
	Heath Pond (Teal Pond)	Created impoundment
	Smaller Heath Pond (Borrow pit Pond)	Created impoundment
1976	Pool 9 (Deer Run Pond and Black Duck	Millet planted
	14 potholes	Created potholes
1977	Pool B (Heron pond and K)	Installed new headwall for water-control structure
1979	Meyer's Ponds	20 ac of shoreline bulldozed and root raked for seeding
	Meyer's Ponds	430 ft of dike was repaired and resloped to reduce angle
1981	Office Entrance Pool (Gravel pit pond)	Created impoundment (maybe 1975?)
	Pool 4 (Beuchat pond)	Created Erie dam No. 4 and impoundment
	Gas wells	Gas Company ordered to pay fines and clean up site due to high concentrations of salt in water samples
1984	Cooper's Marsh (Pool 3)	Nesting Island created
	Pool K (Upper Meyer's Pond)	Fishing Pier constructed
1985	Pool N (Pipeline Pond and Gravel Pit Pond)	Dike resloped, 2 Nesting ilsands created, and new water-control structure installed
	Meyer's Ponds	2 nesting islands restored
1986	Pool N (Pipeline Pond and Gravel Pit Pond)	Installed new water-control structure
	Pool H (Brush Pond)	New half round riser water control-structure
1987	Cooper's Marsh (Pool 3)	Dike breached
1988	Pool 9 (Deer Run Pond and Black Duck	Installed water-control structures
	Pool H (Brush Pond)	Installed water-control structure and reconstructed levee
	Farm field (Seneca Division)	Constructed a drop box and diversion ditch

Continued next page

Table 5, continued.

Year	Location	Development Activities
	Dugout Ponds	Created 3 new dugout ponds
	Nesting Islands	3 nesting islands restored
	Pool C (Bittersweet Pond and B)	One nesting island restored one new one created
	Lone Maple Pond	Restored one nesting island and disked/fertilized pond
	Brushland fields	Created 2 new dugout ponds with nesting islands
1989	Cooper's Marsh (Pool 3)	Replaced water-control structure and resloped levee
	Pool 7S (Trillium pond and Flattail Pond)	Replaced water-control structure (screwgate)
	Dugout Ponds	Created 5 new ponds
	Pool 9	One nesting island created
1990	MSU 17	Created moist soil impoundments in Sugar Lake Division
	Pool 4 (Beuchat pond)	Water-control structure failed
	DU impoundments 1-5	New wetlands in old fields
1991	Office Entrance Pool (Gravel pit pond)	One new nesting island created
	Pool C (Bittersweet Pond and B) and Poold	Restored one nesting island in each pool
	Beaver Ponds	Beaver tubes installed in dams and a water-control
	Wetland potholes	Restored 5 small wetland potholes created in 1960's,
	Old field wetlands	Restored 6 wetlands, placed low level levees or ditch
	Pool B (Heron pond and K)	Replaced water-control structure
1992	Pool 9	9 Nesting islands created
1993	Pool 9	Spillway repaired
	MSU	Develop units already created; two at Seneca and one at Sugar Lake; Created additional MSU at Seneca, 1800' x 3' levee in fallow farm field; 4 cell mois soil unit in Sugar lake in 20 ac fallow farm field…less than ideal topography noted
	Meyer's Ponds	Removed existing concrete structure and replaced with 5' inline vertical cmp attached to concrete slab
1996	Pools C, D, and 7N	Replaced water-control structures
	Levee construction	Constructed 5,900' of levee, reparied existing levees
1997	Pool D (Willow Pond and C)	Replaced water-control structure
	Pool 9	Resurfaced concrete spillway
1998	Pool N (Pipeline Pond and Gravel Pit Pond)	New 18" cmp installed through State Rd 198
	Pool 7N (N. Trillium pond and Flattail Pond)	Restored water-control structure
	Shaffer Rd.	New MSU developed on south side of road
1999	Lone Maple Pond	Replaced water-control structure
	Shaffer Rd.	Installed ditch plug in MSU
2001	Boulder Pond	Replaced water-control structure and repaired levee

of water diversion for natural gas and shale processing. These actions may negatively impact creeks within the Erie NWR which provide resources for a variety of sensitive species. Although, oil and gas well drilling has not affected refuge waters, potential spills would pose a major risk to wetlands throughout the area. Four National Pollutant Discharge Elimination System (NPDES) permits are listed within 0.5 miles of the Erie NWR acquisition boundary but are not expected to be large sources of contaminated water flowing into the refuge (Wurster 2012). Water quality is monitored regularly for surface and well waters on and near the refuge.

Vegetation Management and Community Changes

Major changes in vegetation communities on Erie NWR are identified in Table 6. The following information describes specific chronology and aspects of these changes.

Forest and grassland management on the Erie NWR since its establishment has included physical manipulation of vegetation through timber harvesting, grazing, burning, mowing, planting, and chemical treatments (refuge annual narratives). Timber management occurred on several areas throughout the refuge. For example, in the early-1960s about 300 acres of forest land on the Sugar Lake Division was managed with timber stand improvements and many residual tracts that had formerly been planted in pine for Christmas trees were cut and removed. In 1988, a timber sale and harvest was initiated to improve select stands for American woodcock habitat and subsequent harvests in several compartments continued in subsequent years. Eastern hemlock was the primary species harvested although only a portion of the area slated for harvest was taken due to poor weather and low lumber prices. Low local demand and interest by commercial timber companies caused further harvesting and sales to be discontinued and no harvests have occurred since then. During the late-1980s, a larva infestation of beech trees was documented along with a reduction in bur production on the refuge; these larva were determined to be indicators of malnutrition within this beech population (refuge annual narratives). An experimental study subsequently was designed to fertilize the areas surrounding the infected trees with lime. This action seemed to improve fruit production and reduce larva compared to areas with unfertilized trees, however subsequent liming has not been continued.

Intensive agricultural crop and livestock production gradually declined from the early-1900s to the present the Erie NWR region. Since the 1940s and 1950s, many former grain fields and pasturelands, including fields on Erie NWR, were abandoned and began to be revegetated by brush (Storm et al. 1992). Upon acquisition of the refuge, little haying was done on remnant grassland because of their shrubby condition; more recently some haying and mowing have been reintroduced as a management tool to maintain some grassland habitat. In the early 1960s, refuge permittee farmers grazed approximately 300 acres and farmed approximately 200 acres for oats, corn, and buckwheat on the Sugar Lake Division. In the late-1960s planting of various grass species and trees in abandoned fields on the refuge occurred using Kentucky bluegrass, tall fescue, birdsfoot trefoil, red top clover, reed canary grass, autumn olive, honeysuckle, and several tree species. Over time, locations and types of crops changed on Erie NWR, with the overall amount of cropland acreage increasing through the 1970s with crop rotations of corn, oats, and hay. A shift towards grassland management also occurred at this time, including planting and maintaining dense grassland nesting cover, mowing fields, planting of warm season

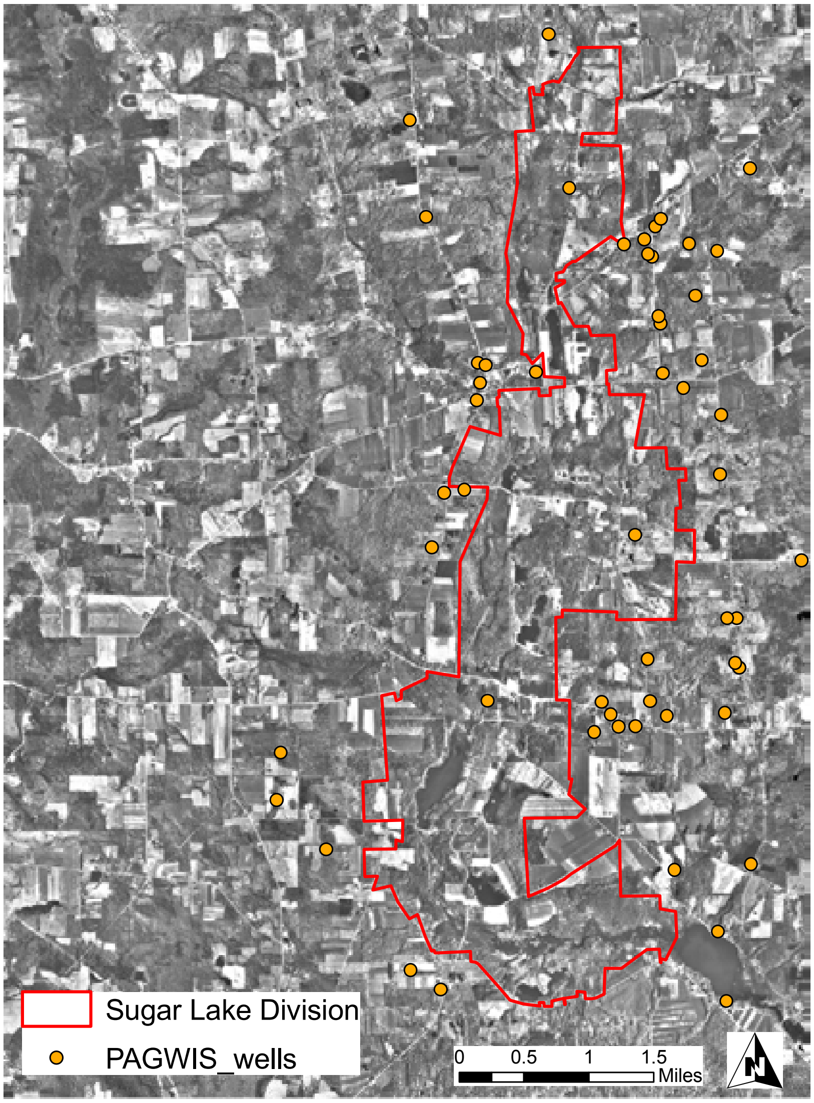

Figure 18. Location of groundwater wells on and near Erie National Wildlife Refuge.

Table 6. Major alterations to community types on Erie National Wildlife Refuge since the late-1800s based on refuge annual narratives, vegetation surveys, literature, regional land use maps, and specific monitoring.

Community type	Alteration
Upland Forest	Clearing, conversion to hay and pasture land, decreased fire frequency, changed species composition
Transition Forest	Clearing, conversion to hay/pasture and cropland, decreased fire frequency, altered water flow, changed species composition
Swamp Forest	Clearing, impoundment and conversion to Shrub/scrub or aquatic states, drainage, reduced hemlock and beech
Floodplain Wetland	Impoundment and prolonged water regimes, ditching, reduction of major disturbance events including periodic drought, sedimentation, vegetation shifts to persistent emergent and submerged aquatic species
Creeks	Channelization, dams, roads, sedimentation, altered seasonal and long-term flow regimes, impaired water quality

grasses, burning, and the termination of grazing on the refuge. Cool season grasses were added to the list of species planted in the late-1980s. Grasslands continued to increase in acreage as changes were made to some farmlands. The refuge had a peak of 800 acres in crop and hay/pasture lands in the late-1980s and 14 farm permitees/cooperators were present on the refuge. However, by the 1990s only 400 cropland acres and 7 cooperators were present on the refuge. By this time the refuge staff were mowing many of the grasslands and applying herbicides to reduce the spread of multiflora rose, reed canary grass, and phragmites. Currently, only 277 acres on the Sugar Lake Division are cooperatively farmed as cropland. Current agricultural fields and old fields occur across a variety of soil types, elevation slopes, and former native habitat types within the Sugar Lake Division of the Erie NWR (Fig. 19a,b). Current wetland impoundments are mainly on Holly silt clay loams and Carlisle muck and in sites of historical floodplain shrub wetland communities, except for some fringe areas that formerly were in transition forest habitat (Fig. 19b). Abandoned crop and hay fields on the Seneca Division occur mostly along the south and west boundary in four loamy soil types: Red Hook Loam, Pope Loam, Chenango gravelly silt loam, and Venango silty clay loam (Fig. 20a). Most fields occur in locations of former transition forest communities (Fig. 20b).

The National Wetland Inventory (NWI) map prepared for Erie NWR in the late-1980s indicated that wetlands present at that time were mostly forested or shrub-dominated vegetation (Figs. 21, 22). Further, the NWI maps identified constructed impoundments on the Sugar Lake Division as mostly "ponded-open water-submergent" and "shrub swamp" habitat (Fig. 23), which was created by prolonged growing season flooding management (see above). National Land Cover Data (NLCD) maps prepared for Erie NWR in the early-2000s indicated that the Seneca Division at that time was primarily woody wetland communities bounded by deciduous forest along with scattered cultivated croplands and hay/ pasture land. In contrast, the NLCD map for the Sugar Lake Division indicated the division was dominated by deciduous forest with cultivated crops and evergreen forest intermixed throughout the area (Fig. 24). A 2007 vegetation mapping project on Erie NWR (NatureServe1 2007) identified that former agricultural fields, now in various stages of succession, occupied about 1,700 acres on the refuge and that the northern hardwoods-black cherry forest species assemblage was the second dominant habitat type with just over 1,000 acres (Figs. 25,26).

Wetland areas on the Sugar Lake Division currently are primarily within managed impoundments and contain diverse wetland vegetation species depending on the historical water management regime of each impoundment. Impoundments that have had regular summer drawdowns contain more herbaceous moist-soil vegetation including smartweed, rice cutgrass, spikerush, and sedges. In impoundments, such as Pools 4 and 9, that have had more permanent and stable growing season water regimes, yellow pond lily, dense persistent emergent species such as cattail and *Phragmites,* and several aquatic plants have become established. For example, the surface of Reitz pond was completely covered by yellow pond lily and much of Pool 9 also was covered by this species as early as 1975 (refuge annual narratives). Invasive weeds within wetlands include reed canary grass (*Phalaris arundinacea*), giant reed (*Phragmites*), sesbania (*Sesbania* spp.), alligator weed (*Alternanthera philoxeroides*), water primrose

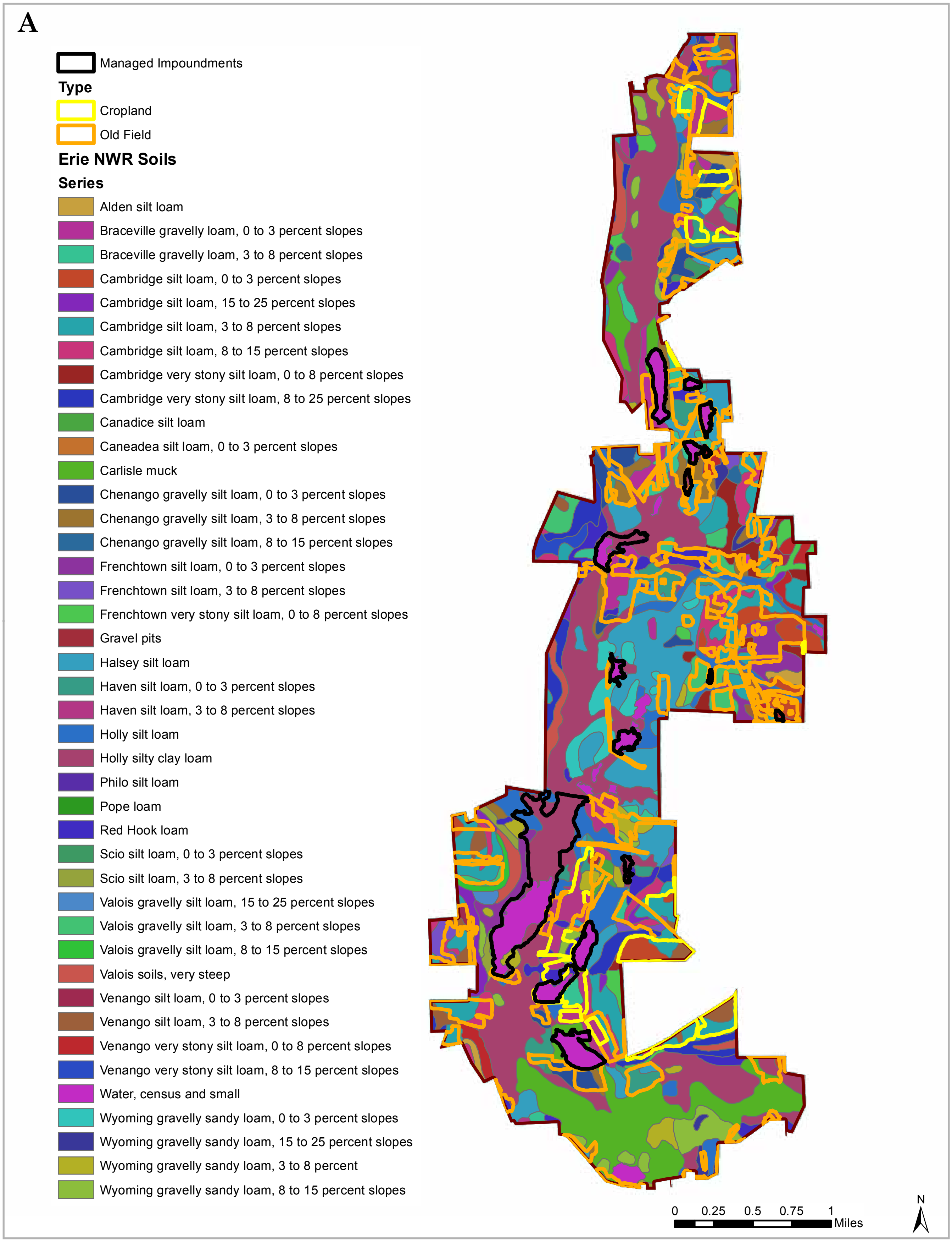

Figure 19. Location of current abandoned old fields, crop fields, and wetland impoundments related to: a) soil type and b) potential historical vegetation distribution from Fig. 16 on the Sugar Lake Division of Erie National Wildlife Refuge.

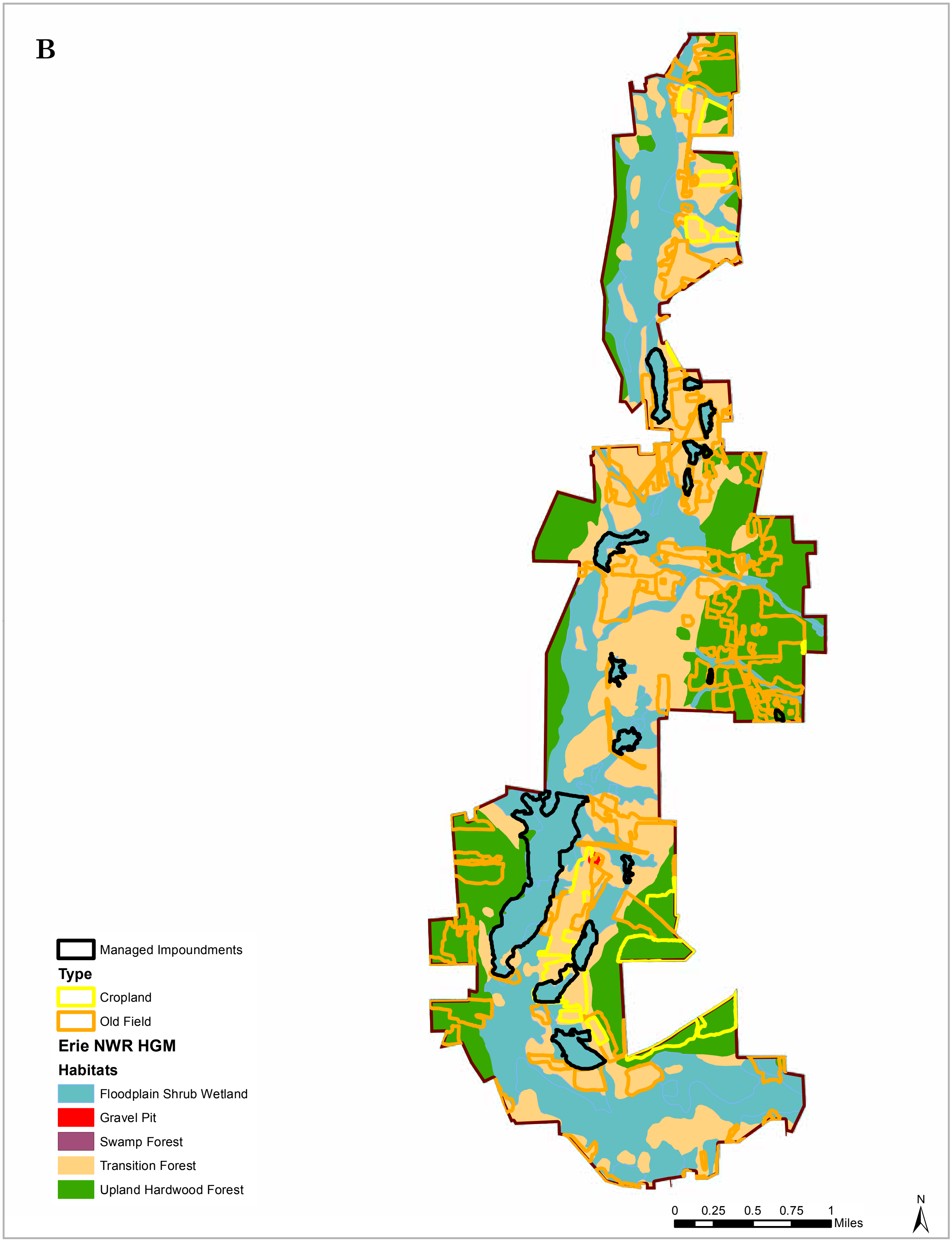

Figure 19, continued. Location of current abandoned old fields, crop fields, and wetland impoundments related to: a) soil type and b) potential historical vegetation distribution from Fig. 16 on the Sugar Lake Division of Erie National Wildlife Refuge.

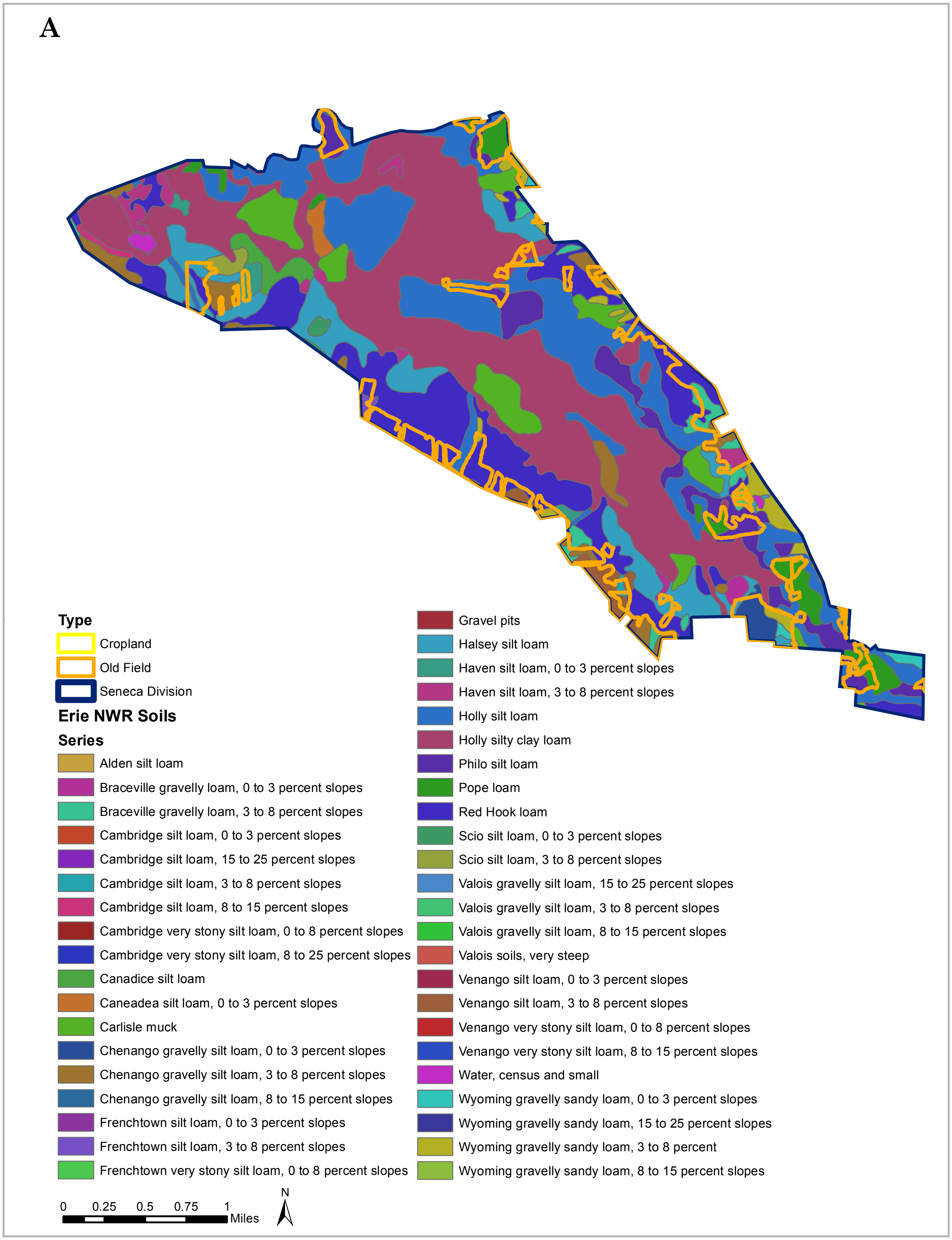

Figure 20. Location of abandoned old fields related to: a) soil type and b) potential historical vegetation distribution from Fig. 16 on the Seneca Division of Erie National Wildlife Refuge.

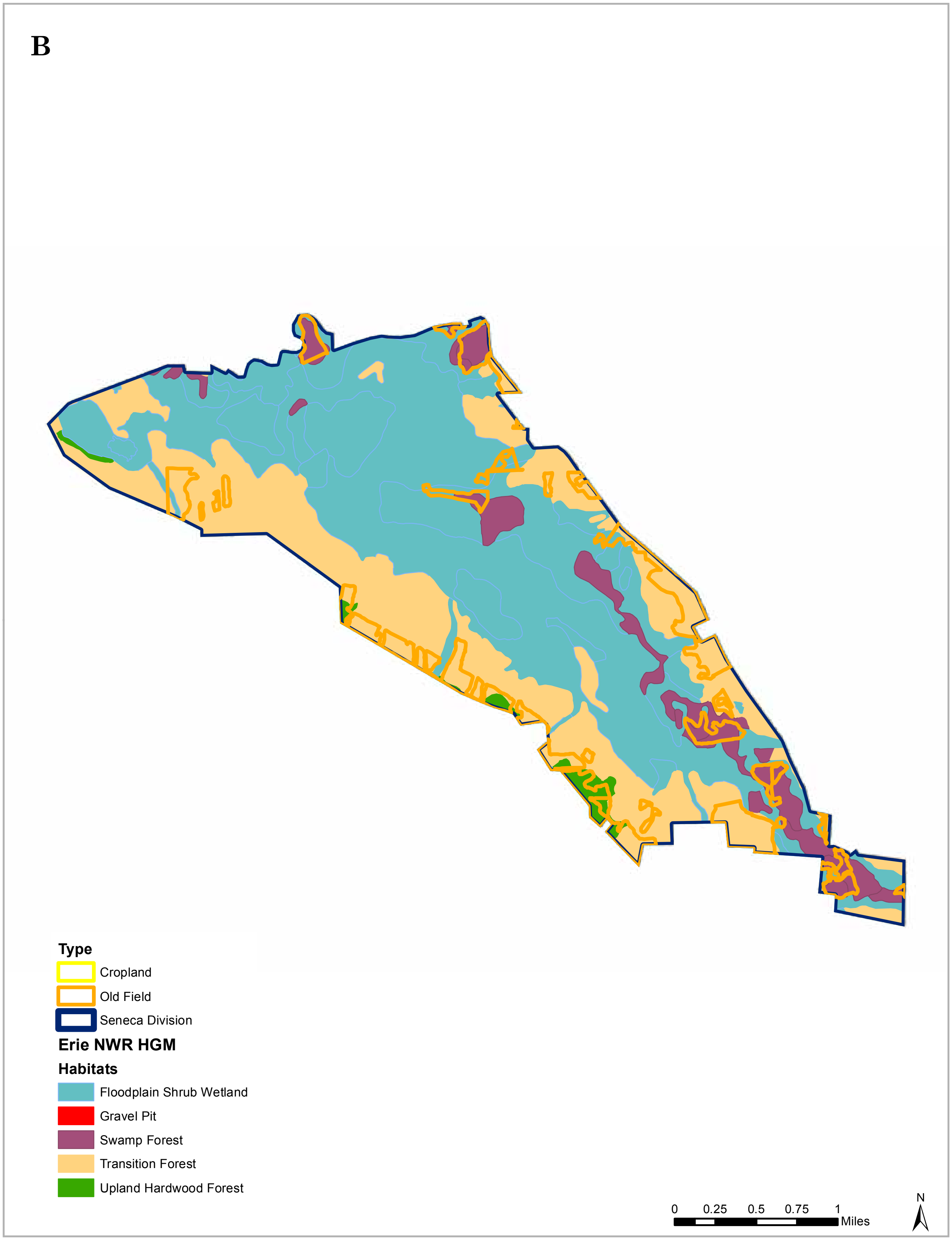

Figure 20, continued. Location of abandoned old fields related to: a) soil type and b) potential historical vegetation distribution from Fig. 16 on the Seneca Division of Erie National Wildlife Refuge.

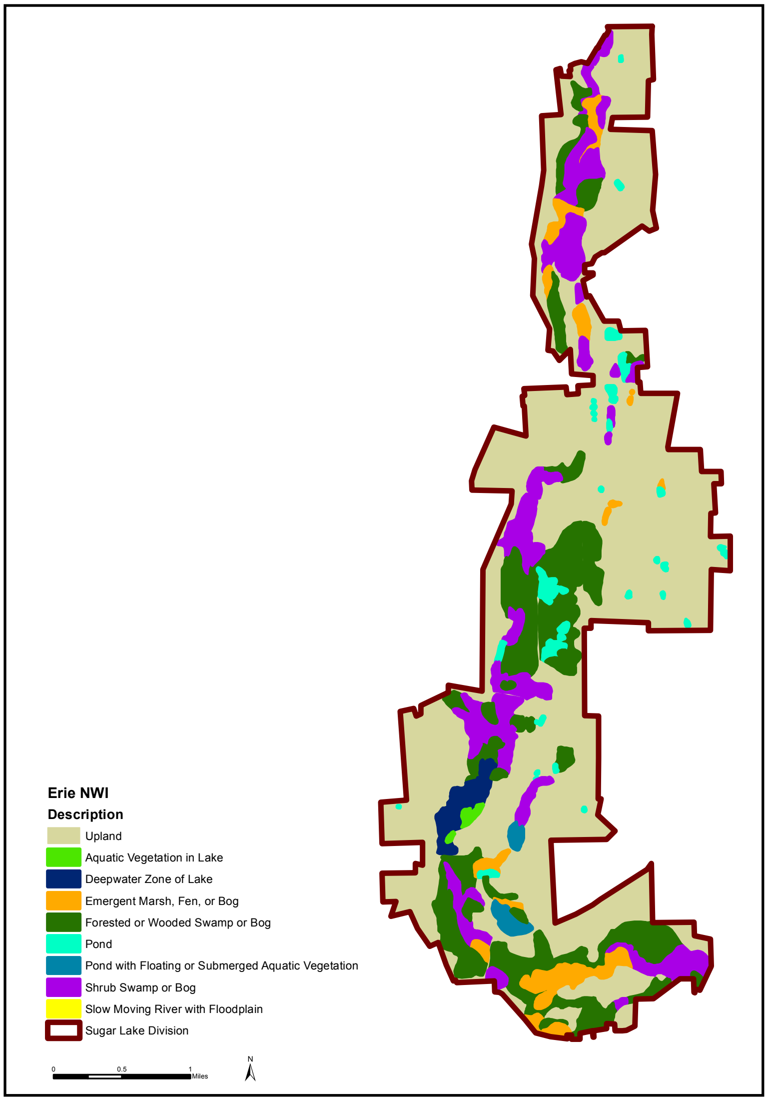

Figure 21. National Wetland Inventory general wetland categories on the Sugar Lake Division of Erie National Wildlife Refuge.

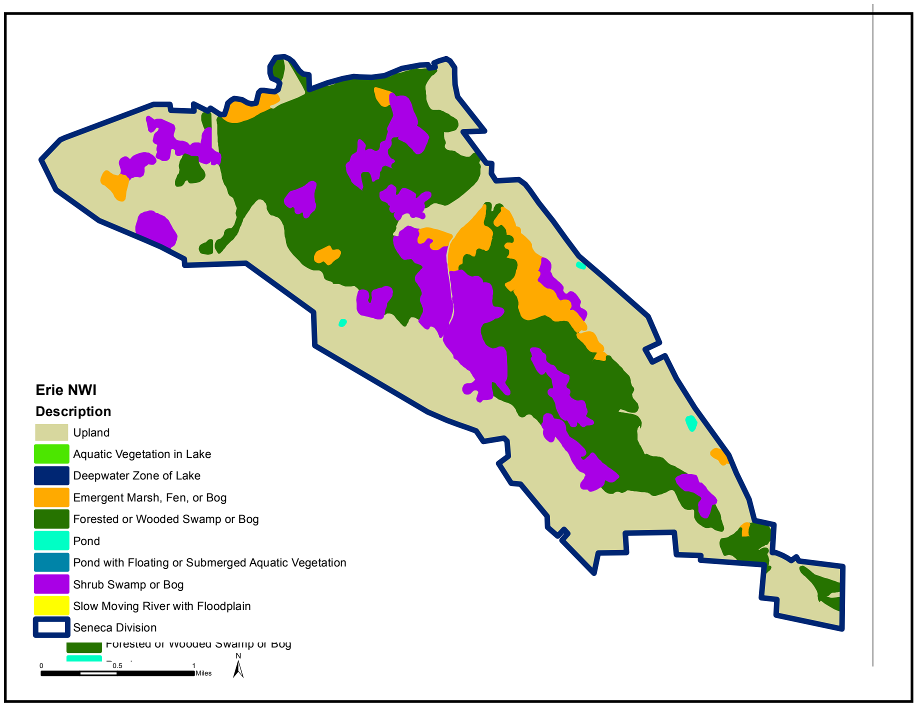

Figure 22. National Wetland Inventory general wetland categories on the Seneca Division of Erie National Wildlife Refuge.

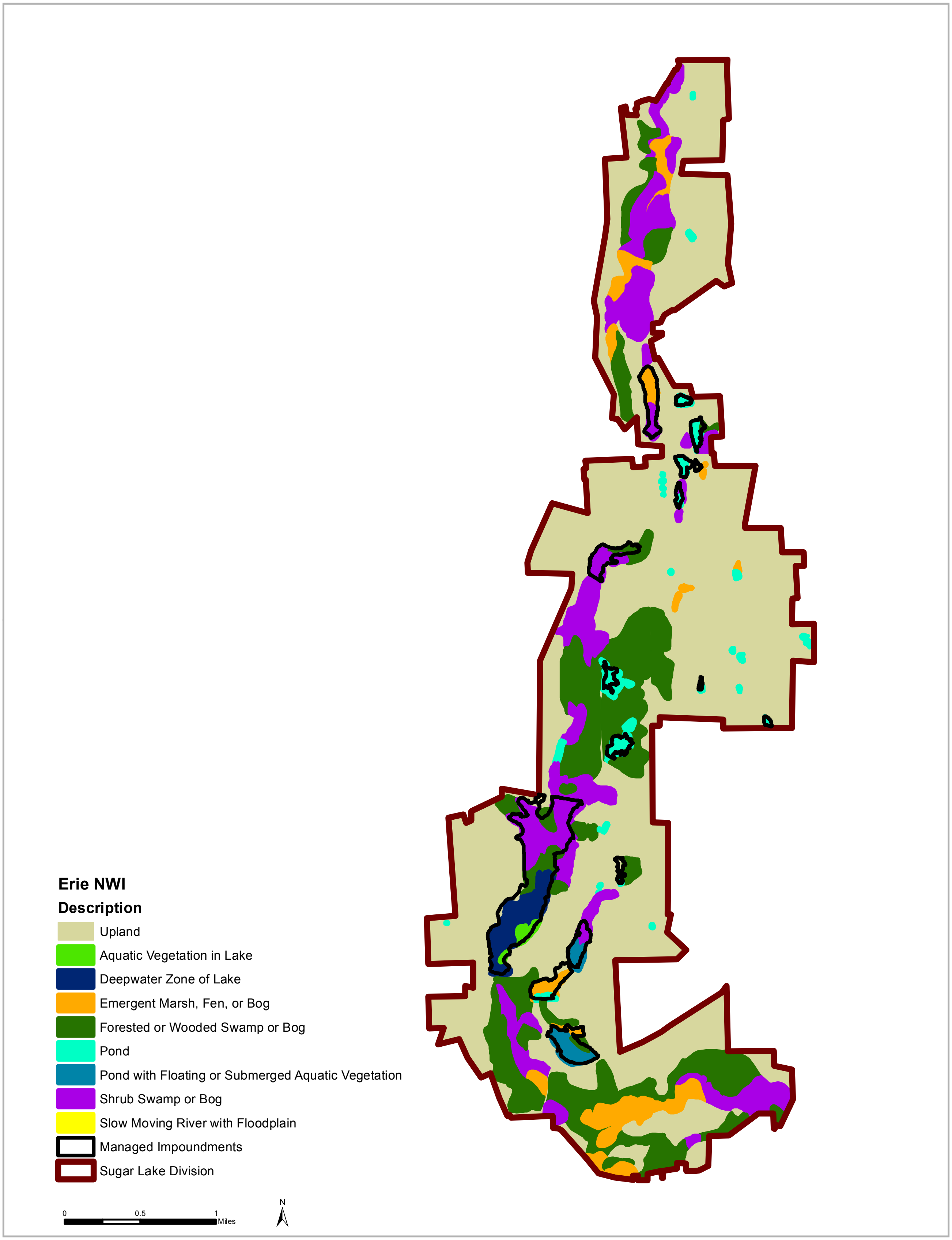

Figure 23. Location of managed wetland impoundments on the Sugar Lake Division of Erie National Wildlife Refuge in relation to National Wetland Inventory wetland categories.

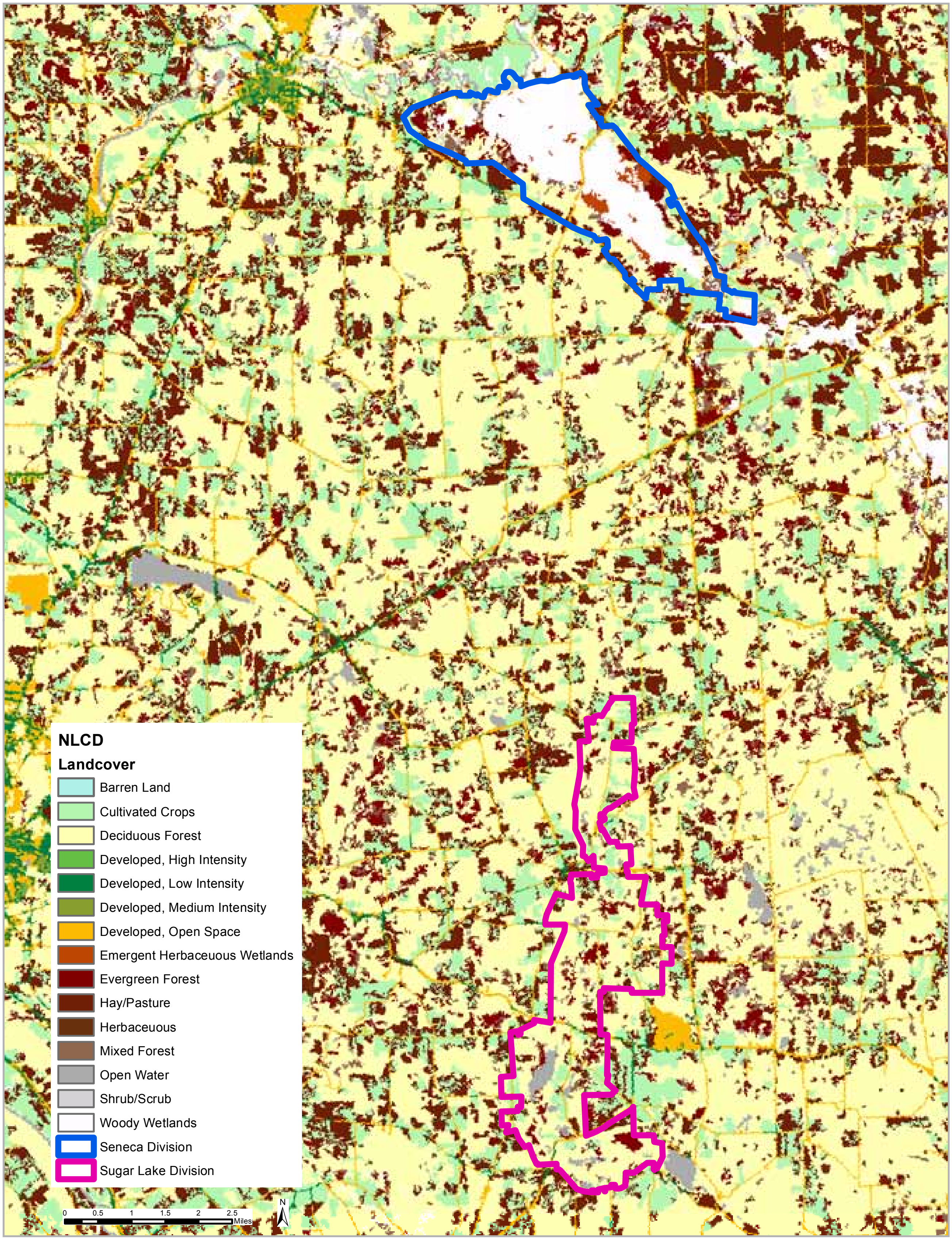

Figure 24. National land cover types on Erie National Wildlife Refuge in the mid-2000s.

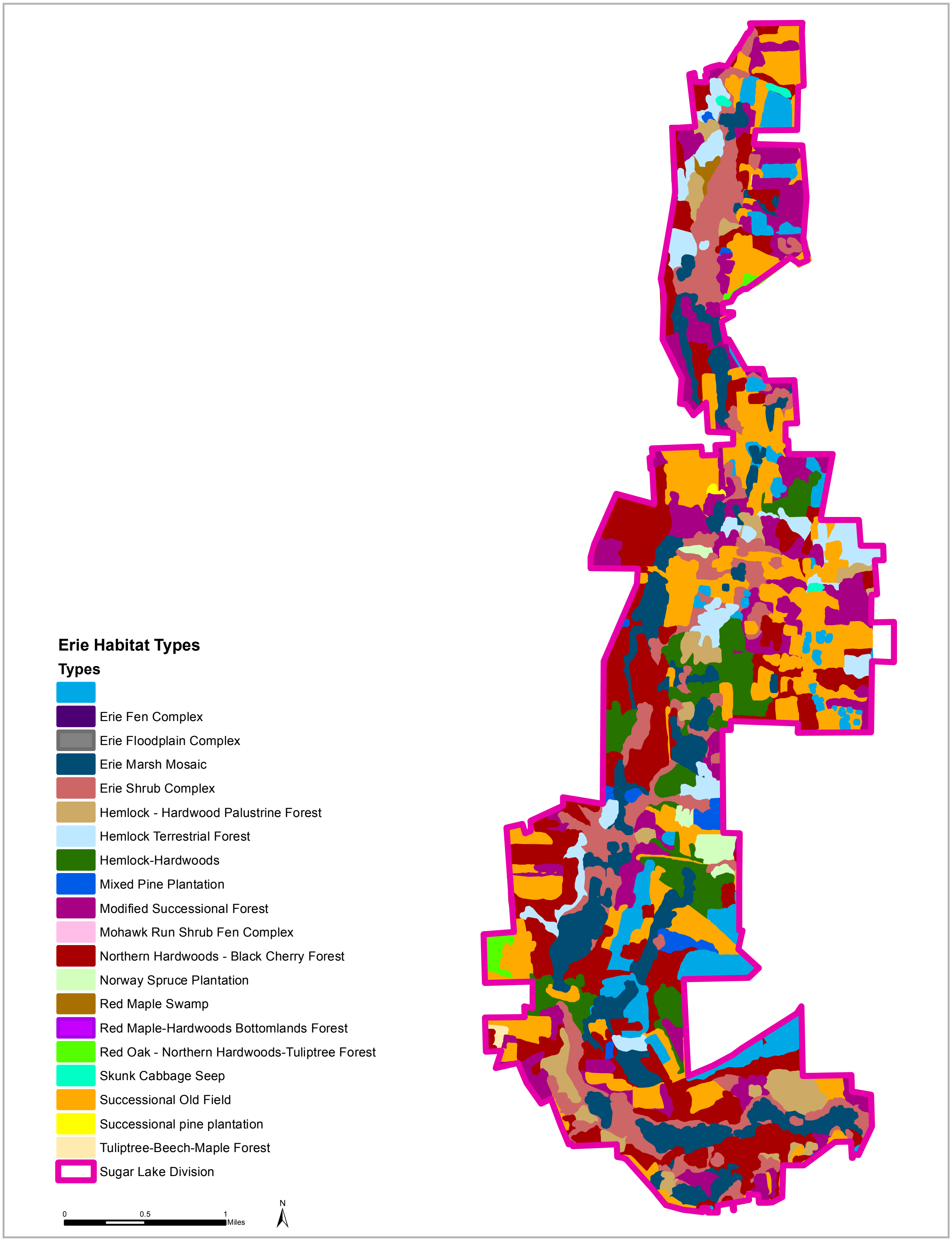

Figure 25. Vegetation habitat types on the Sugar Lake Division of Erie National Wildlife Refuge in 2005. Areas shown in white were not surveyed for vegetation type.

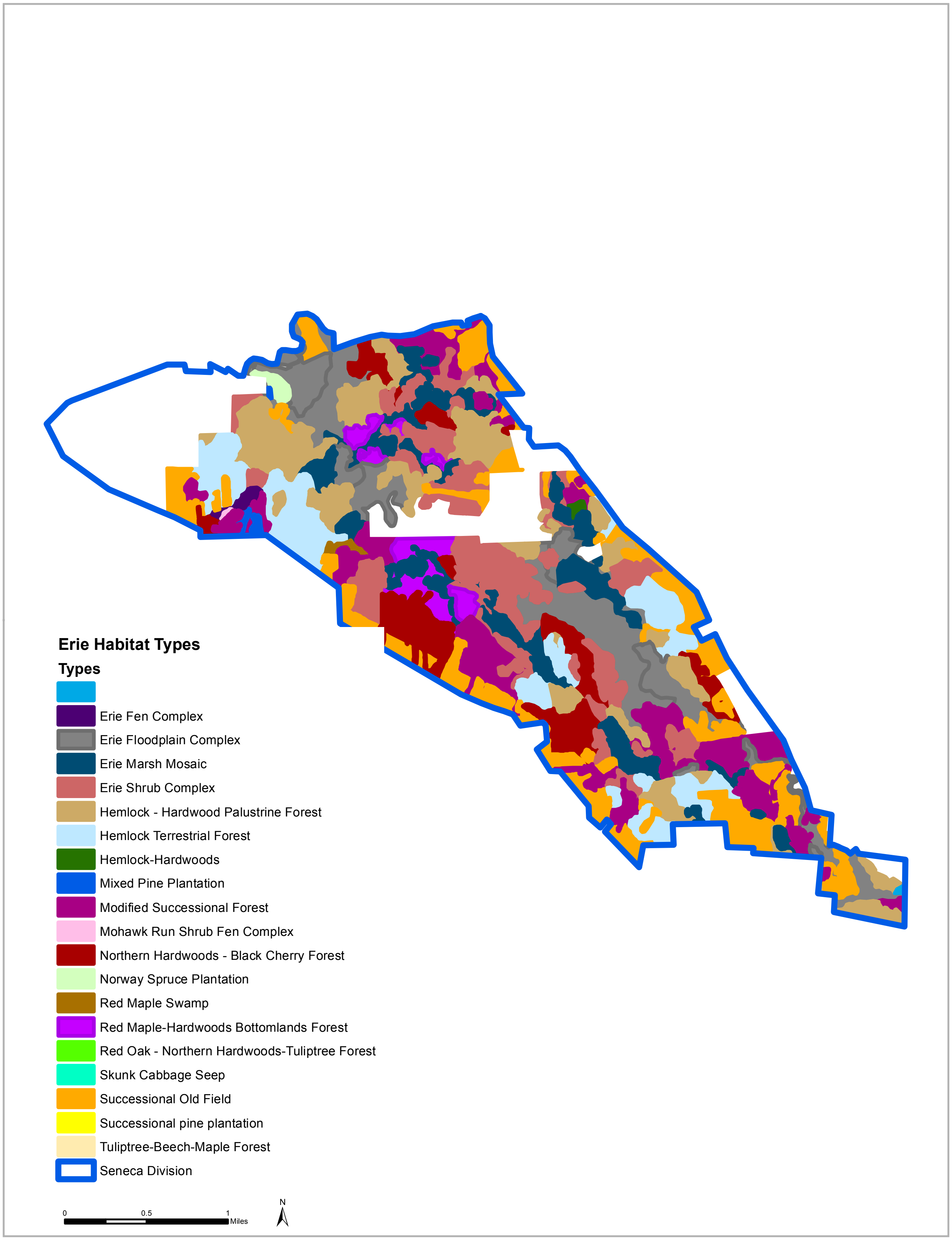

Figure 26. Vegetation habitat types on the Seneca Division of Erie National Wildlife Refuge in 2005. Areas shown in white were not surveyed for vegetation type.

(*Ludwigia palustris*), and giant cutgrass (*Zizaniopsis miliacea*). As an example of invasive species expansion into wetlands, the area along Dead Creek for more than one mile east of Swamp Road has contained dense monotypic stands of reed canarygrass since the early 1990s (Bissell and Danielson 1995). While quantitative data are not available, indirect observations by refuge staff indicate that invasive wetland plant species have increased greatly throughout the Sugar Lake Division during the last two decades.

Erie NWR currently contains several habitats and species of importance that have been identified by various conservation/environmental groups. Erie NWR has been designated as an Audubon IBA as it contains a relatively intact (presumably near-virgin condition) hardwood forest located in the Seneca Division and a critically endangered shrub fen (Tautin 2004). The French Creek watershed, including the Seneca Division region has been characterized as one of the most biologically diverse creek systems in the state of Pennsylvania hosting several endangered and threatened species including plants, fish, and freshwater mussels (Western Pennsylvania Conservancy 2001, 2002). Throughout the mid-1960s and 1970s a total of five natural areas were approved and designated on Erie NWR; two on the Seneca Division and three at the Sugar Lake Division (USFWS 1996). The natural areas on the Seneca Division include the Muddy Creek RNA that contains unique swamps and marshy areas and the Kelly Run Public Use Natural Area (PUNA). The Jacob Guy RNA was established in 1965 on the Sugar Lake Division and contains a remnant sugar maple-American beech-yellow birch forest. The Lake Creek RNA was established in 1972 and contains swamps and marshy areas bounded by ridges and knolls. The Lake Creek PUNA contains trails through a black cherry and eastern hemlock forest. Management of these natural areas traditionally has been relatively passive with an intention of maintaining representative less-altered natural community types, composition, and condition.

Changes in Animal Populations

Little data is available to determine trends in abundance and distribution of fish and wildlife species on Erie NWR. Additionally, even basic inventories of many groups of flora and fauna are not available (Kline 1995). The most consistent long-term species surveys on the refuge have been counts of breeding and migrating waterfowl, which generally show declines over time (unpublished refuge records and annual narrative reports). Data collected from 1978 to 1984 indicated hatch success of locally breeding wood ducks declined over that time period. The causes of this decline are not known, but chemical analyses of fish and wood duck eggs from the refuge did not find unusual levels of contaminants that might have influenced declining hatch success (Rice 1990). Vernal pools on Erie NWR were surveyed during 2004-2010 and found that occupancy of wood frogs (*Lithobates sylvatica*) was low and variable compared to other northeastern U.S. NWRs (Campbell Grant et al. 2011). The same surveys found that spotted salamander (*Ambystoma maculatum*) occupancy apparently has declined over time. Genotyping spotted turtles (*Clemmys guttata*) historically occurred in the Erie NWR region, but field surveys conducted in 2006 did not find any turtles on the refuge (Roblee 2006). American woodcock (*Scolopax minor*) populations have declined over the last 35 years throughout the northeastern U.S. including northwest Pennsylvania, and scattered surveys and observations at Erie NWR suggest a similar decline has occurred there (USFWS 2003, McAuley et al. 2005). Only limited trapping of small mammals has occurred on the refuge, and while many species, especially mice and shrews, are present, the population status of species is unknown, especially for rare bats (Rebar and Ropski 1999). Two invasive animals, common carp (*Cyprinus carpio*) and bullfrog (*Rana* catesbeiana) are now well-established on Erie NWR. Zebra mussel is now found in the French Creek watershed and poses an uncertain threat, especially for the Seneca Division (Kline 1995). Comprehensive lists of wildlife species of conservation concern for Erie NWR have been prepared (Table 7). Of special note are the many fish and mussel species of concern in Muddy Creek on the Seneca Division, which is associated with the very biodiverse French Creek watershed (Western Pennsylvania Conservancy 2001, 2002).

Table 7. Wildlife and plant species found on Erie National Wildlife Refuge.

Species Common Name	Scientific Name	Status	Seasons on Refuge
MAMMALS			
Opossum	*Didelphis virginiana virginiana*		X
Masked Shrew	*Sorex cinereus cinereus*		
Smoky Shrew	*Sorex fumeus fumeus*		
Pygmy Shrew	*Sorex hoyi thompsoni*		
Northern Short-Tailed Shrew	*Blarina brevicauda kirtlandi*		
Least Shrew	*Cryptotis parva parva*	State endangered G5/S1	
Hairy-Tailed Mole	*Parascalops breweri*		
Star-Nosed Mole	*Condylura cristata cristata*		
Little Brown Myotis	*Myotis lucifugus lucifugus*		
Keen's Myotis	*Myotis keenii septentrionalis*		
Small Footed Myotis	*Myotis leibii leibii*	State threatened G3/S1B,S1N	
Silver-Haired Bat	*Lasionytceris noctivagans*	G5/SUB, Proposed state status CR	
Eastern Pipistrelle	*Pipistrellus subflavus subflavus*		
Big Brown Bat	*Eptiscus fuscus fuscus*		
Red Bat	*Lasiurus borealis borealis*		
Hoary Bat	*Lasiurus cinereus cinereus*		
Eastern Cottontail	*Sylvilagus floridanus mallurus*		X
Eastern Chipmunk	*Tamias striatus lysteri*		X
Woodchuck	*Marmota monax monax*		X
Gray Squirrel	*Sciurus carolinensis pennsylvanicus*		X
Fox Squirrel	*Sciurus niger rufiventer*	G5T4T5/SU, state proposed CR	X
Red Squirrel	*Tamiasciurus hudsonicus loquax*		X
Southern Flying Squirrel	*Glaucomys volans volans*		
Northern Flying Squirrel	*Glaucomys sabrinus macrotis*	G5/SU , PE	
Beaver	*Castor canadensis canadensis*		X
Deer Mouse	*Peromyscus maniculatus bairdii*		
White-Footed Mouse	*Peromyscus leucopus noveboracensis*		
Southern Red-Backed Vole	*Clethrionomys gapperi paludiocola*		
Meadow Vole	*Microtis pennsylvanicus pennsylvanicus*		
Woodland Vole	*Microtis etorum scalopsoides*		
Southern Bog Lemming	*Synaptomys cooperi cooperi*		
Muskrat	*Ondatra zibethicus zibethicus*		
Norway Rat	*Rattus norvegicus norvegicus*		
House Mouse	*Mus musculus musculus*		
Meadow Jumping Mouse	*Zapus hudsonius americanus*		
Woodland Jumping Mouse	*Zapaeozapus insignis insignis* or *roanensis*		
Porcupine	*Erethizon dorsatum dorsatum*		
Coyote	*Canis latrans latrans*		
Red Fox	*Vulpes vulpes fulva*		
Gray Fox	*Urocyon cinereoargenteus cinereoargenteus*		
Black Bear	*Ursus americanus americanus*		X
Raccoon	*Procyon lotor lotor*		X
Least Weasel	*Mustela nivalis allegheniensis*	G5/S3 Proposed CU	
Long-Tailed Weasel	*Mustela frenata noveboracensis*		
Mink	*Mustela vison mink*		X
River Otter	*Lontra canadensis*	G5/S3 , proposed CA	X

Cont'd. next page

Table 7, cont'd. Wildlife and plant species found on Erie National Wildlife Refuge.

Striped Skunk	*Mephitis mephitis nigra*		
White-Tailed Deer	*Odocoileus virginianus borealis*		X
Snowshoe Hare	*Lepus americanus virginianus*		
BIRDS			
Waterbirds			
American Bittern	*Botaurus lentiginosus*	PA E G4/S1B	B M
Great Blue Heron	*Ardea herodias*	G5/S3S4B,S4N	
Great Egret	*Ardea alba*	PA E, G5/S1B	B M
Green Heron			
Eared Grebe	*Podiceps nigricollis*		
Least Bittern	*Ixobrychus exilis*	G5/S1B , PA E	B M
Pied-billed Grebe	*Podilymbus podiceps*	G5/S3B,S4N , PA CR	B
Sandhill Crane	*Grus canadensis*		
Sora	*Porzana carolina*	G5/S3B , PA CR	B
Virginia Rail	*Rallus limicola*	G5/S3B	B
Waterfowl			
American Black Duck	*Anas rubripes*		MW
Blue-Winged Teal	*Anas discors*		BM
Bufflehead	*Bucephala albeola*		
Canada Goose (Resident)	*Branta canadensis*		X
Canada Goose (SJBP)			M
Common Merganser	*Mergus merganser*		Rare M
Greater Scaup	*Aythya marila*		Rare M
Green-Winged Teal	*Anas crecca*	G5/S1S2B,S3N , PCA	M
Hooded Merganser	*Lophodytes cucullatus*		BM
Lesser Scaup	*Aythya affinis*		Rare M
Mallard	*Anas platyrhynchos*		BM
Northern Pintail	*Anas acuta*		Rare M
Ring-Necked Duck	*Aythya collaris*		
Tundra Swan	*Cygnus columbianus*		Rare M
Wood Duck	*Aix sponsa*		BM
Shorebirds			
American Woodcock	*Scolopax minor*		BM
Common Moorhen	*Gallinula chloropus*	G5/S3B , Proposed PCA	
Greater Yellowlegs	*Tringa melanoleuca*		M
Killdeer	*Charadrius vociferus*		
Least Sandpiper	*Calidris minutilla*		M
Pectoral Sandpiper	*Calidris melanotos*		M
Semipalmated Sandpiper	*Calidris pusilla*		M
Solitary Sandpiper	*Tringa solitaria*		M
Spotted Sandpiper	*Actitis macularius*		
Wilson's Snipe	*Gallinago delicata*	G5/S3B,S3N , proposed CR	BM
Landbirds			
Acadian flycatcher	*Empidonax virescens*		
Alder Flycatcher	*Empidonax alnorum*		BM
American Goldfinch	*Carduelis tristis*		
American Kestrel	*Falco sparverius*		
American Redstart	*Setophaga ruticilla*		
American Robin	*Turdus migratorius*		
Bald Eagle	*Haliaeetus leucocephalus*	G5/S2B, PT	BM
Baltimore Oriole	*Icterus galbula*		BM
Barred Owl	*Strix varia*		
Bay-Breasted Warbler	*Dendroica castanea*		M

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Table 7, cont'd. Wildlife and plant species found on Erie National Wildlife Refuge.

Belted Kingfisher	*Megaceryle alcyon*		
Black-billed Cuckoo	*Coccyzus erythropthalmus*		BM
Blackburnian Warbler	*Dendroica fusca*		BM
Black-capped chickadee	*Poecile atricapilla*		
Blackpoll Warbler	*Dendroica striata*	G5/S1B , PE	M
Black-Throated Blue Warbler	*Dendroica caerulescens*		BM
Blue-gray gnatcatcher	*Polioptila caerulea*		
Blue Jay	*Cyanocitta cristata*		
Blue-Winged Warbler	*Vermivora pinus*		BM
Bobolink	*Dolichonyx oryzivorus*		BM
Broad-Winged Hawk	*Buteo platypterus*		BM
Brown-headed Cowbird	***Molothrus ater***		
Brown Thrasher	*Toxostoma rufum*		BM
Canada Warbler	*Wilsonia canadensis*		BM
Cedar Waxwing	*Bombycilla cedrorum*		
Cerulean Warbler	*Dendroica cerulea*		BM
Chestnut Sided Warbler	*Dendroica pensylvanica*		
Chimney Swift	*Chaetura pelagica*		BM
Common Nighthawk	*Chordeiles minor*		BM
Cooper's Hawk	*Accipiter cooperii*		
Dark eyed Junco	*Junco hyemalis*		
Downy Woodpecker	*Picoides pubescens*		
Eastern Bluebird	*Sialia sialis*		
Eastern Kingbird	*Tyrannus tyrannus*		BM
Eastern Meadowlark	*Sturnella magna*		BM
Eastern Towhee	*Pipilo erythrophthalmus*		BM
Eastern Wood Pewee	*Contopus virens*		BM
Field Sparrow	*Spizella pusilla*		BM
Golden-Winged Warbler	*Vermivora chrysoptera*		BM
Grasshopper Sparrow	*Ammodramus savannarum*		BM
Gray Catbird	*Dumetella carolinensis*		
Great Crested Flycatcher	*Myiarchus crinitis*		
Great Horned Owl	*Bubo virginianus*		
Hairy Woodpecker	*Picoides villosus*		
Henslow's Sparrow	*Ammodramus henslowii*		BM
Hermit Thrush	*Catharus guttatus*		
Indigo Bunting	*Passerina cyanea*		
Louisiana Waterthrush	*Seiurus motacilla*		BM
Marsh Wren	*Cistothorus palustris*	G5/S2S3B , Proposed CR in PA	BM
Mourning Dove	*Zenaida macroura*		
Northern Cardinal	*Cardinalis cardinalis*		
Northern Flicker	*Colaptes auratus*		BM
Northern Harrier	*Circus cyaneus*	G5/S3B,S4N , Proposed CA in PA	BM
Northern Shrike	*Lanius excubitor*		
Orchard oriole	*Icterus spurius*		
Osprey	*Pandion haliaetus*	G5/S2B , PT	**M**
Peregrine Falcon	*Falco peregrinus*	G4/S1B,S1N , PE	M
Purple Finch	*Carpodacus purpureus*		
Red-Shouldered Hawk	*Buteo lineatus*		
Red-Tailed Hawk	*Buteo jamaicensis*		
Red Winged Blackbird	*Agelaius phoeniceus*		
Rose-Breasted Grosbeak	*Pheucticus ludovicianus*		BM

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Table 7, cont'd. Wildlife and plant species found on Erie National Wildlife Refuge.

Rough-legged Hawk	*Buteo lagopus*		
Ruby-throated Hummingbird	*Archilochus colubris*		
Ruffed Grouse	*Bonasa umbellus*		
Rusty Blackbird	*Euphagus carolinus*		
Scarlet Tanager	*Piranga olivacea*		BM
Sedge Wren	*Cistothorus platensis*	G5/S1B , PA PE	BM
Song Sparrow	*Melospiza melodia*		BM
Tree Swallow	*Tachycineta bicolor*		
Tufted Titmouse	*Baeolophus bicolor*		
Veery	*Catharus fuscescens*		
White-breasted Nuthatch	*Sitta carolinensis*		
White-crowned Sparrow	*Zonotrichia leucophrys*		
White-throated Sparrow	*Zonotrichia albicollis*		
Wild Turkey	*Meleagris gallopovo*		
Willow Flycatcher	*Empidonax traillii*		BM
Wood Thrush	*Hylocichla mustelina*		BM
Yellow-rumped Warbler	*Dendroica coronata*		
Yellow-throated Vireo	*Vireo flavifrons*		BM
Yellow Warbler	*Dendroica petechia*		
AMPHIBIANS			
Hellbender	*Cryptobranchus alleganiensis*	G3G4/S3	
Five-lined Skink	*Eumeces fasciatus*		
Eastern Newt	*Notophthalmus viridescens*		
Northern Cricket Frog	*Acris crepitans*	G5/S1	
Northern Leopard Frog	*Rana pipiens*	G5/S2S3	X
Western Chorus Frog	*Pseudacris triseriata*		
Spring Peeper	*Pseudacris crucifer*		
Bullfrog	*Rana catesbeiana*		
Green Frog	*Rana clamitans*		
American Toad	*Bufo americanus*		
REPTILES			
Eastern Bog Turtle	*Glyptemys muhlenbergii*	F E	
Snapping Turtle	*Chelydra serpentina*		
Painted Turtle	*Chrysemys picta*		
Spotted Turtle	*Clemmys guatta*	G5/S3	X
Wood Turtle	*Glyptemys insculpta*	G4/S3S4	X
Eastern Massasauga	***Sistrurus catenatus***	**G3G4T3T4Q/S1 , PT**	
Eastern Ribbon Snake	*Thamnophis sauritus sauritus*	G5/S3	X
Queen Snake	*Regina septemvittata*	G5/S3	
Smooth Green Snake	*Opheodrys vernalis* aka *Liochlorophis vernalis*	G5/S3S4	
Redbelly Snake	*Storeria occipitomaculata occipitomaculata*		
Milk Snake	*Lampropeltis triangulum*		
Northern Brown Snake	*Storeria dekayi dekayi*		
Northern Water Snake	*Nerodia sipedon*		
Common Garter Snake	*Thamnophis sirtalis*		
FISH			
Bluebreast darter	*Etheostoma camurum*	G4/S2 , PAT	X
Bowfin	*Amia calva*	G5/S2S3, PC	X
Brindled madtom	*Noturus miurus*	G5/S2 , PA T	X

Cont'd next page

Table 7, cont'd. Wildlife and plant species found on Erie National Wildlife Refuge.

Central mudminnow	*Umbra limi*	G5/S3 , PA C	X
Eastern sand darter	*Etheostoma pellucidum*	G3/S1 , E	X
Gilt darter	*Percina evides*	G4/S1S2 , T	X
Hornyhead chub	*Nocomis biguttatus*	G5/S1 , C	X
Longhead darter	*Percina macrocephala*	G3/S2S3 , T	X
Northern brook lamprey	*Ichthyomyzon fossor*	G4/S1 , E	X
Northern madtom	*Noturus stigmosus*	G3/S2 , E	X
Ohio lamprey	*Icthyomyzon bdellium*	G3G4/S2S3 , C	X
Yellow perch	*Perca flavescens*		X
FRESHWATER MUSSELS			
Black sandshell	*Ligumia recta*		X
Clubshell	*Pleurobema clava*	G2/S1S2 , PA & FedE	X
Creek heelsplitter	*Lasmigona compressa*	G5/S2S3 , proposed CR	X
Cylindrical papershell	*Anodontaoides ferussacianus*	G5/S2S3 , proposed CR	X
Elktoe	*Alasmidonta marginata*	G4/S4 , proposed N	X
Fatmucket	*Lampsilis siliquoidea*		X
Fluted-shell	*Lasmigona costata*		X
Giant floater	*Anodonta grandis*		X
Kidney shell	*Ptychobranchus fasciolaris*		X
Long-solid	*Fusconaia subrotunda*	G3/S1 , Proposed PE	X
Mucket	*Actinonaias ligamentina*		X
Northern riffleshell	*Epioblasma torulosa rangiana*	G2T2/S2 , PA & FedE	X
Plain pocketbook	*Lampsilis cardium*		X
Pocketbook			X
Rabbitsfoot	*Quadrula cylindrica*	G3G4/S1 , Proposed PE	X
Rayed bean	*Villosa fabalis*	G2/S1S2 , Proposed E & fedC	X
Round pigtoe	*Pleurobema sintoxia*	G4G5/S2 , proposed E	X
Snuffbox globally rare	*Epioblasma triquetra*	G3/S1 , proposed E	X
Spike	*Elliptio dilatata*		X
Squawfoot	*Strophitus undulatus*		X
Three-ridge	*Amblema plicata*	G5/S2S3 , proposed T	X
Wavy-rayed lampmussel	*Lampsilis fasciola*	G5/S4 , proposed N	X
PLANTS			
Agrimony			
Alsike/Alsatian Clover			
Barren Strawberry			
Birdsfoot Trefoil			

Cont'd next page

Table 7, cont'd. Wildlife and plant species found on Erie National Wildlife Refuge.

KEY

Seasons on the Refuge: B=Breeding, W=Wintering, M=Migration, F=Foraging; X=Present Year-Round; Rare M=Rare Migrant

Status:
Federal T&E = Federal Endangered Species List: T=Threatened, E=Endangered, C=Candidate

State T&E= State of Pennsylvania Threatened and Endangered Species List: PT=Threatened, PE=Endangered, PCR=Candidate rare, PPE=Proposed endangered, PPT=Proposed threatened

G and S Ranks of Rarity. The Nature Conservancy determines the global ranks. State ranks defined by the Pennsylvania Natural Heritage Program as follows:

G1 = Critically Imperiled - Critically imperiled globally because of extreme rarity or because of some factor(s) making it especially vulnerable to extinction. Typically 5 or fewer occurrences or very few remaining individuals (<1,000) or acres (<2,000) or stream miles (<10).
G2 = Imperiled - Imperiled globally because of rarity or because of some factor(s) making it very vulnerable to extinction. Typically 6 to 20 occurrences or few remaining individuals (1,000 to 3,000) or acres (2,000 to 10,000) or stream miles (10 to 50).
G3 = Vulnerable - Vulnerable globally either because very rare and local throughout its range, found only in a restricted range (even if abundant at some locations), or because of other factors making it vulnerable to extinction. Typically 21 to 100 occurrences or between 3,000 and 10,000 individuals.
G4 = Apparently Secure - Uncommon but not rare, and usually widespread. Possibly cause for long-term concern. Typically more than 100 occurrences and more than 10,000 individuals.
G5 = Secure - Common, typically widespread and abundant. Typically with considerably more than 100 occurrences and more than 10,000 individuals.

S1 = Critically Imperiled - Critically imperiled in the state because of extreme rarity or because of some factor(s) making it especially vulnerable to extirpation from the state. Typically 5 or fewer occurrences or very few remaining individuals or acres.
S2 = Imperiled - Imperiled in the state because of rarity or because of some factor(s) making it very vulnerable to extirpation from the state. Typically 6 to 20 occurrences or few remaining individuals or acres.
S3 = Vulnerable - Vulnerable in the state either because rare and uncommon, or found only in a restricted range (even if abundant at some locations), or because of other factors making it vulnerable to extirpation. Typically 21 to 100 occurrences.
S4 = Apparently Secure - Uncommon but not rare, and usually widespread in the state. Usually more than 100 occurrences.
S5 = Secure - Demonstrably widespread, abundant, and secure in the state, and essentially ineradicable under present conditions.

ECOSYSTEM RESTORATION AND MANAGEMENT OPTIONS

SYNOPSIS OF THE ERIE NWR ECOSYSTEM AND CONTEMPORARY ALTERATIONS

Erie NWR contains a diversity of typical Southern Great Lakes forest communities bisected by relatively narrow creek drainages (Sevon 2000). The two divisions of Erie NWR, Seneca and Sugar Lake, contain similar community types but differ in their topographic position and extent of creek valleys and historic floodplains vs. upland hills. The Seneca Division is dominated by the low gradient, low elevation, Muddy Creek drainage system that has a labyrinth, somewhat braided-flow pattern characterized by the nearly parallel flow of Dead Creek, which joins Muddy Creek just south of the confluence with French Creek. Kelley Run and Mohawk Run also flow into French Creek on refuge lands and add additional narrow creek/drainage topographic and ecological context to the site. A unique shrub fen emanates from the glacial hills adjoining the Mohawk Valley. Collectively, the Seneca Division has more wetland habitat than the Sugar Lake Division and is often described as "swampy" (Bissell and Danielson 1995). Relatively little physical development has occurred on the Seneca Division and the primary ecological attributes and hydrological processes are less altered than at the Sugar Lake Division or on surrounding private lands. As one of the few public lands that adjoin French Creek, the Seneca Division provides important regional contributions to the ecological integrity of the entire watershed and offers conservation potential rarely found in other areas (Western Pennsylvania Conservancy 2001). Future conservation strategies for the Seneca Division consequently can focus more on protection and sustaining "more-or-less" natural processes and communities compared to the Sugar Lake Division where more restoration is required to emulate historical ecological community distribution and processes.

The Sugar Lake Division of Erie NWR contains more uplands and steeper valley-upland relief with narrower creek valleys and fewer historical wetlands than at the Seneca Division. Historically, the Sugar Lake Division contained extensive and diverse forest communities including remnants of important, and now rare, palustrine hemlock-beech-birch "swamp forest" communities, "transitional" hemlock-sugar maple-black cherry forest, and "true upland" oak-hickory communities. The presence of marked topographic-hydrological gradients on the Sugar Lake Division offers excellent opportunities for forest conservation and management, that by-and-large have received less management attention than creek valley wetlands (USFWS 1964, 1966, 2006; McCoy 1982; refuge annual narratives). Both the Woodcock and Lake Creek valleys on the Sugar Lake Division have been highly developed and physically altered by levees, dikes/dams, ditches, and water-control structures, which were advocated by the original Master Plan for the refuge based on its authorizing purpose directed toward providing habitat for migratory birds, especially waterfowl (USFWS 1966; McCoy 1979, 1982). While not all of the originally proposed wetland developments were constructed on the Sugar Lake Division, substantial impoundment construction has occurred including the relatively large Pool 4 and 9 impoundments that effectively dam and locally impound Lake Creek. The many other smaller impoundments on the Sugar Lake Division also have altered the hydrological and biotic character of Woodcock and Lake Creeks and subsequent water management has changed the ecological context and resources in these creek valleys. These extensive wetland impoundment developments coupled with the past history of forest clearing and conversion to agricultural uses directs future conservation actions on Sugar Lake more toward active management and restoration than to protection of intact habitats. Many challenges exist to restore both upland and creek valley communities at the Sugar Lake Division and efforts to restore endemic communities and their driving ecological processes will require certain changes in management direction and philosophy.

The primary ecosystem changes in the Erie NWR region have been: 1) alterations to distribution, chronology, and abundance of surface water in creek valleys, especially on the Sugar Lake Division; 2) alteration of native vegetation communities; 3) conversion of small dynamic floodplain wetlands dominated by S/S and beaver ponds to artificially managed and maintained semi-permanently and permanently flooded water regimes in wetland impoundments; and 4) introduction of non-native and invasive plant species, which have changed the character of different wetland communities (Table 5).

A critical issue affecting future conservation and management at Erie NWR is appropriate recognition of the distinct hydrogeomorphic attributes of creek valleys vs. upland glaciated hills. In particular, a major challenge for future management of Erie NWR will be to determine how to restore and emulate natural water regimes along Woodcock and Lake Creeks on the Sugar Lake Division to assist efforts to restore and provide critical valley wetland and palustrine forest communities. Past management plans on the refuge have largely been designed to expand development of wetland impoundments, maintain productive farmland, sustain open grassland in some abandoned fields, and to conduct modest timber stand improvements. Future management issues that affect timing, distribution, and movement of water on the NWR must consider how, and if, they are contributing to desired objectives of restoring native communities and their processes on the refuge. Future management of formerly forested uplands, including the many abandoned agricultural fields on the refuge, will need to be based on goals of community restoration and specific resource objectives. For example, if a refuge goal is the restoration of functional patches of native upland forest species assemblages then individual abandoned fields or existing forest tracts in various states of succession will need to be designated for restoration based on HGM attributes. If some fields are to be maintained in more open states, then the appropriate location for desired grassland/shrub habitat will need to be determined based on soil, topography, and hydrology/drainage attributes.

This report does not provide strategic guidance on the entire suite of refuge restoration and associated management considerations as these must consider, and be guided by, USFWS and refuge-specific policy, authorization, and system-wide goals. However, if at least part of the strategic conservation future of Erie NWR is restoration of endemic communities and their sustaining processes, then this report offers information to help make appropriate decisions. This study also does not address where, or if, the many sometimes competing uses of Erie NWR can be accommodated, but rather this report provides information to support The National Wildlife Refuge System Improvement Act of 1997, which seeks to ensure that the biological integrity, diversity, and environmental health of the (eco) system (in which a refuge sets) are maintained (USFWS 1999, Meretsky et al. 2006, Paveglio and Taylor 2010). Administrative policy that guides NWR goals includes mandates for: 1) comprehensive documentation of ecosystem attributes associated with biodiversity conservation, 2) assessment of each refuge's importance across landscape scales, and 3) recognition that restoration of historical processes is critical to achieve goals (Meretsky et al. 2006). Most of the CCP's completed for NWR's to date have highlighted ecological restoration as a primary goal, and choose historical conditions (those prior to substantial human related changes to the landscape) as the benchmark condition to evaluate system changes (Meretsky et al. 2006). General USFWS policy, under the Improvement Act of 1997, directs managers to assess not only historic conditions, but also "opportunities and limitations to maintaining and restoring" such conditions. Furthermore, USFWS guidance documents for NWR management "favor management that restores or mimics natural ecosystem processes or functions to achieve refuge purpose(s) (USFWS 2001).

GENERAL RECOMMENDATIONS FOR ECOSYSTEM RESTORATION AND MANAGEMENT

Given the above USFWS policies and mandates for ecosystem restoration and subsequent management of NWR's, this HGM study has attempted to objectively understand: 1) the fundamental physical and biological processes that historically formed and sustained the structure and functions of the Erie NWR ecosystem and its communities and 2) what changes have occurred to the system that have caused degradations and that might be reversed and restored to historic and functional conditions within a "new desired" environment. This HGM approach helps identify the historic "role" of ecosystem types and resources at Erie NWR in meeting larger landscape conservation goals and needs at different geographical scales. In many cases, restoration of functional ecosystems on NWR lands, such as at Erie NWR, can help the refuge lands serve as a "core" of critical, sometimes limiting, resources than can complement and encourage restoration and management on adjacent and regional private and public lands. This may be especially important for conservation programs in the important French Creek watershed because public protected lands are limited, especially those adjacent to the creek channel.

The HGM evaluation process, and the discussion of restoration and management options, used in this report is not species-based, but rather seeks to identify options to restore and maintain system-based processes, communities, and resources that ultimately will help support local and regional populations of endemic species, both plant and animal, along with other important ecosystem functions, values, and services. Consequently, recommendations from the HGM evaluation in this study are system-based first, with the goal of restoring and sustaining native communities and their inherent resources, with the assumption that if the integrity of the system is maintained and/or restored, that key resources for species of concern can/will be accommodated (Paveglio and Taylor 2010). This approach is consistent with recent recommendations to manage the NWR system to improve the ecological integrity and biodiversity of landscapes in which they set (Fischman and Adamcik 2011). Obviously, some systems are so highly disrupted that all natural processes and communities/resources cannot be restored, and key resources needed by some species may need to be replaced or provided by another, similar habitat or resource. Nonetheless, a primary objective for refuges including Erie NWR should be to attempt to restore the basic features of former functional landscapes where possible and appropriate.

Based on the context of information obtained and analyzed in this study, we believe that future restoration and management of Erie NWR should consider the following general conservation goals:

1. Manage Erie NWR to help maintain and restore the physical and hydrological character of lands within the biologically rich French Creek watershed.

2. Restore and maintain the diversity, composition, distribution, and regenerating mechanisms of native vegetation communities in relationship to topographic and geomorphic landscape position.

3. Emulate a more natural seasonally- and annually-dynamic water regime in creek corridors and associated floodplain wetlands.

The following general recommendations are suggested to meet these ecosystem restoration and management goals for Erie NWR.

1. Manage Erie NWR to help maintain and restore the physical and hydrological character of lands within the biologically rich French Creek watershed.

The Erie NWR acquisition boundary area is an important contributor to, and recipient of, resources and hydrology of the biologically rich French Creek watershed (Western Pennsylvania Conservancy 2002). Consequently, future management of both divisions of Erie NWR should seek to define the role of refuge lands within a larger landscape-scale conservation and restoration strategy for the watershed. French Creek and its watershed have been recognized as the most biologically diverse ecosystem in Pennsylvania and many recent conservation initiatives have been started to protect, sustain, and restore this system. Lands within Erie NWR represent much of the few public land holdings within the watershed, and the Seneca Division in particular includes land immediately adjacent to the creek and contains considerable tributary creek, wetland, and forest habitats that are less altered compared to other watershed areas. Further, refuge lands contain a few tracts of remnant older-age forest communities, a unique fen, and relatively unaltered creek corridors along Muddy and Dead Creeks. As public land holdings, Erie NWR divisions offer the potential to: 1) protect relatively unaltered remnant community types, 2) manage communities that are in various states of regeneration to attain mature and sustainable community composition and distribution, and 3) restore ecological processes and functional patches of all endemic community types. If conservation strategies for Erie NWR support the return to more natural community distribution and type, then specific management strategies can be developed for each community type and for specific locations to maintain and restore both physical form and the driving ecological processes, especially the natural seasonal and long-term hydrological character of inherent creeks and their floodplains. This more natural, restoration approach helps use the refuge lands as "core" areas for sustaining the overall ecological integrity of the watershed and to expand community types and resources onto adjacent or nearby private lands and other conservation lands. Collectively, restoration and management of both private and public lands will improve the conservation integrity of the watershed and the southern Great Lakes region (The Pennsylvania Conservation Needs Committee 1959, Crawford County Soil and Water Conservation District 1968, USFWS 1988, Western Pennsylvania Conservancy 2001, 2002).

2. Restore and maintain the diversity, composition, distribution, and regenerating mechanisms of native vegetation communities in relationship to topographic and geomorphic landscape position.

The historical distribution of community/habitat types on Erie NWR was determined primarily by topographic position relative to soil distribution and hydrological regime. The abiotic HGM attributes of the two divisions on Erie NWR are somewhat different as is the extent and distribution of natural community types. Consequently, restoration strategies necessarily will be somewhat different between the two divisions. The HGM-based matrix and mapping of potential historical vegetation communities provided in this report identify the current understanding of the locations of communities and their juxtaposition relative to HGM attributes. This HGM model of community distribution undoubtedly will be improved as future information on elevation, slope aspect, and hydrology is refined for individual plant species, but when used in an adaptive management context, it can help guide restoration actions.

The highest upland elevation on both divisions of Erie NWR have well drained glacial till soils and historically contained classic southern Great Lakes oak-maple-beech- hickory dominated forests. These upland forests have been heavily harvested and only a few sites retain relatively natural old-growth stands, such as within the Muddy Creek RNA. This HGM study does not provide an analyses of past harvest or timber management of forest communities on the refuge, but suggests that appropriate future timber management should seek to restore natural stands through various timber stand improvement (TSI), afforestation, fire return interval management, and abandoned field succession management actions. Prescription of appropriate future forest management (of all forest types) on Erie NWR should be developed by professional foresters experienced with Southern Great Lakes communities.

Areas that are transitional from uplands to creek bottoms occurred along the margins of the many creek floodplains that dissect Erie NWR on both divisions. This unique transitional forest community now is rare within the French Creek watershed (e.g., Deets 1994, NatureServe1 2007). Additionally, this transitional forest assemblage is perhaps the most diverse among the forest types of the region and included species found both in lower wetter floodplains settings (such as yellow birch and hemlock) and drier upland sites (such as northern red oak and black cherry). A representative transitional forest stand is present on the Jacob Guy RNA along Allen Road on the Sugar Lake Division. Restoration of this forest type will require careful attention to appropriate HGM location and afforestation technique.

The creek bottoms on both divisions of Erie NWR contain a gradient of community types from deeper permanent water aquatic creek channels and former channel oxbows to S/S and swamp forest on the edges of floodplains. While all of these bottom communities are true wetland habitats, the distribution and type of specific species assemblages and functions is distinct in relationship to soil type and hydrology. Swamp forests occur on saturated to imperfectly drained mineral soils that are acidic. These swamp forests are maintained by short duration seasonal flooding and have considerable diversity in species within short distances of each other relative to slight changes in elevation on floodplain ridges, knolls, former natural levees, and floodplain depressions. The interesting mix and distribution of hemlock, yellow birch, American beech, red maple, and black ash reflects these more subtle elevation/hydrology relationships. The key to maintaining and restoring swamp forests lies in maintaining the topographic heterogeneity of floodplain bottoms and providing short duration, mostly dormant season, flooding regimes. When water regimes in floodplains becomes of longer duration, the swamp forest grades first into S/S habitat with semipermanent flooding regimes, and then to herbaceous "marsh-type" communities. S/S habitats are extensive on Erie, especially in the braided channel system on the Seneca Division. Likely, much of this wetland habitat historically existed in older beaver pond/creek channel complexes of the region and provided important resources for many waterbirds and wetland-dependent wildlife species including use by locally breeding waterfowl such as wood duck, hooded merganser, and black duck. Where floodplain wetlands regularly dried for extended periods during summer, bands or zones of herbaceous "moist-soil" vegetation became established, which were reflooded in fall or the following spring and provided important forage for many waterbirds. These moist-soil sites included edges of beaver ponds and higher elevations in floodplains that were not forested.

Collectively, the high diversity of community types and resources on Erie NWR contributed to the overall diversity and productivity of the French Creek watershed, with the two divisions providing different amounts and distribution of specific habitats. The key to future conservation and provision of resources on the refuge, therefore is in restoring natural distribution of the community complexes by restoring species mixes on appropriate locations and managing ecological processes to create conditions required for regeneration and survival/growth of the various species.

3. Emulate a more natural seasonally- and annually-dynamic water regime in creek corridors and associated floodplain wetlands.

It is clearly understood that a major part of the authorizing purpose of Erie NWR was to provide wetland habitats and resources for migratory birds, especially waterfowl (USFWS 1964). Early Master Plans and subsequent habitat management planning sought to increase the amount and consistency of wetlands on refuge lands for locally breeding and migrating waterfowl. In the 1960s and 1970s the primary action used to increase wetland habitat on Erie NWR was the development of impoundments on the Sugar Lake Division. The largest of these impoundments, Pools 4 and 9, effectively dammed the flow of Lake Creek and subsequently became relatively stagnant permanent water areas with natural summer drawdowns on the impoundment edges. Water permanency also led to introduction of fish into Pond 9 to create a sport fishery. More permanent water regimes in these ponds eventually created conditions that fostered dense coverage by persistent emergent or floating-leaved plants such as cattail and yellow water lily. While providing permanent water regimes emulated, to some degree, the aquatic systems of natural beaver ponds in the various creek drainages of the region, consistent management for this condition in Erie NWR impoundments has not incorporated interannual dynamics of flooding and drying that promotes both primary and secondary productivity of these habitats (Weller 1994, Green et al. 2009). Further, the large dams at Pools 4 and 9 now create potential low and significant hazard conditions for potential dam failures that require intensive, often very rapid response, manipulation of water to allow creek flows to exit the area without compromising downstream private lands and property. Other smaller impoundments on the Sugar Lake Division also increased annually available surface water area on the refuge, but similar to the larger impoundments, did not incorporate natural seasonal and long-term dynamics of flooding and drying (McCoy 1982, refuge annual narratives).

Ultimately, the ecological diversity and productivity of wetlands, both natural and impounded, at Erie NWR will be enhanced and sustained only if more natural flooding and drying regimes, and surface water flow patterns, can be restored and managed (Fig. 27). This restoration and management of natural water flow patterns and dynamics will require some fundamental changes in current water management including careful evaluation of existing water-control capabilities and structures. The challenges in making these water management changes on the Sugar Lake Division include a reevaluation of reasonable regionally-based waterfowl population objectives goals, public recreation opportunities, and physical/engineering designs. Despite early expectations (USFWS 1964), the forested hills and creek valleys of northwestern Pennsylvania probably never supported large populations of breeding or migrating waterfowl (or waterbirds) (Bellrose 1980, USFWS 1988, Ducks Unlimited, Inc. 1994).

SPECIFIC RECOMMENDATIONS FOR RESTORATION AND MANAGEMENT OPTIONS

Many potential ecosystem restoration and management actions can help meet the above general conservation goals. The following list of specific restoration and management options is not intended to be complete and many actions will require collection of additional information to develop specific biological and engineering plans, which is beyond the scope of this report. USFWS refuge and regional staff will need to access which actions are desired and then develop specific plans to meet the following goals.

Goal 1. Strategically manage Erie NWR to help maintain and restore the physical and hydrological character of lands within the biologically rich French Creek watershed.

Sub goal 1.1 Protect rare community/habitat types and remnant patches of all relatively unaltered community types.

The many conservation interests in the French Creek watershed have identified critical community/habitat types that have been highly destroyed and that provide important resources for the many diverse plant and animal species in the region (e.g., Western Pennsylvania Conservancy 2001, NatureServe1 2007). Many of these habitats historically were present on Erie NWR and some remnant patches of certain habitats remain. Especially important, and now limiting, habitats in the watershed include hillside fens, transitional and swamp forest, unaltered creek channels, and seasonal S/S wetlands. The following management actions seem important to achieve these landscape conservation objectives:

- Protect unique natural fens and hillside seeps.
- Protect old-growth remnant stands of all forest types including sites on RNAs.
- Protect and buffer creek corridors from development and disturbance and do not construct additional levees, roads, or water-control structures that would alter natural water flow patterns or hydrological regimes in these waterways.
- Promote acquisition of more USFWS and conservation lands and easements in the watershed, including completion of acquisition of lands within the Erie NWR acquisition boundary, to protect sensitive lands and complete the core of protected lands on the refuge.

Sub goal 1.2. Manage regenerating communities to attain mature and sustainable community composition and distribution.

When Erie NWR was established, most areas had been altered by timber harvest and clearing; agricultural production including small grain farming, haying and pasture management, and orchard development; and impoundment of some drainages. Since establishment, refuge management has maintained some agricultural areas and increased impoundments on creeks (on the Sugar Lake Division), but considerable effort also has been made to allow previously cut timber stands to grow into more mature stands and to allow abandoned fields to regenerate hopefully to former community conditions. Management actions that can facilitate regeneration of natural communities include:

- Evaluate all regenerating forest stands to determine if succession is proceeding toward the naturally occurring community type and condition dictated by HGM attributes. Implement timber stand improve-

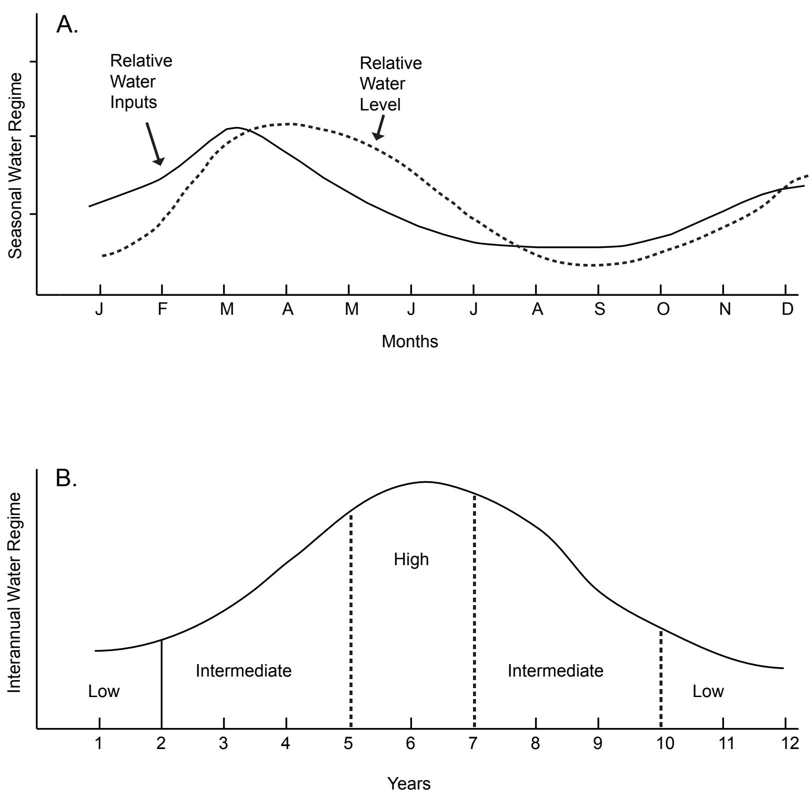

Figure 27. Generalized natural: a) seasonal and b) interannual water regimes in floodplain wetlands on Erie National Wildlife Refuge.

ments to allow naturally occurring species to reach mature states, and to discourage aggressive or invasive species throughout canopy, understory, and ground cover layers.

- Evaluate all abandoned fields to determine which woody species are regenerating relative to the potential historical community types suited for individual sites based on soil, topography, and hydrology conditions (e.g., Figs. 19, 20). Manage abandoned fields using fire, cutting, and intentional planting to shift communities toward former forest conditions.
- Evaluate all creek and floodplain sites to determine changes to natural hydrology and native species presence and extent. Control invasive species and manage water regimes, if they are controlled, to achieve more natural conditions – see recommendations below.

Sub goal 1.3. Restore ecological processes and functional patches of all endemic community types.

The primary ecological processes that created and sustained the Erie NWR ecosystem were highly seasonal inputs of regional precipitation that infiltrated glacial hill slopes and produced runoff to local creeks that eventually flowed into French Creek. Long-term dynamics of annual precipitation caused interannual variation in surface and groundwater resources that sustained creek channel flows and floodplain wetland hydrology and vegetation communities. Little permanent water existed on Erie NWR lands except in creek channels, oxbows, and beaver ponds. During dry periods fire periodically ranged through the area, which along with drought and drying of wetland soils, recycled nutrients and provided bare substrates for both forest and wetland plant regeneration. Changes in these major disturbance processes have altered the ecology of the Erie NWR region, and management should attempt to restore or emulate these processes where possible, including efforts to: 1) slow and reduce surface water, sediment and nutrient runoff into and through refuge lands; 2) convert marginal, highly erosive, lands to native vegetation and wetlands; and 3) restore natural hydrology and fire frequency. Specific actions to enable this management include:

- Further delineate the specific sub-basin areas within the French Creek watershed that contribute the most, or are at the highest potential risk of contributing, sediment, nutrient, and surface water runoff into both divisions of Erie NWR.
- Target local soil and water conservation practices to the above high erosion/runoff sub-basin areas, including U.S. Department of Agriculture and USFWS private lands programs such as grassed waterways, terraces, restoration of grass and forest lands, drop pipes, removal of tile drains, and removal or filling of field ditches.
- Restore natural drainage corridors including removal or modification of unnecessary ditches, roads, levees, and rail lines.
- Conduct additional investigations into the use of fire to manage forest and wetlands including periodicity and intensity/type of fire.

Goal 2. Restore and maintain the diversity, composition, distribution, and regenerating mechanisms of native vegetation communities in relationship to topographic and geomorphic landscape position.

The Erie NWR ecosystem historically contained a diverse mix of community types, each arrayed along gradients of soil type, topography, hydrology, and geology. If a goal for the refuge is to restore at least some semblance of the historical community condition and distribution, then active management will be required. It is understood that maintaining some open field/grassland habitat on Erie NWR has been desired in the past, but the HGM evaluation suggests that little, if any, native grassland historically occurred on the area. Consequently, if restoration of native communities is the goal, then at least most abandoned fields on the refuge should be reforested to appropriate types. Specific restoration actions should include:

Sub goal 2.1. Restore forest communities throughout much of the Sugar Lake Division and upland areas on the Seneca Division.

The majority of lands within the Sugar Lake Division and the upland areas on the Seneca Division historically were forested. Few, if any, patches of grassland were present, and open areas within the forest were primarily small tree gaps caused by wind throw, lightning, or other disturbance. Consequently, restoration of forest should match forest type with HGM attributes including:

- Promote Southern Great Lakes oak-sugar maple-beech-hickory forest on all upland hills and side slopes.
- Promote transitional forest on toe-slopes of glacial hills and higher edges of creek floodplains.
- Promote swamp forest dominated by yellow birch, red maple, and hemlock in floodplains where seasonal flooding occurs.
- Reforest abandoned fields with appropriate tree species based on historical species composition (see Figs. 16, 19, 20).

Sub goal 2.2. Restore S/S and seasonal herbaceous wetlands along Muddy, Dead, Lake, and Woodcock Creeks.

The larger creeks on Erie NWR had substantial flows during spring following snowmelt that seasonally flooded floodplain depressions, especially during wet years. The Muddy-Dead Creek complex on the Seneca Division contained the parallel creek corridors and supported a more extensive semipermanently to seasonally flooded floodplain setting dominated by S/S vegetation while the steeper more separated Woodcock and Lake Creek drainages contained more isolated floodplain depressions that were scattered along the creek corridors. Historically, beaver periodically built dams across drainages, and perhaps even across the major creeks, which created short-term more permanently flooded habitats. Maintaining and sustaining wetlands within the creek floodplains is desirable and should:

- Restore more natural patterns of hydrology in all creeks and floodplain areas (see #3 below)
- Protect the naturally parallel Muddy and Dead Creek corridors on the Seneca Division, which support mainly S/S communities.
- Evaluate water management in all impoundment areas on the Sugar Lake Division to change hydrology to more seasonal regimes that support herbaceous and some S/S communities.

Goal 3. Emulate a more natural seasonally- and annually-dynamic water regime in creek corridors and associated floodplain wetlands.

As previously mentioned, an important driving feature of the Erie NWR ecosystem is the seasonal precipitation and runoff from glacial hills via several creeks into the French Creek and then the Allegheny River system. Historically, small wetlands were present in the relatively narrow creek floodplains, which were recharged by the annual runoff and occasional creek overbank flooding. These wetlands also were sustained by annual drying in summer with prolonged dry conditions occurring in dry years. Beavers historically were present in the system and dam construction created more permanently flooded “ponds” along the creek drainages, but the life span of individual ponds probably was relatively short (20-30 years) and their distribution dynamic as local resources used by beavers diminished at the pond site from permanent flooding and/or long-term hydrology changes caused beavers to move elsewhere. Fortunately, the Muddy and Dead creek (and other small “run”) drainages have not been highly physically altered on the Seneca Division. In contrast, the Woodcock and Lake Creek drainages have been highly impounded on the Sugar Lake Division. Erie NWR may wish to maintain these latter impoundments, but at least some consideration should be given to restoring more natural water flow patterns and wetland hydrology with the following objectives:

Sub goal 3.1. Restore natural topography and water flow patterns in Woodcock and Lake Creeks and their small tributary drainages.

Woodcock and Lake Creeks are among the larger drainages in the French Creek watershed and periodic pulses of precipitation and runoff were important natural events that caused short term flooding in their narrow floodplains and recharge of wetland hydrology and nutrients. In contrast, few areas along the creeks were impounded (except scattered beaver ponds) or caused restrictions in flow. Generally, restoring at least some aspects of natural flow patterns in desirable to hydrological regimes associated with, and required by, the different wetland (and swamp and transitional forest) habitats on the refuge. Specific management recommendations to restore topography and water flow include:

- Evaluate all roads, ditches, levees/dams, and water-control structures to determine structures that are not critical or functional to, or that are impeding, water management and remove or modify unnecessary ones.

- Evaluate water storage and spillway – flood water flow capacities in the major spillways on Dams 4 and 9 to improve water passage through the Lake Creek system so that downstream damage to property and lands is not at high risk.
- Improve water flow through road levees and corridors where roads across drainages are maintained, including state highways 198 and 27 and several county roads. Water flow under and across roads could potentially be reengineered with additional culverts, bridges, and low water crossings, permeable fill, and other methods.
- Remove water diversion or impoundment infrastructure on all higher elevation glacial hill and upper drainage locations that formerly were forested habitats (Fig. 19b).
- Do not construct additional impoundments, roads, or levees in floodplain or drainage locations unless the new structure is consistent with restoration objectives.

Sub goal 3.2. Protect and restore ground and surface water resources and manage for natural hydroperiods.

Specific recommendations for future water management on Erie NWR include:

- Implement the recommendations in the WRIA for monitoring and improving water quality and quantity on the refuge.
- Manage small impoundments (if they are retained) for short duration seasonal flooding in spring to emulate natural hydroperiods (Fig. 27a) and encourage seasonal herbaceous moist-soil vegetation. These small impoundments should be mostly dry during dry periods of the long term precipitation pattern (Fig. 27b), and during this time manipulation and disturbance of moist-soil vegetation can be conducted to maintain productivity, species composition, and discourage invasive and undesirable wetland vegetation (Fredrickson and Taylor 1982).
- Manage larger impoundments, especially Pools 4 and 9, for more naturally dynamic semipermanent water regimes including seasonal drawdowns of pond edges during summer and early fall and periodic dewatering (without intention of permanent water levels) during dry periods of the long term precipitation cycle (Fig. 27). Past management over four decades has shifted these wetland impoundments to more permanent (Pool 9) and semipermanent to permanent (Pool 4) conditions and with annually consistent water regimes that have reduced diversity of vegetation, expanded coverage by persistent emergent and floating-leaved plants, reduced secondary production, and lowered use by waterbirds. This water management can be reversed back to emulate more natural water regimes found in the historically smaller widely scattered beaver ponds in the region.
- Carefully monitor the Muddy and Dead Creek drainage corridors and creek channels and remove obstructions that could cause more permanent water regimes and community shifts to open water or aquatic states.

MONITORING AND EVALUATION

The current understanding of the Erie NWR ecosystem has been greatly enhanced by past monitoring and evaluation studies of vegetation and animal communities, water quality and quantity, and specific management actions. Certain baseline and trend data for refuge communities and attributes are limited however, and additional analyses of vegetation distribution and relationships with hydrogeomorphic attributes of the system should be conducted and will improve understanding of, and provide the foundation for, future management options. Future management of Erie should continue key monitoring studies and also conduct select directed studies as needed. Monitoring should be determined primarily by refuge objectives, but some measures should be collected that indicate how factors related to ecosystem structure and function are changing, regardless of whether the restoration and management options identified in this report are undertaken. Ultimately, the success in restoring and sustaining communities and ecosystem functions and values at Erie NWR will depend on how well the physical integrity and hydrological processes and events, especially the surface water runoff patterns, can be restored, maintained, and emulated by management actions. Uncertainty exists about the future of some important water issues and the ability of the USFWS to make some system changes because they are not completely under the control of the USFWS. Also, specific techniques for certain management actions, such as controlling and reducing introduced plant species, are not entirely known.

Whatever future management actions occur on Erie NWR, activities should be done in an adaptive management framework where: 1) predictions about community response and water issues are made (e.g., increased diversity and vigor of transitional forest) relative to specific management actions (e.g., restoration of seasonal soil saturation and regular fire recurrence) in specific locations or communities (e.g., floodplain edges and lower hill slopes), 2) follow-up monitoring is conducted to evaluate ecosystem responses to the action, and then 3) determine how management actions and strategies can be modified based on results of the monitoring and evaluation. Information and monitoring needs for Erie NWR related to the hydrogeomorphic information evaluated in this report are identified below:

GROUND AND SURFACE WATER QUALITY AND QUANTITY

- Revised and updated information on all water-control and conveyance structures and determining annual water budgets for all wetland management units and the refuge as a whole.
- Annual monitoring of water management and storage/flooding especially as related to future changes in water use and management identified in this report.
- Completion of bathymetry and detailed topographic information for all wetland impoundments.
- Routine monitoring of water quality and contaminant issues in relation to water source and routing. Regular monitoring of surface and ground water in key reference locations related to HGM-determined communities should be established.
- Water flow metering at key points in the refuge.

RESTORING NATURAL TOPOGRAPHY, WATER FLOW PATTERNS, AND WATER REGIMES

This report identifies several physical and management changes that could help restore some more natural topography, water flow, and flooding/drying dynamics in managed wetlands. These changes include restoring at least some more natural water flow through natural drainages and managing impoundments (that are retained) for more natural spring-flooded seasonal flooding regimes. Further, restoring interannual dynamics of flooding and at least partial drying of the Pool 4 and 9 impoundments is desired. The following monitoring will be important to understanding effects of these changes if implemented:

- Obtain LiDAR topography information for both divisions of the refuge.
- Annual monitoring of water use and distribution including water source, delivery route and mechanism, extent and duration of flooding and drying, and relationships with non-refuge water and land uses.
- Documentation of how water moves across hill slopes and through creek corridors.
- Evaluation of surface and ground water interactions and flow.

LONG-TERM CHANGES IN VEGETATION AND ANIMAL COMMUNITIES

The availability of historic vegetation information coupled with regularly documenting changes in general and specific vegetation communities is extremely important to understand the long-term changes and management effects on Erie NWR. Also, regular monitoring of at least some select animal species or groups helps define the capability of the Erie NWR ecosystem to supply key resources to, and meet annual cycle requirements of, animals that use the refuge and regional area. Important survey/monitoring needs include:

- Detailed inventory and mapping of plant species composition, distribution, productivity, and coverage in all habitats, especially forest areas.
- Coverage, including expansion and contraction rates of invasive and woody species.
- Abundance, chronology of use, survival, and reproduction of key waterbird and Neotropical migrant songbirds including dabbling ducks, geese, shorebirds, and passerines.
- Rates and occurrence of fire, grazing, and mechanical disturbances in wetlands and grasslands.
- Occurrence, distribution, and abundance of amphibians and reptiles.

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