Water Resource Inventory and Assessment

Summary Report - FY17

Northeast Region

December 2017

Noel Turner
U.S. Fish and Wildlife Service
300 Westgate Center Drive
Hadley, MA 01035

Fred Wurster
U.S. Fish and Wildlife Service
3100 Desert Road
Suffolk, VA 23434

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1. Executive Summary

The Water Resource Inventory and Assessment (WRIA) program is an inventory of physical water resources and an assessment of water resource threats and needs on U.S Fish and Wildlife Service (USFWS) National Wildlife Refuges (NWR). The goal of every WRIA is to provide a basic understanding of the water resources that are important to the facility and assess the potential threats to those resources. The ultimate outcome of the WRIA project is to develop strategies for addressing threats to refuge water resources.

This report includes water resources inventory and assessment information on 25 Northeast Region refuges. Information included in this report is from WRIA interviews completed at 12 NWRs in Fiscal Year 2017 (FY17) and 13 WRIA reports, or draft reports, completed between 2012 and 2017. By the end of FY17, WRIAs were completed on 72 percent of the total eligible refuge acquisition boundary area in the Northeast Region.

25 refuges included in this review:

Aroostook **Assabet River** **Blackwater** **Bombay Hook** **Canaan Valley** **Cape May** **Cherry Valley** **Chincoteague** **Erie**	**Great Meadows** **Great Swamp** **Iroquois** **John Heinz** **Missisquoi** **Montezuma** **Moosehorn** **Ohio River Islands**	**Parker River** **Patuxent** **Rappahannock** **Nulhegan Basin Division (Conte)** **Sunkhaze Meadows** **Umbagog** **Wallkill River** **Wallops Island**

Through the WRIA interview process, information on physical water resources (streams, lakes, wetlands, springs, groundwater aquifers, etc.) for each refuge was gathered from literature reviews and communication with refuge staff. The information included in these reviews covers water quality and quantity, water resource threats and needs, and management of water resources on the refuges. Additional information, including land use, stream networks, and groundwater dependent ecosystems was determined from GIS exercises. Principal findings from the 25 WRIAs included in this review are outlined below and discussed in more detail in this report.

1.1 Findings

1. Refuges with the most watershed area in each land use category:

Forested	Wetland	Agriculture	Urban
Canaan Valley **Nulhegan Basin Division** **Umbagog**	**Cape May** **Great Swamp** **Parker River**	**Iroquois** **Montezuma** **Blackwater**	**John Heinz** **Patuxent** **Great Meadows**

2. Refuges with the highest density of freshwater, non-tidal streams in refuge watersheds:

Highest Stream Density
Erie **Great Meadows** **Ohio River Islands**

3. Refuges with the most headwater streams in refuge watersheds:

Most Headwater Streams
Great Swamp **Erie** **Cherry Valley**

4. Refuges with the most refuge area in each National Wetland Inventory (NWI) category:

Palustrine	Estuarine	Lacustrine	Riverine	Upland
Great Swamp **Missisquoi** **Iroquois**	**Cape May** **Moosehorn** **Rappahannock**	**John Heinz** **Umbagog** **Missisquoi**	**Ohio River Islands** **John Heinz** **Great Meadows**	**Cherry Valley** **Nulhegan Basin** **Moosehorn**

5. Refuges with the most potential groundwater dependent wetlands:

Most Groundwater Dependent Wetlands
Cape May **Wallkill River** **Canaan Valley**

6. Refuges with the most wetland impoundment acreage:

Most Wetland Impoundments
Montezuma
Iroquois
Chincoteague

7. Refuges with the highest density of roads:

Highest Road Density
Patuxent
Assabet River
Montezuma

8. Refuges with the highest concentration of impaired streams:

Most Impaired Streams
Great Meadows
Parker River
Ohio River Islands

9. Refuges with the most USGS water monitoring sites in refuge watersheds:

Most USGS Monitoring
Cape May
Blackwater
Ohio River Islands

10. Refuges where annual precipitation totals have increased the most in the last 20 years:

Greatest Increase in Annual Precipitation Totals
Moosehorn
Cape May / Bombay Hook
Great Meadows

11. Refuges where average temperatures have increased the most in the last 20 years:

Greatest Increase in Average Annual Temperature
John Heinz
Iroquois
Great Meadows

12. Most common threats to refuge water resources

Most Common Water Quality Threats	Most Common Water Supply Threats
Nutrient Pollution **General Contaminants** **Sedimentation**	**Altered Flow Regimes** **Excess Surface Water** **Compromised Water Management Capability**

13. Most common causes of threats to water quality

Nutrient Pollution	General Contaminants	Sedimentation
Agricultural Runoff	**Industrial Effluent**	**Agricultural Runoff**
Waste Water Treatment Facilities	**Garbage / Solid Waste**	**Urban Runoff**
Urban Runoff	**Urban Runoff**	**Logging / Forestry**

14. Most common causes of threats to water supply

Altered Flow Regimes	Excess Surface Water	Compromised Water Management
Dams	**Inefficient Water Infrastructure**	**Inefficient Water Infrastructure**
Levees / Dikes	**Changing Frequency of Extreme Precipitation Events**	**Dams / Locks**
Roads / Culverts	**Changing Rainfall Patterns**	**Surface Water Diversions**

2. Water Resource Inventory and Assessment - Background and Introduction

The Water Resource Inventory and Assessment (WRIA) program is an inventory of physical water resources and an assessment of water resource threats and needs on U.S Fish and Wildlife Service (USFWS) National Wildlife Refuges (NWR). The goal of every WRIA is to provide a basic understanding of the water resources that are important to the facility and assess the potential threats to those resources. The ultimate outcome of the WRIA project is to assist refuges with water resource threats and needs, identified through the inventory and assessment process, to provide higher quality aquatic habitats. Information collected on refuge water resources is available through the WRIA database in the USFWS Environmental Conservation Online System (ECOS). The information collected for the WRIAs can be used to support Comprehensive Conservation Plans, Hydro-Geomorphic Assessments, and other habitat management plans.

The long-term goal of the National Wildlife Refuge System (NWRS) WRIA effort is to provide up-to-date data on a facility's water quantity and quality in order to protect adequate supplies of clean and fresh water. An accurate water resources inventory is essential to prioritize issues and tasks, and to take prescriptive actions that are consistent with the established purposes of the refuge. Ultimately, the region (and headquarters) would like to address these water resource threats and needs.

Region 5 initially completed WRIAs for refuges in the form of a lengthy report. A contractor and the regional hydrologist worked together to assess the refuge water resources and contacted refuge staff for information on water resource threats and needs. After the WRIA reports proved to be time-consuming, a new approach was established to focus on refuge water resource threats and needs to populate the national database. In Fiscal Year 2017, WRIA interviews, focusing on water resource threats and needs, were conducted at twelve Region 5 refuges.

Through the WRIA interview process, information was gathered from literature reviews and communication with refuge staff on physical water resources (streams, lakes, wetlands, springs, and groundwater), water quality, water quantity, water resource threats and needs, and management of water resources on the refuges. Additional information, including land use, stream networks, and groundwater dependent ecosystems, about the refuges was determined from GIS exercises.[1]

Following the WRIA interviews, a wealth of information about water resources was compiled into a single document for regional staff and the refuges. Water resource threats and needs were summarized in a national database. This report is a summary and basic analysis of water resources, common threats, and resource needs on the 25 refuges in Region 5 that have been part

[1] For the purposes of this review, all GIS analyses rely on the refuge acquisition boundary. Therefore, acreage estimates presented in this report are relative to the acquisition boundary, not the actual land ownership.

of the WRIA process thus far. The 25 Region 5 NWRs from the FY17 WRIA project and completed or draft WRIA reports are included in this summary report (Table 1; Figure 1).

Table 1. Refuges included in this summary that have been a part of the WRIA process and the identifying code.

Refuge Name	Refuge Code	FY17 WRIA	WRIA Report
Aroostook	ARO	X	
Assabet River*	ASR		X
Blackwater	BLK	X	
Bombay Hook	BMH		X
Canaan Valley	CAV		X
Cape May	CPY		X
Cherry Valley	CHV	X	
Chincoteague*	CHN		X
Erie	ERE		X
Great Meadows*	GRM		X
Great Swamp	GRS	X	
Iroquois	IRQ	X	
John Heinz	TCM	X	
Missisquoi	MSQ	X	
Montezuma	MNT		X
Moosehorn	MSH		X
Ohio River Islands	ORI	X	
Parker River	PKR		X
Patuxent	PWR		X
Rappahannock	RPP	X	
Nulhegan Basin Division of Silvio O. Conte	SON	X	
Sunkhaze Meadows	SNK	X	
Umbagog	LKU		X
Wallkill River	WLK	X	
Wallops Island*	WAL		X

**Great Meadows and Assabet River, as well as Chincoteague and Wallops Island, share the same WRIA reports.*

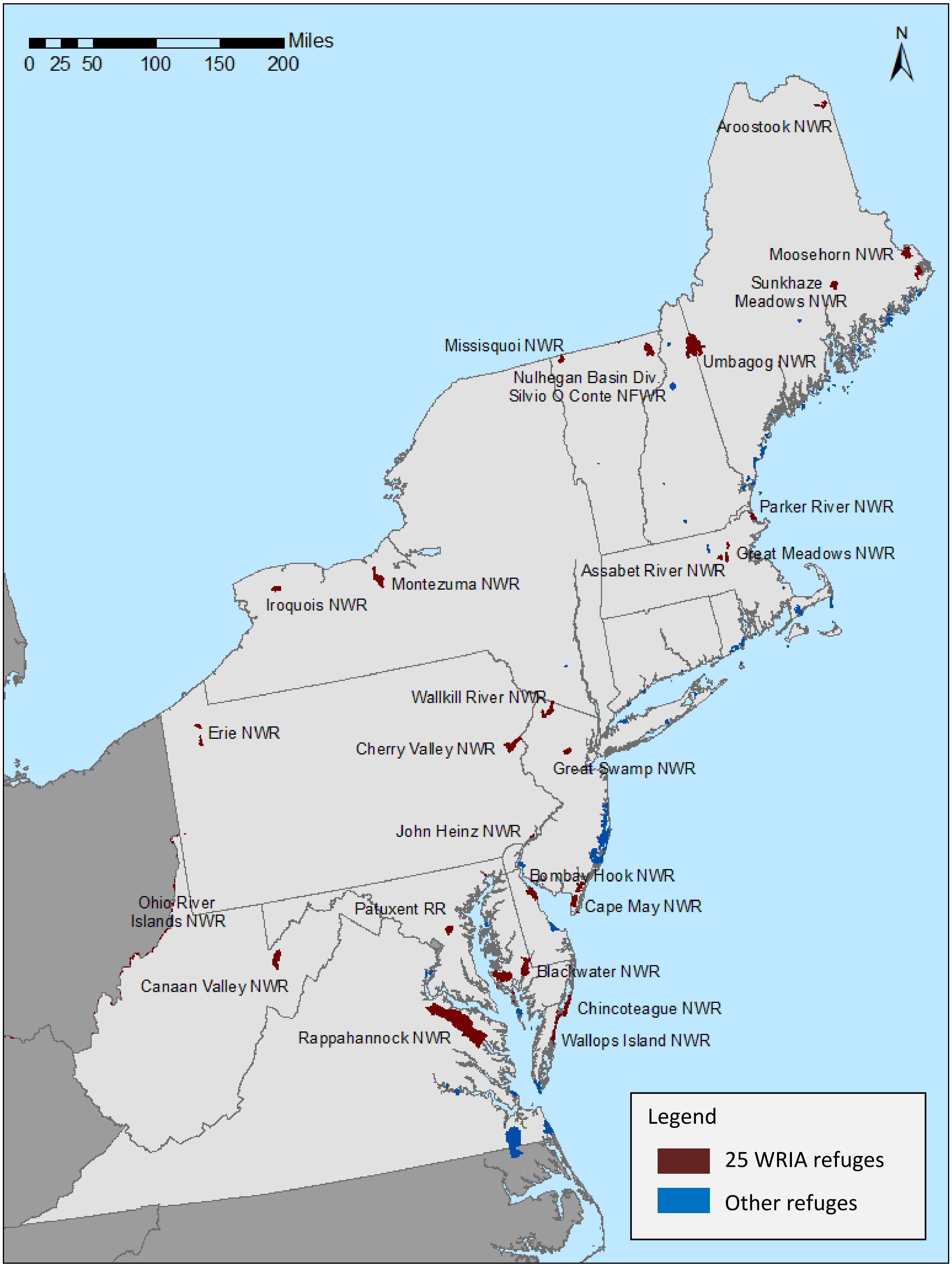

Figure 1. Refuges included in the FY17 WRIA process and refuges with completed WRIA reports (maroon), and other Region 5 refuges (blue).

3. Natural Setting

Each of the refuges that have been a part of the WRIA process has unique aquatic habitats and water resources that depend on their physical setting in the landscape. The following sections describe the 25 refuges' topography, watersheds, geology, soils, and land use.

3.1. Topography & Hydrologic Units

Just as the water resources of the refuges in Region 5 vary, so do the topographic locations. Refuges are located at a range of elevations from sea level to about 2,000 feet above mean sea level. Many classification systems have been developed to better categorize common themes and locations across the United States. Classification systems related to geography used in the WRIA process include physiographic province, landscape conservation cooperatives (LCCs), and hydrologic units. Physiographic provinces were developed as a classification system based on landforms, which are defined by elevation ranges and geology. LCCs are regional groupings based on similar landscapes and ecosystems. Based on topography and stream orders, hydrologic units (or watersheds) can be used as another classification system. These physical landscape characteristics provide general knowledge about refuge water resources, such as flow, stream networks, and groundwater.

3.1.1. Physiographic Province

The United States is divided into physiographic provinces which are based on land forms, as first described by Fenneman in 1917. The Northeast Region can be separated into nine physiographic provinces as listed in Table 2 and displayed in Figure 2. Some of the more common physiographic provinces are briefly described below:

- Atlantic Coastal Plain refuges, such as Blackwater NWR, have very little topographic relief – no more than 10 feet.
- Refuges in the Appalachian Piedmont (Great Swamp NWR) have rolling hills with around 100 feet of relief.
- The Appalachian Valley and Ridge, where Cherry Valley NWR and Wallkill River NWR are located, is recognized for long, linear valleys and ridges with a few hundred feet of elevation change.
- The New England Uplands are hilly with dissecting valleys and the occasional monadnock (Sunkhaze Meadows NWR).
- In the Interior Plains – Central Lowland physiographic province, where Iroquois NWR is located, topography is defined by glaciation events which resulted in gently rolling topography (Fenneman, 1928).

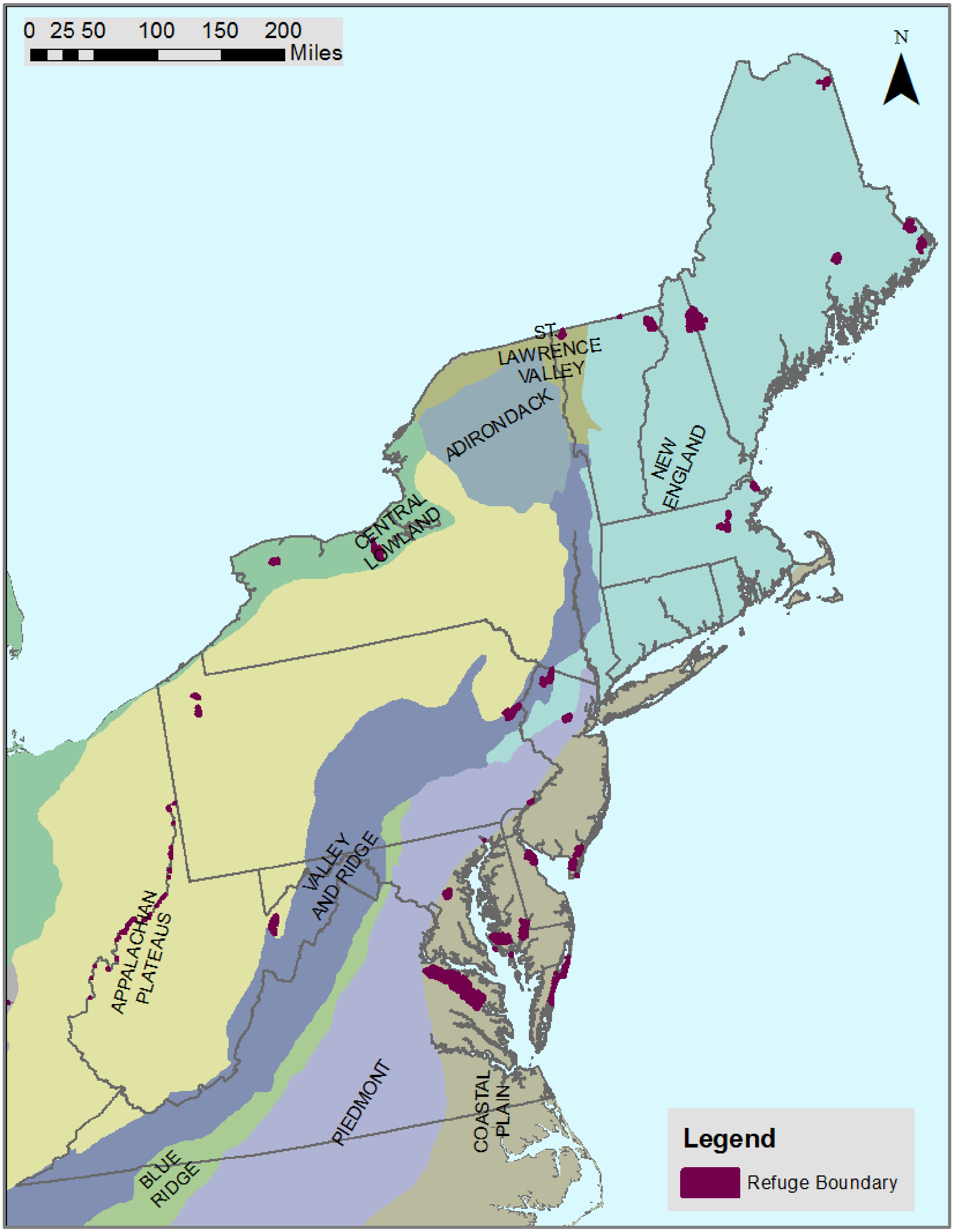

Figure 2. Physiographic provinces in the Northeast Region and National Wildlife Refuges included in this study (Fenneman and Johnson, 1946).

Table 2. Physiographic provinces of the Northeast region and the refuges located in each province.

Physiographic Province	Refuges
Atlantic Coastal Plain	Blackwater, Bombay Hook, Cape May, Chincoteague, John Heinz, Patuxent, Rappahannock, Wallops Island
Appalachian Piedmont	Great Swamp
Appalachian Valley and Ridge	Cherry Valley, Wallkill River
Appalachian Plateaus	Canaan Valley, Erie, Ohio River Islands
New England	Assabet River, Great Meadows, Moosehorn, Parker River, Aroostook, Sunkhaze Meadows, Nulhegan Basin, Umbagog
Appalachian St. Lawrence Valley	Missisquoi
Interior Plains Central Lowland	Iroquois, Montezuma

3.1.2. Landscape Conservation Cooperatives

Refuges in USFWS Region 5 are part of four different landscape conservation cooperatives (LCCs): North Atlantic, Appalachian, South Atlantic, and Upper Midwest and Great Lakes. LCCs are designed to protect natural and cultural resources by creating a landscape-scale network of strategic conservation, science, and partnerships. The vision statement of each of the four LCCs provides some mention of healthy ecosystems and human communities while adapting to climate change (LCC Network, 2017). Most refuges in Region 5 are located in the North Atlantic LCC (Table 3). None of the refuges included in this review are located in the South Atlantic LCC.

Table 3. LCCs of the Northeast region and refuges located in each LCC.

LCC	Refuges
North Atlantic	Aroostook, Assabet River, Blackwater, Bombay Hook, Cape May, Chincoteague, Great Meadows, Great Swamp, John Heinz, Missisquoi, Moosehorn, Nulhegan Basin, Parker River, Patuxent, Rappahannock, Sunkhaze Meadows, Umbagog, Wallops Island
Appalachian	Canaan Valley, Cherry Valley, Ohio River Islands, Wallkill River
Upper Midwest and Great Lakes	Erie, Iroquois, Montezuma

3.1.3. Region of Hydrologic Influence

WRIAs focuses on water resources within the geographic extent of the refuge acquisition boundary, and more broadly on water resources within a Region of Hydrologic Influence (RHI) containing the refuge. The RHI describes some portion of the watershed—either the entire or partial watershed—upstream of the refuge that affects the condition of water resources on the refuge. This construct anchors the refuge in the greater watershed and thereby provides a reference for discussing the refuge within a watershed context. Because water travels down gradient, it is the activities occurring upstream of the refuge that influence water quantity (e.g., diversions, withdrawals, land cover changes) or water quality (e.g., pollution from agricultural, urban, or industrial land uses) on the refuge. In this riverine system, activities occurring downstream of the refuge are less likely to directly affect water resources on the refuge. Accordingly, the focus of the RHI is primarily on areas upstream of the refuge.

Refuge RHIs are determined by using the U.S. Geological Survey (USGS) National Hydrography Dataset (NHD) watershed delineation of hydrologic unit code 10 digit numbers (HUC-10). By definition, the RHI is all HUC-10s that intersect the refuge boundary. After communication with refuge staff, some refuge RHIs were edited to better reflect areas in the RHI that influence water resources on the refuge (Figure 3).

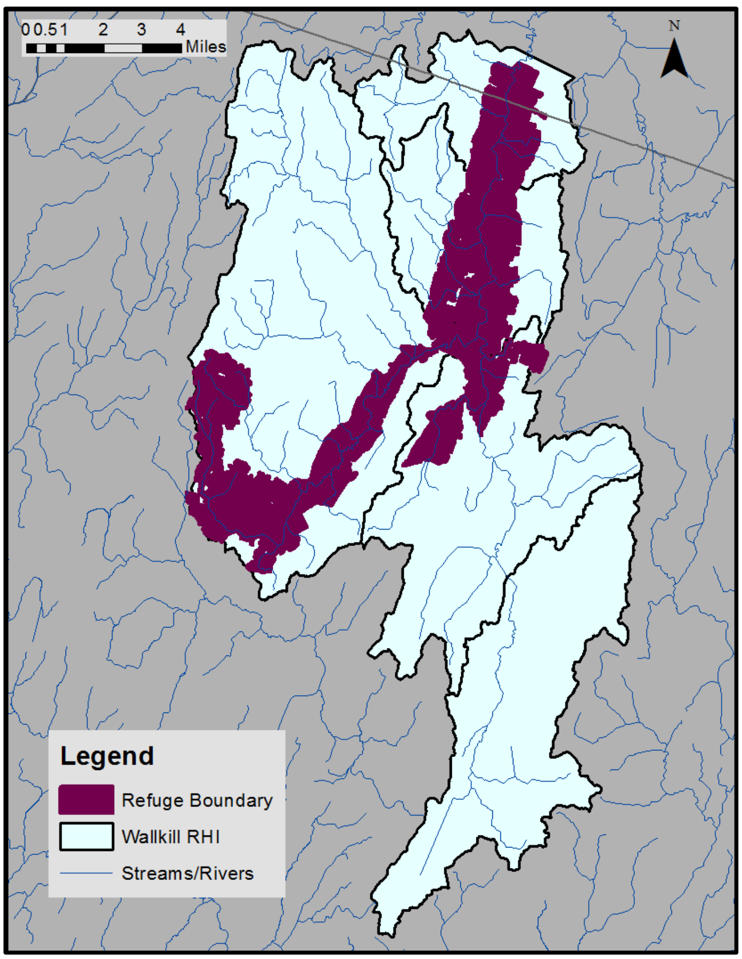

Figure 3. Example of a refuge RHI at Wallkill River NWR. Streams are included to visualize the watersheds.

Refuge RHI area is compared with refuge acquisition area boundary to evaluate the relative percentage of the RHI included in a refuge's acquisition boundary (Table 4). Theoretically, refuges with acquisition boundaries that include a large percentage of the RHI have greater influence in the watershed than refuges whose acquisition boundaries include little of the RHI.

Table 4. Refuge RHI acreages and the percent area that the acquisition boundary occupies within the RHI.

Refuge	RHI Area (acres)	Percent of RHI Included in Acquisition Boundary (%)
Rappahannock	726,646	39
Nulhegan Basin	92,477	30
Great Swamp	33,544	28
Cherry Valley	89,143	23
Bombay Hook	113,099	18
Wallkill River	99,353	17
Iroquois	93,271	12
Parker River	56,029	12
Blackwater	773,900	9.9
Umbagog	877,113	9.4
Canaan Valley	279,629	8.9
Chincoteague	210,865	8.6
Moosehorn	454,307	7.6
Cape May	358,507	6.1
Montezuma	465,247	4.8
Sunkhaze Meadows	249,173	4.7
Patuxent	291,567	4.5
Erie	416,888	2.3
Wallops Island	210,865	2.2
Great Meadows	256,175	2.1
Aroostook	318,237	1.6
Missisquoi	774,646	1.0
Assabet River	256,175	0.94
John Heinz	146,776	0.82
Ohio River Islands	2,599,998	0.23

For the purpose of this summary, RHIs (Table 4) were used to assess land use impacts on the refuge, potential water quality threats to the refuge (including Clean Water Act impairments and NPDES permits), and water monitoring stations in the watershed.

3.2. Geology

Knowledge of the geology of the region where refuges are located is crucial information to understand the flow, natural chemistry, and sources of water on refuges. Across Region 5, the geology is highly variable and complex, resulting in unique landscapes where refuges are located. The Northeast United States landscape has been altered by mountain building events, glacial episodes, and coastal processes. In many cases, both surficial and bedrock geology are important in understanding water resources. Geology plays a key role identifying potential groundwater-dependent ecosystems on refuges (Section 4.1.5.1).

3.2.1. Bedrock Geology

Consolidated, hard rocks are classified as bedrock geology. Types of bedrock geology include sedimentary (ie. shales, limestones, sandstones), igneous (ie. granite and basalt), and metamorphic (ie. slate and gneiss) rocks (Figure 4). The types of bedrock geology are important as they result in different types of landscapes (due to erodibility) and characteristics of water flow on refuges (Table 5).

- **Sedimentary** rocks often house productive aquifers that are important for groundwater movement on refuges. Limestone is usually a structurally strong but chemically weak rock, meaning the rock is resistant and a dominant landform in some cases and highly porous and weathered in others. Limestone bedrock is often a high yield aquifer due to secondary porosity (voids that are enlarged after the rock has formed, usually by chemical weathering). On the other hand, shales often confine groundwater, or only allow movement along fractures and joints.

- **Igneous** rocks, such as granite and basalt, are generally strong rocks that form noticeable landforms. Basalt ridges frame the basin where Great Swamp NWR is located. Water movement through igneous rocks is usually along joints and fractures. The Nulhegan Basin (where Nulhegan Basin Division is located) is a special case of weak igneous rocks that were formed by an igneous intrusion into the metamorphic rocks.

- **Metamorphic** rocks (gneiss, slate, and marble for example) are formed when sedimentary or igneous rocks undergo heat and pressure. This change in form usually occurs during mountain building events. Fractures and joints are also formed during the events, which are the likely pathways of water flow.

Table 5. Rock types and refuges that are predominantly found in each bedrock type.

Bedrock Type	Refuges
Sedimentary	Aroostook, Canaan Valley, Cherry Valley, Erie, Great Swamp‡, Iroquois, Missisquoi, Montezuma, Ohio River Islands, Sunkhaze Meadows, Wallkill River
Metamorphic	Nulhegan Basin, Umbagog*
Igneous	Assabet River, Great Meadows, Great Swamp‡, Moosehorn, Parker River, Umbagog*
No dominant bedrock*	Blackwater, Bombay Hook, Cape May, Chincoteague, John Heinz, Patuxent, Rappahannock, Wallops Island

‡ Great Swamp NWR has sandstone and shale sedimentary rocks under the glacial sediments in the valley and igneous basalt ridges.

Umbagog NWR has both metamorphic and igneous bedrock.

**meaning that the bedrock is too deep to have an impact on surface processes or aquifers.*

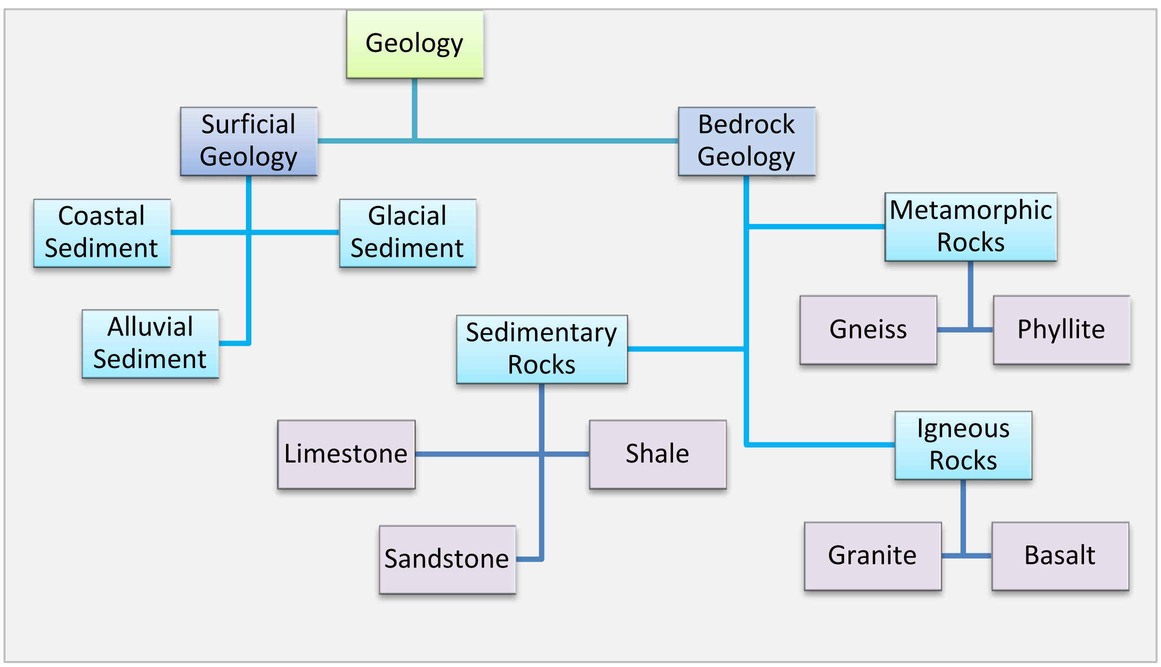

Figure 4. Flow chart of the three rock types and examples of each.

3.2.2. Surficial Geology

Surficial geology describes the unconsolidated sediments that are formed by surficial processes, which dominate much of the Northeast. Coastal and glacial sediments are most prominent in Region 5 and influence water resources on refuges. Alluvial (deposited by rivers and streams) sediments are less prominent in the region but are locally important (Table 6). Landscapes without exposed bedrock and dominated by unconsolidated sediments tend to have a flat or gently rolling topography. Sediment sizes range from clays and silts to sands and gravels. Generally, clays and silts hold surface water (wetlands) and sands are more permeable (likely good aquifers and recharge areas).

- **Coastal sediments** tend to be mostly sand with some clay from ocean regressions in the past. The sandy substrate facilitates rapid groundwater movement to surface water systems. These sands are also aquifer recharge areas, meaning that surface processes can easily influence groundwater quality.

- **Glacial sediments** can result in both aquifers and confining units on refuges in the Northeast. Types of glacial sediments on refuges ranges from glacial till (fine grained; silt, clay, and fine sands) to glacial outwash (coarse grained; sands, gravels, and boulders). The last Glacial Maximum left glacial sediments at land surface across most of the Northeast Region (Figure 5). Glacial lakes deposited clays that are highly impermeable and house extensive wetlands and peatlands on refuges (i.e. Iroquois NWR and Great Swamp NWR). Glacial outwash aquifers are important at Nulhegan Basin Division and Great Swamp NWR (Table 6). Isolated pockets of glacial sediments are found at Cherry Valley NWR and Wallkill River NWR.

- **Alluvial sediments**, deposited by rivers and streams, vary in size from clay to pebbles and are often sorted. The extent of alluvial sediments usually extends the width of the floodplain to previous terraces (if present). The inflow or outflow of water in these sediments can reverse depending on the time of year and water levels in surface water and groundwater.

Table 6. Types of surficial sediments and refuges overlying those sediments.

Surficial Geology Type	Refuges
Coastal Sediments	Blackwater, Bombay Hook, Cape May, Chincoteague, Parker River‡, Patuxent⁂, Rappahannock☿, Wallops Island
Glacial Sediments	Aroostook, Assabet River, Erie, Great Meadows, Great Swamp, Iroquois, Montezuma, Moosehorn, Nulhegan Basin, Parker River‡, Sunkhaze Meadows, Umbagog
Alluvial Sediments	John Heinz, Missisquoi, Ohio River Islands, Patuxent⁂
No dominant surficial sediments*	Canaan Valley, Cherry Valley, Wallkill River

⁂ Patuxent RR has alluvial sediments on the immediate surface. The coastal sediments, under the alluvial sediments, are an important aquifer for the refuge and surrounding areas.

☿ Coastal sediments dominate hydrology at Rappahannock NWR; however, alluvial sediments common around the Rappahannock River and tributaries.

‡ Parker River NWR has both coastal and glacial sediments that are important to hydrologic and ecologic characteristics of the refuge.

**meaning bedrock geology is dominant.*

Figure 5. The southernmost extent of the last glacial maximum (blue line) in the Northeast Region (light gray). The 25 refuges in this study are the maroon colored polygons.

3.3. Soils

Soils can provide information on run-off patterns, parent material, and aquifer recharge. Types of soils on refuges range from well drained to poorly drained and sandy to mucky peat. Soils are key to understanding wetlands and groundwater recharge potential on refuges.

Many of the refuges with significant palustrine wetlands are in areas with extensive silt and clay soils deposited by glacial lakes. Peatlands formed on impervious glacial lake sediments. Refuges found in relict glacial lake beds include Great Swamp, Iroquois, and Montezuma.

Soils that are developed during saturated, flooded, or ponded conditions and become anaerobic are classified as hydric soils (NRCS). For the purposes of this analysis, soil units that had greater than 20% area hydric soils were considered "hydric" (Figure 6). Organic soils have a high composition of decaying plant material, which could be deposited under saturated conditions (Figure 7). Most organic soils are also hydric; therefore, many refuges had soils that were both hydric and organic (Figure 8). Organic soils are indicative of hydrologic processes that support peat accumulation. Peat deposits, or peatlands, are important wetlands that often support unique plant communities.

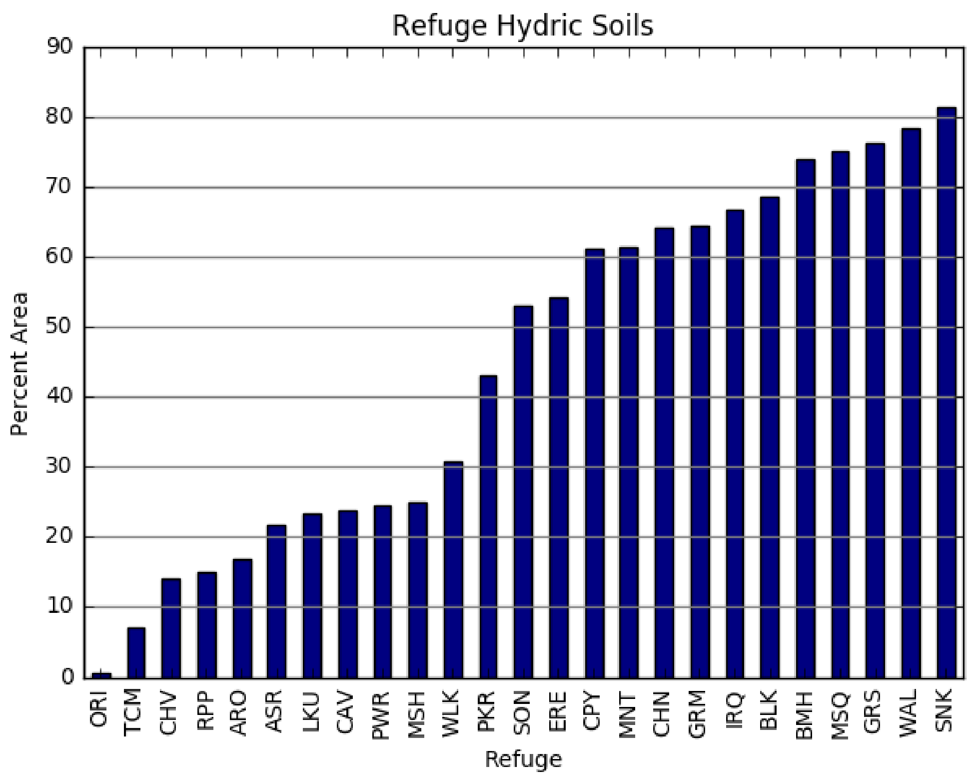

Figure 6. Refuge hydric soils (greater than 20% within the unit) by percent of refuge acquisition boundary area. All 25 refuges have hydric soils.

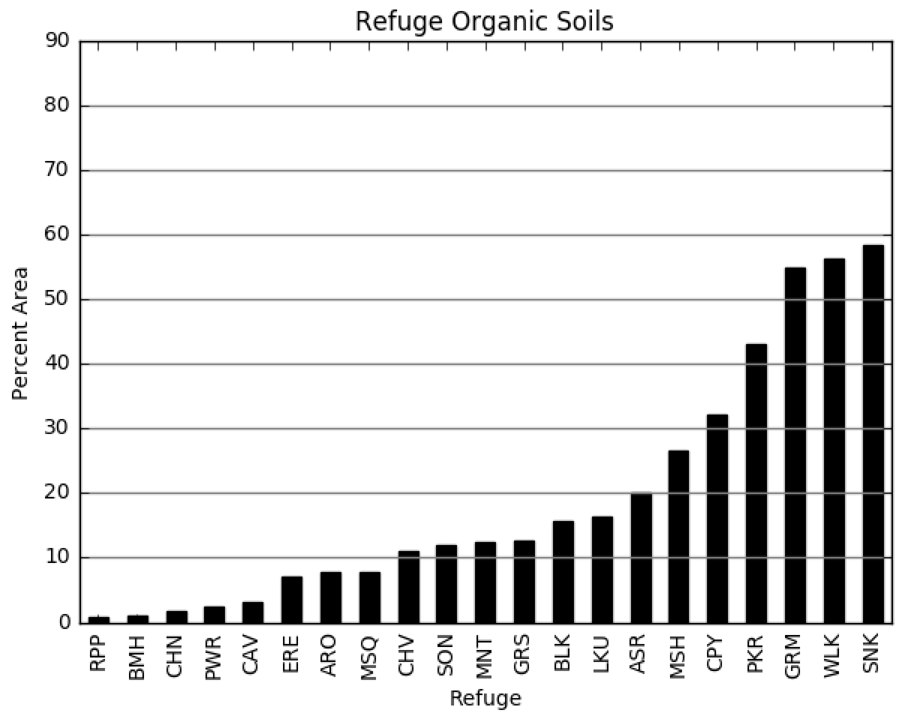

Figure 7. Refuge organic soils by percent of total acquisition boundary area. Excludes refuges with no organic soils (Iroquois NWR, John Heinz NWR, Ohio River Islands NWR, and Wallops Island NWR).

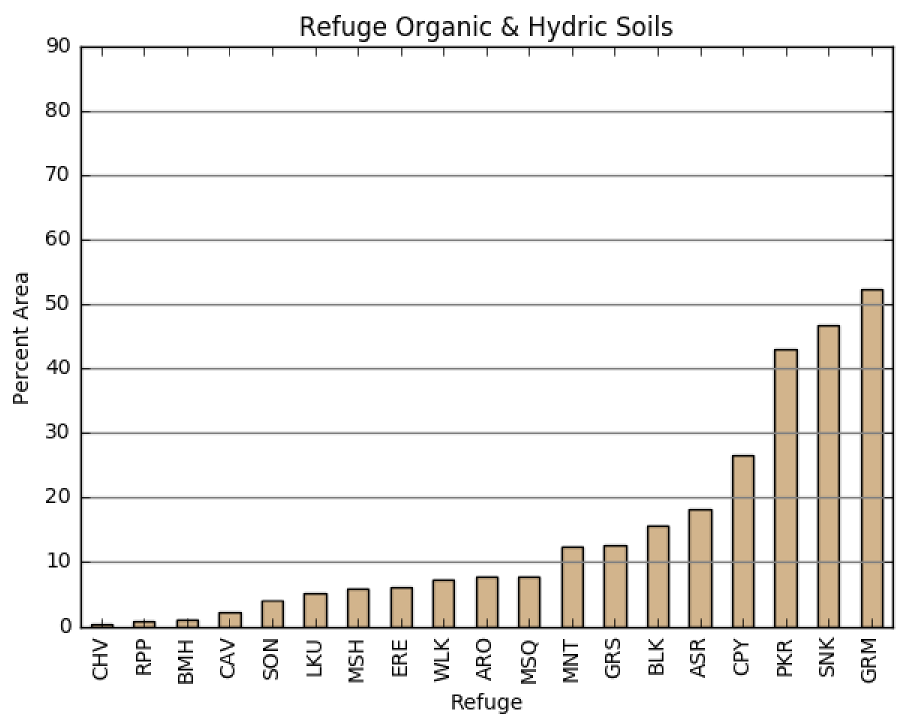

Figure 8. Refuges with soils that are both organic and hydric by percent of refuge acquisition boundary area. Excludes refuges that do not have both soil types (Chincoteague, Iroquois, John Heinz, Ohio River Islands, Patuxent, and Wallops Island).

3.4. Land Use

The National Land Cover Database (NLCD) serves as the definitive Landsat-based, 30-meter resolution, land cover database for the Nation. NLCD is created by the Multi-Resolution Land Characterization (MRLC) consortium, a group of federal agencies who coordinate and generate consistent and relevant land cover information at the national scale for a wide variety of environmental, land management, and modeling applications. For the purposes of this WRIA summary, the most recently available (2011) NLCD land cover classifications have been reviewed to assess the dominant land use in refuge RHIs. NLCD land cover classifications have been lumped into more generalized classes (Homer et al., 2015) (Table 7). Figures 10-14 shows land use types for the RHIs of refuges in the generalized classes of urban, forest, agriculture, wetland, and other (open water, barren, and shrub) as a percent of total RHI area. Forests are the most common land use type in all 25 refuge RHIs (Figure 9).

Table 7. Refuge RHI land use percentages. The shaded cells are the highest land use percentage per RHI. Units are percent.

Refuge	Urban	Forest	Agriculture	Wetland	Other
ARO	5.5	46.4	26.1	13.6	8.4
ASR	39.4	36.1	4.5	15.3	4.8
BLK	5.2	8.5	31.1	32.4	22.7
BMH	8.9	1.5	27.0	30.7	32.0
CAV	3.5	86.2	3.9	2.8	3.5
CHN	4.6	6.7	19.7	30.7	38.2
CHV	11.7	69.5	15.9	1.3	1.5
CPY	18.9	14.1	2.3	36.0	28.7
ERE	8.3	55.1	30.5	2.8	3.4
GRM	39.4	36.1	4.5	15.3	4.8
GRS	26.3	29.7	8.2	34.2	1.6
IRQ	5.0	8.3	57.6	27.7	1.4
LKU	1.4	76.9	0.1	5.7	15.9
MNT	6.6	11.7	55.8	11.7	14.3
MSH	3.4	57.4	1.8	15.0	22.4
MSQ	5.5	50.4	22.9	7.3	13.9
ORI	13.8	65.4	14.8	0.1	6.0
PKR	17.4	31.0	6.8	33.9	10.9
PWR	51.2	26.6	13.5	5.9	2.8
RPP	9.3	42.6	19.2	10.9	18.1
SNK	4.2	62.3	0.8	24.8	7.9
SON	0.6	83.5	0.2	10.6	5.1
TCM	67.2	13.1	5.4	8.1	6.3
WAL	4.6	6.7	19.7	30.7	38.2
WLK	13.0	39.2	28.8	16.1	2.9
Average	**15.0**	**38.6**	**16.8**	**16.9**	**12.6**

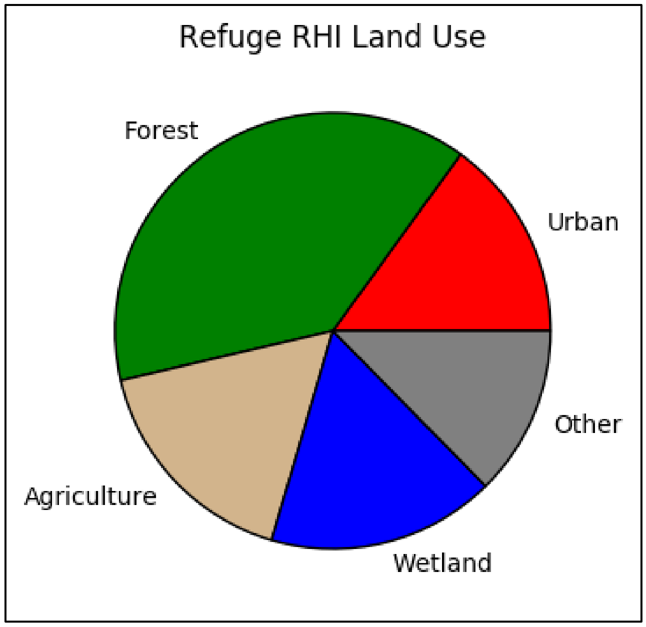

Figure 9. The average land use percentages of all refuge RHIs in this study.

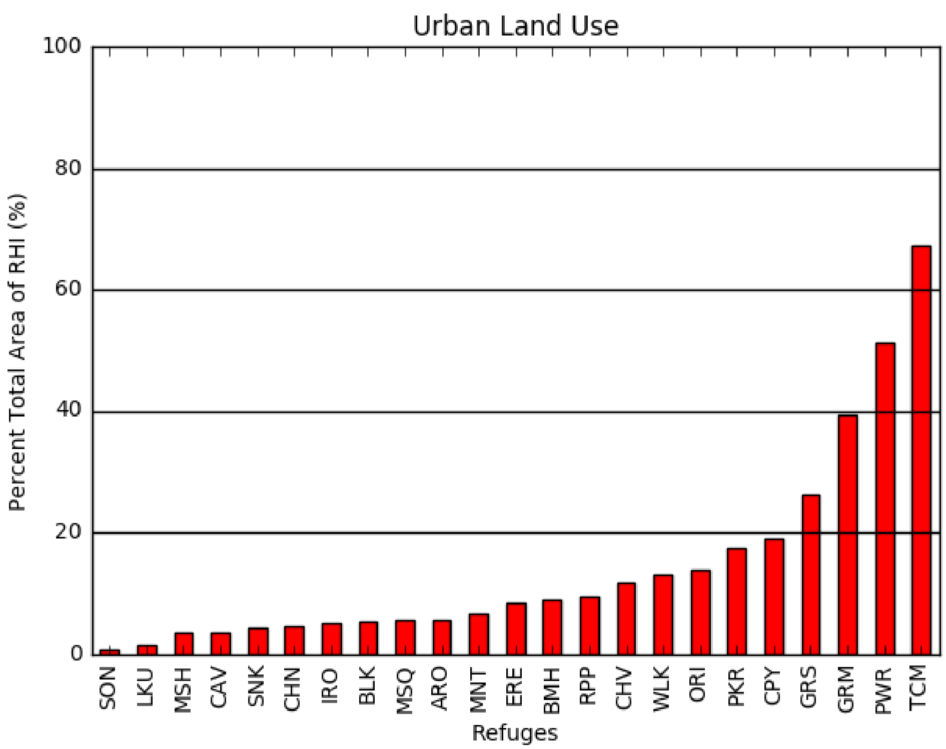

Figure 10. Urban land use percentages in the refuge RHIs.

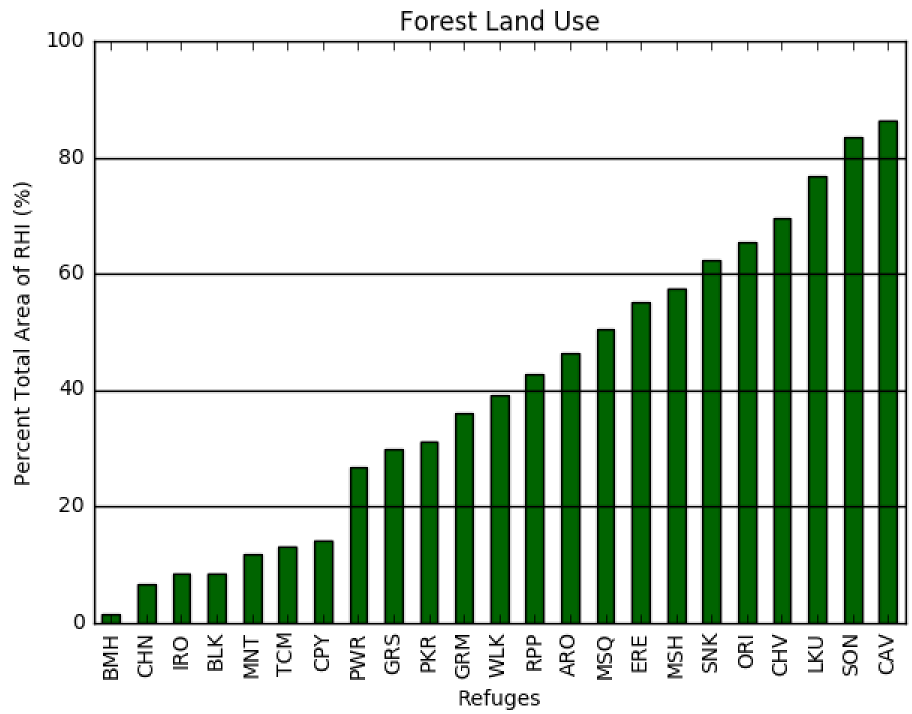

Figure 11. Forest land use (deciduous, evergreen, and mixed) percentages in the refuge RHIs.

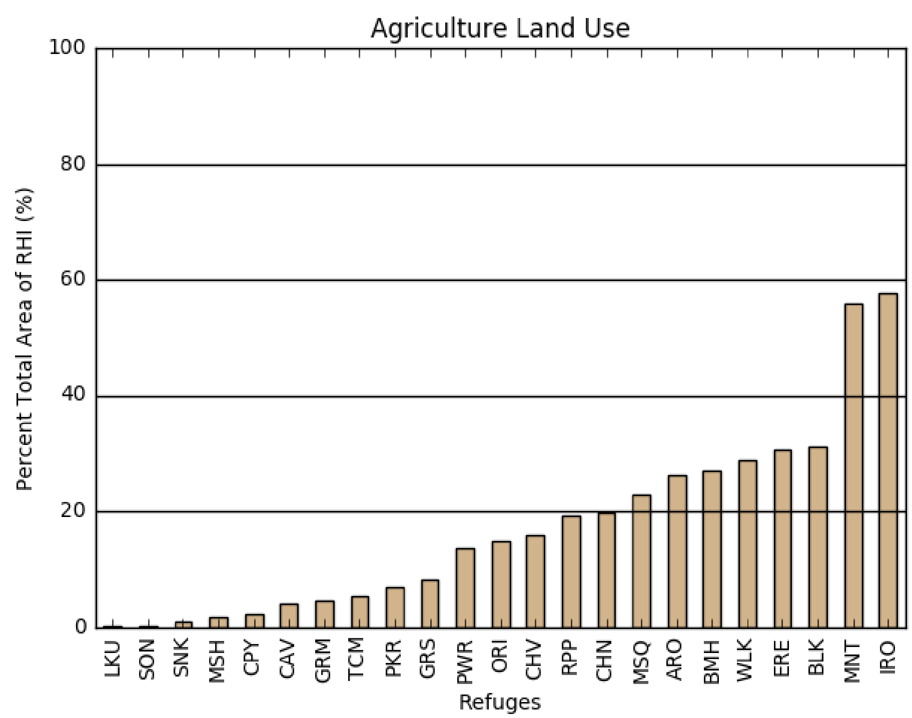

Figure 12. Agricultural land use (row crops and pastures) percentages in the refuge RHIs. Many of the refuges with the higher percentages of agriculture also have agriculture related water resource threats (Section 5).

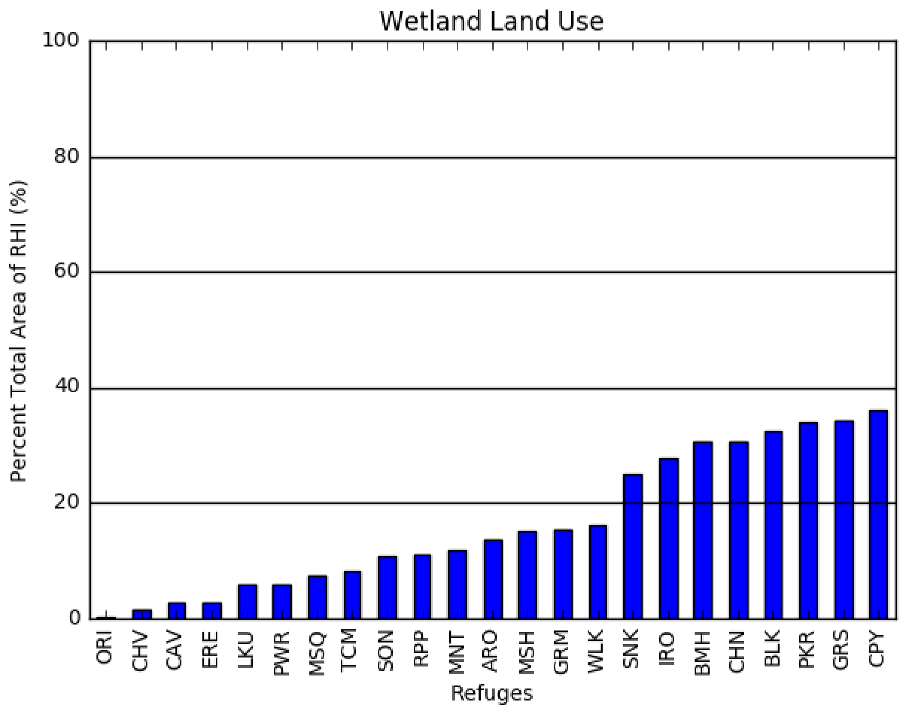

Figure 13. Wetland land use (herbaceous and woody) percentages in the refuge RHIs.

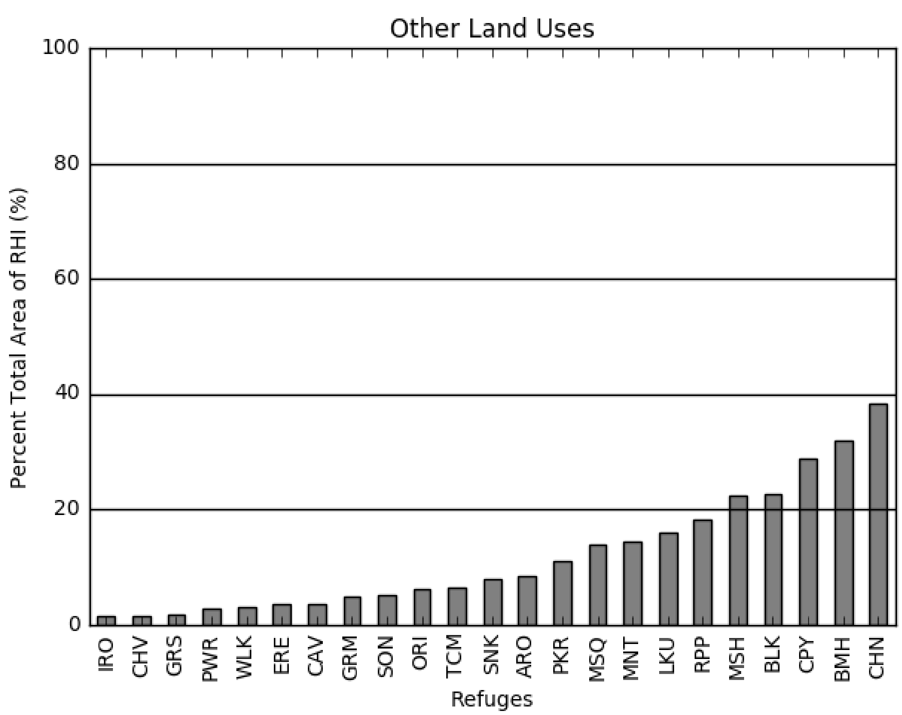

Figure 14. Other land use (open water, barren, shrub, and grasses) percentages in the refuge RHIs. Refuges with the highest percentages of other land use types have large areas of open water.

4. Inventory

This section of the Water Resources Inventory and Assessment (WRIA) summarizes basic information of a refuge's water resources, water-related infrastructure, water quality, water monitoring, water rights, and climatic trends. Data from this section is incorporated into the national WRIA database. Because of the coarse scale of these data, they are not expected to be a perfect representation of stream and water body locations.

4.1. Water Resources

Surface water features include lakes, ponds, springs, impoundments, reservoirs, rivers, streams, and creeks. Groundwater resources include regional and local aquifers that are important to the surface water resources of the refuge. Also included are wetlands identified in National Wetland Inventory maps that cover the refuge area.

4.1.1. Rivers / Streams / Creeks

The EPA and USGS collaborative project NHDPlusV2.1 was used to define rivers, streams, and creeks on refuges. NHDPlus was chosen over NHD because the stream networks are more complete. The linear water features on refuges as defined by NHDPlus include intermittent streams, but the larger rivers and streams are the focus of this analysis (USEPA and USGS, 2012).

The total stream lengths varied between the refuges (Table 8). Many of the large refuges had more total stream length; therefore, normalizing stream length to the refuge area provides a better representation of which refuges protect habitat closely associated with streams and rivers. Because the NHDPlus data includes both tidal and non-tidal waterways we removed tidal influenced streams for our analyses. Of the refuges reviewed for this study Erie, Great Meadows, and Ohio River Islands have the most non-tidal streams per refuge area (Figure 15).

Table 8. Ranges of total freshwater, non-tidal stream miles on refuges. Wallops Island has no non-tidal streams on the refuge.

Total Number of Stream Kilometers	Refuges
0-25	Aroostook, Assabet River, Blackwater, Bombay Hook, Cape May, Chincoteague, Iroquois, John Heinz, Missisquoi, Parker River
25-50	Great Meadows, Great Swamp, Ohio River Islands, Sunkhaze Meadows
50-75	Cherry Valley, Erie, Moosehorn, Nulhegan Basin, Patuxent
75-100	Canaan Valley, Montezuma, Wallkill River
100+	Rappahannock, Umbagog

Most of the refuges located in the Atlantic Coastal Plains physiographic province have rivers and streams that are tidally influenced. Not all of the streams are tidally influenced on these refuges (Figure 16). Some of these streams may be brackish, but others are freshwater.

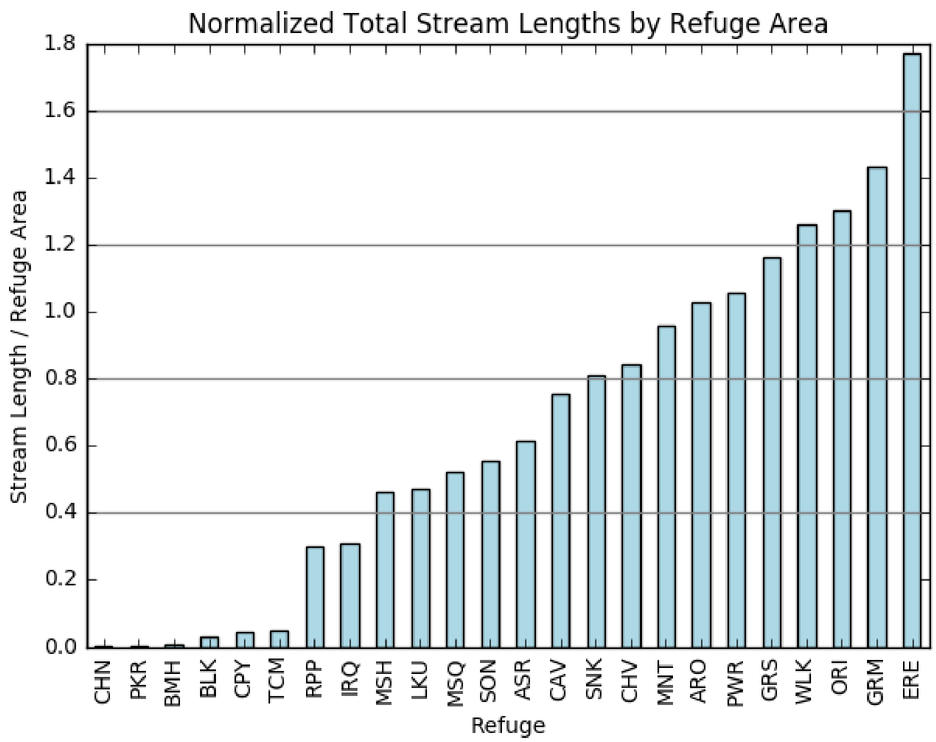

Figure 15. Refuge total non-tidal stream length, normalized by stream length (kilometers) per refuge area (square kilometers).

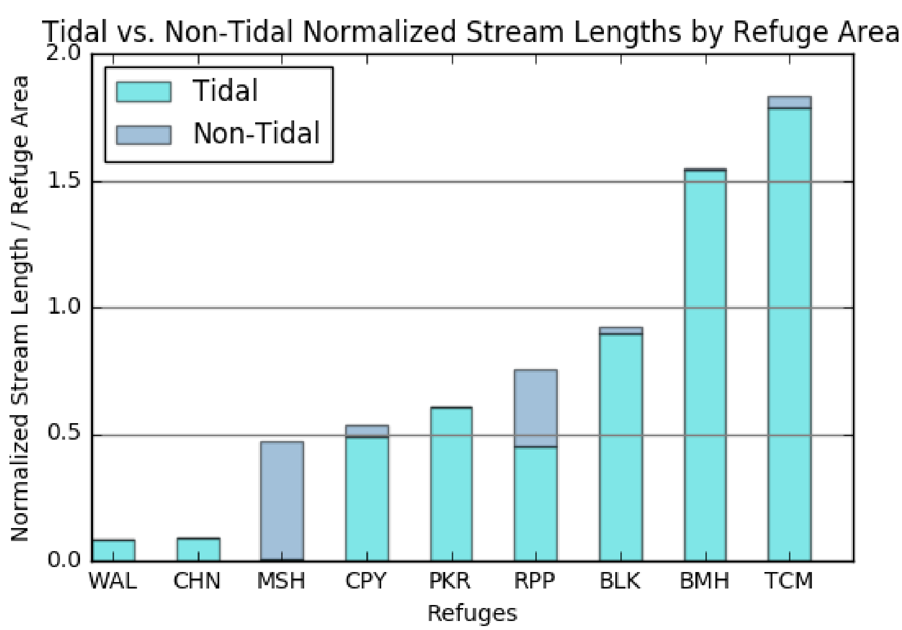

Figure 16. Tidal and non-tidal streams of refuges in the Coastal Plain physiographic province. The refuge stream lengths are normalized by refuge area.

4.1.1.1. Stream Networks

NHDPlus has a stream order attribute where the flowlines are ranked based on the Strahler stream order (McKay et al., 2012; USEPA and USGS, 2012). Refuge location in a watershed can be estimated by stream orders. A refuge with lower stream orders is most likely located in the headwaters of the watershed; a refuge with higher numbers is located on the coast or near another large body of water (Table 9). Most refuges in this study protect headwater streams (stream order 1, 2, and 3) (Figure 17; Table 10). The 25 refuges containing freshwater non-tidal streams are ranked by stream order in Figures 18-23.

Table 9. Examples of each steam order. Refuge streams were used where relevant.

Stream Order	Example	Stream Order	Example
1	Headwater streams, intermittent	**7**	Susquehanna River
2	Small brooks	**8**	Ohio River (Ohio River Islands)
3	Butterfield Brook (Aroostook)	**9**	Missouri River
4	Sunkhaze Stream (Sunkhaze Meadows)	**10**	Mississippi River
5	Concord River (Great Meadows)	**11**	Nile River
6	Seneca River (Montezuma)	**12**	Amazon River

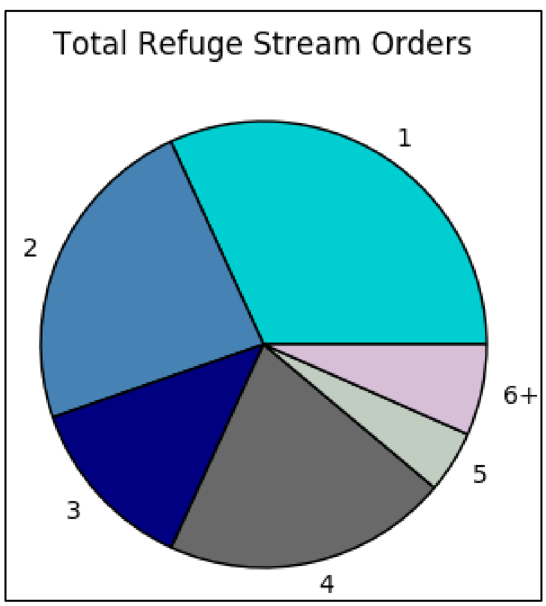

Figure 17. Pie chart of stream orders of non-tidal streams on all refuges in this study.

Table 10. The most common freshwater, non-tidal stream order on refuges. Wallops Island has no non-tidal streams on the refuge.

Stream Order	Refuges
1	Blackwater, Canaan Valley, Cape May, Cherry Valley, Chincoteague, Great Swamp, John Heinz, Montezuma, Moosehorn, Parker River, Rappahannock, Sunkhaze Meadows, Umbagog, Wallkill River
2	Aroostook, Assabet River, Erie, Nulhegan Basin
3	Bombay Hook
4	Great Meadows, Iroquois, Missisquoi, Patuxent
6+	Ohio River Islands

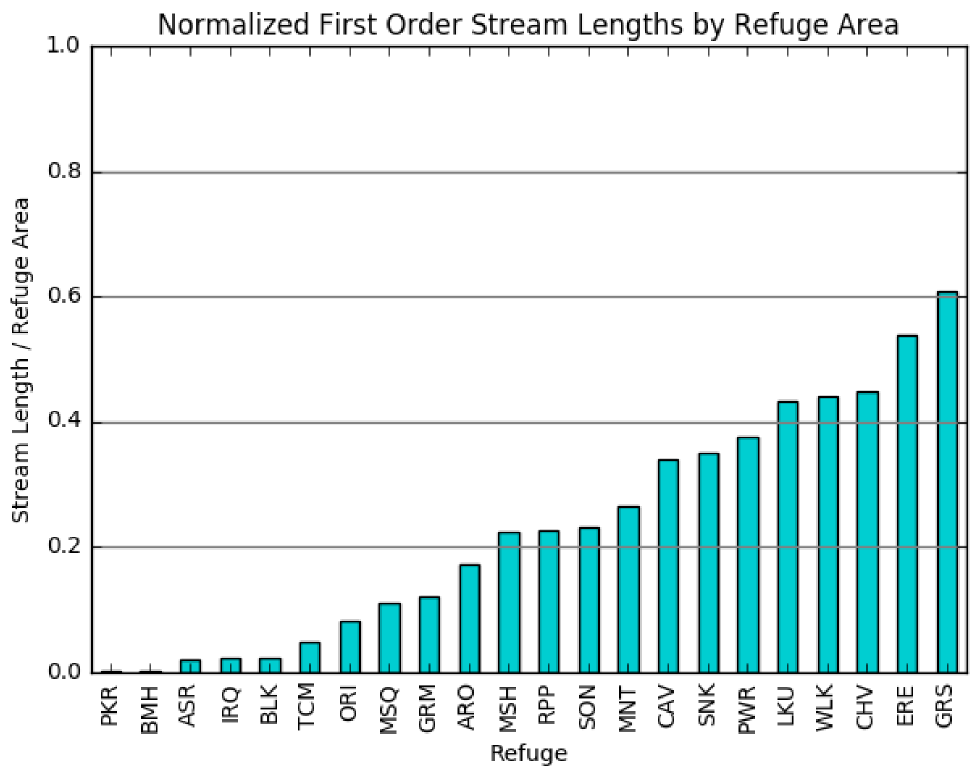

Figure 18. First order non-tidal streams on refuges, plotted by lengths (kilometers) normalized by refuge acquisition boundary area.

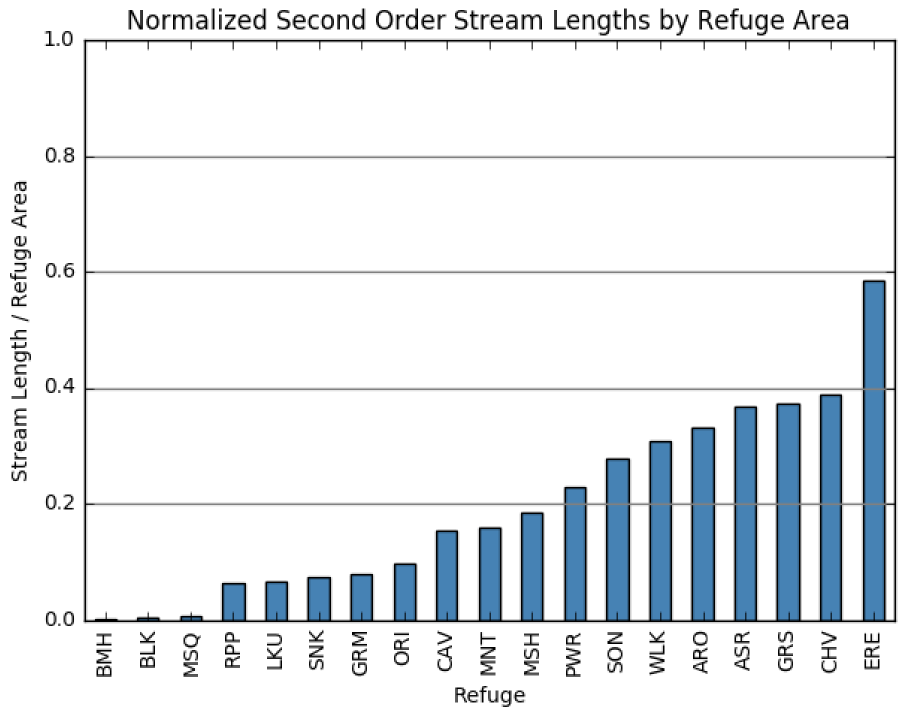

Figure 19. Second order non-tidal streams on refuges, plotted by lengths (kilometers) normalized by refuge acquisition boundary area.

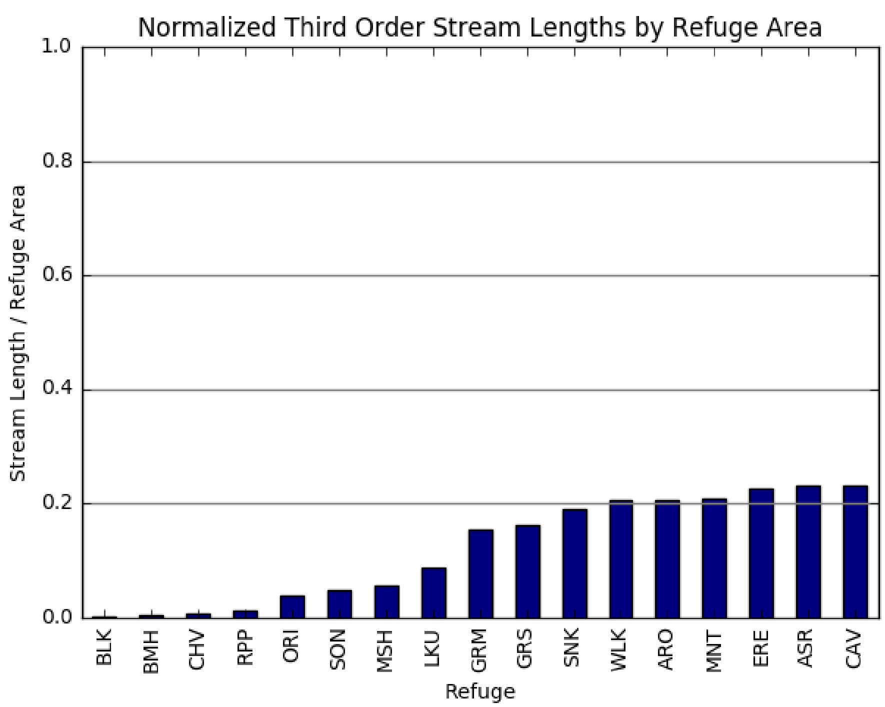

Figure 20. Third order non-tidal streams on refuges, plotted by lengths (kilometers) normalized by refuge acquisition boundary area.

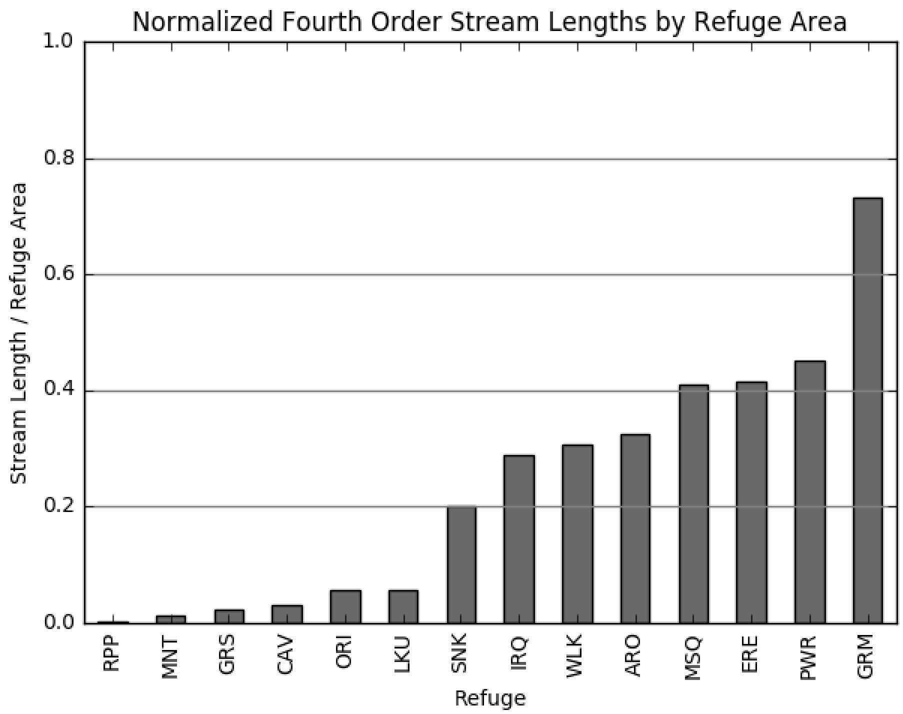

Figure 21. Fourth order non-tidal streams on refuges, plotted by lengths (kilometers) normalized by refuge acquisition boundary area.

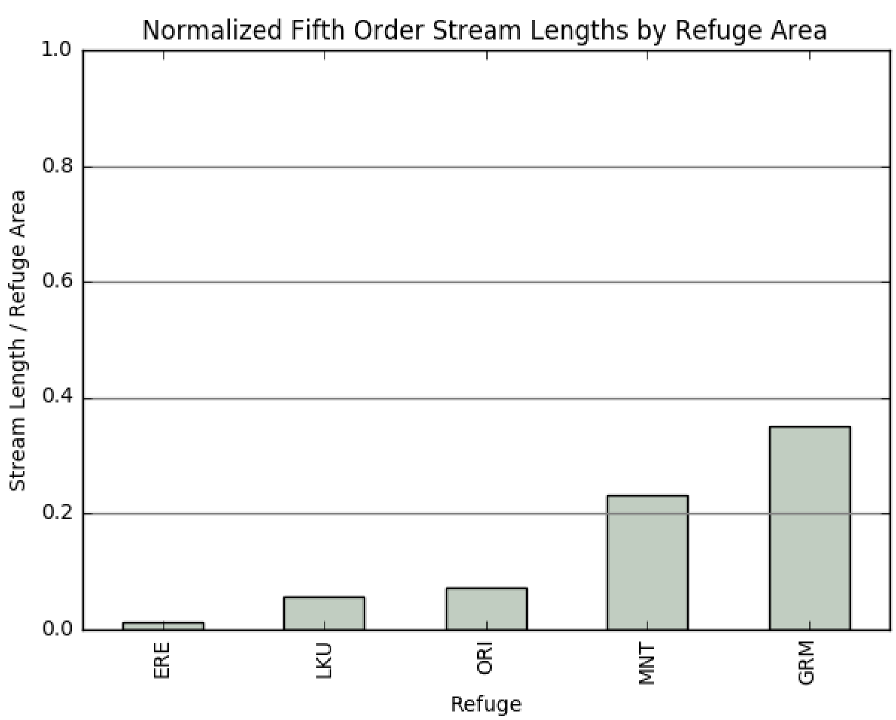

Figure 22. Fifth order non-tidal streams on refuges, plotted by lengths (kilometers) normalized by refuge acquisition boundary area.

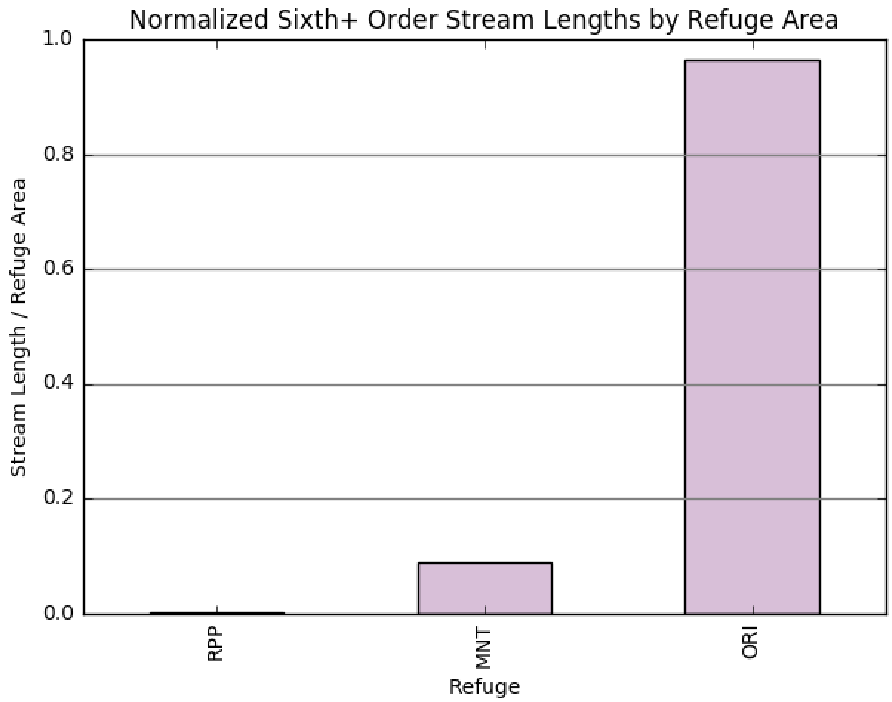

Figure 23. Sixth order and above non-tidal streams on refuges, plotted by lengths (kilometers) normalized by refuge acquisition boundary area.

4.1.2. Lakes and Ponds

Lakes and ponds on refuges were identified using the National Wetland Inventory (NWI) freshwater lakes and ponds classification. Impoundments on refuges are often included in the lake/pond designation because impoundments often are open water areas. Wallkill River and Ohio River Islands did not have any NWI lake/pond features within their approved boundaries. Other refuges, such as Montezuma, Missisquoi, Moosehorn, and Umbagog are bordering large lakes (Cayuga Lake, Lake Champlain, Meddybemps Lake, and Umbagog Lake respectively), which often drive local hydrology on the refuges (Figure 24). Coastal refuges also have lake/pond features; however, these waterbodies are brackish and tidal influenced in most cases (Figure 25) (USFWS, 2016).

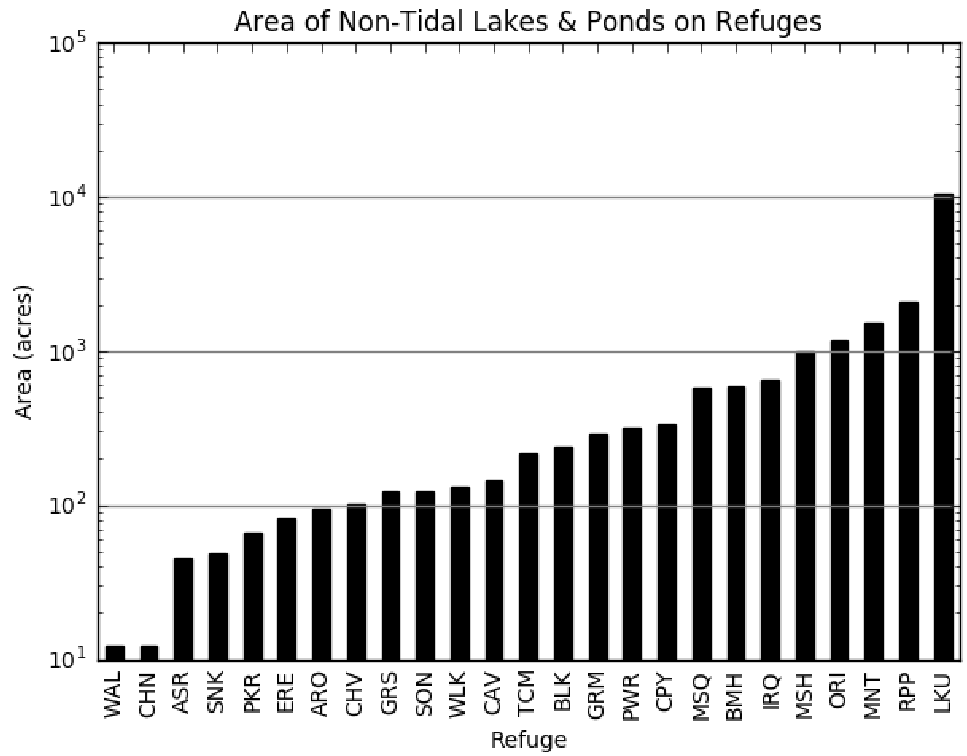

Figure 24. The area (acres) of lakes and ponds on refuges, displayed in a semi-log plot.

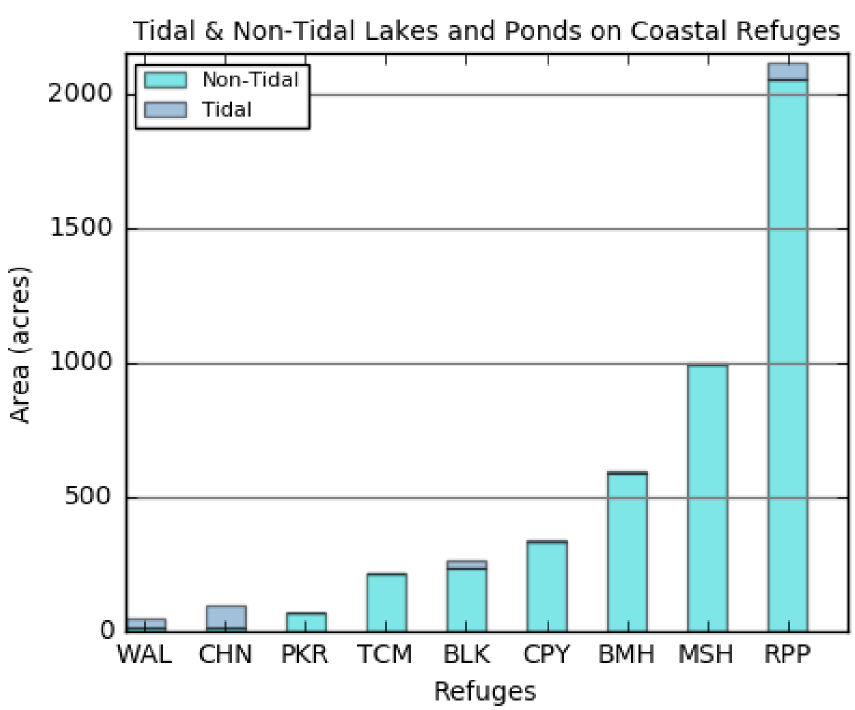

Figure 25. Area of tidal and non-tidal lakes and ponds on coastal refuges.

4.1.3. Wetlands

The National Wetland Inventory (NWI) is a branch of the Service established in 1974 to provide information on the extent of the nation's wetlands (Tiner, 1984). NWI produces maps of wetland habitat as well as reports on the status and trends of the nation's wetlands. Using the *Classification of Wetlands and Deepwater Habitats of the United States* (Cowardin et al. 1979), wetlands have been inventoried and classified for approximately 90% of the conterminous United States and approximately 34% of Alaska. Cowardin's classification places all wetlands and deepwater habitats into 5 "systems": marine, estuarine, riverine, lacustrine, and palustrine. Most of the wetlands in the United States are either estuarine or palustrine (Tiner 1984). The different systems can be broken down into subsystems, classes, and hydrologic regimes based on the wetland's position in the landscape, dominant vegetation type, and hydrology (Table 11; Figure 26).

Table 11. Percent acquisition boundary area of wetland types (according to NWI) and upland percentages per refuge. The most common wetland type for each refuge is shaded. The refuges are ranked from the most wetlands to the most uplands.

Refuge	Freshwater Forest/Shrub	Freshwater Emergent	Lake	Freshwater Pond	Riverine	Estuarine Wetland	Estuarine Deepwater	Upland
MSQ	46.5	26.8	7.3	0	5.2	0	0	14.2
CHN	3.2	0.3	0.1	0.4	0	58.9	22.2	14.9
PKR	1.1	3.5	0.5	0.6	0	60.9	18.4	15.0
BMH	2.9	2.2	0.4	2.5	0.2	61.4	13.4	17.0
WAL	3.3	7.6	0.6	0.3	0	56.4	11.4	20.4
GRS	58.2	14.8	0	1.3	1.2	0	0	24.5
TCM	4.3	19.3	14.4	3.2	31.0	0	0	27.8
CPY	49.2	0.3	0.9	0.3	0	17.3	2.5	29.5
IRQ	38.8	21.2	3.9	2.0	0.9	0	0	32.2
BLK	22.3	2.0	0.1	0.3	2.5	23.8	15.8	33.2
GRM	39.4	13.8	3.2	0.6	6.9	0	0	36.1
SNK	55.9	2.1	0	0.3	1.0	0	0	40.7
ORI	0.7	0.3	7.1	0.2	47.6	0	0	44.1
MNT	24.7	15.4	6.3	0.4	2.7	0	0	50.5
ERE	30.8	14.6	0	0.8	0.8	0	0	53.0
WLK	16.6	17.4	0.2	0.6	1.8	0	0	63.4
RPP	7.0	1.2	0.3	0.5	3.9	2.8	12.2	72.1
CAV	13.0	13.5	0	0.6	0.4	0	0	73.3
LKU	10.5	0.6	12.4	0.3	0.3	0	0	75.8
ARO	19.4	1.7	1.3	0.3	1.0	0	0	76.3
ASR	13.1	4.8	1.3	0.6	2.1	0	0	78.1
PWR	14.5	1.2	1.0	1.5	1.2	0	0	80.6
MSH	6.4	4.9	1.9	0.9	0.3	2.3	2.3	81.0
SON	16.7	0.5	0.3	0.2	0.7	0	0	81.6
CHV	3.9	0.4	0.1	0.3	0.7	0	0	94.6
Average	**20.1**	**7.6**	**2.5**	**0.8**	**4.5**	**11.4**	**3.9**	**49.2**

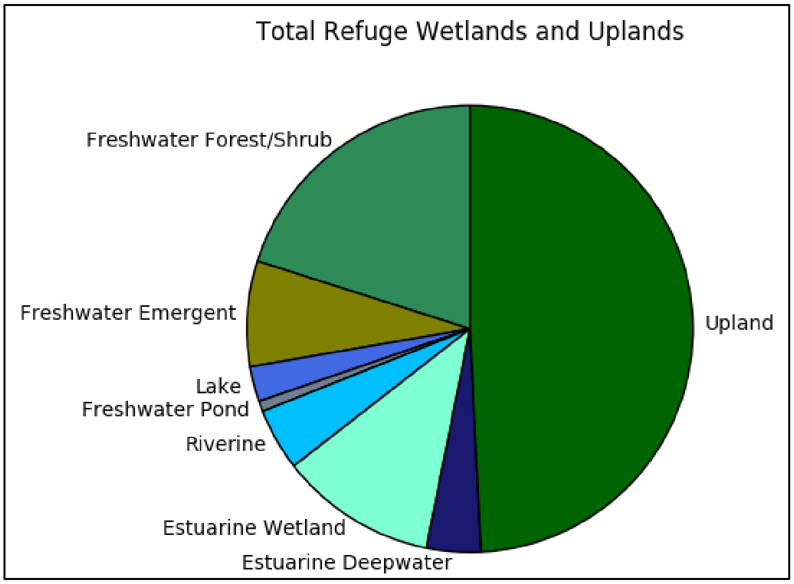

Figure 26. The total wetland classification and upland percentages of all of the refuges in this summary.

4.1.3.1. Palustrine Wetlands

Palustrine wetlands are defined by Cowardin et al. (1979):

Palustrine*: The Palustrine System includes all nontidal wetlands dominated by trees, shrubs, persistent emergents, emergent mosses or lichens, and all such wetlands that occur in tidal areas where salinity due to ocean derived salts is below 0.5% (e.g., inland marshes, bogs, fens, and swamps).*

All refuges in this study have palustrine wetlands (Figure 27). The forest/shrub and emergent type palustrine wetlands are the most common. Freshwater pond wetlands are man-made in most cases, with the occasional beaver pond. Missisquoi is the only refuge without freshwater pond wetlands. Most refuges have less than 1% total area as freshwater pond.

4.1.3.2. Lacustrine Wetlands

As defined by Cowardin et al. (1979), lacustrine wetlands are:

Lacustrine: *the Lacustrine System includes wetlands and deepwater habitats with all of the following characteristics: 1) situated in a topographic depression or a dammed river channel; 2) lacking trees, shrubs, persistent emergents, emergent mosses or lichens with greater than 30% areal coverage; and 3) total area exceeds 8 ha (20 acres). . . . Lacustrine waters may be tidal or nontidal, but ocean-derived salinity is always less than 0.5o/oo.*

Lacustrine wetlands form a fraction of a percent to nearly 15 percent of the refuge acquisition boundary area where they occur (Figure 28). Lacustrine wetlands are not present at all of the refuges in this study. Refuges without lacustrine wetlands include Canaan Valley, Erie, Great Swamp, and Sunkhaze Meadows.

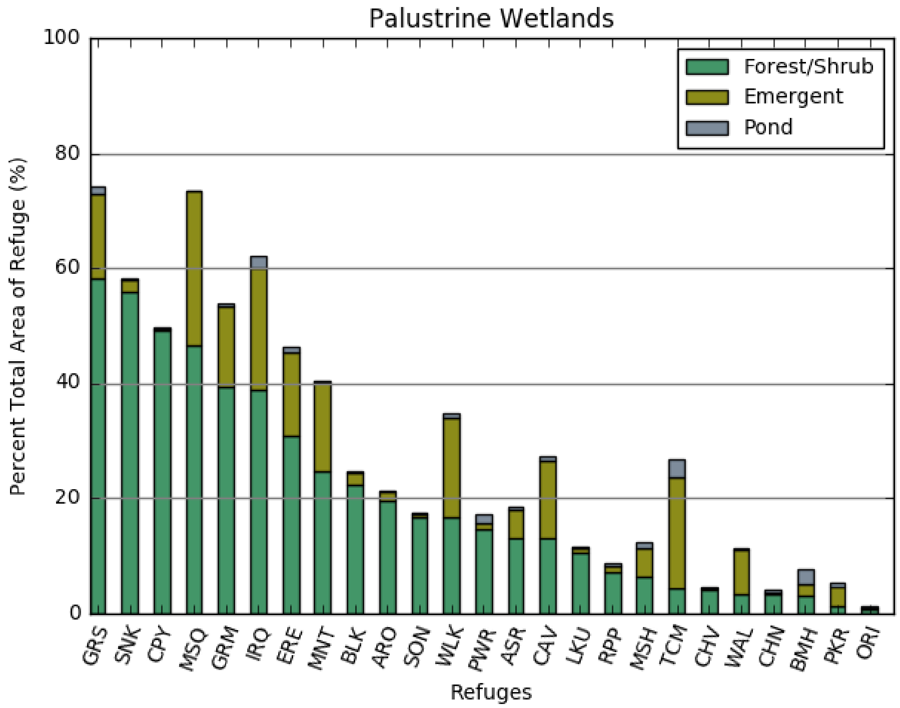

Figure 27. Refuges with palustrine wetlands (forest/shrub, emergent, and ponds) and the percent total area of the refuge that the wetlands occupy.

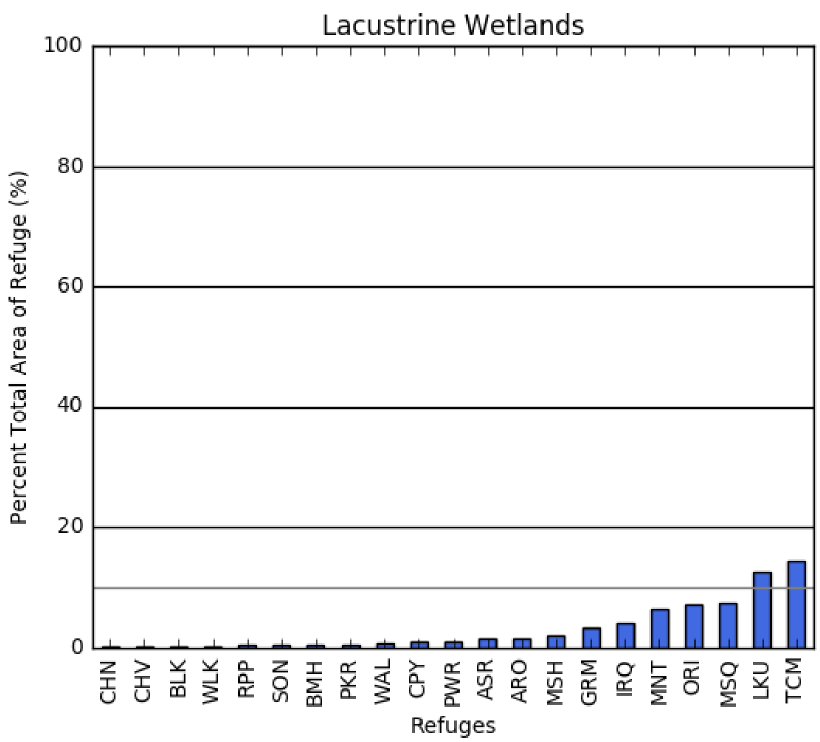

Figure 28. Refuges with lacustrine wetlands and the percent total area of the refuge that the wetlands occupy.

4.1.3.3. Riverine Wetlands

Riverine wetlands are defined by Cowardin et al. (1979) as:

Riverine: *The Riverine System includes all wetlands and deepwater habitats contained within a channel, with two exceptions: (1) wetlands dominated by trees, shrubs, persistent emergents, emergent mosses, or lichens, and (2) habitats with water containing ocean-derived salts in excess of 0.5 ‰. A channel is "an open conduit either naturally or artificially created which periodically or continuously contains moving water, or which forms a connecting link between two bodies of standing water" (Langbein and Iseri 1960).*

Most refuges in this study have riverine wetlands; which range from 1 percent to nearly 50 % of the refuge acquisition boundary area (Figure 29). Ohio River Islands and John Heinz appear to be outliers in that the riverine wetlands are greater than 10 percent of the refuge acquisition boundary area. Refuges that do not have riverine wetlands are Cape May, Chincoteague, Parker River, and Wallops Island. Those refuges are all coastal refuges with mostly estuarine wetlands, and are likely too saline to be classified as riverine wetlands.

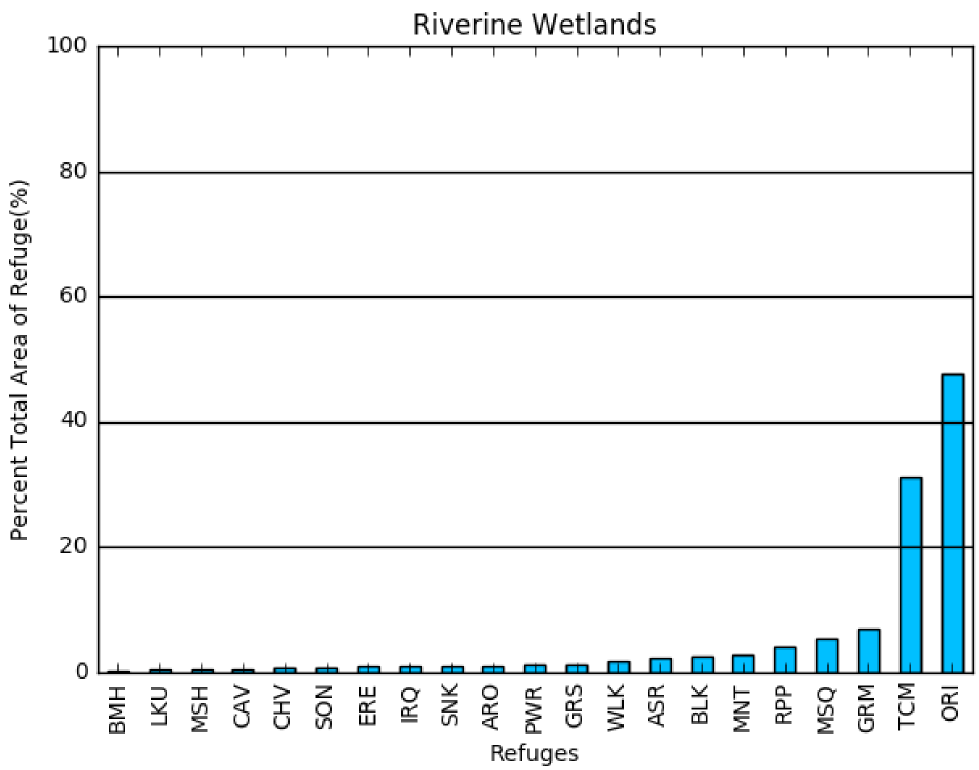

Figure 29. Refuges with riverine wetlands and the percent total area of the refuge that the wetlands occupy.

4.1.3.4. *Estuarine Wetlands*

Cowardin et al. (1979) defines estuarine wetlands as:

Estuarine: *the Estuarine System consists of deepwater tidal habitats and adjacent tidal wetlands that are usually semi-enclosed by land but have open, partly obstructed, or sporadic access to the open ocean. The Estuarine System extends (1) upstream and landward to where ocean-derived salts measure less than 0.5% during the period of average annual flow; (2) to an imaginary line closing the mouth of a river, bay, or sound; and (3) to the seaward limit of wetland emergents, shrubs, or trees where they are not included in (2).*

Refuges with estuarine wetlands are located in either the Atlantic Coastal Plain or New England Seaboard Lowland physiographic provinces. Refuges in these provinces that do not have estuarine wetlands are Assabet River, Great Meadows, John Heinz, and Patuxent (Figure 30). The majority of the refuges in this study do not have estuarine wetlands.

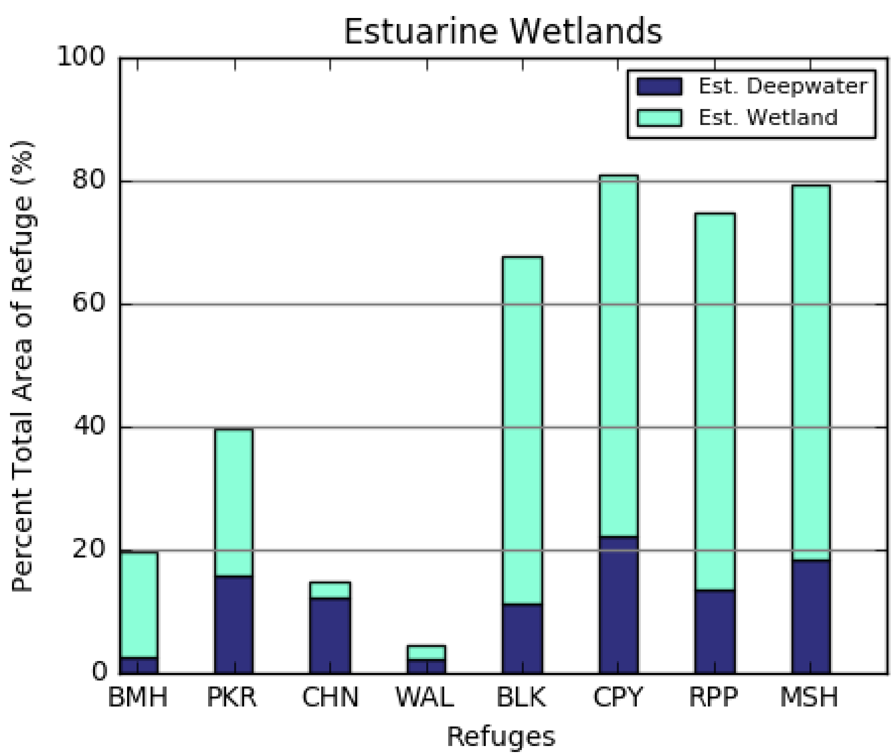

Figure 30. Refuges with estuarine wetlands (including deep-water) and the percent total area of the refuge that the wetlands occupy.

4.1.3.5. Uplands

Upland areas are characterized as non-wetland upland forests or meadows (Figure 31). More details on upland habitat types for each of the refuges can be found in Comprehensive Conservation Plans (CCPs) or Habitat Management Plans (HMPs).

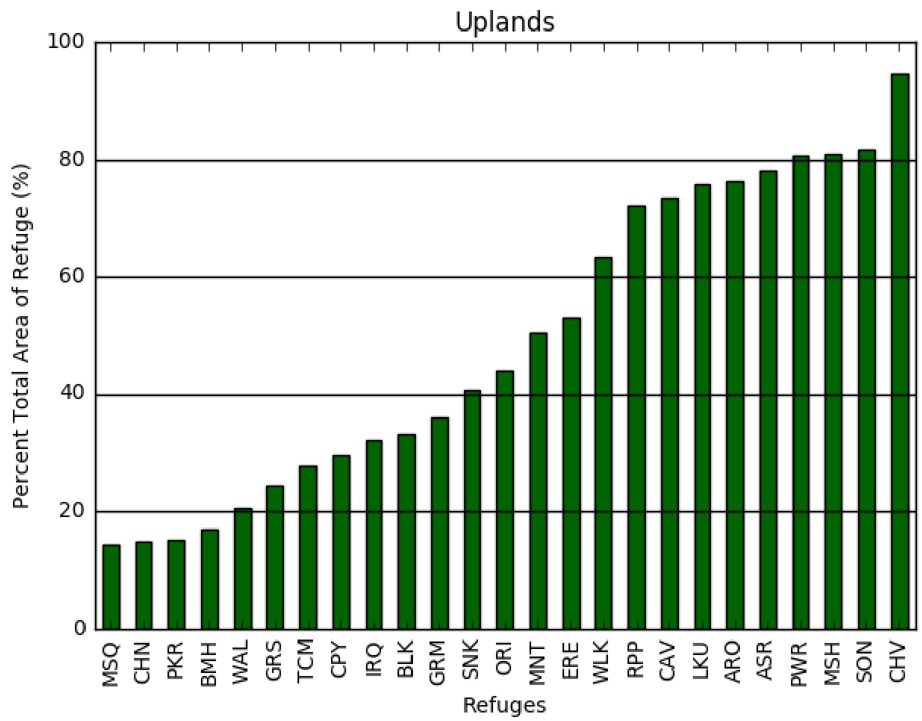

Figure 31. Refuge uplands and the percent total area of the refuge that the uplands occupy.

4.1.3.6. Vernal Pools

Vernal pools are small wetlands that fill with water during the winter months and dry up during the summer (Mitsch and Gosselink, 2015). The seasonal drying makes vernal pools unsuitable for fish populations. The absence of fish reduces predation which makes vernal pools important habitat for some amphibians and other organisms such as fairy shrimp.

Table 12. Refuges with vernal pools and part of the USGS vernal pool survey.

Refuges With Vernal Pools		
Aroostook*	Great Swamp*	Patuxent*
Assabet River*	Iroquois*	Rappahannock*
Canaan Valley*	John Heinz*	Sunkhaze Meadows*
Cape May	Moosehorn*	Umbagog*
Cherry Valley	Nulhegan Basin*	Wallkill River*
Erie*	Ohio River Islands*	

** Indicates refuges part of the USGS vernal pool survey.*

4.1.4. Springs

A spring is defined as a location where the water table is at ground surface. Springs tend to be thought of as a distinct outflow point. Seeps are similar to springs, but tend to be spread out over a large area with no distinct output. Springs and seeps often host unique species that benefit from constant temperatures and unique water chemistry. Wetlands, lakes, and streams that are fed by springs and seeps can be classified as groundwater-dependent ecosystems because springs are found where groundwater aquifers approach the land surface (see Section 4.1.5.1).

Springs on refuges were identified using mapped springs in the USGS National Water Information System (NWIS) database. Most of the springs in the NWIS database have been used for groundwater water quality sampling or groundwater level measurements (USGS, 2016). There are many springs on refuges and across the country that have not been captured by the USGS NWIS database (Table 13). Refuges with USGS mapped springs likely also have many more unmapped springs and seeps. Iroquois NWR has historical springs (Sour Springs) that were once bottled to cure ailments; however, these springs at Iroquois NWR are not mapped by USGS.

Table 13. Refuges where springs are important water resources.

Refuges with USGS mapped springs	Canaan Valley, Cherry Valley, Great Meadows, Ohio River Islands
Refuges that have unmapped springs and seeps	Aroostook, Great Swamp, Iroquois, Montezuma, Nulhegan Basin, Rappahannock, Umbagog [ǂ], Wallkill River

ǂ Umbagog only has seeps, no known springs.

4.1.5. Groundwater

Groundwater is the drinking source for more than 50 percent of the United States. However, the main use of groundwater in the United States is for irrigation purposes (Clark and Briar, 2001). Groundwater is also an important source of water for rivers, lakes, and wetlands and is particularly important for unique ecosystems like Calcareous Fens, Pocket Swamps, Atlantic White Cedar Swamps, and Hardwood Seepage Forests. WRIAs evaluate aquifers underlying refuges to assess how groundwater supports refuge water resources and potential threats due to groundwater pumping. This is particularly important at refuges on the Atlantic Coastal Plain (see Table 2) where groundwater is the primary source of water for agriculture, industrial, and municipal uses (Masterson et al. 2016).

Aquifers underlying the refuges (Figure 32) are a reflection of the local and regional geology (see Section 3.2). Many refuges have important surficial aquifers that are composed of glacial, coastal, or alluvial sediments:

- **Glacial aquifers** are dominant in the northeast region as the last glacial maximum extended through northern Pennsylvania and New Jersey (Figure 5).

- **Coastal aquifers**, located in the Atlantic Coastal Plain physiographic province, are mostly consolidated or semi-consolidated sands. These aquifers are usually high producing, but are easily contaminated by human activity on the surface.

- **Alluvial aquifers** are sediments deposited by streams and rivers. These aquifers are local important and can be high producing in certain areas. Depending on the flow of the adjacent stream and the water table level, alluvial aquifers can either provide base-flow to streams or recharge from the stream.

- **Bedrock aquifers** are the principal aquifers at refuges without one of the three aquifer types listed above. Water in bedrock aquifers is stored and transported through cracks and fractures in the rock. Where these fractures approach the land surface water flows between the aquifer and surface water features or form springs. In general, bedrock aquifers in this review are composed of sedimentary rocks, limestone and sandstone, and often yield less water than other aquifer types. Exceptions are in limestone bedrock aquifers, where chemical weathering can increase the size of voids and fractures, increasing the water yield in places. These aquifers, often referred to as karst aquifers, are likely to support springs and seeps. Additionally, contaminants usually move through karst aquifers rapidly.

Glacial Aquifers

- Aroostook
- Assabet River
- Erie
- Great Meadows
- Great Swamp
- Iroquois
- Montezuma
- Moosehorn
- Nulhegan Basin
- Parker River‡
- Sunkhaze Meadows
- Umbagog

Coastal Aquifers

- Blackwater
- Bombay Hook
- Cape May
- Chincoteague
- Parker River‡
- Patuxentᴥ
- Rappahannockȣ
- Wallops Island

Alluvial Aquifers

- John Heinz
- Missisquoi
- Ohio River Islands
- Patuxentᴥ
- Rappahannockȣ

Bedrock Aquifers*

- Canaan Valley
- Cherry Valley
- Wallkill River

‡ Parker River has both glacial and coastal aquifers
ᴥ Patuxent has both coastal and alluvial aquifers
ȣ Rappahannock is underlain by predominantly coastal aquifers; however, there are likely local alluvial aquifers.
****** Bedrock aquifers are dominant at the listed refuges.***

Figure 32. Lists of refuges that have glacial, coastal, and alluvial surficial aquifers, and bedrock aquifers.

4.1.5.1. Groundwater-Dependent Ecosystems

In addition to being a drinking water source for humans, groundwater also provides water to many surface water features. In wetlands and streams fed by groundwater, water temperatures and the water supply are more stable throughout the year. Additionally, groundwater flow can impart unique chemical compositions to surface water that supports unique flora and fauna. In the western United States, groundwater-dependent ecosystems (GDEs) are recognized as important for the conservation and management of water resources as severe droughts and human population growth threatens these unique ecosystems (Howard and Merrifield, 2010). The hydrologic processes supporting these features are thought to be more resilient to changing climate patterns and are expected to serve as important refugia to aquatic species in the future.

We analyzed various geospatial data to determine where potential groundwater-dependent ecosystems (GDEs) are located on the 25 refuges in this review. GIS data used to identify potential GDEs are all publicly available and include U.S. Geological Survey (USGS) National Water Information System (NWIS) and National Hydrography Dataset (NHD) springs, National Wetland Inventory (NWI) palustrine wetlands and lakes, Soil Survey Geographic Database (SSURGO) organic and hydric soils, NHD flowlines, USGS Base Flow Index (BFI), USGS Karst Map, USGS surficial geology map, USGS state geologic maps with faults, and digital elevation models (DEMs).

Using the geospatial data listed above, potential GDEs were identified on all of the refuges included in this study. Potential GDEs are grouped into different physical water resource features: springs, streams, lakes, and wetlands.

Springs

Springs by definition are a surface expression of groundwater; therefore they are entirely dependent on groundwater. The USGS NWIS dataset was used to define springs for the GDE analysis. As noted in Section 4.1.4, only four refuges have NWIS springs:

Refuges with USGS springs	
Canaan Valley	**Great Meadows**
Cherry Valley	**Ohio River Islands**

Field surveys at the refuges would likely identify many more refuges with springs.

Groundwater-Dependent Streams

The contribution of groundwater to stream flow is referred to as “base-flow.” The USGS Base Flow Index (BFI), calculates the ratio of base-flow to total flow for USGS stream gaging stations (Wolock, 2003). A high base flow index indicates a large percentage of the stream flow is derived from groundwater. A low base flow index indicates a large percentage of stream flow is derived from overland flow and near surface flow processes. The USGS BFI data was used to identify NHDPlus streams on refuges that are likely groundwater-dependent. For the purposes of this review, groundwater-dependent streams were defined as having a BFI greater than or equal to 50 percent. About 70% of the 25 refuges in this study have at least some streams with a BFI of greater than or equal to 50 percent (Table 14). On 11 refuges, all of the NHDPlus streams had BFI exceeding 50% indicating streamflow is highly dependent on groundwater.

Table 14. Streams with greater than or equal to 50% BFI on refuges.

Stream BFI	Refuges
100%	Aroostook, Assabet River, Blackwater, Bombay Hook, Cape May, Chincoteague, Great Meadows, Montezuma, Moosehorn, Parker River, Wallops Island
50 – 99%	Cherry Valley, John Heinz, Patuxent, Rappahannock
1 – 49%	Nulhegan Basin, Sunkhaze Meadows, Wallkill River
0%	Canaan Valley, Erie, Great Swamp, Iroquois, Missisquoi, Ohio River Islands, Umbagog

Groundwater-Dependent Lakes

Many of the refuges have large waterbodies as described in Section 4.1.2. However, for the purposes of the GDE analysis, ponds and man-made lakes were excluded. While some of those man-made features may in fact be groundwater-dependent, they were excluded because they are not natural features. Completing a field reconnaissance at the refuges will provide more information on man-made waterbodies and their reliance on groundwater.

The National Wetland Inventory (NWI) data was used to define potential GDE lakes. Wetland features identified as lacustrine wetlands were included in the GDE analysis as lakes after removing man-made waterbodies. Potential GDE lakes were identified at 8 of the 25 refuges:

Refuges with potential GDE lakes			
Assabet River **Great Meadows**	**Iroquois** **Missisquoi**	**Montezuma** **Moosehorn**	**Nulhegan Basin** **Umbagog**

Groundwater-Dependent Wetlands

NWI data was used to define wetlands that are potentially groundwater-dependent. Only palustrine wetlands with a 'Seasonally Saturated' ('B') hydrologic modifier were included as potential GDE wetlands as they are most likely to be supported by groundwater (USFWS, 2016). These palustrine wetlands were then ranked for probable groundwater dependence by comparing their location with other geospatial data indicative of groundwater discharge processes that support wetland features. Palustrine, seasonally saturated wetlands that intersect, or are near, these other geospatial features are thought to have a higher probability of being dependent on groundwater than wetlands that do not intersect these data layers. Criteria for ranking probability of groundwater dependence for wetlands are listed below:

- **Soil.** Intersecting soil types with more than 20% hydric or organic soil classifications, as defined by SSURGO data (Section 3.3).
- **Geology**:
  - Intersecting carbonate bedrock (USGS Karst Map) near the land surface, under <50 feet of glacial sediments, or unconsolidated carbonates near the land surface.
  - Intersecting permeable surficial geology (USGS surficial geology map) that is course grained and thin (Section 3.2.2).
  - Within 100 m of a geologic fault (USGS state geologic maps).
  - Within 100m of a geologic contact between two different geologic rock or sediment types (USGS state geologic maps).
- **BFI streams.** Within 100 meters of a stream with a BFI $\geq$50%.
- **Topographic position.** Located at the base of topographic features like, terraces, scarps, ridges, dunes, and hills. Defined as the toe of a slope, using the "Curvature" function in ArcGIS.

Table 15. Number of potential GDE wetlands at each refuge and ranking of wetlands. Lower rankings indicate a higher probability of groundwater dependence.

Refuge	Total Potential GDE wetlands	GDE Wetland Rankings
Cape May	1233	4-10
Wallkill River	1143	3-10
Canaan Valley	673	3-10
Great Swamp	667	6-10
Rappahannock	455	4-10
Nulhegan Basin	161	5-9
Moosehorn	134	7-10
Erie	59	7-10
Bombay Hook	56	5, 7-9
Iroquois	36	7-10
Missisquoi	34	6-10
Blackwater	15	6-8
Umbagog	11	5-10
Great Meadows	8	6, 7
Chincoteague	5	7-9
Montezuma	4	7-9
Sunkhaze Meadows	3	7, 9
Aroostook	2	5, 10
Cherry Valley	2	7
Ohio River Islands	2	8, 9
Parker River	2	7, 8
TOTAL	**4705**	**3-10**

Palustrine seasonally saturated wetlands that overlap with all of the geospatial data layers above have the greatest potential for being groundwater dependent. About 84% of refuges (Table 15) in this review had some potential wetland GDEs (see examples in Figures 33 and 34). Potential GDE wetlands were not identified at Assabet River, John Heinz, Patuxent, and Wallops Island.

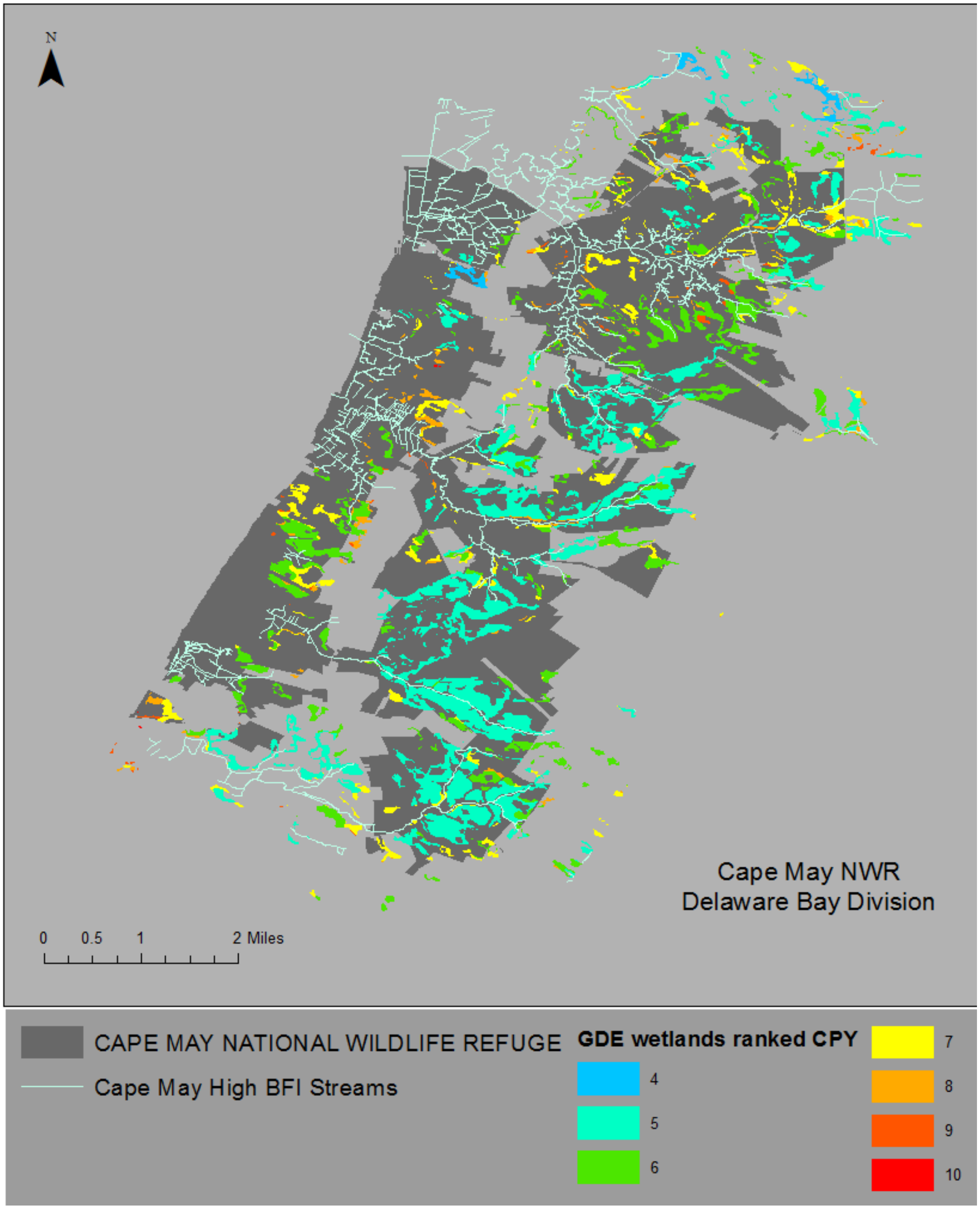

Figure 33. Potential GDEs at Cape May NWR – Delaware Bay Division. Lower rankings indicate a higher probability of groundwater dependence. Note that only stream and wetland potential GDEs were identified through this exercise at Cape May NWR.

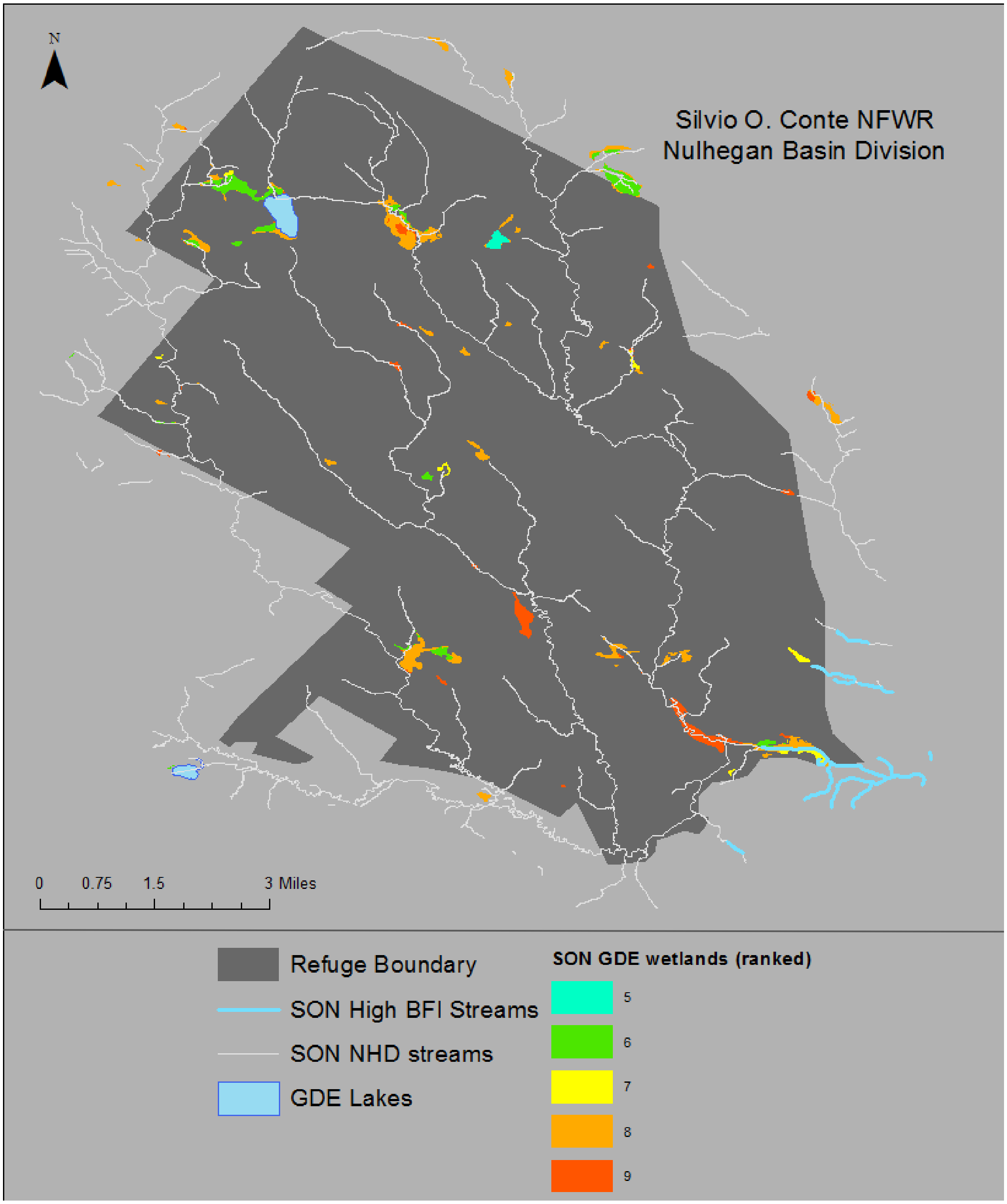

Figure 34. Potential GDEs at Nulhegan Basin Division of Silvio O. Conte NFWR. Lower rankings indicate higher probability of groundwater dependence. Only springs are missing as potential GDEs.

4.2. Water Related Infrastructure

Water related infrastructure refers to the assets at a refuge that control the movement of water on the landscape. These can include infrastructure constructed by USFWS (i.e. wetland impoundments) or legacy infrastructure that was constructed by others prior to refuge ownership (i.e. roads, dikes, mill dams, etc.). Many of these types of features are accounted for in the National Wildlife Refuge System's Service Asset Maintenance Management System (SAMMS) database. The aim of the WRIA is to summarize information and provide additional context on a refuge's water resource infrastructure.

4.2.1. Impoundments

Wetland impoundments were built by the US Fish and Wildlife Service on many refuges to provide nesting foraging, and brooding habitat for waterfowl and other migratory birds. Many impoundments were built to restore historic wetlands that may have been drained for agricultural or urban and suburban development. There are 230 impoundments on 15 of the 25 refuges in this study. Total impoundment acreage on these 15 refuges is 18,642 acres (Table 16).

Table 16. Refuges with wetland impoundments, including the number of impoundments and total acreage of those impoundments.

Refuge	Number of Impoundments	Impoundment Total Acreage
Montezuma	17	6,031
Iroquois	18	4,000
Chincoteague	14	2,658
Missisquoi	3	1,252
Moosehorn	31	1,073
Bombay Hook	20	879
Patuxent	72	570
Great Swamp	5	480
Blackwater	25	450
Erie	16	326
Wallkill	1	300
Parker River	3	262
Great Meadows	2	200
John Heinz	1	145
Aroostook	2	16
TOTAL	**230**	**18,642**

Water control structures associated with impoundments on refuges include stop-logs, box culverts, ditches and canals, slide gates, screw gates, and flaps. In general, it is common to see water control structures at refuge impoundments that are aged, undersized, blocked with debris, or no longer functioning.

4.2.2. Canals / Ditches

Ditches and canals are man-made features that alter water movement on refuges. Many ditches were prior to refuge ownership to drain wetlands and direct water to nearby streams. At many coastal refuges, ditches were built for mosquito control purposes by local mosquito control agencies. In addition to the ditches there are navigation canals near refuges that also impact refuge hydrology. In many cases, spoil removed during ditch construction was used to build dikes and roads adjacent to the ditches and canals. These features can act like small dams that restrict water movement and create impounded conditions on the landscape (Table 17).

Table 17. Refuges where water resources are negatively impacted by management of canals or ditches. Blackwater, Bombay Hook and Montezuma are impacted by both canals and ditches.

Ditches	Aroostook, Blackwater, Bombay Hook, Canaan Valley, Cape May, Cherry Valley, Chincoteague, Great Meadows, Great Swamp, John Heinz, Montezuma, Parker River, Rappahannock, Wallkill River
Canals	Blackwater, Bombay Hook, Iroquois, Montezuma
No ditches or canals	Assabet River, Erie, Missisquoi, Moosehorn, Nulhegan Basin, Ohio River Islands, Patuxent, Sunkhaze Meadows, Umbagog, Wallops Island

4.2.3. Dams

Dams fundamentally alter flood regimes, sediment transport, and in-stream aquatic ecosystems in rivers (Collier et al. 1996). Weiskel et al. (2010) summarize the three impacts dams have on river ecosystems. These impacts apply to river reaches upstream and downstream of the dam:

1. Dams change flow regimes and sediment transport.
2. Dams can change water temperature and concentration of dissolved oxygen
3. Dams restrict the passage of nutrients, fish and other aquatic biota.

At the refuge scale, effects of dams will vary depending on the refuge's location relative to a particular dam. For example, immediately downstream of a dam, sediment-starved water released from the dam often causes excessive erosion in the river channel (Collier et al. 1996). Alternatively, sediment accumulates in the impounded river reach upstream of a dam (Collier et al. 1996). To a large extent, the number of dams on a river is positively correlated with the river's degree of hydrologic alteration (Weiskel et al. 2010). As alterations to rivers' flow regimes, sediment supplies, and connectivity increase, there is a corresponding decline in the number of fish that depend on riverine flow conditions (Armstrong et al. 2010).

Water resources are negatively affected by dams on about half of the refuges in this study (Table 18). In most cases, the dams alter flow regimes, result in compromised water management capabilities, and alter important habitats on refuges (see Section 5 for more information). Aroostook and Iroquois have dams both on and off the refuge that negatively impact water resources. Several refuges not listed in Table 18 have small dams on, or near, the refuge but these were not a concern to refuge staff (i.e. Great Swamp).

Table 18. Refuges where water resources are negatively impacted by dams.

Refuge	On Refuge Dams	Off Refuge Dams
Aroostook	X	X
Assabet River		X
Erie	X	
Great Meadows		X
Iroquois	X	X
Montezuma		X
Ohio River Islands		X
Parker River		X
Patuxent	X	X
Umbagog		X

4.2.4. Roads

Refuge staff identified roads and road crossings as one of the greatest threats to refuge water resources. Roads can degrade aquatic habitat by increasing sedimentation, fragmenting habitat, and providing pathways for invasive species (Lugo and Gucinski, 2000). Roads can impact the natural movement of water across the landscape, particularly when they cross wetlands and streams and are equipped with undersized culverts or bridges.

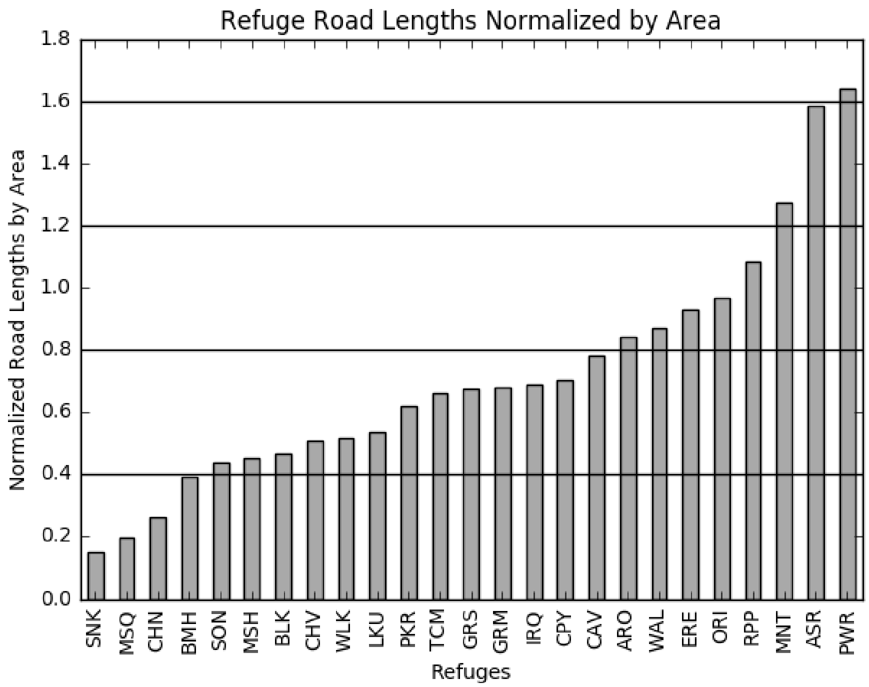

Figure 35. The total length of refuge roads, normalized by the refuge area.

In general, large refuges have more roads. However, the relative impact of roads may be small because their overall density is less than on small refuges. To assess road density between refuges of varying sizes, the total length of refuge roads was normalized to refuge acquisition boundary area (Figure 35).

Geospatial data used for this analysis does not include all refuge roads, especially seasonal refuge roads. Therefore, more accurate shapefiles of all refuge roads and trails will provide a better interpretation of the impacts road have on refuges.

4.3. Water Quality

Water quality information included in the WRIA is derived from the Reach Access Database (RAD) maintained by the U.S. Environmental Protection Agency (EPA). Additional data are publically available at the EPA's "Envirofacts" website. These databases were used to collect information on listed impaired waters and National Pollutant Discharge Elimination System (NPDES) permits in and around the refuges. The Contaminant Assessment Process further describes current and future contaminant threats on refuges.

4.3.1. Clean Water Act Impairments and TMDLs

Section 305(b) of the Clean Water Act requires each state produce a comprehensive biennial report on the quality of the state's waters. Section 303 (d) requires states to identify water bodies where water quality standards are not met. Total Maximum Daily Loads (TMDL) are designed to help the EPA and States develop plans for cleaning water bodies and removing them from the 303(d) list. State agencies are responsible for collecting water quality data to determine 303d impairments.

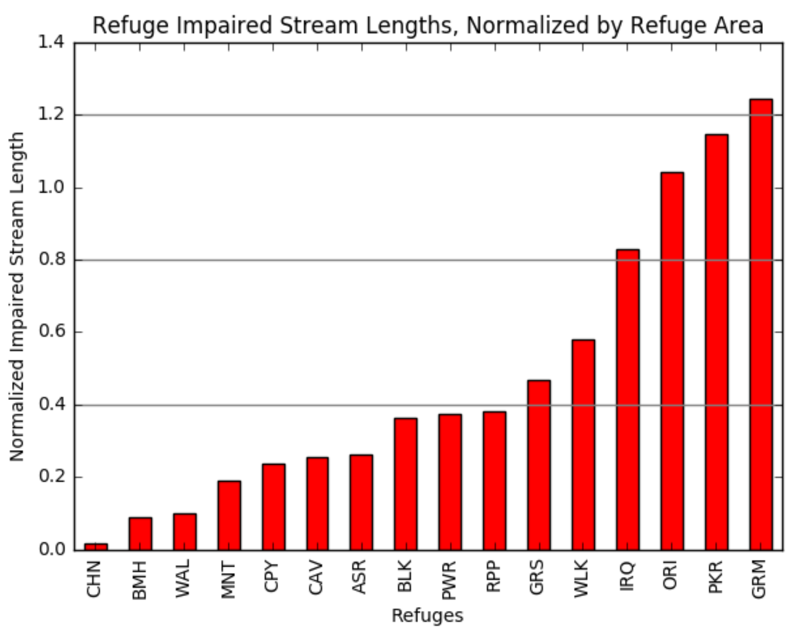

Figure 36. Refuges with 303(d) impaired streams within the refuge boundary, normalized by the refuge area.

Sixty-four percent of the refuges in this study have 303(d) impaired streams on site. Impaired stream length, normalized by refuge area (Figure 36) indicates Great Meadows, Parker River, and Ohio River Islands have the highest density of impaired streams. Water quality sampling on refuges with many stream impairments would provide a better idea of the impacts the poor water quality has on the water resources and the aquatic species. Refuges without any 303(d) impaired streams are Aroostook, Cherry Valley, Erie, John Heinz, Missisquoi, Moosehorn, Nulhegan Basin, Sunkhaze Meadows, and Umbagog (USEPAOW, 2016). The absence of any impaired streams near John Heinz is unusual given its location and obvious water contamination problems. It is likely the database used to identify impaired streams has not been updated for Pennsylvania and impairment information needs to be found through other means.

4.3.2. NPDES Permits

NPDES permits are co-issued to businesses and municipalities by state departments of environmental protection to regulate the quality and quantity of pollutants discharged into waters of the United States. Stormwater and treated wastewater are two examples of discharges regulated under the NPDES program. Permits require the permittee to conduct monitoring of select parameters at defined frequencies. Parameters may include measures of water quantity (e.g., flow) and water quality (e.g., nutrients, bacteria, suspended solids, pH). NPDES permits are associated with specific locations where pollutants are discharged into receiving waters. In theory the number of permits in a watershed is indicative of the likelihood of contamination in a river or stream.

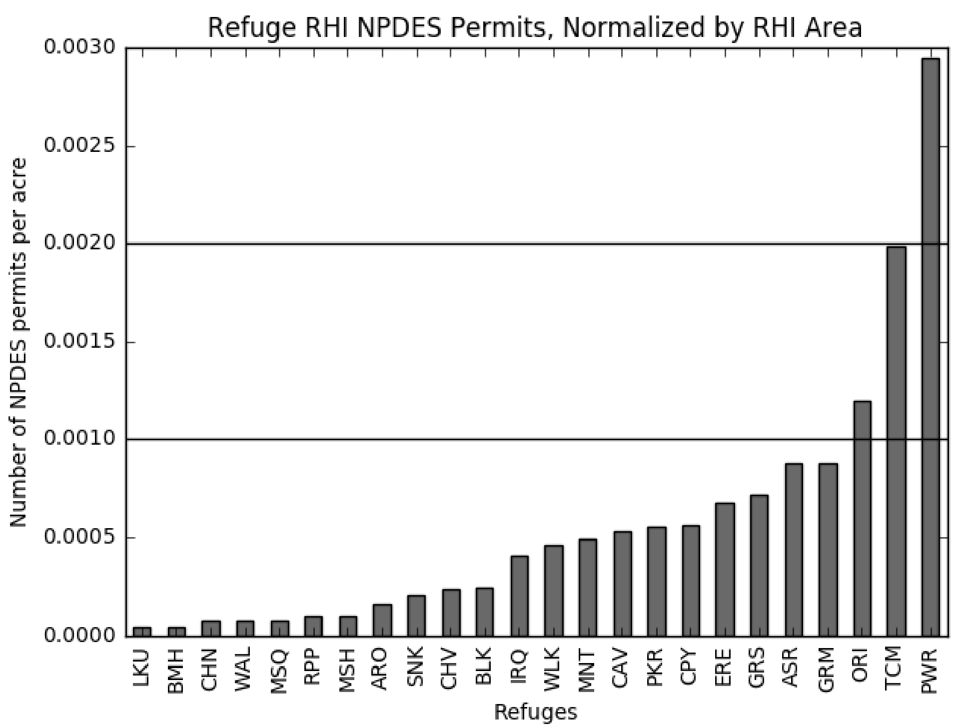

Figure 37. NPDES permits in refuge RHIs, normalized by the area of the RHI in acres.

All refuges in this study, except Nulhegan Basin Division, have NPDES permits in the RHI that could influence water quality on the refuge. Ohio River Islands and Patuxent have the highest number of NPDES permits with 3,109 and 860 permits, respectively (Figure 37). However, when normalized by the RHI area, Patuxent and John Heinz have the highest density of NPDES permits in their RHIs.

4.3.3. Contaminant Assessment Process

Contaminants Assessment Process (CAP) reports are completed by contaminant biologists to identify contamination concerns on and near refuges. The CAP reports gather information on contaminants that threaten fish and wildlife resources on the refuges. Topics covered in the CAP reports include documented threats, suspected threats, species assessment, management activities, areas of concern, air transport pathways, biotic pathways, water pathways, and contaminant source information. Assabet River NWR and Ohio River Islands NWR do not have a completed CAP report (Table 19).

Table 19. Dates (years) of the most recent CAP report for each refuge.

Year	Refuges
1999	Blackwater
2001	Nulhegan Basin
2004	Bombay Hook
2005	Patuxent, Wallkill River
2006	Aroostook, Moosehorn
2008	Sunkhaze Meadows
2011	Canaan Valley, Cape May, Great Swamp
2012	Erie, Great Meadows, Iroquois, John Heinz, Montezuma
2013	Chincoteague, Parker River, Wallops Island
2014	Rappahannock
2015	Cherry Valley, Missisquoi, Umbagog

4.4. Water Monitoring

Water monitoring can be broadly categorized as either water quality or water quantity focused. Water quality monitoring typically consists of collecting surface water or groundwater samples for chemical analyses in a laboratory or with sensors deployed in the field. Alternative protocols may use techniques such as aquatic invertebrate sampling as a proxy for water quality. Water quantity monitoring typically includes the flow rate in a stream or the water level in a groundwater aquifer. WRIAs also consider weather stations and tide gages as other types of water-related monitoring.

4.4.1. USGS Water Monitoring

The U.S. Geological Survey (USGS) is the principal federal agency monitoring surface water and groundwater in the United States. The WRIA analysis identifies USGS surface water (stream, lake, and estuary) and groundwater monitoring sites within the refuge RHIs (Table 20). Most USGS sites include both water quantity and water quality measurements; however, not all stations have both. All but 2 refuges (Great Swamp and Nulhegan Basin Division) have USGS monitoring sites within their RHI. Surface water monitoring sites are the most common in the region (Table 20). Refuges with the largest number of groundwater monitoring sites are all located in the Atlantic Coastal Plain physiographic province, with the purpose of monitoring conditions in the Coastal Plains Aquifer.

Table 20. Numbers of USGS monitoring sites in refuge RHIs.

Refuge	Total # of Sites	# of Surface Water Sites	# of Groundwater Sites
Cape May	30	12	18
Blackwater	24	7	17
Ohio River Islands*	24	21	3
Missisquoi	15	15	0
Patuxent	13	13	0
John Heinz	11	5	6
Umbagog	9	7	2
Assabet River/ Great Meadows	7	5	2
Montezuma	7	3	4
Rappahannock	7	4	3
Chincoteague/ Wallops Island	6	1	5
Erie	6	5	1
Moosehorn	5	4	1
Wallkill River	4	3	1
Canaan Valley	3	3	0
Parker River	2	1	1
Aroostook	1	1	0
Bombay Hook	1	1	0
Cherry Valley	1	1	0
Iroquois	1	0	1
Sunkhaze Meadows	1	1	0
TOTAL	**178**	**113**	**65**

Ohio River Islands RHI does not include USGS water monitoring sites that are located in Ohio or Kentucky.

4.4.2. Tidal Monitoring

Water levels in tidal bays, rivers, and oceans are an important information need for coastal refuges. Most refuges do not have on-refuge tidal water monitoring – instead, they gather the tidal information from NOAA and USGS. The coastal refuges of this study all have a tidal monitoring station on refuge or nearby (Table 21).

Table 21. Refuges with tidal monitoring on or near the refuge and the recording agency.

Refuge	Monitoring Agency	On Refuge	Off Refuge	Location
Blackwater	USGS	X		Sharptown, MD
	NOAA		X	Cambridge, MD
Bombay Hook	USGS		X	Bowers, DE
	NOAA		X	Ship John Shoal, NJ
Chincoteague	USGS		X	Chincoteague, VA
	NOAA		X	Wachapreague, VA
Cape May	USGS		X	Cape May & Stone Harbor, NJ
	NOAA		X	Cape May, NJ
Moosehorn	USGS		X	Calais, ME
	NOAA		X	Eastport, ME
Parker River	USGS	X		Plum Island, MA
	NOAA		X	Boston, MA
Rappahannock	NOAA		X	Windmill Point, VA
John Heinz	NOAA		X	Marcus Hook & Philadelphia, PA
Wallops Island	USGS		X	Chincoteague, VA
	NOAA		X	Wachapreague, VA

4.4.3. Other Water Monitoring

Most refuges in the region have a local university, non-profit, or state agencies that conduct water monitoring on the refuge or in the refuge's RHIs (Table 22). In the absence of other data, refuges rely on information collected by these outside organizations to make decisions. Refuges that do not have known outside organizations conducting water monitoring are Cape May, Erie, Moosehorn, and Wallkill River.

Table 22. Refuges with outside FWS water monitoring.

Refuge	Organization	Type of Monitoring
Aroostook	Maine Dept. of Environmental Protection	Surface water quality and groundwater quality
	Air Force	Groundwater quality
	Micmac tribe (Fred Corey)	Groundwater quality
Assabet River	OARS	Water quality and streamflow
	Massachusetts Dept. of Environmental Protection	Water quality and streamflow
Blackwater	Nanticoke River Alliance	Water quality
Bombay Hook	Delaware Dept. of Natural Resources and Environmental Control	Water level and velocity in tidal channels
Canaan Valley	U.S. Forest Service	Continuous stream temperatures
	West Virginia Dept. of Environmental Protection	Water quality
Cherry Valley	Stroudsburg Water Research Institute	Water quality
	East Stroudsburg University	Water quality
	William Penn Foundation	Water quality
	Wildlands Conservancy	Water quality
Chincoteague	Assateague Island National Seashore	Groundwater levels
	Virginia Dept. of Environmental Quality	Water quality
	Virginia Dept. of Health- Beach monitoring	E. coli and fecal coliform
	National Park Service	Long term water quality
Great Meadows	OARS	Water quality and streamflow
	Massachusetts Dept. of Environmental Protection	Water quality and streamflow
	Town of Sudbury, Dept. of Public Works	Water levels on Sudbury River and Hop Brook
Great Swamp	Great Swamp Water Management Committee/ Great Swamp Watershed Association	Water quality
Iroquois	University of Buffalo	Flow measurements at Structure L
John Heinz	U.S. EPA	Water quality monitoring near landfills
	Darby Creek Valley Association	Stream monitoring and invertebrates
Missisquoi	Missisquoi River Basin Association	Nutrients and turbidity
	University of Vermont	Climate modeling of Lake Champlain, algae sampling
	Lake Champlain Committee	Algae bloom monitoring
	Friends of Northern Lake Champlain	Water quality
Montezuma	New York State Canal Corporation	Water levels in Cayuga Lake and Erie Canal
	New York Dept. of Environmental Conservation	Water quality
Moosehorn	Maine Geological Survey	Groundwater levels
	Maine Dept. of Environmental Protection	Surface water toxics monitoring
	U.S. EPA	Lake water quality parameters

Table 22 (con't)

Refuge	Organization	Type of Monitoring
Nulhegan Basin	Trout Unlimited	Stream temperatures and invertebrates
Ohio River Islands	U.S. Army Corps of Engineers	Water levels at locks and dams
	Ohio River Valley Water Sanitation Commission	Water quality
	West Virginia Dept. of Environmental Protection	Water quality
Parker River	Plum Island Long-Term Ecological Research	Water levels in estuary and marsh
	Massachusetts Audubon Society	Water quality
	Massachusetts Div. of Marine Fisheries	Water quality
Patuxent	U.S. Army: Fort George Meade	Water quality, invertebrates, groundwater quality
	Maryland Dept. of Natural Resources	Water quality and invertebrates
	Patuxent Riverkeepers	Water quality
	Anne Arundel County	Stream morphology and invertebrates
	Prince Georges County	Water quality and invertebrates
Rappahannock	Alliance for the Chesapeake Bay	Water quality
	Chesapeake Bay Program	Water quality
Sunkhaze Meadows	Maine Dept. of Environmental Protection	Stream temperatures
Umbagog	Biodiversity Research Institute	Mercury in loons at Umbagog Lake
Wallops Island	Virginia Dept. of Environmental Quality	Water quality

Table 23. Water monitoring data gaps on refuges in the FY 17 WRIA analysis.

Refuge	Water Quality	Water Quantity	Comments
Assabet River	X	X	Wetland water levels
Bombay Hook	X	X	Establish quality and quantity baselines
Canaan Valley	X	X	Monitor gas well activity
Cape May		X	Establish quantity baseline
Great Meadows	X	X	
Great Swamp	X		Establish quality baseline
Iroquois	X	X	Establish quality baseline; continuous groundwater levels
John Heinz		X	Water level in Hoy's Pond
Montezuma	X	X	Water quantity in impoundments
Ohio River Islands	X		Continuous baseline water quality
Parker River		X	
Patuxent	X		Establish quality baseline
Sunkhaze Meadows	X		Establish quality baseline
Wallops Island		X	Groundwater level monitoring at Lucky Boy Fen

4.4.4. Water Monitoring Data Gaps

Most refuges need some water monitoring to help inform management decisions and actions. Refuges that expressed interest in additional water monitoring at their refuges or where additional monitoring would aid refuge management are identified in Table 23.

4.5. Water Rights

In the Eastern United States, water rights are attached to riparian land (land bordering a river, lake, or stream). Riparian land owners have the right to a "reasonable" use of the water adjacent to their land provided other riparian land owners are not injured. Because of the uncertainty around "reasonable", states have adopted regulations that require permits for water use. Ten states in Region 5 regulate water use through a permitting program (Table 24).

Water use permits grant users the "right" to use a defined volume of water from a surface water body or groundwater aquifer. In the Northeast, permits are required when the use exceeds a threshold volume, typically recorded in gallons per day (gpd).

Table 24. Region 5 states with water use regulations.

State	Surface Water Regulations	Groundwater Use Regulations	Water Storage Regulations
Connecticut	X	X	X
Delaware	X	X	
Maine	X	X	
Maryland	X	X	
Massachusetts	X	X	
New Hampshire		X	
New Jersey	X	X	
New York		X	
Vermont		X	
Virginia	X	X	

In addition to the 10 states listed in Table 24, there are several geographical areas with their own water use permitting requirements (Table 25). In some cases regulations in these areas may be more stringent than in the surrounding state and permits are issued directly by the non-state regulatory agency (i.e. Susquehanna River Basin Commission).

The National Wildlife Refuge Administration Act requires the Service acquire water rights under state water law. Refuges in states with water use regulations require a permit if; 1) water is diverted from a surface water body or pumped from a groundwater aquifer, and 2) the amount of water diverted exceeds a defined threshold volume. The typical refuge water use that meets these definitions are diversions to fill wetland impoundments. Permits are not issued for instream water use or wetland water use. Therefore refuges cannot secure permits to protect the ecological benefits of minimum water levels or flow volumes.

Table 25. Region 5 non-state areas where water use is regulated.

Agency / Area	Surface Water Regulations	Groundwater Use Regulations
Susquehanna River Basin Commission	X	X
Delaware River Basin Commission	X	X
Interstate Commission of the Potomac River Basin	X	
Great Lakes Commission	X	X
Eastern Shore Groundwater Management Area (VA)		X
Eastern Virginia Groundwater Management Area		X
Long Island New York Counties		X
New York State Canal Corporation	X	
New Jersey Pinelands Commission	X	X
New Jersey Highlands Protection Area	X	X

The majority (90%) of refuges in Region 5 do not divert water from surface water or groundwater. Instead, they rely on direct precipitation to meet refuge management objectives. There are 4 refuges included in this review that divert surface water and groundwater to fill impoundments (Table 26).

Table 26. Refuges diverting surface water to support refuge purposes.

Refuges	Surface Water Diversions	Groundwater Diversions	Permitting Agency
Montezuma	X		New York State Canal Corporation
Great Meadows	X		Letter from State of MA identifying use as non-consumptive
Patuxent		X	Groundwater use permit from state of MD
Blackwater		X	Groundwater use permit from state of MD

At present, none of the refuges in this review, "need" state-issued permits for refuge water use. However, water use regulations in the Northeast regularly change and it is necessary to keep updated on new developments. Overall, water use regulations in the Northeast are not affecting refuges ability to manage water or meet habitat objectives.

4.6. Climate Trends

The Refuge Climate Assessment Tool (RCAT) is a program, written in R, which analyzes monthly climate data from NOAA's National Climate Data Center's Global Historical Climate Network (GHCN) stations. RCAT was used to determine long-term trends in precipitation and temperature at locations near refuges (Table 27). Figure 38 is an example of the long-term climate data included in the RCAT analysis. Bombay Hook and Cape May, as well as Chincoteague and Wallops Island, have the same GHCN stations for this climate trend analysis. Long-term changes in sea level were acquired from NOAA.

Table 27. Precipitation and temperature trends near refuges using RCAT. Precipitation and temperatures are annual averages. Positive values show an increasing trend and negative values show a decreasing trend for the period of record. Shaded cells indicate the trend is statistically significant.

Refuge	Station Location	Dates of Analysis	Precip. Slope	Tavg Slope	Tmin Slope	Tmax Slope
ARO	Presque Isle, ME	1948-2016	0.0098	0.0318	0.0347	0.0320
ASR	Lowell, MA	1893-2016	0.0368	0.0031	-0.0070	0.0133
BLK	Patuxent River NAS, MD	1945-2016	0.0689	0.0095	-0.0101	0.0288
BMH/CPY	Cape May, NJ	1942-2016	0.1681	0.0141	-0.0048	0.0362
CAV	Parsons, WV	1958-2016	-0.1409	-0.0325	-0.0204	-0.0452
CHN/WAL	Salisbury, MD	1949-2016	0.0800	0.0153	0.0032	0.0335
CHV	Stroudsburg, PA	1927-2016	0.0085	0.0375	0.0485	0.0250
ERE	Titusville, PA	1955-2016	0.0756	0.0208	0.0365	0.0073
GRM	Maynard, MA	1964-2016	0.1679	0.0422	0.0537	0.0298
GRS	Canoe Brook, NJ	1931-2016	0.0611	0.0386	0.0630	0.0180
IRQ	Batavia, NY	1932-2016	0.0407	0.0449	0.0367	0.0575
LKU	First Connecticut Lake, NH	1930-2016	0.0628	-0.0025	0.0027	-0.0071
MNT	Auburn, NY	1898-2016	0.1259	-0.0015	-0.0083	0.0036
MSH	Woodland, ME	1920-2016	0.1798	0.0045	0.0157	-0.0066
MSQ	Enosburg Falls, VT	1893-2016	0.0216	0.0244	0.0290	0.0196
ORI	Parkersburg, WV	1926-2016	0.0221	-0.0097	-0.0194	0.0004
PKR	Haverhill, MA	1900-2016	0.1347	-0.0108	-0.0233	0.0005
PWR	Laurel, MD	1896-2014	0.0461	0.0261	0.0462	0.0063
RPP	Warsaw, VA	1900-2016	0.0954	0.0285	0.0329	0.0225
SNK	Bangor, ME	1953-2016	-0.0049	0.0217	-0.0070	0.0473
SON	Colebrook, NH	1961-2016	-0.0324	-0.0243	-0.0022	-0.0474
TCM	Philadelphia, PA	1948-2016	0.0510	0.0491	0.0610	0.0354
WLK	Sussex, NJ	1894-2016	0.0403	-0.0150	-0.0248	-0.0048

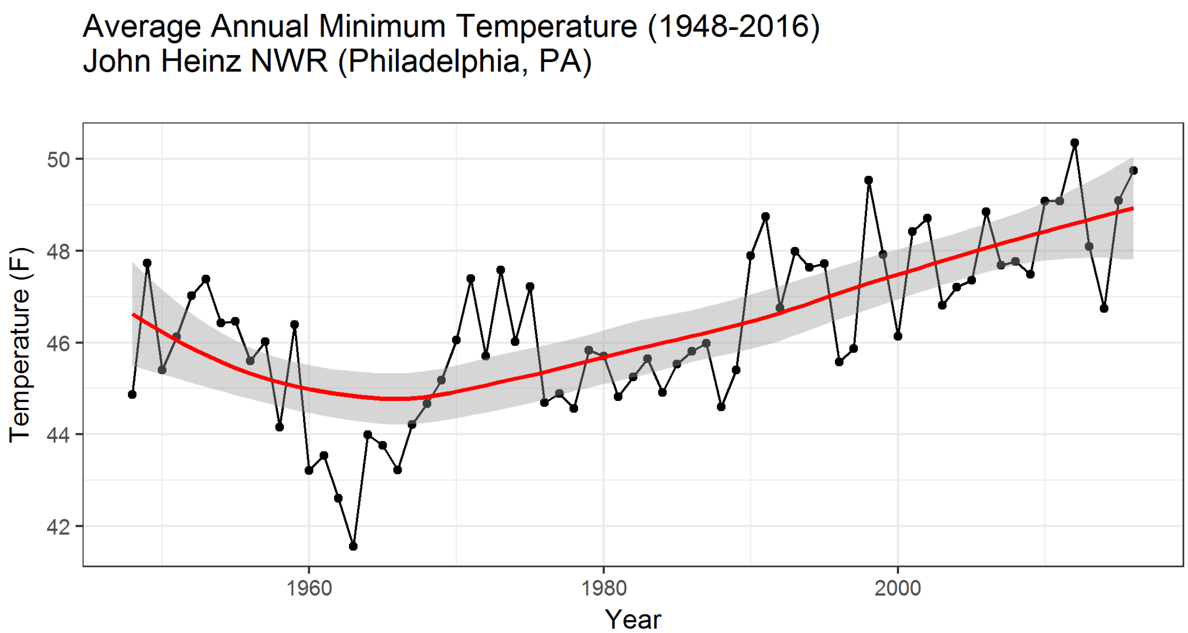

Figure 38. Average annual minimum temperature (black) and slope (red) with uncertainty (gray) as calculated by RCAT near John Heinz NWR.

4.6.1. Precipitation

The amount of annual precipitation is increasing on 20 (80%) refuges in this study (Figure 39). The highest increases in precipitation exceed 0.16 inches / year at weather stations near Moosehorn, Bombay Hook/Cape May, and Great Meadows. Canaan Valley is observing statistically significant decreasing trend in long-term annual precipitation. Other refuges with statistically significant increases in precipitation are Montezuma (0.13 in./yr.), Parker River (0.13 in./yr.), Rappahannock (0.10 in./yr.), and Umbagog (0.06 in./yr.).

The GHCN dataset does not include information on extreme precipitation events. Climate change predictions call for an increase in extreme precipitation events (Melillo, Richmond, and Yohe, 2014). Region 5 refuges have already experienced devastating storms in recent years (i.e. Hurricane Sandy and Irene) that resulted in greatly altered ecosystems, requiring costly and time-consuming restoration efforts. To be prepared for future events, we recommend that DNRCP build on this initial precipitation review and analyze trends in extreme precipitation events near refuges.

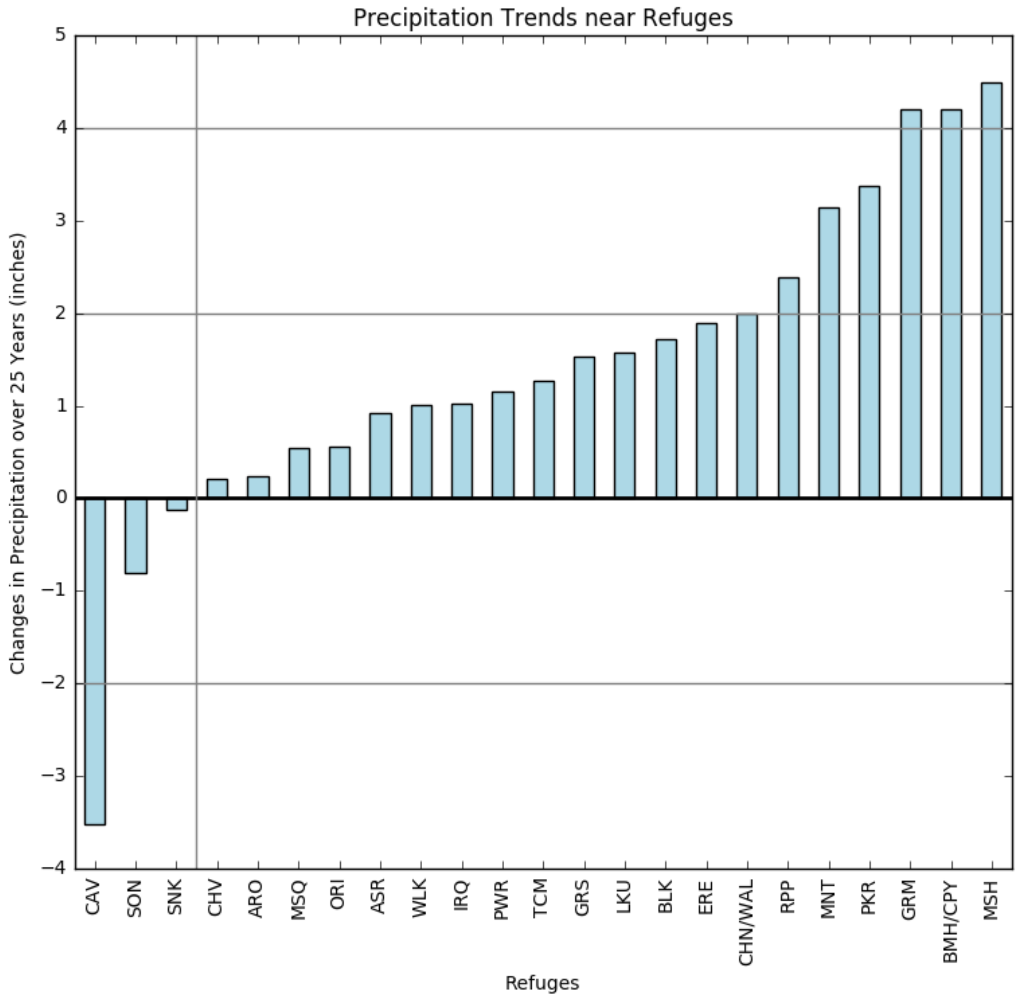

Figure 39. Estimated change in precipitation at locations near refuges over a 25 year interval. Calculated from the annual precipitation trend slope (Table 27).

4.6.2. Temperature

The RCAT temperature analysis indicates that annual average and maximum temperatures are increasing on most refuges in this study (Figure 40-42). Increasing temperatures for the Northeast are predicted under various climate change scenarios. Other causes of increasing temperatures can be related to the "heat island" effect of urban areas. Decreasing temperature trends are somewhat contradictory to the conventional wisdom about modern temperatures. However, at least one study has documented decreasing temperature trends at high elevation sites in the mid-Atlantic (Pitchford et al. 2012).

Average annual temperatures on refuges are increasing at 16 (70%) of refuge climate stations in this study (Figure 40). Seven (30%) refuge climate stations have decreasing average annual temperatures; however only Canaan Valley and Parker River have statistically significant decrease. Refuges (John Heinz, Iroquois, and Great Meadows) with the highest increasing trends in annual average temperature, greater than 1.0 °F increase over 25 years, are all statistically significant.

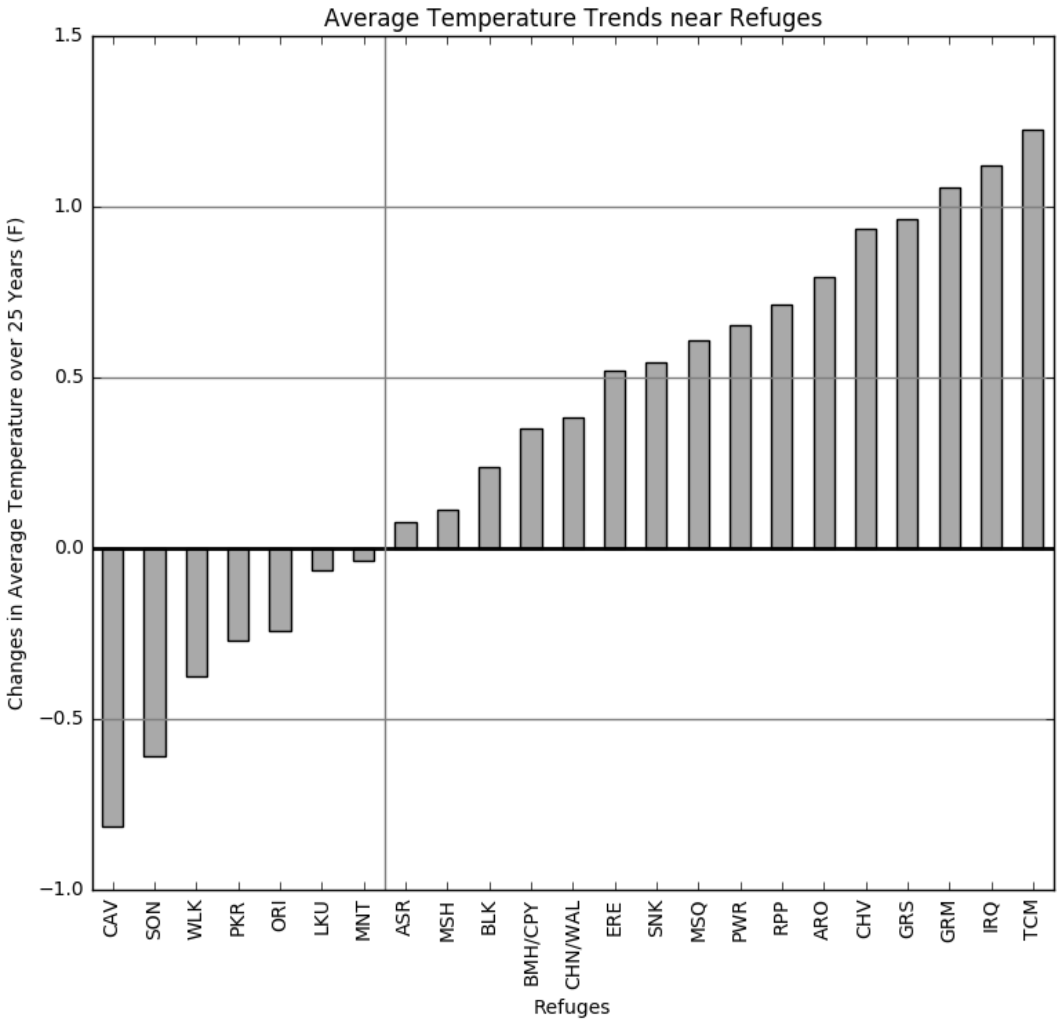

Figure 40. Estimated changes in average temperature trends at locations near refuges over a 25 year interval. Calculated from the annual average temperature trend slope (Table 27).

Minimum temperatures are increasing near some refuges and decreasing near others (Figure 41). Wallkill River and Parker River annual minimum temperatures are significantly decreasing by more than 1.0 °F over 50 years. The highest increases in minimum annual temperature are at Great Swamp and John Heinz, at more than 1.5 °F over 25 years.

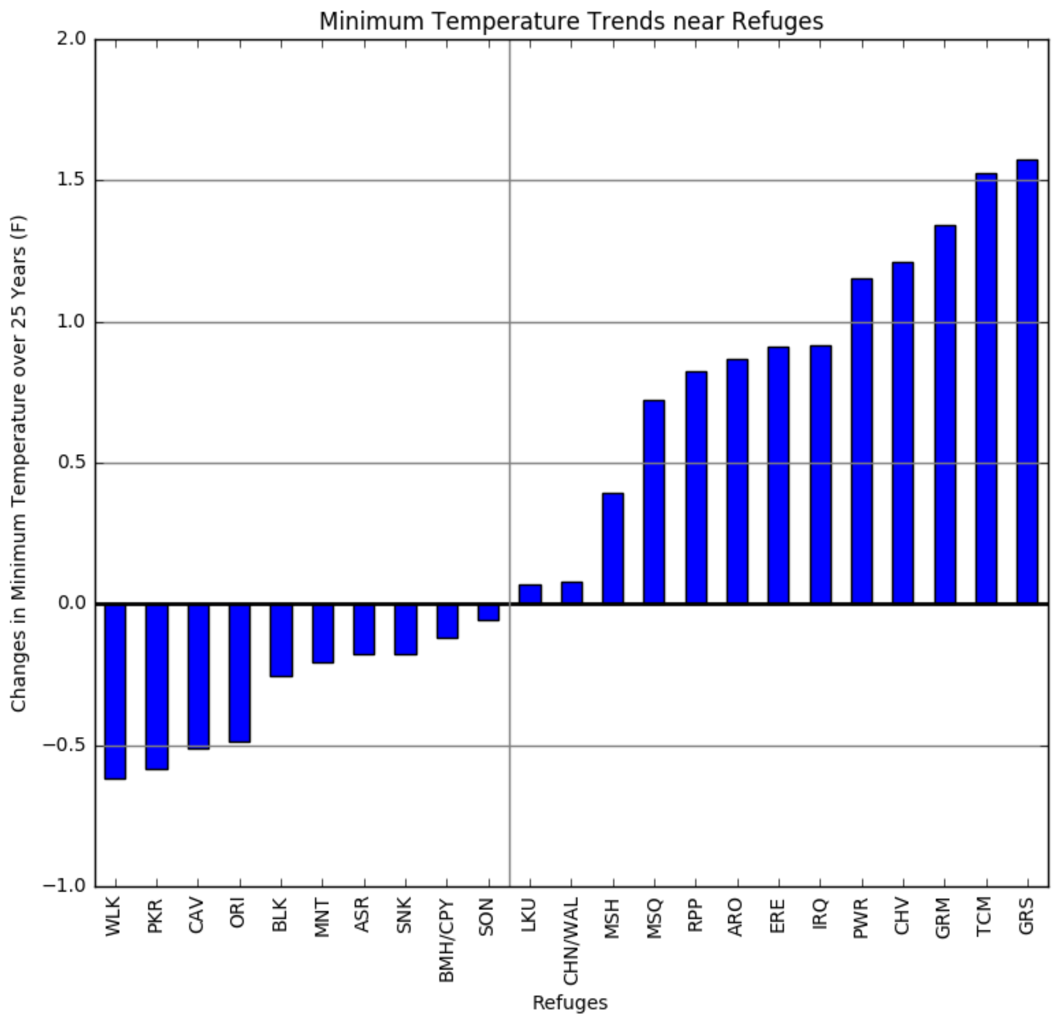

Figure 41. Estimated change in minimum temperatures at locations near refuges over a 25 year interval. Calculated from the annual minimum temperature trend slope (Table 27).

Maximum temperatures near 18 (78%) refuges in this study are increasing (Figure 42). Maximum temperatures near Iroquois and Sunkhaze Meadows are both statistically significant increasing trends, at 0.06 and 0.05 °F per year, respectively. Alternatively, Nulhegan Basin and Canaan Valley are observing significant decreasing trend in annual maximum temperature at more than 1.0 °F over 25 years.

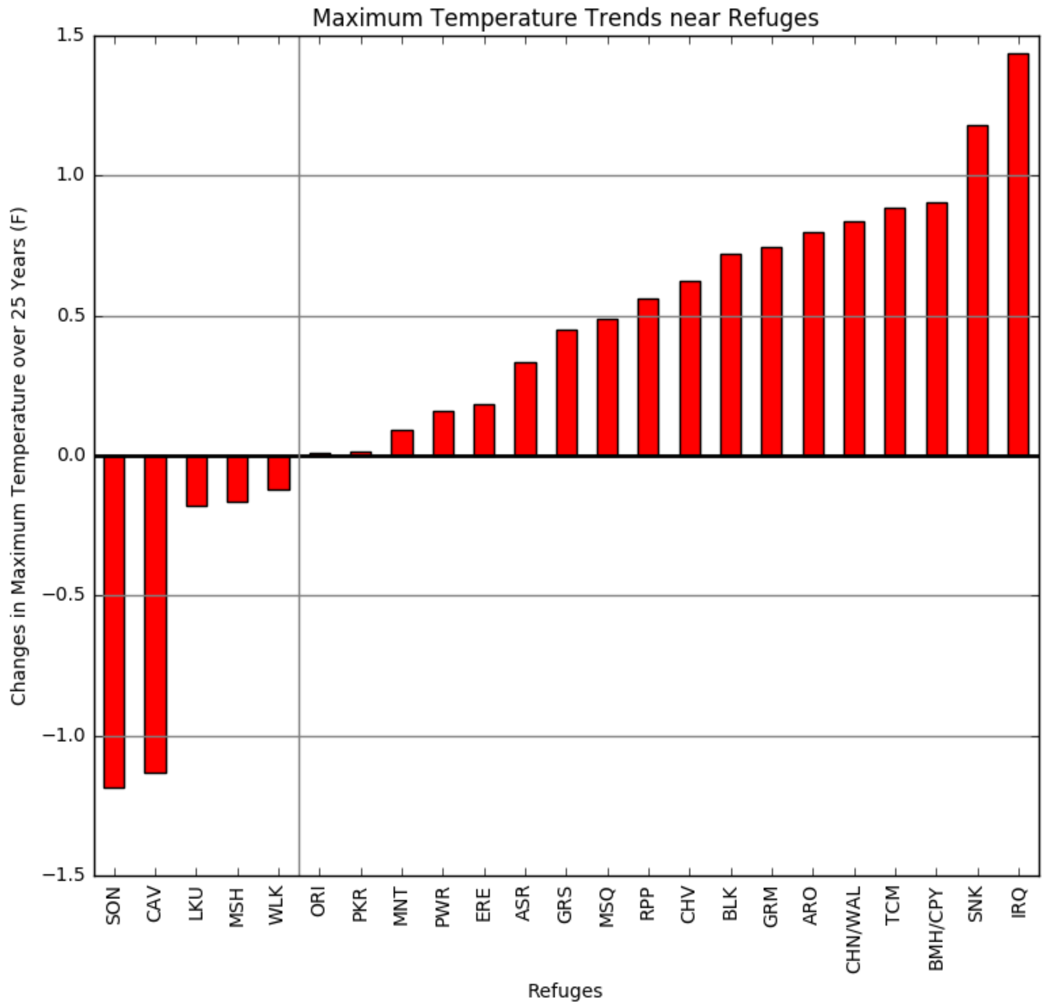

Figure 42. Maximum temperature trends at locations near refuges over a 25 year interval. Calculated from the annual maximum temperature trend slope.

4.6.3. Sea Level Trends

Sea level on the Northeast Coast is increasing. The most drastic sea level increases are centered around the Chesapeake Bay (Figure 43). Climate change induced sea level rise is occurring; however, other processes exacerbate rising sea levels in the mid-Atlantic. The Northeast is rebounding from the weight of the last glacial maximum. Similar to a see-saw, the Northeast is moving up in elevation and the Mid-Atlantic is moving down, causing sea levels to rise (Boon, Brubaker, and Forrest, 2010). Additionally, there is evidence the Chesapeake Bay region is subsiding due to increased groundwater pumping and sediment loading (Kearney and Stevenson, 1991).

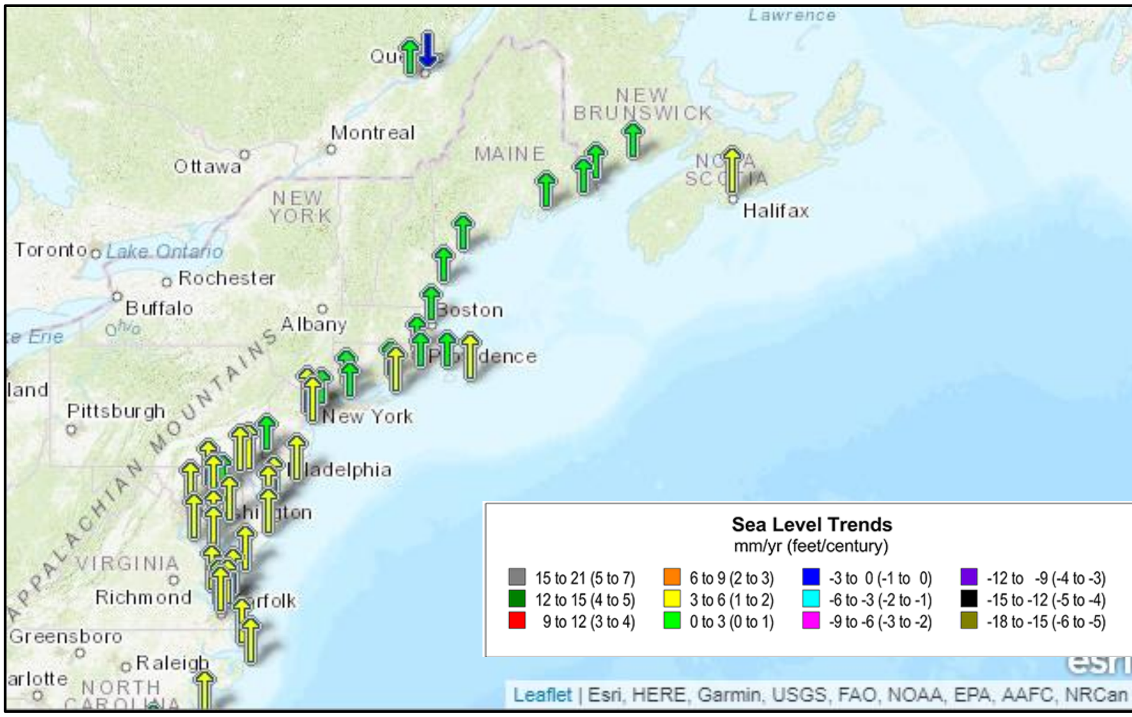

Figure 43. Sea level trends on the East Coast of the U.S. (NOAA, 2013).

4.6.4. Future Climate Predictions

The Intergovernmental Panel on Climate Change (IPCC) predicts the U.S. Northeast will experience earlier spring snowmelt and reduced summer runoff as the global climate warms in response to human emissions of greenhouse gasses (Bates et al. 2008, Mack 2008). Hayhoe et al. (2007) review historic climate data and climate change models to evaluate the Northeast's response to global climate change. Results of their analyses are summarized below:

Temperature

Air temperature records in the Northeast show consistent signs of warming since the 1970s with the greatest increases occurring during the winter months. Warming trends are expected to continue and rates of warming increase under different climate modeling scenarios. As temperatures warm the frequency of extreme warm temperatures will increase also.

Precipitation

Precipitation records in the US Northeast show a consistent increase in annual precipitation totals over the last century. Under different climate modeling scenarios, winter precipitation is expected to increase while summer precipitation is expected to remain unchanged or decrease. Heavy, intense precipitation events are expected to become more common also.

Snowpack

The amount of snow cover has decreased across the Northeast in the last 30 years. This trend is expected to continue with less precipitation falling as snow in the winter months.

Streamflow Patterns

Since 1970, peak snowmelt runoff has occurred earlier in the year and the peak runoff values have been rising in winter and early spring. These patterns are expected to continue as wetter winters and warmer temperatures decrease winter snowpacks. The response to seasonal snowmelt will become less pronounced as more winter precipitation falls as rain. Peak flows are expected to be concentrated in the winter and early spring months and minimum streamflow will continue to be concentrated in the summer months. Minimum flows will be lower than the recent past and the duration of the summer low flow period is expected to increase.

Drought

Modeling scenarios predict that the frequency of severe, persistent drought (>6 months) will remain at rates observed in the recent past. However, hotter drier summers and periodic precipitation deficits are expected to increase the frequency of short- (1–3 months) and medium-term (3–6 months) droughts. Periods of drought will be most pronounced at the end of the growing season in the late summer and early fall.

5. Threats

The threats section reviews threats facing water resources on the 25 refuges covered in this review. Threats to water resources are grouped into four categories: water quantity, water quality, aquatic habitat threats, and infrastructure (dams and roads).

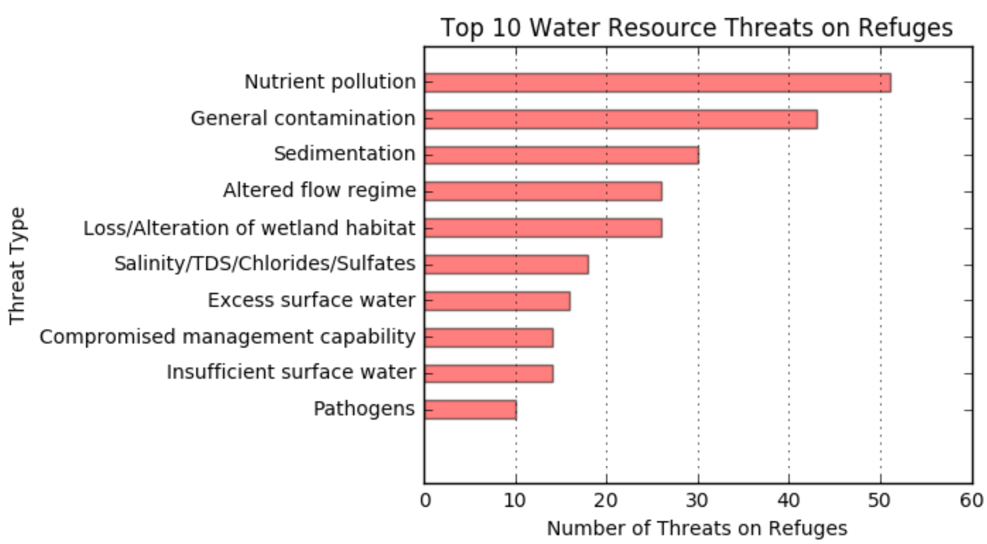

Figure 44. The top water resource threats on refuges and the occurrence of each threat.

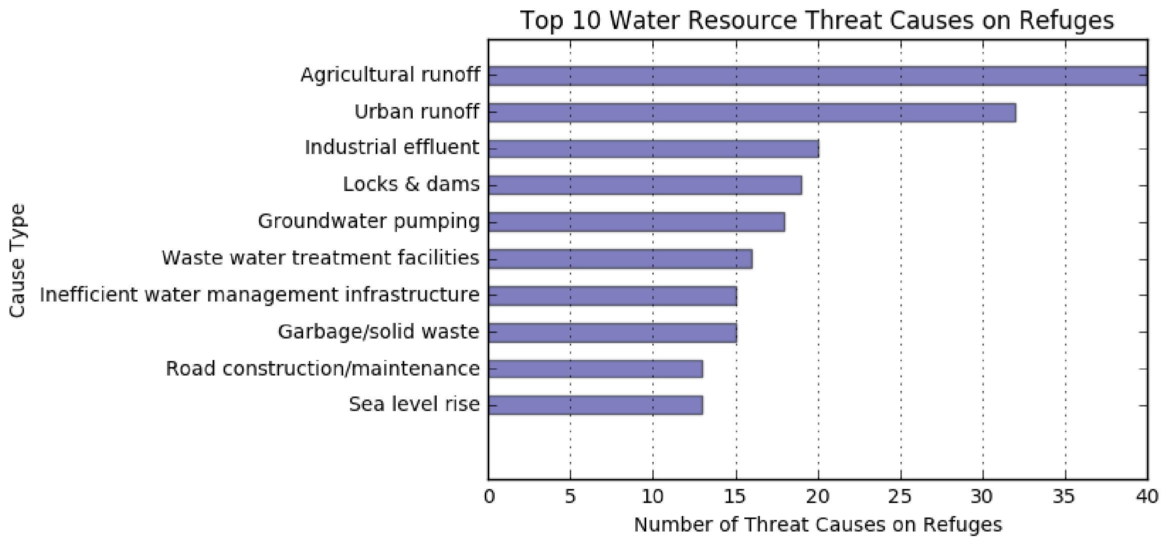

Figure 45. The top water resource threat causes on refuges.

5.1. Water Quantity Threats

Water quantity threats refer to situations that compromise refuge habitat due to excess or insufficient water. Recurring causes of water quantity threats are infrastructure and climate. The most common water quantity threats that impact refuges are (Figure 46):

- **Altered flow regimes**
  Aquatic species are adapted to wet and dry cycles in wetlands and streams. Altered flow regimes refer to hydrologic cycles that have changed from their natural patterns in such a way that refuge habitat is being negatively impacted. Changes to a flow regime are often due to on and off-refuge infrastructure or changing climate patterns.
- **Excess surface water**
  Hydrologic conditions on the refuge are too wet to maintain habitat and meet refuge objectives. Examples are flooding due to inadequate infrastructure, or legacy infrastructure that keeps wetland habitat inundated and drowns desirable wetland vegetation.
- **Compromised management capability**
  Aging, damaged, or inadequately sized water control infrastructure compromises the Service's ability to meet refuge objectives. A typical example is water control structures that are decades old and have degraded to a point where they cannot be operated to achieve management objectives.
- **Insufficient surface water**
  Hydrologic conditions on the refuge are too dry to maintain habitat and meet refuge objectives. A typical example is wetland drainage due to ditching or tile drains.

- **Insufficient groundwater**
  Hydrologic conditions are too dry to maintain habitat and meet refuge objectives. The cause of drying is driven by groundwater pumping that lowers the water table, which leads to drier conditions in refuge wetlands and streams.

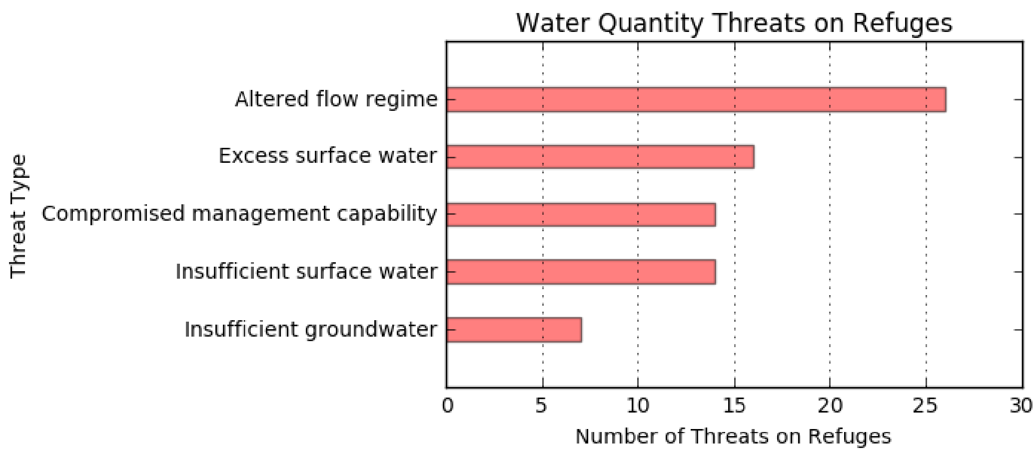

Figure 46. Water quantity threats and the number of water quantity threat occurrences on refuges.

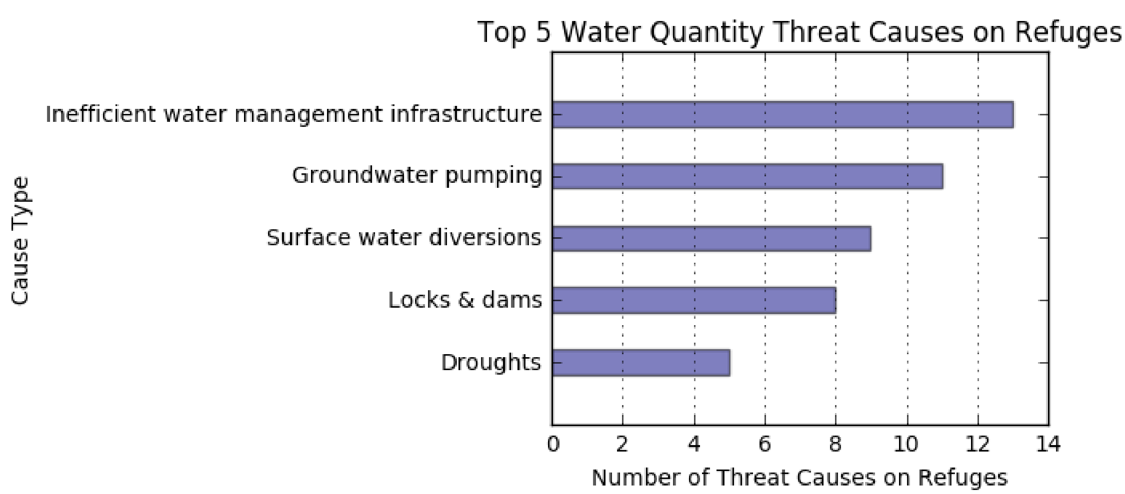

Figure 47. The top causes of refuge water quantity threats. Groundwater pumping and surface water diversions include agricultural, industrial, and municipal extractions.

5.1.1. Altered Flow Regimes

Eleven of the refuges studied are threatened by altered flow regimes. Altered flow regimes are similar to the water quantity and compromised management capability threats listed below, however altered flow regimes tend to be on and off-refuge human-induced threats that change the way water moves through the refuge (Table 28).

Table 28. Refuges negatively impacted by altered flow and the causes of the threats.

Refuge	On Refuge	Off Refuge	Cause
Aroostook	X		Roads/culverts
Blackwater		X	Impervious surfaces
Bombay Hook		X	Groundwater pumping
Canaan Valley		X	Development of watershed
		X	Surface water diversions
		X	Headwater reservoirs
Cape May		X	Groundwater pumping
Erie	X		Aging water management infrastructure
John Heinz	X		Failing dikes
Ohio River Islands		X	Locks and dams
Parker River	X		Ditches and tidal flow restrictions
Patuxent	X		Dams
		X	Groundwater pumping
		X	Reservoir
	X		Road construction
		X	Impervious surfaces
Sunkhaze Meadows	X		Roads/culverts

Table 29. Refuges threatened by excess surface water and the causes of the threats.

Refuge	Cause
Assabet River	Extreme precipitation
Blackwater	Ditches and channelization
Great Meadows	Extreme precipitation
Great Swamp	Urban run-off
Great Swamp	Extreme precipitation
Iroquois	Change in precipitation patterns
Iroquois	Surface water diversion (future)
John Heinz	Urban run-off
Missisquoi	Change in precipitation patterns
Nulhegan Basin	Roads/culverts
Wallkill River	Ditches

5.1.2. Excess Surface Water

Refuges in the region experience times of excess and insufficient surface water. Excess surface water on refuges is caused by precipitation events and altered hydrology (Table 29). Both extreme precipitation events and changes in precipitation patterns can result in excess surface water on refuges. These precipitation changes are results of climate change. Humans alter hydrology by developing landscapes in many different ways. Often, water is directly diverted into streams, via ditches, canals, or storm-water drainage systems, which changes runoff patterns and alters natural hydrologic regimes.

5.1.3. Compromised Water Management Capability

Compromised water management capabilities affect the ability of refuges to meet refuge purposes at eleven of the studied refuges. Water management capabilities are compromised when the ability of refuge staff to manage water is limited or outside of their control. Causes of compromised water management capabilities include legacy infrastructure (inefficient, inadequate, or damaged water management infrastructure), altered hydrology (dams, ditches, and canals), management by non-FWS organizations, undersized infrastructure, sea level rise and flooding, and industrial diversions (Table 30).

Table 30. Refuges threatened by compromised water management capability, either on or off the refuge, and causes of the threats.

Refuge	On Refuge	Off Refuge	Cause
Aroostook	X	X	Inter-basin transfer
Blackwater		X	Legacy infrastructure
Bombay Hook	X		Legacy infrastructure
Chincoteague	X		Undersized water control structures
		X	Sea level rise
Great Swamp	X		Legacy infrastructure
Iroquois		X	Industrial surface water diversion (future)
John Heinz	X		Aged water control structures
Missisquoi	X		Flooding/high water levels
Montezuma	X		Legacy infrastructure
		X	Canals
Moosehorn	X		Legacy infrastructure
Ohio River Islands		X	Locks and dams

5.1.4. Insufficient Surface Water

Insufficient surface water on refuges is largely caused by droughts and water diversions. Most droughts in the Northeast Region are short term, lasting 3-6 months. Climate change predictions for the Northeast indicate that droughts will become more frequent (Melillo, Richmond, and

Yohe, 2014). Water diversions that cause insufficient surface water on refuges include dams, hydraulic fracturing, groundwater pumping, and inter-basin transfers (Table 31).

Table 31. Refuges threatened by insufficient surface water and the causes of the threats.

Refuge	Cause
Aroostook	Surface water diversions
Assabet River	Droughts
Blackwater	Droughts
Canaan Valley	Hydraulic fracturing
Great Meadows	Droughts
Great Meadows	Groundwater pumping
Great Meadows	Surface water diversions
Iroquois	Droughts
Montezuma	Droughts
Ohio River Islands	Locks and dams
Parker River	Groundwater pumping
Parker River	Inter-basin transfers
Patuxent	Groundwater pumping
Rappahannock	Hydraulic fracturing (future)

5.1.5. Insufficient Groundwater

The Northern Atlantic Coastal Plains Aquifer System is experiencing a decrease in water table elevation of up to 2 feet per year in places due to private, municipal, industrial, and agricultural pumping (Masterson et al., 2011). Over-pumping of aquifers is likely to become more common in the Northeast as the human population increases and there is more demand for freshwater. Most refuge habitats are dependent on groundwater to a certain extent (see Section 4.1.5.1), however only a quarter of the refuges in this study currently, or in the near future, have groundwater supply concerns (Table 32).

Table 32. Refuges threatened by insufficient groundwater and the causes of the threats.

Causes		Refuges
Industrial groundwater pumping	Future	Iroquois, Rappahannock
	Current	Ohio River Islands
Municipal groundwater pumping		Cherry Valley, Patuxent
Agricultural groundwater pumping		Blackwater

5.2. Water Quality Threats

Water quality threats are the most common type of threat to refuge water resources identified in this review. Most causes of water quality threats are related to urban and agricultural land use. The most common water quality threats that impact refuges are (Figure 48):

- **Excess Nutrients**
  High concentrations of nitrogen and phosphorous are found in many refuge water resources. Excess nutrients can lead to the increased growth of nuisance aquatic plants and algae which can result in decreases light penetration and low dissolved oxygen concentrations. Sources of excess nutrients include fertilizer applications on agricultural land and wastewater treatment facilities.
- **Other Contaminants / Altered Water Chemistry**
  General and unknown contamination occurs on many refuges in the Northeast. In most cases, the refuge staff do not have enough information to describe the contaminant, but they know that the waters are threatened by a source of contamination. Sources of general contamination on refuges are industrial waste sites and garbage.
- **Sedimentation**
  Excess sediment from land use activities in the watersheds draining into the refuge can lead to poor light penetration in refuge waters and degrade aquatic habitat by burying coarse sediment in fine grained sediments.
- **Salinity / TDS / Chlorides / Sulfates**
  The health of many aquatic species can be affected by an increase in salts in freshwater. Salts can be natural or introduced by human activities such as waste water treatment, road salt application, mining, and other industrial inputs.
- **Mercury**
  Atmospheric deposition of mercury is common on all lands in the Northeast.

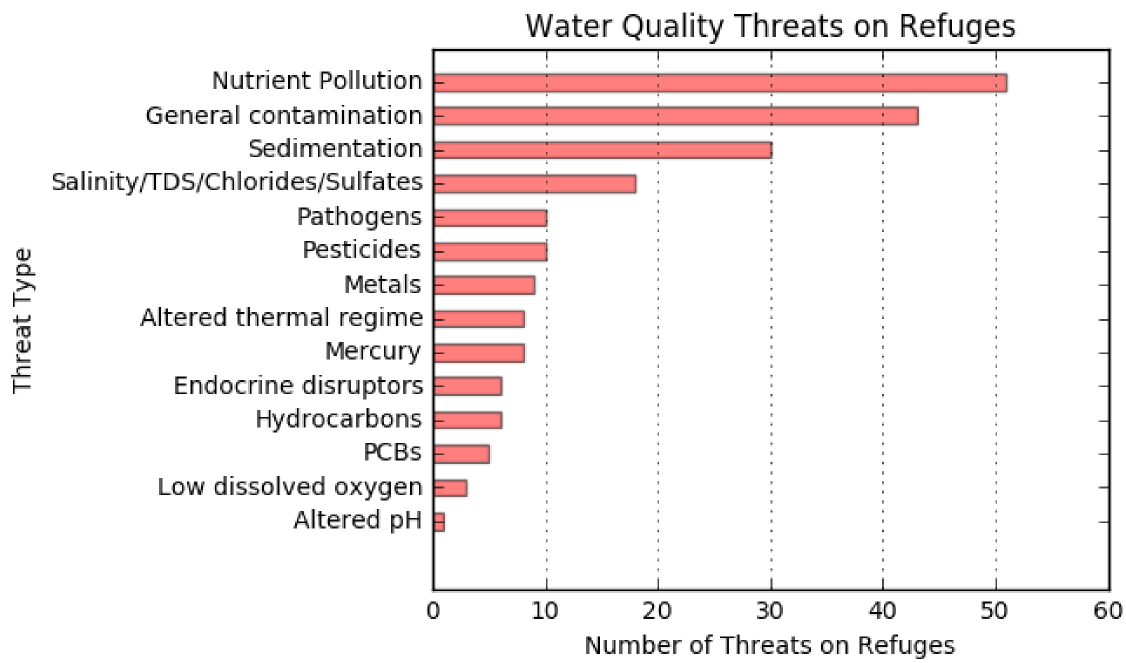

Figure 48. The number of water quality threats on refuges, defined by threat type.

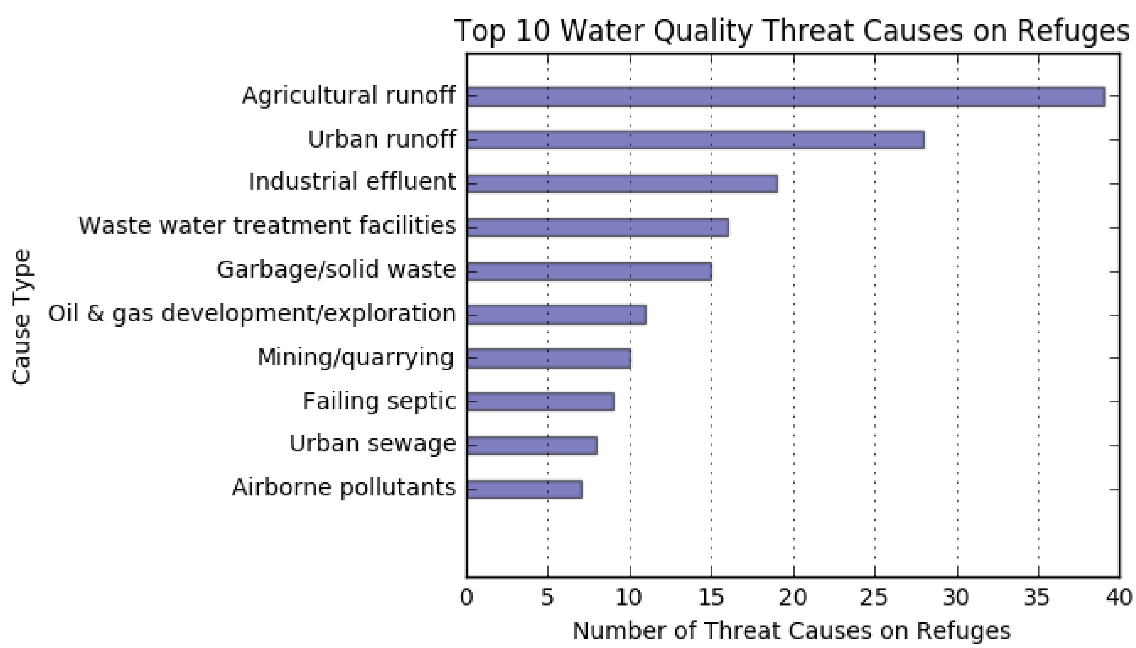

Figure 49. The top 10 water quality threat causes on refuges.

5.2.1. Excess Nutrients

Nutrient pollution refers to excess nitrogen and phosphorus concentrations in refuge water resources. Nitrogen and phosphorus are naturally occurring and needed by many species in aquatic systems. However, when the amount of nutrients in the system becomes too much, algae and other plant growth rapidly increases. This increase can lead to harmful algal blooms and low dissolved oxygen that negatively impact aquatic species. Additionally, increased nitrogen in drinking water is harmful to humans, especially infants (USEPA, 2017).

Refuge water resources on 92% of the refuges in this study are threatened by excess nutrients. Excess nutrient concentrations are typically caused by nutrient laden agricultural and urban run-off (Table 33). No nutrient impairments have been observed at Moosehorn and Nulhegan Basin Division.

Table 33. Causes of nutrient pollution and affected refuges (organized by most common to least common cause).

Cause of Nutrient Pollution	Refuges
Agricultural run-off	Aroostook, Blackwater, Bombay Hook, Chincoteague, Erie, Iroquois, Missisquoi, Montezuma, Rappahannock, Sunkhaze Meadows, Wallops Island
Urban run-off	Assabet River, Canaan Valley, Cape May, Great Meadows, Great Swamp, Parker River, Patuxent, Wallops Island
Failing septic	Aroostook, Blackwater , Bombay Hook, Cherry Valley, Chincoteague, Erie, Parker River, Wallkill River
Waste water treatment facilities	Assabet River, Canaan Valley, Great Meadows, Great Swamp, John Heinz, Ohio River Islands, Patuxent, Sunkhaze Meadows, Wallkill River
Extreme precipitation events	Great Meadows, Montezuma
Urban sewage	Aroostook
Combined animal feeding operations	Iroquois
Cropland drainage/tiling	Missisquoi
State regulations not enforced	Missisquoi
Livestock	Wallkill River
Industrial effluent	Wallops Island

5.2.2. Other Contaminants / Altered Water Chemistry

Forms of water quality contamination that do not include excess nutrients, sediment, or mercury are lumped in the WRIA database as an “other” category. The most common types of other contamination or altered water chemistry are garbage/solid waste and industrial effluent.

Garbage and solid waste contamination threats are usually from landfills on or adjacent to refuges. Industrial effluent threats are from historic military use of refuge lands. Most of the other contamination threats have more than one cause (Table 34).

Table 34. Refuges affected by other contaminants and altered water chemistry.

Refuge	Cause	Example
Aroostook	Garbage/solid waste	Landfills from military activities
	Industrial effluent	From historic military activities
	Urban run-off	From industrial park
Blackwater	Mining/quarrying	Sand & gravel mining
	Urban run-off	Impervious surfaces
Bombay Hook	Garbage/solid waste	From historic military activities
Canaan Valley	Mining/quarrying	Acid mine drainage
	Oil and gas development	Fracking wastewater spills
Cape May	Garbage/solid waste	
	Failing septic	
Cherry Valley	Oil and gas exploration	Potential natural gas exploration
	Oil and gas development	Pipeline
	Mining/quarrying	Limestone quarries
Erie	Industrial effluent	
Great Meadows	Industrial effluent	
Great Swamp	Invasive species	In impoundments
	Garbage/solid waste	Landfill
	Industrial effluent	
Iroquois	Pipelines and utility corridors	Potential for pipeline
John Heinz	Garbage/solid waste	Landfill
	Urban run-off	Trash
	Oil and gas development	Pipeline Spills on Delaware River
	Industrial effluent	
Missisquoi	Invasive species	Aquatic
Montezuma	Garbage/solid waste	Landfill
Moosehorn	Industrial effluent	
Nulhegan Basin	Public use/recreation	Sewage and trash
Ohio River Islands	Mining/quarrying	Acid mine drainage
	Urban run-off	
	Garbage/solid waste	Landfills
	Oil and gas development	Groundwater contamination from fracking
Parker River	Sea level rise	Affect estuary water chemistry
	Urban run-off	

Table 34 (con't)

Refuge	Cause	Example
Patuxent	Garbage/solid waste	Former Ft. Meade groundwater plume
	Industrial effluent	From historic military activities
	Urban run-off	Storm-water
Rappahannock	Hydraulic fracturing	Potential exploration
	Mining/quarrying	Sand & gravel mining
Sunkhaze Meadows	Garbage/solid waste	Landfills adjacent to refuge
	Logging/forestry	Adjacent to refuge, past and present
Wallkill River	Invasive species	Impoundment quality
	Industrial effluent	Volatiles in groundwater
Wallops Island	Industrial effluent	From historic military activities

5.2.3. Sedimentation

Excess sediment impacts water resources by changing river or lake bottoms from rock or gravel stream beds into silty, mucky bottoms. Additionally, sediment in the water column blocks sunlight which negatively impacts the growth of submerged aquatic vegetation. Species that are affected by excess sediment are those that cannot swim away, such as mussels and snails.

Agriculture is the number one cause of sedimentation in the region (Table 35). Sediment from agricultural activities can enter streams and lakes when best management practices are not followed. Adequate riparian buffers are often not maintained on farmlands, which allows farming practices, such as row crops or grazing, to occur immediately adjacent to streams. Refuges not affected by sedimentation are Aroostook, Assabet River, Cape May, Moosehorn, and Parker River.

Table 35. Causes of excess sediment and affected refuges (organized by most common to least common cause).

Cause of sedimentation	Refuges
Agricultural run-off	Blackwater, Bombay Hook, Cherry Valley, Chincoteague, Erie, Iroquois, Missisquoi, Montezuma, Ohio River Islands, Rappahannock, Sunkhaze Meadows
Urban run-off	Canaan Valley, Great Swamp, John Heinz, Patuxent, Wallops Island
Logging/forestry	Cherry Valley, Nulhegan Basin, Rappahannock
Aging water management infrastructure	Great Meadows, Great Swamp
Extreme precipitation events	Canaan Valley, Montezuma
Road construction	Canaan Valley, Patuxent
Oil and gas development	Ohio River Islands
Mining/quarrying	Sunkhaze Meadows
Altered riparian vegetation	Wallkill River

5.2.4. Salinity / TDS / Chlorides / Sulfates

Natural waters have some concentration of dissolved ions due to the substrate that the water flows through. Some natural waters also have increased levels of ions (i.e. oceans, Salt Lake, groundwater). However, human activities can also influence the amount of ions in water. We can measure these chemical alterations by salinity and total dissolved solids (TDS), which provides insight to the amount of chlorides and sulfates in solution. Salinity is the amount of salt in solution. TDS is a measure of all dissolved constituents and elements in water. Chlorides and sulfates are specific types of salts that may be dissolved in water. An increase in salts in water can be detrimental to aquatic species. Waste water treatment facilities and road salt are main contributors of chlorides to water in the Northeast. Sulfates are naturally occurring in groundwater that flows through rocks that contain sulfate minerals, but sulfates are also a result of many industrial releases (specifically mining and oil and gas development) (Table 36).

Table 36. Causes of salinity / TDS / chloride / sulfate water quality threats on refuges. Ranked from most common to least common cause.

Threat Cause	Refuges
Urban runoff	Aroostook, Cherry Valley, Great Swamp, John Heinz, Missisquoi
Sea level rise	Blackwater, Bombay Hook, Parker River
Groundwater pumping: agriculture	Blackwater, Bombay Hook
Wastewater treatment facilities	Great Swamp, Ohio River Islands
Off refuge water infrastructure	Blackwater
Increase in drought frequency/severity	John Heinz
Oil & gas development	Ohio River Islands
Mining/quarrying	Iroquois
Industrial effluent	Iroquois
Drainage ditches	Bombay Hook

5.2.5. Mercury

In the Northeast United States, mercury accumulates in the sediment of lakes, ponds, and wetlands through deposition from the atmosphere. Methylmercury, produced by microbes in the sediment, is bioavailable to many organisms in wetlands ecosystems which leads to the persistence of mercury in the food chain (Krabbenhoft and Rickert, 1995). Several of the refuges with mercury threats (Table 37) have had studies completed by local universities or other groups to determine the impacts of mercury on wildlife.

Table 37. Causes of mercury on refuges and those refuges affected by mercury contamination.

Causes of Mercury Threats	Refuges
Airborne pollutants	Erie, John Heinz, Ohio River Islands, Patuxent, Umbagog
Industrial effluent	Great Meadows
Urban development	Missisquoi

5.3. Aquatic Habitat Threats

Protecting refuges from threats to aquatic habitat are often the primary goal of refuge staff. The most common threats that negatively affect aquatic habitat include (Figure 50):

- **Loss/alteration of wetland habitat**
  Wetlands in the Northeast are important habitats for many unique species. Sea level rise, groundwater pumping, and infrastructure are some of the main causes that are leading to loss of wetlands in the region.
- **Impaired stream connectivity**
  Waterways in the Northern states are dotted with dams and road crossings, which are often barriers to aquatic species.

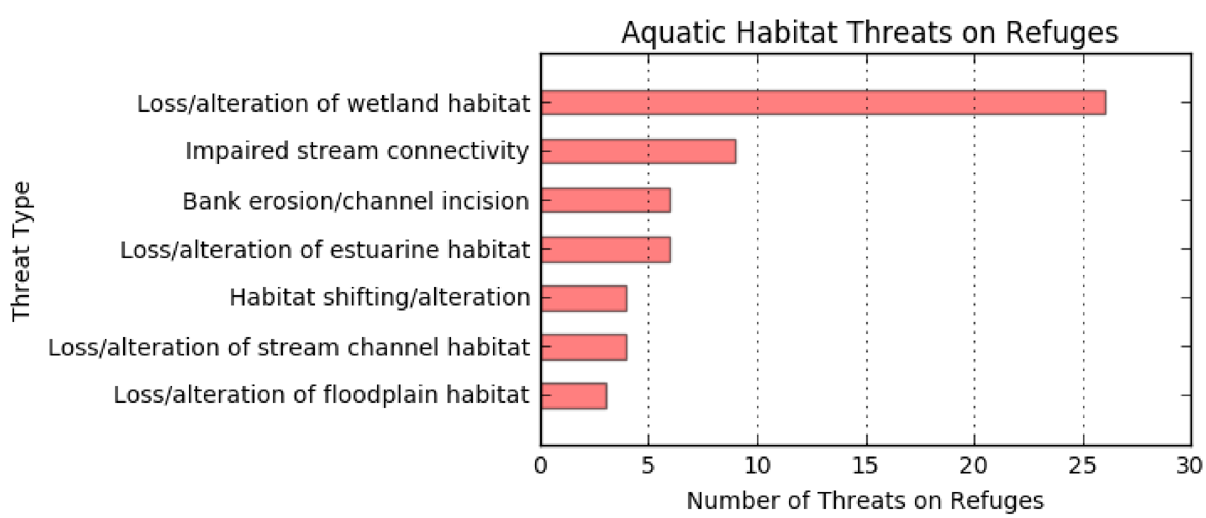

Figure 50. Aquatic habitat threats on refuges and the numbers of threat occurrences.

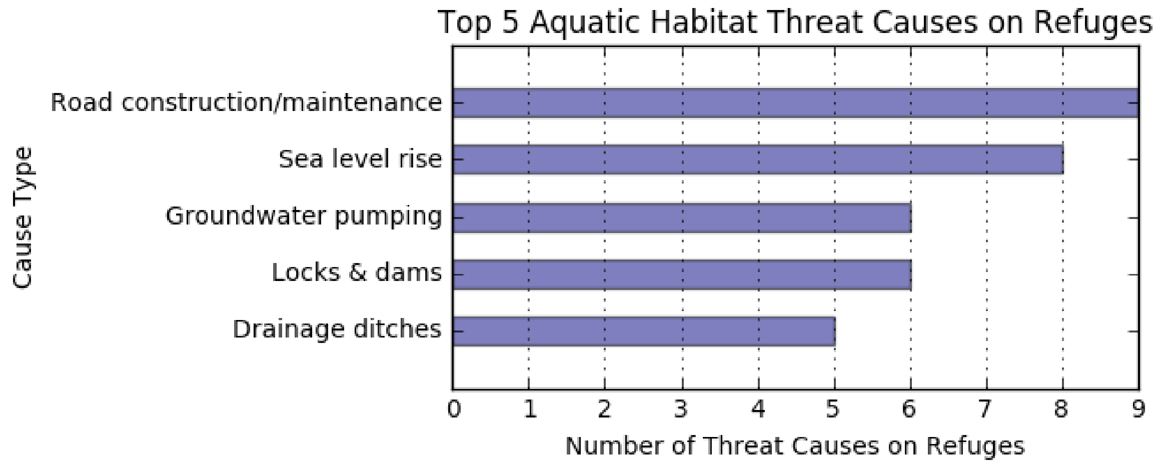

Figure 51. The top 5 aquatic habitat threat causes.

5.3.1. Loss / Alteration of Wetland Habitat

Wetlands are an important component of many of the refuges in the northeast region. Some refuges were established to protect unique wetlands. For example, Sunkhaze Meadows NWR was established to protect Maine's second largest peatland from peat mining.

Causes of loss or alteration of wetland habitat include sea level rise, groundwater pumping, infrastructure, agriculture, urban development, invasive species, and wildlife (Table 38). Infrastructure causes include locks, drainage ditches, aging water management infrastructure, non-FWS infrastructure management, and roads and culverts. Agricultural causes include agricultural run-off, cropland drainage and tiling, and livestock. Wildlife that cause a loss or alteration of wetland habitat are most frequently associated with beavers that inundate wetlands.

Table 38. Causes wetland loss or alteration and affected refuges (organized by most common to least common cause).

Causes of Wetland Loss/Alteration		Refuges
Sea level rise		Blackwater, Cape May, Chincoteague, Rappahannock, Wallops Island
Groundwater pumping	***Municipal***	Cape May, Patuxent
	Industrial	Wallops Island
Infrastructure causes		Blackwater, Canaan Valley, Cape May, Montezuma, Ohio River Islands, Umbagog
Agricultural causes		Blackwater, Chincoteague, Montezuma
Urban development		John Heinz, Wallkill River
Invasive species		Blackwater, John Heinz
Wildlife sources		Wallkill River

5.3.2. Impaired Stream Connectivity

At refuges in the Northeast, many dams and undersized culverts at road crossings block passage to key aquatic species. Roads and culverts are the cause of threats to stream connectivity on refuges; however, aging water management infrastructure and historical infrastructure also impair stream connectivity on refuges (Table 39).

Table 39. Refuges with impaired stream connectivity and the causes of the impairment.

Refuge	Cause
Assabet River	Culverts
Canaan Valley	Dams, Roads
Cape May	Levees, tide gates, culverts, dams
John Heinz	Urban development
Missisquoi	Roads/culverts
Montezuma	Roads
Parker River	Dams
Patuxent	Roads

5.4. Threats Caused by Infrastructure

Infrastructure constructed on refuges prior to FWS acquisition or shortly thereafter, often compromises water management capability on refuges. Infrastructure is the cause of many of the threats described above (Sections 5.1-5.3). Man-made barriers like roads and dikes hold water on the land. Ditches and canals act as conduits that facilitate drainage or the movement of salt water landward. Roads and off-refuge dams are the most common types of infrastructure that threaten refuge water resources. Some of the infrastructure that compromises refuge water resource management are located off-refuge and operated by non-FWS organizations with different water management objectives.

6. Threat Assessment

This review of 25 refuges allows for some general conclusions about the nature of refuge water resources in the Northeast and threats to those water resources. Not surprisingly, human-induced land use alterations are the main cause of threats to refuge water resources.

Nutrient pollution is the most common type of threat to refuge water resources on refuges in Region 5 and across the nation. General contamination or other altered water chemistry is the second most common water quality threat in Region 5. Many threats are lumped into this category because the exact type of contamination is unknown due to limited water quality data at refuges. Numerous Clean Water Act 303(d) impairments, nutrient pollution threats, and other altered water chemistry are reasons to further investigate water quality on refuges.

Threats to the refuge water supplies are most frequently caused by water control infrastructure (i.e. dams, culverts, dikes, etc.) and off-refuge water withdrawals. Many water supply threats can be addressed by improving relations with off-refuge water managers and developing accurate maps of water control infrastructure that includes refuge roads, stream crossings, and culverts. Working to replace or remove aquatic barriers will improve connectivity for aquatic species and also restore natural hydrologic flow conditions. Groundwater withdrawal is an imminent threat for many refuges. Unsustainable groundwater pumping can draw down aquifers that support sensitive ecosystems that depend on groundwater. Establishing groundwater level monitoring on refuges is the best action for refuges threatened by nearby groundwater pumping.

The most common threats to aquatic habitat are the loss and alteration of wetland habitat and impaired stream connectivity. Infrastructure and sea level rise are the most common causes of the aquatic habitat threats. We can work to improve infrastructure on refuges; however, sea level rise is will continue to occur regardless of management actions. The best option for reducing wetland loss due to sea level rise is to allow wetland migration.

Natural threats to water resources are also prominent among refuge concerns. Sea level rise and changing weather patterns are threatening refuge water resources at all refuges in the Northeast. Precipitation patterns are predicted to shift in the Northeast because of a warming climate. Most refuges are already observing increases in annual precipitation, which compromises water management capabilities, especially where water control infrastructure is damaged or no longer functioning.

Certain activities (i.e. agricultural runoff) cause multiple threats to refuge water resources (i.e. sedimentation, nutrient pollution, and wetland loss/alteration). Refuge actions that help address activities that cause multiple threats to refuge water resources are more likely to lead to successful changes to the health of aquatic ecosystems.

6.1. Water Resource Project Needs and Recommendations

A goal of the WRIA process is to identify water resource threats on refuges and to assess what is needed to address those threats. DNRCP can support refuges by helping address these needs. During the WRIA process, refuge staff worked with DNRCP staff to identify projects that would help address threats to refuge water resources (Table 40 – 50). Projects that are relatively simple and require no more than 1-2 weeks to complete by existing DNRCP staff are listed in Table 40. Projects that are more involved, requiring expertise not currently in DNRCP and/or require several months to complete are listed in Tables 40-50.

Table 40. Relatively simple projects and information needs identified by refuges during the WRIA process.

Need Description	Refuge
Correlation of USGS gages across the lake to Errol Dam gage	**Umbagog**
Analysis of existing tidal and water quality data on and around refuge	**Blackwater**
Information gaps on water and aquatic habitats on refuge	**Rappahannock**
Collect groundwater well information from DNREC	**Bombay Hook**
Assess existing water monitoring	
Finish WRIA report	**Moosehorn**
Assess existing water monitoring data	**Patuxent**
Look at timing, duration, and magnitude of spring floods on Lake Champlain	**Missisquoi**
NDVI study to look at floodplain forest tree die-offs	
Analysis of trends in extreme precipitation events near refuges	**All Refuges**

Table 41. Infrastructure related project needs as identified by refuges during the WRIA process.

Project Description	Refuge
Install water control structure at Durepo Pond	**Aroostook**
Replace old infrastructure and culverts	
Repair/replace infrastructure to prevent/reduce saltwater intrusion	**Blackwater**
Remove agricultural ditches and restore natural hydrology	
Restore ditches along roads (ponding currently occurs in roads and fields)	
Hydrologic study - looking specifically at water control structures, culverts, roads, dikes, etc.	**Bombay Hook**
Inventory infrastructure	**Cape May**
Map refuge infrastructure	**Erie**
Restore old impoundment - for public use	**Great Swamp**
Remove historical ditching in wetlands	
Raise water control structure in Pool 2	
GPS locations and elevations of water control structures	**Iroquois**
New culverts and replace water control structures in impoundment	**John Heinz**
Inventory infrastructure	**Montezuma**
Replace culverts or create a new adequate cost effective design	**Nulhegan Basin**
Construct more longitudinal dikes to prevent loss of islands	**Ohio River Islands**
Restore ditches along roads (ponding currently occurs in roads and fields)	**Rappahannock**
Fix Laurel Grove Pond overflow pipe and earthen dam	
Install culverts in secondary roads	**Umbagog**

Table 42. Water quantity project needs, identified by the WRIA process.

Project Description	Refuge
Groundwater and wetland level monitoring	**Assabet River**
Reduce impacts of flooding	**Blackwater**
Establish water quantity monitoring	**Bombay Hook**
Surface water quantity monitoring to see if off-refuge diversions impact refuge water resources	**Canaan Valley**
Initiate baseline water level monitoring	**Cape May**
Monitor vernal pool water levels	
Continuous water level monitoring of Sudbury and Concord Rivers	**Great Meadows**
Continuous groundwater level monitoring in wells	**Iroquois**
Monitor water level in Hoy's Pond	**John Heinz**
Reduce open water and prevent marsh loss in impoundment	
Quantify the amount of water entering the refuge	**Montezuma**
Monitor water quantity in the impoundment system	
Coordinate with USACOE to seasonally adjust water levels	**Ohio River Islands**
Establish water level monitoring	**Parker River**

Table 43. Water quality project needs, identified by the WRIA process.

Project Description	Refuge
Study: Are nutrients assisting in marsh loss by limiting below ground biomass?	**Blackwater**
Establish water quality monitoring	**Bombay Hook**
Install water quality monitoring sensors	**Canaan Valley**
Monitor water quality around gas wells	
Establish baseline water quality monitoring	**Great Swamp**
More baseline water quality monitoring	**Iroquois**
Gather more information of water quality of springs	**Montezuma**
Establish water quality monitoring of inflowing streams	
Continuous water quality monitoring	**Ohio River Islands**
Water quality sampling	**Sunkhaze Meadows**
Reduce sedimentation	**Wallkill River**

Table 44. Groundwater investigations needed by refuges.

Project Description	Refuge
Groundwater model of the effects of center-pivots adjacent to the refuge	**Blackwater**
Identify wetlands that may be compromised by groundwater development	**Bombay Hook**
Field check groundwater-dependent ecosystems	**Cape May**
Monitor streams and wetlands depedent on groundwater. Determine threats to groundwater.	
Study groundwater influence on Hoy's Pond	**John Heinz**
Continuous groundwater level monitoring in wells	**Iroquois**
Study temperature of groundwater flowing into the Ohio River	**Ohio River Islands**
Investigate saline groundwaters	
Groundwater monitoring and modeling at Lucky Boy Fen	**Wallops Island**

Table 45. Road related project needs on refuges.

Project Description	Refuge
Remove/replace Shorter's Wharf Road	**Blackwater**
Map historic logging roads and rail grades	**Canaan Valley**
Raise Trolley Bed Road	**John Heinz**
Map logging roads on refuge	**Umbagog**

Table 46. Aquatic restoration needs on refuges.

Project Description	Refuge
Prevent marsh loss - erosion control, thin layer deposition	**Blackwater**
Habitat protection and restoration for turtles, mussels, salamanders, and pollinators	**Cherry Valley**
Riparian restoration	**Ohio River Islands**
Help getting through the restoration permitting process	**Wallkill River**

Table 47. Aquatic invasive needs on refuges.

Project Description	Refuge
Protect refuge from phragmite monoculture	**Blackwater**
Reduce phragmite	**John Heinz**
Aquatic invasives monitoring	**Umbagog**
Manage invasive species in impoundments	**Wallkill River**

Table 48. Bathymetry needs on refuges.

Project Description	Refuge
Impoundment bathymetry study	**John Heinz**
Complete additional bathymetry surveys	**Montezuma**
Umbagog Lake bathymetry	**Umbagog**

Table 49. Mussel inventory needs on refuges, as identified by the WRIA process.

Project Description	Refuge
eDNA for dwarf wedge mussels	**Cherry Valley**
Mussel survey to determine if algal blooms are harming populations	**Missisquoi**
Mussel inventories of Umbagog Lake and rivers on refuge	**Umbagog**

Table 50. Spring/seep inventory needs on refuges.

Project Description	Refuge
Map springs and seeps	**Canaan Valley**
Model impacts of quarry on springs	**Iroquois**
Gather more information on refuge springs	**Montezuma**

Table 51. Miscellaneous refuge project needs.

Project Description	Refuge
Convert agriculture fields into moist soil impoundments	**Blackwater**
Hydrologic study of Darby Creek and the impoundment	**John Heinz**
Aquatic connectivity study -- red belly turtles	**John Heinz**

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