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A Freshwater Conservation Assessment for the Upper Delaware River Basin

Floodplains, Headwaters, Wetlands, and Freshwater Conservation Areas

We conducted a freshwater assessment for the Upper Delaware River Basin, a land of abundant forests and streams that supplies drinking water to over 15 million people. Our analysis focused on three key components of freshwater systems: Floodplains, Headwaters, and Wetlands. Floodplains were analyzed using The Nature Conservancy's Active River Area framework which spatially defines an ecological and process-based floodplain footprint. Building from this, we developed floodplain units of analyses referred to as Floodplain Cores, Corridors, and Complexes, which enable a multi-scale approach to floodplain conservation efforts. Similarly, for headwaters, we defined an ecological, process-based unit of analysis referred to as Headwater Networks. These networks combine the small watersheds of first-order streams with the riparian corridor of second-order streams. Wetlands were organized at the HUC10 watershed scale. We identified a suite of metrics to evaluate and prioritize floodplain, headwaters, and wetlands. Using floodplains as our focus, we applied these metrics and analysis to the prioritization of floodplain systems. Recognizing the importance of identifying and conserving freshwater biodiversity at the network scale, we used The Nature Conservancy's Barrier Assessment Tool to identify the most the most longitudinally connected components of the freshwater system. Finally, we illustrate the results of these analyses to create a freshwater blueprint for the Upper Basin.

Prepared by Su Fanok, Michele DePhilip, Ellen Creveling, Mari-Beth DeLucia,and Tara Moberg of The Nature Conservancy's Delaware River Basin Integrated Landscape Team

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Acknowledgements

The Freshwater Conservation Assessment for the Upper Delaware River Basin is the result of the dedication and commitment of many individuals and organizations. This project is the culmination of several years of work and deliberation by members of The Nature Conservancy's (TNC) Delaware River Basin Integrated Landscape Team. Challenged with evaluating the freshwater resources of the Delaware River Basin, we utilized new tools such as the Active River Area, to evaluate the floodplains and riparian corridors of the basin.

First introduced to the Active River Area by Mark Smith, the Director of TNC's North American Freshwater Program, Mark continues to be a source of inspiration, encouragement, and support to our team throughout this project. Additional TNC colleagues also have provided invaluable insights and time to this project, by fielding calls, reviewing methods, and simply by being there during times of need. Noteworthy among them are Colin Apse, Analie Barnett, and Arlene Olivero. Periodic infusions of encouragement and ideas were gained along the way from a host of TNC colleagues including, Doug Bechtel, Darren Crabtree, Christian Marks, and Brad Stratton.

We have greatly benefited from The Nature Conservancy's Land Protection for Freshwater Conservation Seminar series. Led by Analie Barnett a landscape ecologist with TNC, five TNC sites shared their insights and lessons learned as they worked through a similar freshwater planning process.

In addition to members of TNC, the organizations listed below have provided their expertise, time, and data to this project. Their knowledge of the basin and places within in it has greatly improved this effort.

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Organizations

- Academy of Natural Sciences
- Cornell University
- Delaware (DE) Coastal Programs
- DE Natural Heritage Program
- Delaware State University
- Delaware Valley Regional Planning Authority
- Delaware River Basin Commission
- National Park Service
- Natural Lands Trust
- New Jersey (NJ) Department of Environmental Protection
- NJ Natural Heritage Program
- National Oceanic and Atmospheric Administration
- North Jersey RC&D
- New York (NY) State Department of Environmental Protection
- NY Heritage Program
- NY City Department of Environmental Conservation
- Pennsylvania (PA) Department of Environmental Protection
- PA Fish and Boat Commission
- PA Natural Resource Conservation Service
- PA Natural Heritage Program
- Partnership for the Delaware Estuary
- Patuxent Wildlife Research Center
- Pinchot Institute for Conservation
- Rutgers University
- Stroud Water Research Center
- U.S. Army Corps of Engineers
- U.S. EPA, Region III
- U.S. Fish and Wildlife Service
- U.S. Geological Survey – Northern Appalachian Research Laboratory
- Upper Delaware Council

Table of Contents

List of Figures

List of Tables

A Freshwater Conservation Assessment for the Upper Delaware River Basin

Floodplains, Headwaters, Wetlands, and Freshwater Conservation Areas

A team of freshwater scientists from The Nature Conservancy within the four states of the Delaware River Basin conducted an assessment of the freshwater ecosystems of the Upper Delaware River Basin. The project area includes a diversity of freshwater flora, fauna, and aquatic system types. We focused our assessment on three critical components of a freshwater network that supports much of the region's aquatic biodiversity: floodplains, headwaters, and wetlands.

The results of this assessment will be incorporated into a more comprehensive assessment of the Delaware River and Estuary. Through this assessment, which is funded by National Fish and Wildlife Foundation (NFWF), The Nature Conservancy, Natural Lands Trust, and the Partnership for the Delaware Estuary will engage partners to identify priority conservation areas and develop strategies for conserving and restoring freshwater, estuarine, and marine shellfish habitats in the Delaware River Basin and Estuary. Results will be available in summer 2011.

Floodplains

Floodplains are key components of freshwater systems. Naturally dynamic, the interaction of external processes such as climate, hydrology, sediment regimes, and geomorphology create a mosaic of habitats that shift through time and space. These areas exhibit few parallels with other systems and offer a diversity of habitat types and unique functional benefits (Naiman and Decamps 1997). Providing the geomorphic setting for floodplain forests, ice-scour grasslands, and mixed-hardwood shrublands, these systems help to regulate light, temperature, nutrient, sediment, and flow regimes of adjacent rivers while also supporting broadly-based food webs that help sustain a diverse assemblage of fish and wildlife (Committee on Riparian Zone Functioning and Strategies for Management 2002).

As the boundary between terrestrial and aquatic systems, floodplains provide a lateral ecotone between land and water, forming a complex gradient between the river channel and nearby uplands. Floodplains include semi-permanently to seasonally flooded vegetation of the riverbed, banks and islands, as well as temporarily flooded and saturated floodplain communities. This landscape is organized by the severity and frequency of flooding, ice scour, direction of flow, and differences in substrate. They also provide a vertical ecotone between surface water and groundwater (Ward et al. 1999). Longitudinally, riparian corridors frame our waterways enabling species dispersal along the riverine corridor. Finally, by augmenting the storage capacity of the riverine system, floodplains can also assist in the attenuation of peak flows, thereby reducing the risk of extensive flooding.

Headwaters

Headwater systems are the regions in a watershed where overland flow and allochthonous input (material originating outside the stream channel) from hillslopes and zero-order basins (unchannelized hallows) eventually converge to form ephemeral and first and second-order stream channels. Headwater systems represent an important transition between physical processes, morphological characteristics, and ecological communities (Gomi et al. 2007, May 2006).

Terrestrial processes typically dominate these upper position systems. Stream chemistry is highly dependent on the region's soil and geology, and flow is highly dependent upon seasonal snowmelt, precipitation, and groundwater contributions. These areas provide highly variable environments for resident and migrating species. The mixture of groundwater and surface water in headwater springs and wetlands provide spawning areas and refugia during times of temperature and flow-related extremes, while also shielding species from predators and high flow velocities (Hack and Goodlett 1960, Gomi et al. 2002, Meyer et al. 2007).

What headwaters lack in size, they make up for in abundance. Gomi (2007) identified steep forested headwater catchments in Oregon as those with drainage areas <1 km^2, yet headwaters can constitute as much as 60-80% of the cumulative channel length in mountainous terrains and 70-80% of the total watershed area (Schumm 1965, Shreve 1969, Sidle et al. 2000, Meyer and Wallace 2001).

Headwater processes and attributes sustain the biological diversity of headwaters and downstream systems. Material inputs, organic and inorganic materials, are periodically exported downstream where they serve as the basic building blocks for the food web of stream systems (Saunders 2002, Meyer et al., 2007, Wipfli et al. 2007, Smith et al. 2008).

Wetlands

Concentrated in the glaciated section of the High Allegheny Plateau, wetlands are a dominant focal feature in the project area. They provide essential habitat for both aquatic and terrestrial species and provide numerous ecosystem services.

Wetlands play a vital link in the life cycle of 75% of the fish and shellfish commercially harvested in the United States and up to 90% of the recreational fish catch (Dahl et al. 2006). The diverse and abundant vegetation in wetlands provides food for aquatic species living within the wetlands, while also supplying essential nutrients and detritus to downstream consumers. Wetlands also create habitat, (e.g., for breeding) and shelter (e.g., for refugia from predators) for terrestrial, aquatic, and amphibian species that move between terrestrial and freshwater habitats (National Oceanic and Atmospheric Administration (NOAA) 2001, Dahl et al. 2006).

Hydrologically, wetland systems retain and store precipitation, surface water, and high-flows and allow for extended recharge to groundwater systems. Wetlands are analogous to the kidneys of a freshwater system, filtering and transforming nutrients. Preserving these areas preserves critical habitat, supports the health of freshwater species and systems, and helps to minimize the negative effects of flooding (National Oceanic and Atmospheric Administration (NOAA) 2001, Dahl et al. 2006).

Freshwater Conservation Areas

Freshwater conservationists are challenged with defining an effective framework for identifying freshwater conservation areas. These areas must recognize the intimacy between terrestrial and aquatic processes and the necessity for longitudinal and lateral connectivity, while supporting the unique function of freshwater systems. Frissel (1993), Pringle (2001), Saunders (2002), and Abell (2007) provide frameworks for identifying freshwater conservation areas. Thieme et al. (2007) pilots an approach for large-scale conservation planning that focuses on protecting high-quality examples of representative aquatic system types, maximizing aquatic connectivity, while also seeking to complement existing terrestrial conservation plans.

In this assessment, we apply many of these concepts to identify floodplain conservation areas. At the core of this effort is the application of the *active river area* framework. Developed by scientists from the Conservancy in collaboration with river scientists in the northeastern U.S., the *active river area* is a spatially-explicit yet process-based framework for defining areas of interaction between flowing waters and land (Smith et al. 2008). We used the *active river area* framework and the accompanying spatial data to develop a freshwater conservation blueprint for the Upper Delaware River Basin

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Project Area

The project area includes the Upper Delaware River Basin, extending upstream from the Delaware Water Gap National Recreation Area to the headwaters of the basin in the Catskills of New York (Figure 1).

The study area is characterized by medium to high elevation streams. Stream gradient varies but high gradient tributaries are predominant. In Pennsylvania, many of these tributaries flow off the Glaciated Low Plateau, through steep ravines that are often dominated by eastern hemlocks (*Tsuga canadensis*) (Fanok et al. 2009). Major mountain ranges include the Catskills in New York and the Kittatinny Ridge in Pennsylvania and New Jersey. Stream chemistry is primarily acidic, but calcareous systems exist in proximity to the Delaware Water Gap. The Delaware River mainstem is the core of the aquatic system stitching together the portions of the basin in NY, NJ and PA.

The Delaware River is the longest and last free-flowing (undammed) major river east of the Mississippi. However, its tributaries are highly fragmented by dams used for flood control, drinking water storage, and recreation. In addition, the study area is within a two-hour drive of nearly 25 million people and provides drinking water to almost 15 million (Kauffman et al. 2008). No other river system of its size provides as many people with water (Albert 2005).

Aquatic biodiversity still thrives in the region, but impacts have been seen. A mussel survey conducted by the Biological Resources Division of the U.S. Geological Survey in 2001 found eight species of freshwater mussels within the Delaware Water Gap National Recreation Area. Six of these species are endangered, threatened, or of special concern in New Jersey or Pennsylvania. One of these species, the dwarf wedge mussel *(Alasmidonta heterodon),* is also federally endangered (National Park Service 2007). By far the most common and abundant species of mussel found in the survey was the eastern elliptio *(Elliptio complanata),* which

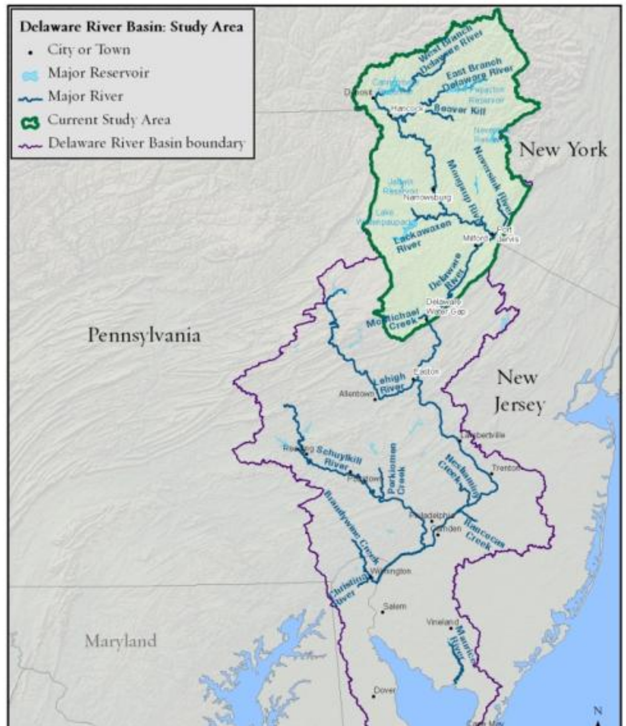


Figure 1. The Upper Delaware River Basin constitutes the upper third of the basin. While dominated by forests, rapid growth in the last decade and energy development are regional concerns.

accounted for nearly 98% of all the mussels in this section of the Delaware River.

Diadromous fish populations, including American Eel (*Anguilla rostrata)*, American Shad (*Alosa sapidissima)*, sea lamprey (*Petromyzon marinus*), alewife (*Alosa pseudoharengus*), and striped bass (*Morone saxatilis*) also occur in the basin's rivers and streams. For the American eel, the Delaware River Basin may still provide one of the most significant strongholds on the Atlantic Coast. Schuler (2010) offers the following: "While eel numbers have greatly declined in many rivers in the northern part of the species' range – most notably the St. Lawrence – the Delaware still possesses a relative abundance. This means that the Delaware stands as an important conservation priority and possibly a key to the survival of the species".

This project focused on the Upper Basin, but results for the entire basin are illustrated where available.

Units of Analysis

Floodplains
The active river area represents the channels and riparian lands necessary to accommodate the physical system and ecological processes associated with the river system (Smith et al 2008). This active river area framework informs river conservation by accounting for and mapping the areas and processes that form, change, and maintain a wide array of habitat types and conditions in and along rivers and streams. The spatial model of the active river area was developed for rivers in the northeastern U.S. by the Conservancy's Eastern Science Office in Boston, MA.

Using this regional model, we mapped floodplains for all rivers in the Delaware River Basin that are greater than 200 square miles in drainage area. Streams in drainage areas of this size generally are considered to be in the transfer or depositional zones of a riverine system. In these zones, lower elevation rivers with gentler slopes begin to widen and meander across a broader valley-floor resulting in more extensive floodplains (Schumm 1977).

We also made several enhancements to the regional model by a) linking the active river area model to the National Hydrographic Dataset – Plus; and b) analyzing and mapping the extent of various land cover types, protected areas, overlap with FEMA 100-year floodplain, and several other attributes within the active river area footprint.

Building from this *active river area* footprint, we developed units of analysis that enabled us to evaluate the floodplain at multiple scales. We refer to these units as **floodplain cores, corridors, and complexes**. The advantage of this multi-scale analysis is that it retains the finer level of detail represented by floodplain patches while also being able to combine patches into corridors and complexes of increasing size and extent.

As disturbance-driven systems, we wanted our analysis to identify units - Floodplain Complexes that are appropriate to the scale of floodplain communities and the dominant processes that form them. Floodplain complexes group floodplain communities occurring under particular environmental conditions lending insights into ecosystem functionality, while also providing a template for floodplain conservation design (Fike1999).

We created the following rules to define floodplain cores, corridors, and complexes.

1. Cores are defined as areas of natural cover (forest and wetland cover) greater than 250 acres in the *active river area* (Figure 2A).

2. Corridors embed Cores and are defined as:
   a. Natural and undeveloped cover patches of any size along a stream reach that contains a core (Figures 2B and 2C), and
   b. Natural and undeveloped cover patches greater than 100 acres that are adjacent to a core (Figure 2B and 2C).

3. Complexes unite cores and corridors along major rivers and across rivers of different sizes (Figure 2D)

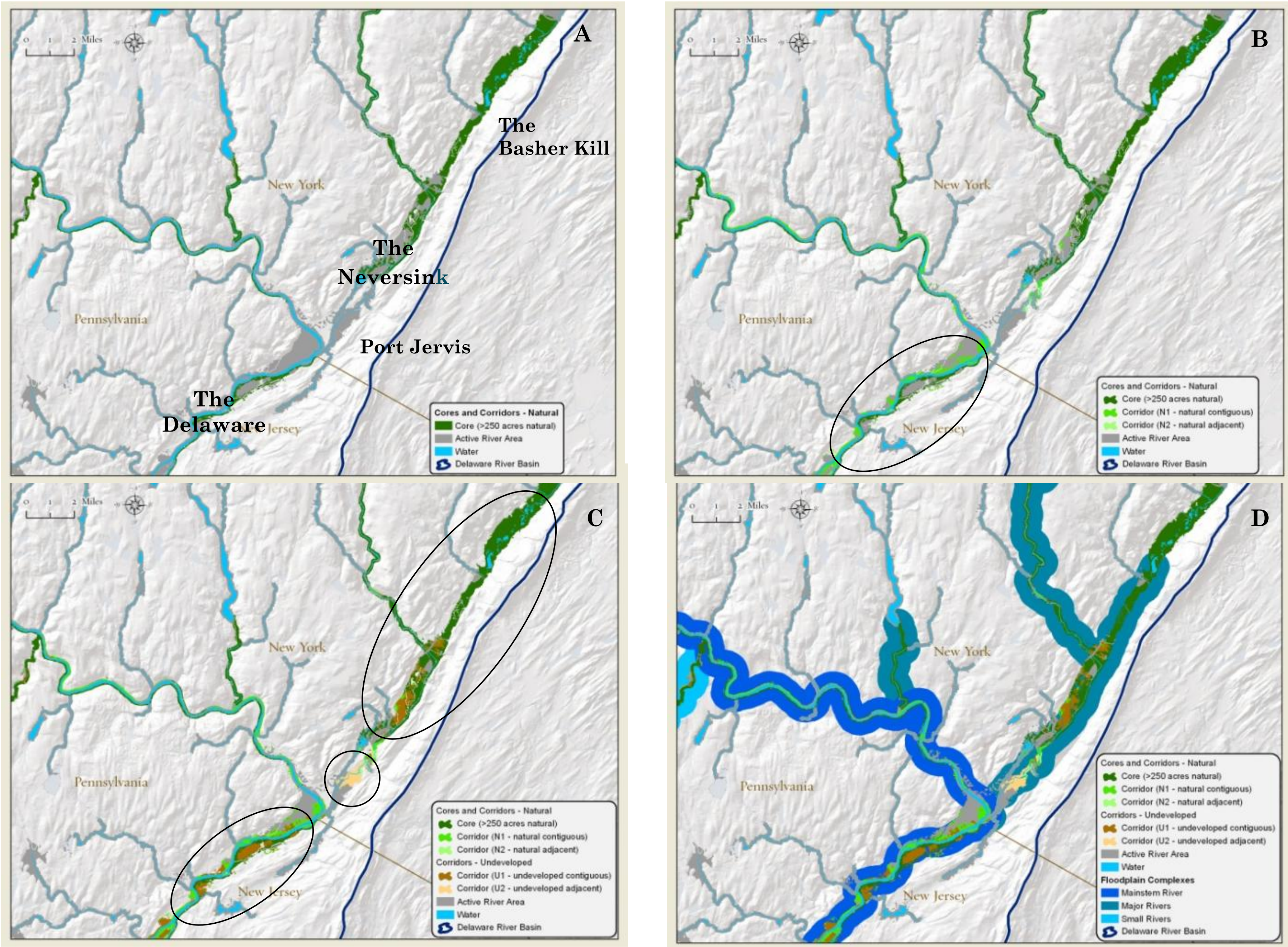


Figure 2. Floodplain Cores, Corridors, and Complexes near Port Jervis, New York. A) Floodplain cores are represented as dark green patches along the Neversink and Basher Kill Rivers; B) Natural cover corridors of any size begin to fill in areas around cores and natural cover corridors > 100 acres extend corridors; C) Undeveloped cover corridors add agricultural cover to the corridors. Undeveloped corridors of any size fill in areas around cores and undeveloped cover corridors > 100 acres extend corridors upstream and downstream; and D) Floodplain complexes combine cores and corridors along the mainstem Delaware River with those on the Neversink.

To determine the most appropriate size threshold for our analysis, we visually and iteratively evaluated cores of various sizes. Cores greater than 250 acres identified representative clusters of floodplain patches across the basin. Ecologically, this size patch is also of sufficient size to support the breeding habitat needs of several floodplain species.

In the Connecticut Basin, the size of floodplain necessary to support breeding habitat for floodplain species ranged from 25 to approximately 1000 acres (Olivero and Anderson 2006). Other assessments of the North Atlantic Coast and the Northern Appalachians (Anderson et al. 2006b, Anderson et al. 2006a) determined that a minimum floodplain size of 50 acres was necessary, based partially on the co-occurrence of known rare species or communities.

Based on these studies, we believe that a 250 acre core is a useful starting size that will support a number of representative and rare floodplain species. We built on these cores, filling in and adding adjacent natural and undeveloped corridor areas. Thus, the floodplain complexes increased in size, which we expect will thereby support a wide range of representative species with varying habitat needs.

Along the mainstem Delaware River, complexes extended most of the length of the mainstem and did not always break naturally based on changes in land cover/land use. To identify discrete complexes and units that are manageable for conservation purposes, we evaluated how slope and water quality changes could be applied to break the mainstem into separate complexes. We also evaluated how institutional breaks, such as the Delaware River Basin Commission's (DRBC) Interstate Water Quality Zones and the HUC8 boundaries supported this process. Finding many similarities between ecological and institution breaks, we used DRBC's Interstate Water Quality Zones to guide mainstem complex breaks, but modified them per ecological information and expert guidance (Erik Silldorff, personal communication, November 2010).

Data Sources: TNC's Active River Area Tool 2009, TNC's Ecological Land Units 2007, TNC's Internal Secured Areas Dataset 2008, DRBC Water Quality Zones 2001, DRBC Wild and Scenic Designations 2008, NHD Plus Flowlines and Catchments 2006, USDA-NRCS, USGS, EPA Watershed Boundary Dataset (WBD) HUC8, 10, 12 2007, US County Boundaries National Atlas of the United States 2001.

Headwaters

For streams with drainage areas less than 200 square miles, we developed a unit of analysis referred to as a headwater network. The headwater network is comprised of two distinct but connected parts:

- Small catchments (drainage areas < approximately 4 square miles)
- Downstream riparian corridors and material contribution zones (for streams with drainage areas between approximately 4 and 40 square miles)

These two discrete units were combined and summed to an intermediate watershed scale (i.e. HUC10 watershed) scale (Figure 3).

The Northeast Aquatic Habitat Classification System defines streams with drainage areas less than 3.861 square miles as headwaters, as they capture the majority of first-order streams mapped per the NHD Plus (Olivero and Anderson 2008). These small drainages capture the

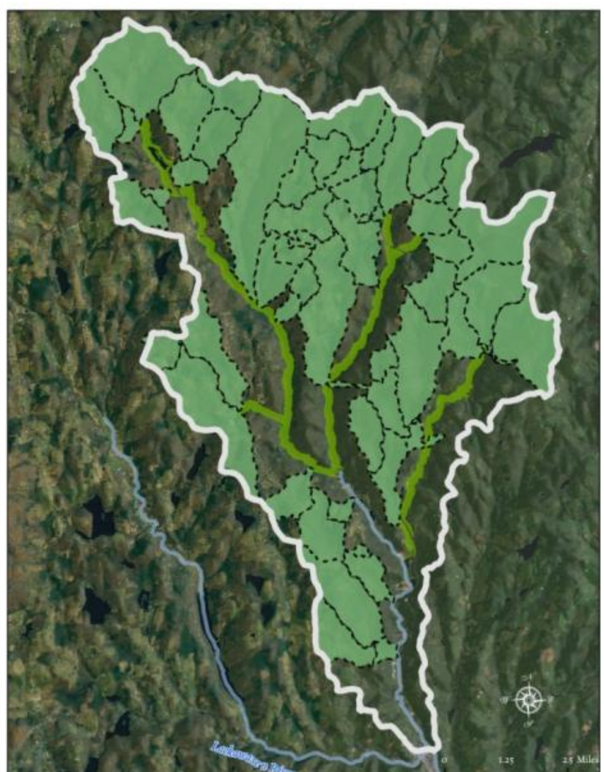


Figure 3. Headwater Network for the Dyberry Creek . Headwater networks are defined by small catchments (<3.861 mi2) linked to downstream riparian corridors and summed to the HUC10 watershed.

processes and attributes of hillslopes and zero-order basins. We represent these streams using the entire catchment. By doing so, we capture under-represented streams not delineated due to mapping inconsistencies.

Headwater catchments were then linked to the downstream riparian corridor or material contribution zones of catchments with a drainage area between 3.862 and 38.61 square miles. Material contribution zones were mapped using the *active river area* tool and are defined as those areas directly adjacent to the stream channels that regularly contribute significant amounts of material, both organic and inorganic, to stream systems (Smith et al. 2008). In these areas, ephemeral streams eventually transition to perennial first and second-order streams.

Headwater networks – comprised of headwater catchments and riparian corridors – were then organized within HUC10 watershed boundaries. Watersheds were selected as the reporting units for our analysis as they define an interacting freshwater system and act as the principle distributional constraint for freshwater organisms (Sowa et al. 2004). We chose the HUC10 scale, as many processes critical to populations and communities occur at the small to intermediate watershed scale (defined as watersheds with drainage areas between 30-200 square miles)(Fausch et al. 2002). Watersheds also provide ecologically meaningful and commonly used management "units" around which conservation planning efforts often develop (Olivero and Anderson 2006).

Data Sources: NHD Plus Flowlines and Catchments 2006, USDA-NRCS, USGS, EPA Watershed Boundary Dataset (WBD) HUC8, 10, 12 2007.

Wetlands

Wetlands were identified using the National Land Cover Dataset (NLCD 2001). We analyzed these wetlands at the HUC10 watershed scale to be consistent with the headwater unit of analysis. Open water features such as ponds, lakes, and reservoirs were removed from the analysis.

Wetland in Pike County, Pennsylvania © Su Fanok/TNC.

Data Sources: TNC Eastern Region Conservation Science. 2005. Ecological Land Unit model

MEASURES OF AQUATIC INTEGRITY

To evaluate the condition of our three freshwater targets – floodplains, headwaters, and wetlands - we first determined each target's key ecological attributes (KEAs). KEAs are the aspects of a target's biology or ecology that, if present, defines a healthy target and if missing or altered, would lead to the outright loss or extreme degradation of that target over time. Although differences exist between each target's KEAs, we found we could group the KEAs into five categories of aquatic integrity within which individual metrics were developed to specifically address the ecological needs and sensitivity of each target. The five elements of aquatic integrity include: Aquatic Connectivity, Hydrologic Alteration, Water Quality, Resiliency, and Size.

Target	KEAS Measures of Aquatic Integrity	Indicator Metric
Floodplains	Aquatic Connectivity →	Functional Network Size
	Hydrologic Alteration →	Dam Storage as a Percent of Mean Annual Flow Percent of Floodplain in 100-yr Floodplain
Headwaters	Water Quality →	Impervious Cover Natural Cover
	Resiliency →	Baseflow
Wetlands	Size →	Floodplain Complex Acreage in Natural Cover Wetland Acreage in Watershed Functional Network Size

Aquatic Connectivity
The upstream/downstream connectivity of freshwater rivers is important to consider, as in-stream barriers can prevent the longitudinal movement of water, sediment, nutrients, organic matter, as well as aquatic organisms (Ciruna and Braun 2005). Connected streams are critical for the movement and dispersal of host fish for mussels, for local migratory species, and for diadromous fish species.

Using TNC's Barrier Assessment Tool (BAT) we identified which aquatic systems were more connected upstream through their headwaters and downstream to the mainstem and ultimately to the Delaware Bay. This tool calculates the available upstream, downstream, or cumulative stream network size that is not blocked by barriers. By adding the length of all tributaries until it reaches either a barrier or a river source, it defines the **size of a functional or connected network.**

Research efforts are exploring the link between stream network complexity and ecological processes like species colonization, dispersal, and the ability of species to respond or adapt to habitat degradation (Grant et al. 2007, Lechter et al. 2007). The availability (size) of a connected stream network must be sufficient to allow dispersal and colonization from one habitat to another, whether to complete various life history stages or to move in response impacts.

In addition, we evaluated the lateral connectivity of floodplains by determining the amount of each complex that is within the 100-year floodplain. This analysis identifies those floodplains that are still hydrologically connected to the river and it further identifies areas of potential flood storage. This metric was not applied to the headwater networks as the 100-year floodplain delineation becomes incomplete in these areas.

Data Sources: NY, NJ, PA State Dam Inventories 2010, Army Corps National Inventory of Dams (NID)1999, Federal Emergency Management Agency 100- and 500-year floodplains FEMA Map Service Center - Digital Q3 Available for region as of 2007. [1]

[1] The results of our functional connected networks analysis are preliminary due to limitations in available datasets. Access to more complete dam data and review of dam location precision is needed to improve the accuracy of these results.

Hydrologic Alteration

Freshwater and riparian ecosystems are highly dynamic and require natural variations in water flow to support the processes that sustain their biodiversity over time (Smith et al. 2008). An ecologically functional floodplain requires interaction with a river that retains a flow regime with sufficient variability to encompass the flow levels and events that support important floodplain processes. Human-induced alterations to the flow magnitude, timing, duration, and rate of change of flow can cause various negative impacts throughout an affected watershed. (Poff et al. 1997).

Dams for flood control, hydropower, and water supply not only act as barriers to movement, but they also alter the natural variations in flow. The volume of water stored in reservoirs as a proportion of mean annual streamflow, referred to as a **dam storage ratio**, provides another indicator of the degree of impact dams may have on the system.

Several studies have demonstrated increased hydrologic alteration as dam storage ratio increases (Zimmerman et al. 2006, Vogel et al. 2007, Fitzhugh and Vogel, in review). We analyzed dam storage ratios at two scales, by reach and by intermediate watershed (HUC10), to estimate the risk of hydrologic alteration. We consider reaches with a storage ratio >0.5 (or 50 %) at high risk of hydrologic alteration, consistent with published thresholds (Zimmerman et al. 2006, Fitzhugh et al., in review).

Data Sources: NY, NJ, PA State Dam Inventories 2010, Army Corps National Inventory of Dams (NID)1998, ESRI GDT 1:100,000K Roads 2003.

Water Quality

Chemical regimes of aquatic systems can be measured using a suite of water quality parameters, such as dissolved oxygen, nutrients, pH, and temperature—all factors that are important for the health of aquatic species. However, because consistent water quality data are not standardized across the region (and thus are not directly comparable), we concentrated on surrogates for impacts to water quality, such as impervious and natural cover.

Even low levels of impervious cover (between 1% and 3%) have been shown to have significant impacts on aquatic species (Baker 2010, Cuffney et al. 2010). A study of northeastern brook trout populations in watersheds with less than 82% natural cover, were likely to be extirpated whereas in watersheds with greater than 90% natural cover, populations were likely to be intact (Hudy et al. 2005).

We analyzed the acreage and percent of **natural cover** for floodplains. We analyzed impervious cover for headwater targets.

Data Sources: Multi-Resolution Land Characteristics Consortium (MRLC) National Land Cover Dataset (NLCD) Impervious Surface 2001, Multi-Resolution Land Characteristics Consortium (MRLC) NLCD 30m Land Cover 2001.[2]

Size

The size of conservation areas need to be large enough for species and ecosystems to be able to recover from natural and anthropogenic disturbances (Groves 2003). This notion of "being large enough" was one of the driving forces behind the development and identification of floodplain complexes, which need to be large enough for species to recover from disturbances such as flooding and ice scour.

For wetlands, we evaluated the acreage and density of wetlands within floodplains and headwater networks.

We also evaluated the **size (length) of connected aquatic systems** using the BAT and further evaluated the percentage of each floodplain complex included in a functional network. While a measure of size, this is also a measure of the aquatic ecosystem's resiliency to change.

[2] Point source data were not in the analyses due to data inconsistencies and data incompatibility across state lines. Although preliminary places of conservation interest have been identified, prior to strategy implementation, partners should consider the further implications of water quality factors not included in this analysis, such as point source discharges.

Resiliency

Resiliency incorporates the concepts of both population viability and the ecological integrity of communities and ecosystems (Shaffer 1981, Angermeir and Karr 1994). While this project does not specifically address species targets and therefore population viability, processes such as fire and flooding also need to be within a natural range of variability (Landres et al. 1999).

Baseflow is the component of stream flow that can be attributed to groundwater (Wolock 2003). It is essential to maintaining temperature regimes that are healthy for aquatic organisms, to enabling the chemical transfer of nutrients and minerals between surface and groundwater systems, to maintaining perennial flow in many smaller headwater stream systems, and to augmenting surface water flows in larger streams (Winter et al. 1998, Fanok 2000, Ciruna and Braun 2005). Hydrologic interactions may be particularly important in headwater streams, where the extent of the groundwater/surface water mixing environment (i.e., hyporheic zone) is proportionately greater than in larger streams.

Using groundwater availability data obtained from the United States Geological Survey (Sloto and Buxton 2007), we assessed the **volume of groundwater available and the percent of groundwater used** in each headwater network. Headwaters with high baseflow contributions and low groundwater use are areas that provide refugia to aquatic flora and fauna during times of temperature and flow-related stress.

As global climate change, increased fragmentation of the landscape and other threats continue to escalate, providing for and identifying where there is resiliency in freshwater networks, through groundwater refugia or network connectivity, is critical.

Data Sources: TNC's Barrier Assessment Tool 2010. U.S. Army Corps National Inventory of Dams (NID) 1999. NY, NJ, PA State Dam Inventories 2010, NHD Plus Waterfalls 2006, ESRI GDT 1:100,000K Roads 2003, USGS Pennsylvania Water Science Center, USGS Groundwater Availability Data, Sloto and Buxton 2007.

Results and Discussion

The results and discussion in this section focus on the identification of floodplain complexes and analysis of key ecological attributes for floodplains. Results for the headwaters and wetlands will be included in the report to the National Fish and Wildlife Foundation in 2011.

Floodplains

By mapping floodplain complexes using the criteria for cores, corridors, and complexes, we identified sixty-two floodplain complexes in the Delaware River Basin: six occur along the mainstem, twelve occur along major tributaries, and forty-four occur along small rivers (Figure 4).

For each of the 62 complexes, we calculated metrics related to longitudinal connectivity, lateral connectivity, degree of hydrologic alteration, amount of natural cover, and the amount of protected area. In Table 1, we summarize these statistics for mainstem, major river and small river floodplain complexes

Because the Delaware River mainstem is unfragmented by dams, all mainstem complexes are associated with a functional connected network that is over 500 miles long (including the Delaware mainstem and the length of all connected tributaries). Of the three sizes of complexes, the mainstem complexes also have the highest percent of area within the 100-year floodplain (61%), the highest total protected acres (111,646 acres) and the highest percent of protected acres (27%). Mainstem complexes are most affected by upstream dam storage due to several large reservoirs in the Upper Basin that have potential to affect streamflow on the mainstem.

In contrast, the small river complexes are the least impacted by upstream dam storage. Small river complexes also contribute the highest amount of total natural acres (65,041 acres). More detailed results that allow comparison of individual mainstem and major river complexes are included in the Results Summaries that follow.

Table 1. Summary statistics for mainstem, major river, and small river floodplain complexes.

Aquatic Integrity: Metrics	Mainstem Complexes	Major River Complexes	Small River Complexes
Longitudinal Connectivity			
Average Percent of each Complex in a Functional Network >500 mi. long	100%	45%	34%
Lateral Connectivity			
Average Percent of each Complex in the 100-yr Floodplain	61%	57%	47%
Hydrologic Alteration			
Average Percent of each Complex with Dam Storage<5%	0% (although 61% of the complexes are between 5-25%)	58%	88%
Water Quality & Size (Acreage/Complex)			
Minimum Natural Acres	1,345	399	183
Maximum Natural Acres	9,068	11,789	5,150
Average Natural Acres	3,992	4,008	1,478
Total Natural Acres	23,949	48,091	65,041
Percent Natural Acres	75%	69%	64%
Total Protected Acres	111,646	14,950	22,080
Percent Protected	27%	23%	19%

Table 4. Floodplain Complex Summary Statistics

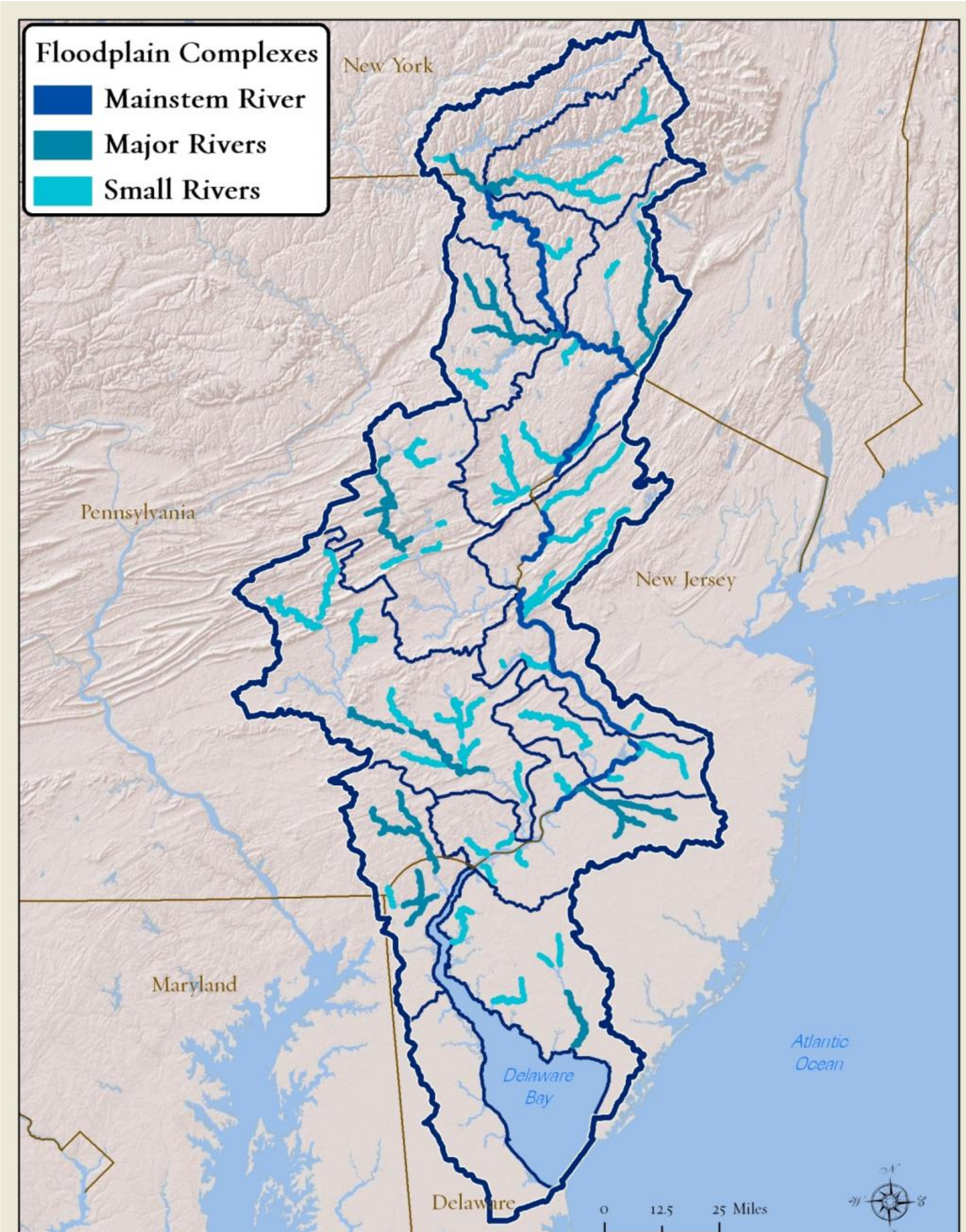


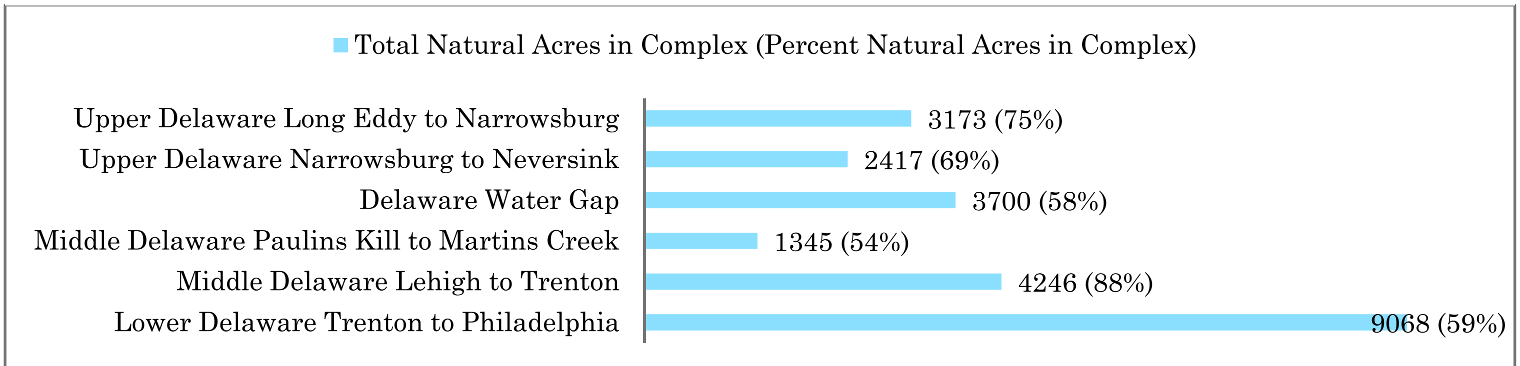
Figure 4. Floodplain Complexes throughout the Delaware River Basin stratified by river size.

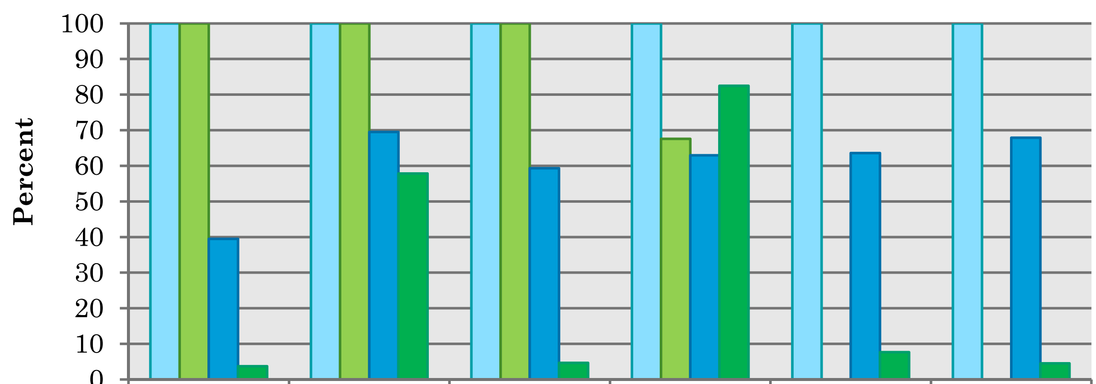
RESULTS SUMMARY: FLOODPLAIN COMPLEXES ON THE DELAWARE RIVER MAINSTEM

Six floodplain complexes were identified along the Delaware River Mainstem. These floodplain complexes encompass the majority of the mainstem Delaware River, although they are not continuous from the Delaware Bay upstream to Hancock, NY. Because they are associated with the mainstem, they are part of a functional network that is over 500 miles long. Flow alteration impacts are most significant in the Upper Basin where several water supply dams on major tributaries alter flow in this portion of the mainstem.

Three mainstem complexes occur in the Upper Delaware Basin: the Upper Delaware Long Eddy to Narrowsburg, Upper Delaware Narrowsburg to Neversink, and the Delaware Water Gap complexes. All three complexes occur in two designated Wild and Scenic reaches of the Delaware River. The percent of natural acres in these complexes is extremely high at 75%, 69%, and 58% respectively. The Delaware Water Gap complex has the highest percentage of protected area in the basin (83%) (Table 2).

Table 2. Summary statistics for floodplain complexes along the Delaware River mainstem.





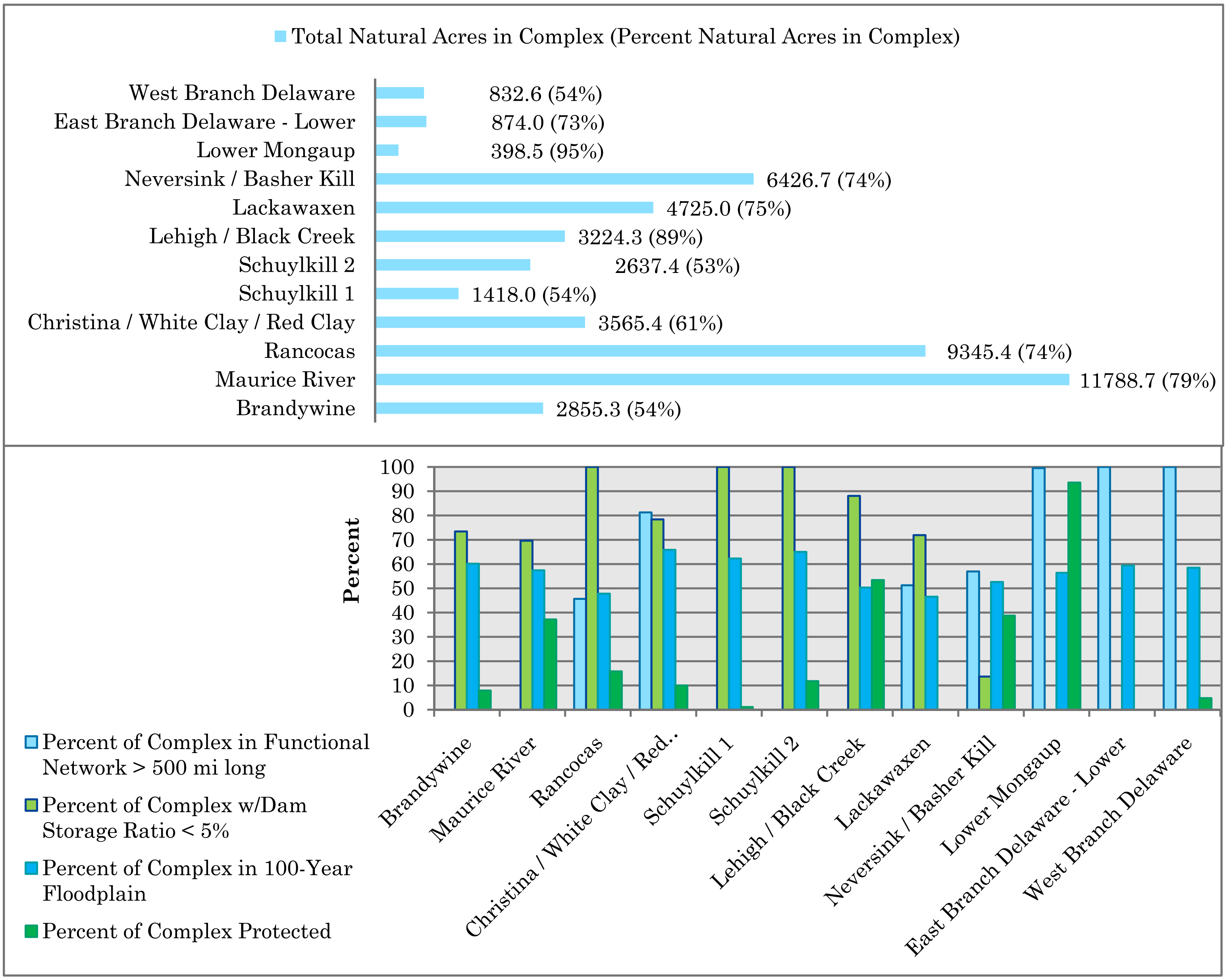
	Lower Delaware Trenton to Philadelphia	Middle Delaware Lehigh to Trenton	Middle Delaware Paulins Kill to Martins Creek	Delaware Water Gap	Upper Delaware Narrowsburg to Neversink	Upper Delaware Long Eddy to Narrowsburg
Percent of Complex in Functional Network > 500 mi long	100.0	100.0	100.0	100.0	100.0	100.0
Percent of Complex w/Dam Storage Ratio between 5 - 25%	100.0	100.0	100.0	67.6	0.0	0.0
Percent of Complex in 100-Year Floodplain	39.5	69.5	59.3	63.0	63.6	67.9
Percent of Complex Protected	3.7	57.8	4.7	82.5	7.7	4.5

RESULTS SUMMARY: FLOODPLAIN COMPLEXES ON MAJOR RIVERS

Twelve floodplain complexes were identified along eleven different major rivers in the basin. Three complexes – the West Branch Delaware, the East Branch Delaware (Lower) and the Lower Mongaup – are entirely connected to the Delaware mainstem and three more have at least some portion of the complex connected to the large functional mainstem network. Although fragmentation within these six complexes is low, four of these complexes have a dam storage ratio of >25%, meaning they are at risk of hydrologic alteration from upstream water supply and hydropower reservoirs. The remaining eight complexes (all down-basin from the Lackawaxen) have a very low risk of hydrologic alteration.

Four complexes have more than 1000 protected acres within them. The amount of protected area within floodplain complexes on major rivers varies from zero to 94%. The Lackawaxen has one of the highest percentages of natural cover (75%) but one of the lowest percentages of protected area (< 0.1%). The lower Mongaup, the Neversink/Basher Kill, and the Lehigh/Black Creek Complexes have more than 40% of their lands already protected (Table 3).

Table 3. Summary statistics for floodplain complexes along major rivers



Once we calculated the metrics related to lateral and longitudinal connectivity, hydrologic alteration, water quality and size for each complex, we further analyzed complexes by combining several metrics. We compared floodplain complexes using three different metrics:

1. Connectivity: Functional Connectivity Network Size
2. Hydrologic Alteration: Dam Storage Ratio
3. Natural Cover: The Acreage and Percent of Natural Cover

Opperman (2010) states that, "the key attributes of ecologically functional floodplains include three basic elements: (1) hydrologic connectivity, (2) a variable hydrograph reflecting seasonal precipitation patterns which retains a range of both high and low flow events, and (3) sufficient spatial scale to encompass dynamic processes and for floodplain benefits to accrue to a meaningful level". The metrics we selected, connectivity, hydrologic alteration, and natural cover acreage applied to the scale of floodplain complexes, address these three key attributes of ecologically functional floodplains (Figures 5-7).

Applying a technique developed by TNC (Olivero 2007), we combined metrics to identify a subset of complexes that scored highly for at least two of the three metrics. By noting which metric thresholds were met and which were not, this approach provides more than just a list of floodplain complexes that potentially have the most integrity with respect to key ecological attributes. It also provides a starting point for the development of conservation strategies.

Thresholds for each metric were determined by averaging values within each of the three size classes. Individual complexes were evaluated relative to the average and range of values within each size class. Table 4 includes the analysis metrics and the threshold values for mainstem, major river, and small river floodplain complexes.

Table 4. Summary of metrics applied to analysis of floodplain complexes with threshold values for each metric per floodplain complex river size.

Axes of Comparison	Mainstem Floodplain Complexes	Major River Floodplain Complexes	Small River Floodplain Complexes
Percent of Complex occurring within a specified size Functional Connectivity Network	100% of complex in functional network >500 miles long	>50% of complex in functional network >100 miles long	>50% of complex in functional network >100 miles long
Percent of Complex occurring along a river with a specified Dam Storage Ratio	>50% of complex has dam storage ratio between 5-25%	>50% of complex has dam storage ratio <5%	>50% of complex has dam storage ratio <5%
Complex Acreage and Percent Natural Cover is above the mean	Acreage and percent natural cover are both above the mean (3991 acres and 67%)	Acreage and percent natural cover are both above the mean (4008 acres and 70%)	Acreage and percent natural cover are both above the mean (1478 acres and 66%)

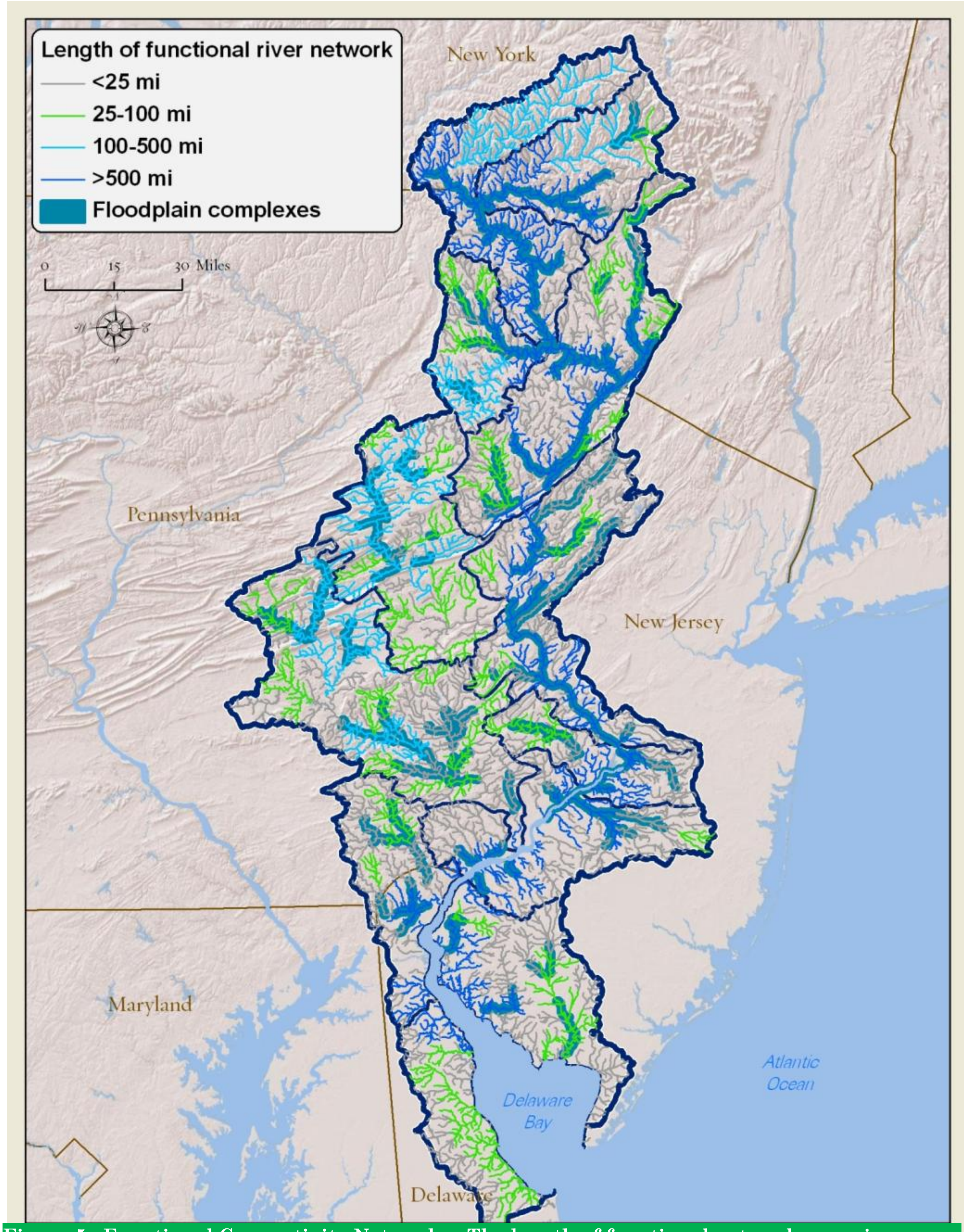


Figure 5. Functional Connectivity Networks. The length of functional networks per river reach are illustrated for floodplain complexes throughout the Delaware River Basin.

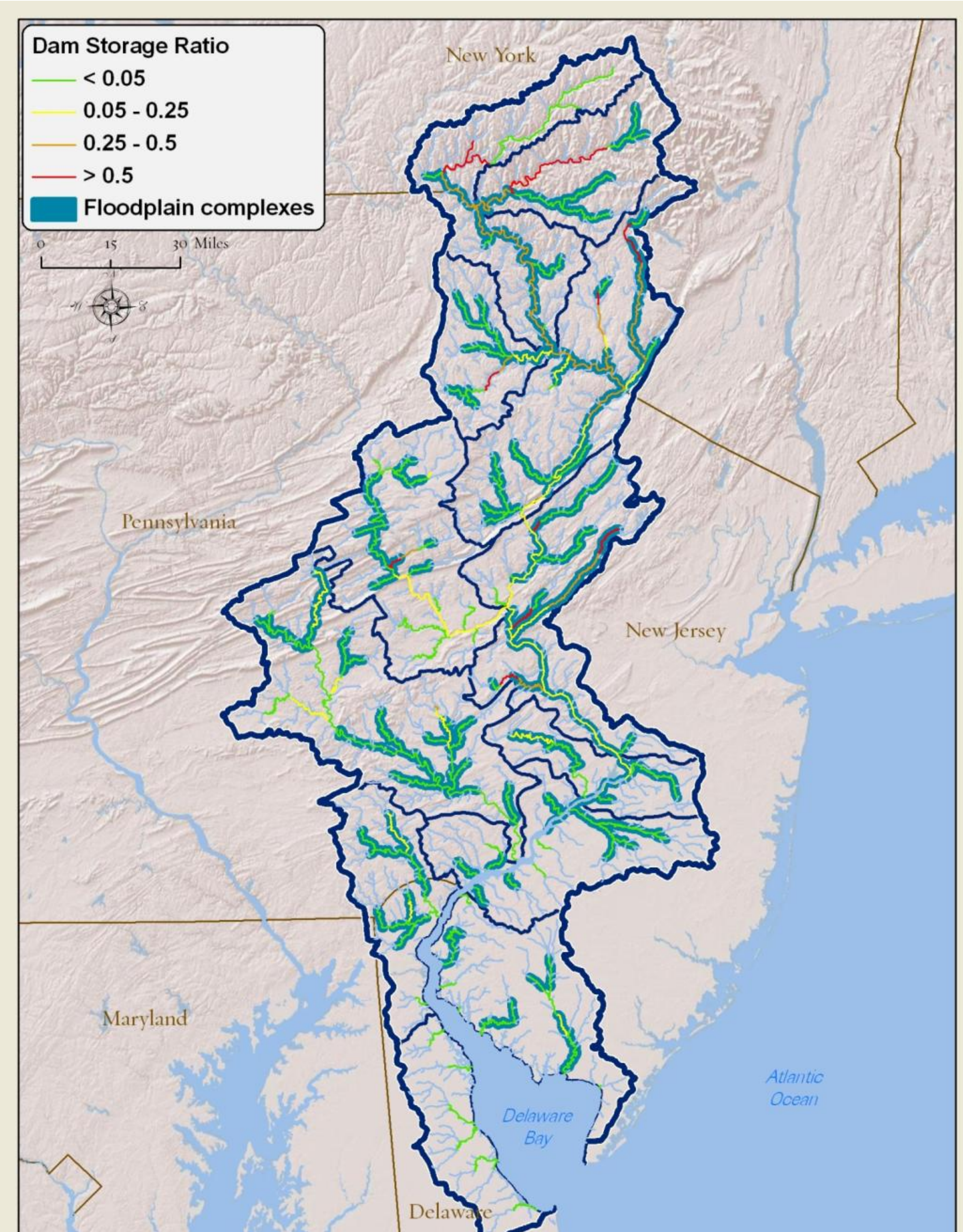


Figure 6. Hydrologic Alteration: Dam Storage Ratios. Dam storage ratios are illustrated per river reach for floodplain complexes throughout the Delaware River Basin.

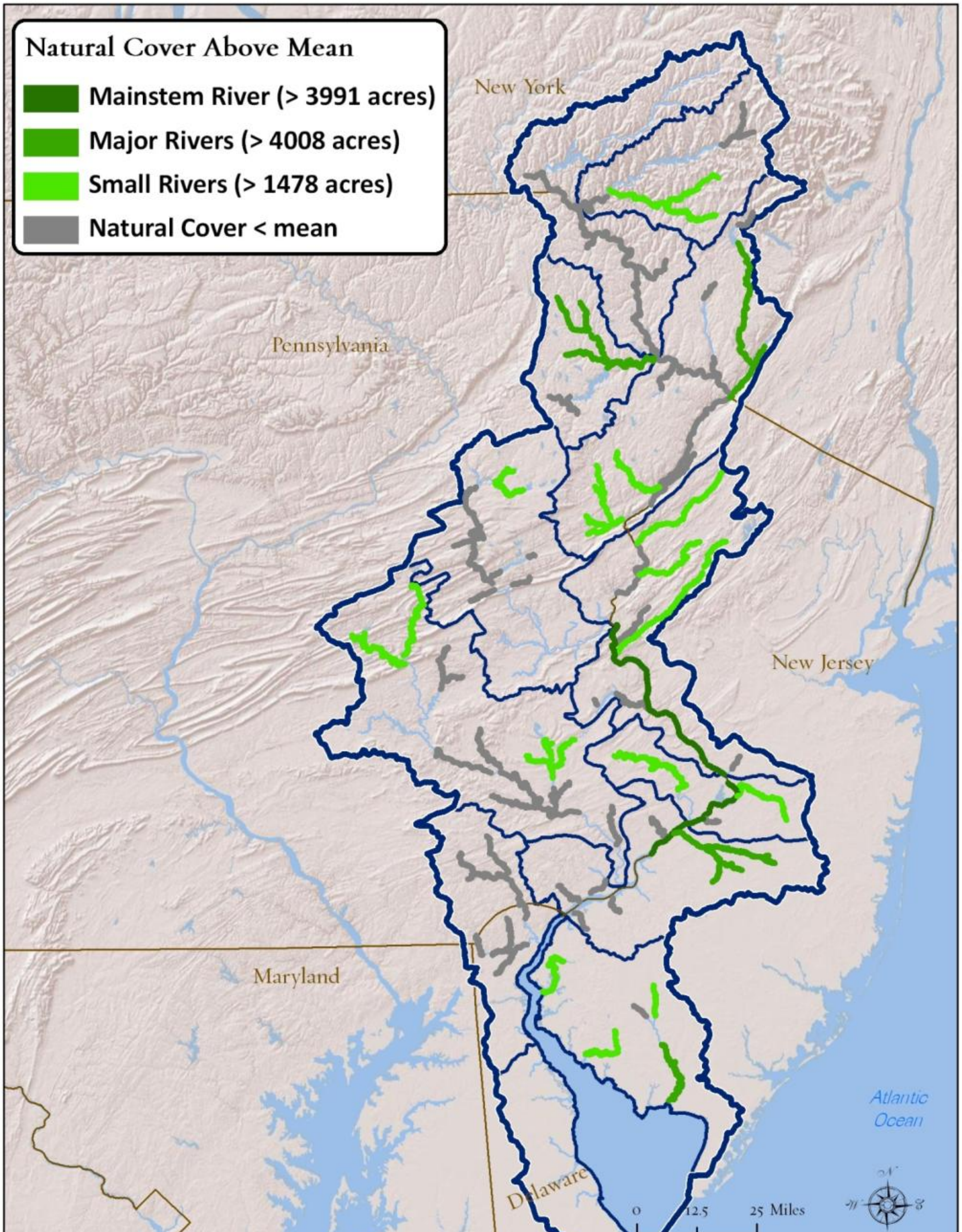


Figure 7. Floodplain Complex Natural Cover. This figure illustrates which of the floodplain complexes have natural cover acreage above the mean for the mainstem, major river, and small river complexes. The mean value for natural cover acreage is shown in the parenthesizes in the legend.

We identified floodplain complexes that met thresholds for at least two out of the three metrics. For example, the mainstem Delaware Water Gap floodplain complex meets the functional network size and the dam storage ratio thresholds. Meeting two out of the three, it is included in the subset of sites. The mainstem Lehigh to Trenton floodplain complex, meeting all three metric thresholds, is also selected. Table 5 illustrates the subset of floodplain complexes that emerged from this analysis. Four combinations of metrics resulted from the analysis:

3CHN	Connectivity, hydrological alteration, and natural cover thresholds (3 metrics) all were met. All thresholds were met.
2CH-N:	Connectivity and hydrologic alteration thresholds (2 metrics) were met. Natural cover threshold was NOT met.
2CN-H :	Connectivity and natural cover thresholds (2 metric) were met. Hydrologic alteration threshold was NOT met.
2HN-C:	Hydrologic alteration and natural cover thresholds (2 metric) were met. Connectivity threshold was NOT met.

Through this process, a total of thirty-eight or 61% of the floodplain complexes were identified as meeting thresholds for at least two metrics (Table 5). The number of complexes selected increases as river size decreases: four priority complexes were selected along the mainstem, seven along major rivers, and the remaining twenty-seven were selected along small rivers.

Figure 8 shows all sixty-two floodplain complexes identified through our **core, corridor, and complex analysis** that occur within the Delaware River Basin. These sixty-two complexes provide a starting point for our floodplain conservation priorities. This figure also highlights the subset of thirty-eight complexes that emerged by combining metrics as described above. This subset provides context for the development of strategies.

Six (16%) of the complexes met the thresholds for all three metrics including:

1. The Beaver Kill/Willowemoc River Complex
2. The Lackawaxen River Complex
3. The Bush Kill Complex
4. The Flat Brook Complex
5. The Lehigh/Tobyhanna Complex
6. The Mainstem Delaware Complex from the Lehigh River to Trenton

These complexes are located along riverine systems that are minimally impacted by dams, storage reservoirs, and land conversion. Land protection efforts complimented by ecological management and regulatory safeguards are necessary to ensure the effective conservation of these areas.

Thirty two complexes met two out of the three metric thresholds. These complexes show impacts to one of their key ecological attributes. Of these thirty-two, twenty-three did not meet the natural cover; seven did not meet the connectivity threshold, and two did not meet the hydrologic alteration threshold. Being able to identify impacted key ecological attributes is a fundamental strength of this approach.

Table 5. Floodplain complexes meeting at least two out of the three metric thresholds.

Priority Floodplain Complex	State	River Size	Metric Combinations		Potential Strategy
			Met	Not Met	
Delaware Water Gap	PA/NJ	Mainstem	2CH	N	Restoration/Management
Paulins Kill to Martins Creek	PA/NJ	Mainstem	2CH	N	Restoration/Management
Lehigh to Trenton	PA/NJ	Mainstem	3CHN		Protection
Trenton to Philadelphia	PA/NJ	Mainstem	2CH	N	Restoration/Management
Christiana (including the Red and White Clay Creeks)	DE	Major River	2CH	N	Restoration/Management
Lehigh/Black Creek	PA	Major River	2CH	N	Restoration/Management
Lackawaxen	PA	Major River	3CHN		Protection
Maurice	NJ	Major River	2HN	C	River Reconnection
Neversink/Basher Kill	NY	Major River	2CN	H	Sustainable Flow
Rancocas	NJ	Major River	3HN	C	River Reconnection
Schuylkill 1	PA	Major River	2CH	N	Restoration/Management
Aquashicola/Buckwha	PA	Small River	2CH	N	Restoration/Management
Beaver Kill/Willowemoc	NY	Small River	3CHN		Protection
Bush Kill	PA	Small River	3CHN		Protection
Callicoon	NY	Small River	2CH	N	Restoration/Management
Chester	PA	Small River	2CH	N	Restoration/Management
Cohansey	NJ	Small River	2CH	N	Restoration/Management
Crosswicks Creek	NJ	Small River	3HN	C	River Reconnection
Darby	PA	Small River	2CH	N	Restoration/Management
Equinunk	PA	Small River	2CH	N	Restoration/Management
Flat Brook	NJ	Small River	3CHN		Protection
Lehigh/Tobyhanna	PA	Small River	3CHN		Protection
Little Schuylkill	PA	Small River	2CN	H	Sustainable Flow
Lizard Creek	PA	Small River	2CH	N	Restoration/Management
Lower Tohickon	PA	Small River	2CH	N	Restoration/Management
Maiden	PA	Small River	2CH	N	Restoration/Management
Manatawny	PA	Small River	2CH	N	Restoration/Management
Mantua	NJ	Small River	2CH	N	Restoration/Management
Muddy	PA	Small River	2HN	C	River Reconnection
Oquaga	NY	Small River	2CH	N	Restoration/Management
Pennypack	PA	Small River	2CH	N	Restoration/Management
Perkiomen	PA	Small River	2HN	C	River Reconnection
Raccoon	NJ	Small River	2CH	N	Restoration/Management
Salem	NJ	Small River	2CH	N	Restoration/Management
Upper East Branch of the Delaware	NY	Small River	2CH	N	Restoration/Management
Upper Maurice	NJ	Small River	2HN	C	River Reconnection
Upper Schuylkill/West Branch	PA	Small River	2HN	C	River Reconnection
Wallenpaupack	PA	Small River	2CH	N	Restoration/Management

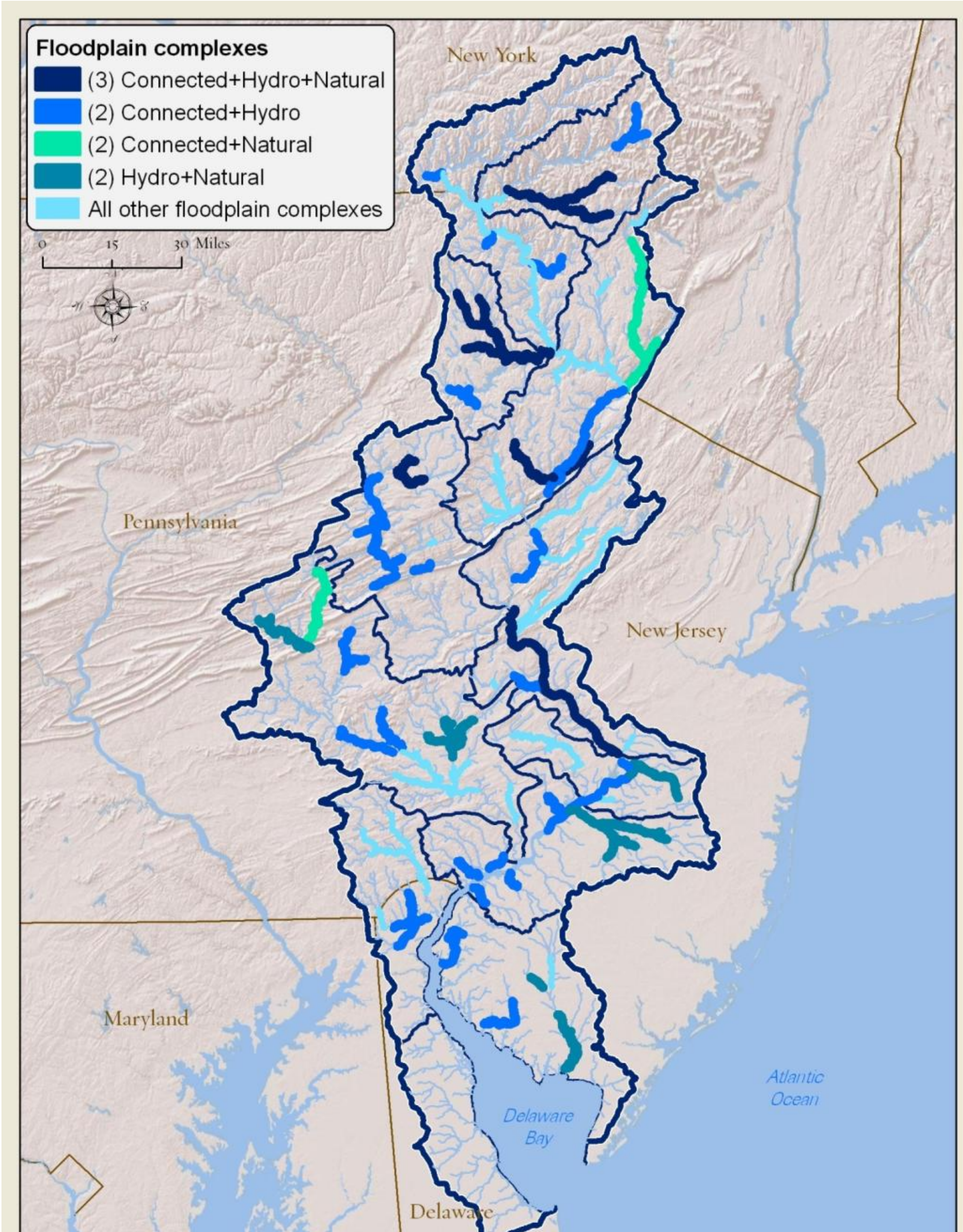


Figure 8. Floodplain Complexes in the Delaware River Basin. Sixty-two floodplain complexes are illustrated. This figure also highlights the subset of thirty-eight complexes that emerged through a combination of metrics.

Complexes impacted by land conversion are candidates for floodplain restoration and management efforts. Rehabilitation efforts re-establishing native species and managing non-native species competition are crucial. Methods to improve flood storage on floodplain lands in agricultural production are being tested in other regions of the county (Kinver 2009). Local, regional, and federal incentive programs that financially support restoration and ecological management in the floodplain are vital to the success of any conservation strategy

Complexes impacted by hydrologic alteration can be improved by ecological flow management strategies which aim to develop more ecologically-based reservoir release and operating schedules.

Opportunities to reconnect fragmented rivers through dam removal projects, dam management and re-operations, and aquatic passage structures are available throughout the basin. TNC's **B**arrier **A**ssessment **T**ool (BAT) can assist in the prioritization of dam removal opportunities. This tool provides a common foundation for the prioritization of stream barriers.

This analysis approach is very flexible enabling different metrics, different combinations of metrics, and different thresholds to be used and changed as assorted project goals, funding sources, partner needs, and threats are considered. With each change, variations in the sites selected will emerge representing the differing goals directing the analysis.

This type of analysis identifies strategies at the local level, but by organizing the display by strategy, cross-cutting opportunities to implement strategies at the regional, state, and national level begin to emerge.

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Conclusions

Our project aimed to identify important floodplains, headwaters, wetlands and the connections between them. Our units of analyses capture the representative biodiversity of the region and are defined by the ecological processes that support these systems. They also provide tangible management units for conservation efforts across the basin.

Funding from this project enabled us to complete our floodplain prioritization while also laying the foundation for future headwaters and wetland analyses. Through a recently received grant from the National Fish and Wildlife Foundation (NFWF), this work will continue in 2011. Through NFWF our headwater and wetlands analyses will continue. In addition, we'll broaden our analysis to include biological data, investigate the applicability of recently-released and anticipated to be released in the next year data sources, and engage partners in further peer-review of our process and results.

Floodplain complexes were defined to be multiple use areas, similar to the multiple-use modules concept presented by Noss and Harris (1986). The floodplain **core, corridor, and complexes** concept provides a framework for adaptive and integrated management. For example, within the highest-quality area – floodplain cores – land use activities would be most restricted. Therefore, strategies for core areas would typically involve acquisition or easement. Floodplain corridors, including patches of various sizes both in natural and agricultural cover, provide opportunities for both restoration and management.

The headwater network unit of analysis enabled us to compare headwaters at the unit of a HUC10 watershed, but this unit of analysis also lends to the individual examination of each of its component parts. Small headwater catchments within a HUC10 can be further analyzed and prioritized. Sections of riparian corridor again can be further investigated. Recognizing the constraints of whole-catchment watershed conservation efforts, being able to identify discrete, yet ecologically-based pieces of the watershed provides place-based direction to conservation efforts and complements those efforts aimed at reducing the impacts of stormwater runoff, sewage discharges and other point sources including commercial and industrial discharges (Saunders 2002).

Losses to wetlands and floodplain have caused not only the widespread loss of river, floodplain, and estuary species, but in many places have actually increased flood risks by creating a false sense of security and encouraging inappropriate floodplain development. Headwater development has resulted in the burial or total elimination of headwater streams. In the Chesapeake Bay watershed, the USGS found that 20% of all streams were buried, with smaller headwater streams being more extensively buried than larger streams (Elmore and Kaushal 2008).

Floodplains are topographically unique in occupying nearly the lowest position in the landscape, thereby integrating catchment-scale processes. Headwaters also are topographically unique, but in contrast to floodplains, rather than integrating catchment-scale process, headwaters are where stream system and catchment-scale processes originate. Wetlands occupy space in both floodplains and headwaters and offer unique habitats and functional benefits to species and people alike.

The conservation of floodplains, headwaters, and wetlands is a critical first step to ensuring the health and viability of aquatic ecosystems.

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