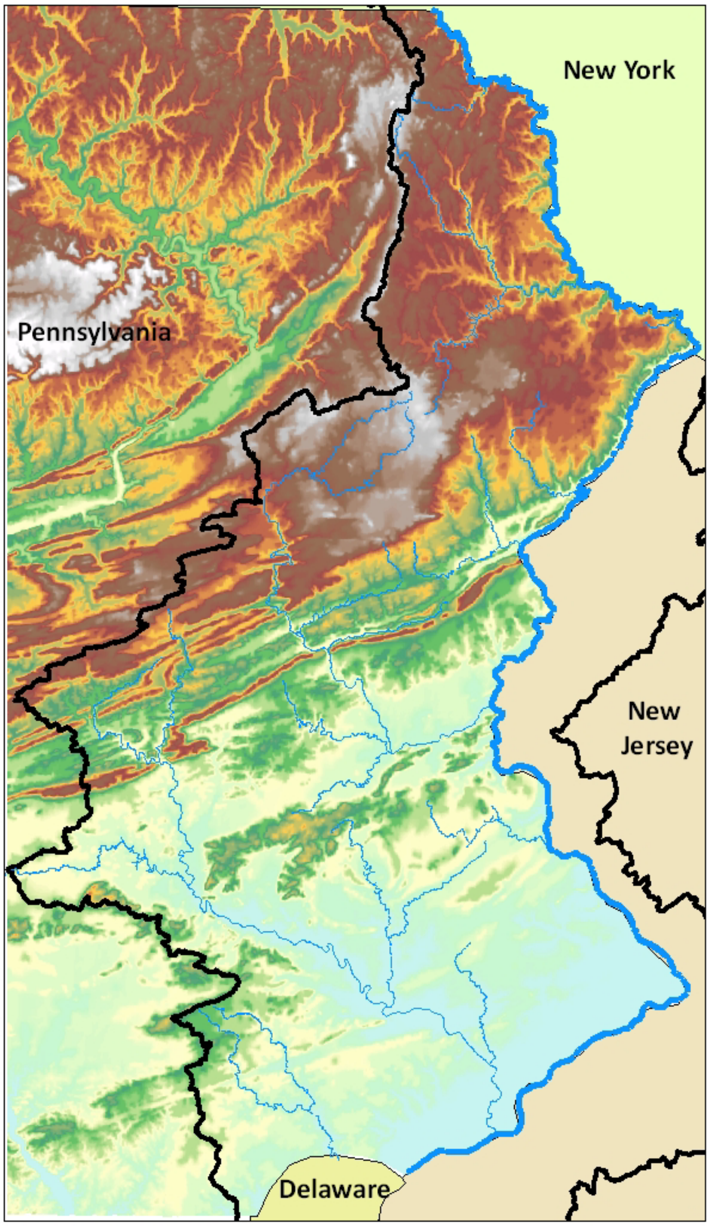
Delaware River Management Plan

A management plan focusing on the large river habitats of the West Branch Delaware River and Non-tidal reach of the Delaware River of Pennsylvania



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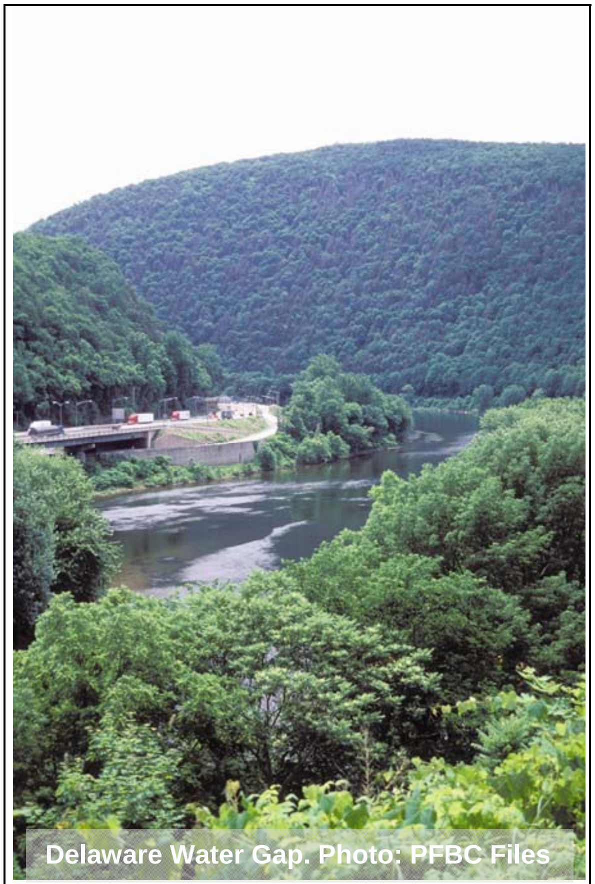
THANK YOU!

Executive Summary

The Delaware River Basin is the third largest drainage within Pennsylvania. The basin drains 12,756 square miles across the states of Pennsylvania, New York, New Jersey, and Delaware. Just over half of the total drainage falls within the Commonwealth of Pennsylvania. The Delaware River flows unimpeded for 330 miles from its origin at Hancock, NY to the entrance of the Delaware Bay.

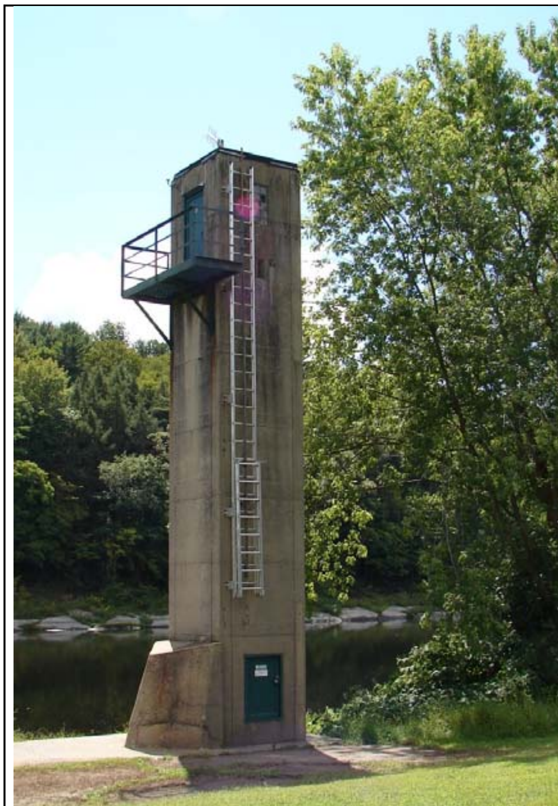
The Delaware River's connectedness among the four states necessitates a joint effort in the stewardship of the river's natural resources. The Delaware River Basin Commission (DRBC), which is comprised of the basin state governors, or their appointees, and a Federal representative, provides a unified approach for managing the river basin's water resources. Additionally, approximately 152 miles (77%) of the non-tidal reach of the Delaware River have been designated part of the National Wild and Scenic Rivers system managed by the National Park Service. The Pennsylvania Fish and Boat Commission (PFBC) is responsible for the protection and management of the Commonwealth's aquatic resources including the shared border waters of the West Branch Delaware and Delaware rivers.


Delaware Water Gap. Photo: PFBC Files

The Delaware River Management Plan is designed to guide future actions by the PFBC and aid other stakeholders by providing information and information needs about the river's invaluable aquatic resources. Ultimately, it is the goal of this management plan to protect, conserve and enhance the aquatic resources of and provide fishing and boating opportunities on the West Branch Delaware and Delaware rivers. The management plan encompasses the mainstem reaches of the West Branch Delaware River on the Pennsylvania-New York border, and the non-tidal waters of the Delaware River to the head of tide at Trenton, NJ.

The protection and management of the West Branch Delaware and Delaware rivers face many challenges. An estimated 55% of the basin landscape is dominated by forest cover, 26% is in agricultural use, and 15% is developed. Wetlands account for only 4% of the landscape (DRBC 2008 Delaware River *State of the Basin* report). Historically, the Delaware River Basin's water quality has been significantly impacted by industrialization, urbanization and agricultural land use. Degradation of water quality in the Delaware River began as early as colonial times and continued into the late 1980's, culminating in a reoccurring pollution block within the Philadelphia region of the Delaware River. This temporary block prohibited the occurrence of fish and the movement of migratory species throughout the system. Advances in the treatment of municipal and industrial waste led to the elimination of the pollution block and improved water quality in many parts of the Delaware River Basin. The recent boom related to natural gas development of the Marcellus shale poses a new risk to the ecosystem health of the Delaware River Basin. The PFBC, through its working relationship with the Pennsylvania Department of Environmental Protection (PA DEP), will seek to develop a dialog to identify fisheries-based criteria to support a high-quality warm-water designation for inclusion in existing water quality protection criteria. The PFBC will continue to provide commentary and expertise related to our trust species to the PA DEP and DRBC, the agencies authorized to regulate water quality and water withdrawals and flow management throughout the Delaware River Basin.

River flows have long been manipulated by the combined outflow from three New York City (NYC) reservoirs. Management of these reservoirs is linked to 1954 U. S. Supreme Court Decree, which among other things, provides for the supply of up to 800 million gallons per day of water to the NYC metropolitan area. The Decree stipulates the use of reservoir releases for maintaining a river flow objective of 1,750 cfs at Montague, NJ. Over the years since the 1954 Decree, reservoir releases have been managed through a series of evolving programs based on unanimous agreement by the Parties to the Decree (States of New Jersey, New York and Delaware, Commonwealth of Pennsylvania, and New York City). The so-called “Flexible Flow Management Program” (FFMP) is the current framework for managing diversions and releases from NYC's Delaware River Basin reservoirs. This program was designed by the Decree Parties to support multiple flow management objectives, including water supply; drought mitigation; flood mitigation; protection of the tailwaters fishery; a diverse array of habitat needs in the main stem, estuary and bay; recreational goals; and salinity repulsion in the Delaware estuary related to maintaining adequate water quality for municipal water supply withdrawals from the estuary. Extensive brown trout and rainbow trout fisheries exist in the West Branch Delaware River and the Delaware River above Callicoon, NY. These fisheries are supported primarily by releases from the NYC reservoirs.



U.S. Geological Survey, Montague Gage Station. Photo: USGS

Recent studies have linked the flow regime to habitat availability based on the required need of various trout life stages and species guilds. In 2010, the New York Department of Environmental Conservation (NYDEC), Division of Fish, Wildlife and Marine Resources and the PFBC published a white paper describing recommended river flows from a coldwater ecosystem perspective. The PFBC will continue to advocate the recommendations described in the white paper and cooperate with NYDEC to assess trends in trout populations in the upper Delaware River. The PFBC will continue to interact with Pennsylvania's Decree Party representative and associated work groups to support the improved management of reservoir releases for the protection of the coldwater aquatic resource.

West Branch Delaware River. Photo: PFBC Files

Besides trout, the PFBC manages other gamefish, non-game fish, reptiles, amphibians, and aquatic invertebrates. The Pennsylvania State Wildlife Action Plan (SWAP) is a benchmark resource designed to proactively manage the state's non-game resources and provide direction for the approval and funding of State Wildlife Grant projects. In the West Branch Delaware and Delaware rivers, limited information is available for characterizing non-game fish populations. Synoptic surveys have addressed the occurrence and habitat utilization of identified priority species of concern (e.g., dwarf wedgemussel and bridle shiner) within the SWAP. Many other commonly abundant non-game fish serve important ecological roles. Community composition can be altered by introductions of invasive species. The PFBC will work to safeguard non-game fish while assessing the proliferation of invasive species through the development of a survey program designed to characterize aquatic communities instead of focusing on individual fish species.

Smallmouth bass represent the single largest recreational fishery in the mainstem Delaware River. The PFBC annually monitors the smallmouth bass population. The bass population is typically well supported by multiple size and age classes; however, its abundance can fluctuate annually depending upon a variety of influences. These population fluctuations can, at times, be significant. Channel catfish and walleye are also popular sport fisheries. Long-term information pertaining to these populations is limited. The PFBC will continue to monitor the population of smallmouth bass and develop monitoring protocols for the channel catfish and walleye populations. These programs will be adjusted, as necessary, to best measure the populations and manage them in accordance with their respective statewide management plans.

The Delaware River Basin supports diadromous species including striped bass, American shad, American eel and river herring. While the resurgence of the Atlantic coast striped bass population is a tremendous success, the coast-wide decline of American shad and river herring threatens a natural historical legacy. Since the agency's inception in 1866, the PFBC has been tasked with returning American shad to historic population levels in the Commonwealth's waters. Interstate management strategies for diadromous fishes that inhabit the state waters of the Atlantic coast are under the direction of the Atlantic States Marine Fisheries Commission (ASMFC), of which Pennsylvania is a member. Interstate fisheries issues are also vetted through the Delaware River Basin Fish and Wildlife Management Cooperative (DRBFWMC). It is in cooperation with these two organizations that the PFBC actively supports programs aimed at rebuilding the stocks of migratory species. Recent efforts by the PFBC have included monitoring the annual adult spawning population in the Delaware River and supporting a restoration program within the Lehigh and Schuylkill rivers, major tributaries to the Delaware River. In 2009 and 2010, the ASMFC approved Amendments 2 and 3, respectively, to the Interstate Fishery Management Plan for Shad and River Herring. These amendments included significant restrictive management actions for river herring and American shad populations by the year 2012 (river herring) and 2013(American shad). These management efforts will be adjusted, based upon restoration success for the tributary waters and the development of a shad management plan as required by ASMFC Amendment 3 by the collective basin states through the DRBFWMC.

Given its close proximity to the major metropolitan areas of Pennsylvania, New York and New Jersey, the wild and scenic characteristics of the West Branch Delaware and Delaware rivers offer vast opportunities for memorable experiences for millions of people. Some of these opportunities, which are available within the three National Parks and various state and municipal public lands located throughout the river basins, include fishing, recreational boating on water trails, and nature viewing. The PFBC strives for public awareness and involvement in fishing and boating. These activities include providing access to biological reports, developing educational curricula for grades K-12, and various other outreach programs. Through the efforts of the PFBC and our partners, we hope to realize the full potential of this resource through a broader interdisciplinary approach.

1.0 Introduction

The Delaware River Basin is the third largest drainage within Pennsylvania. The basin drains 12,756 square miles across the states of Pennsylvania, New York, New Jersey, and Delaware. Just over half of the total drainage (6,780 square miles) falls within the Commonwealth of Pennsylvania. Forming portions of Pennsylvania's borders with New York and New Jersey, the West Branch Delaware River and Delaware River offer outdoor enthusiasts from not only the tri-state area but from around the country opportunities to participate in a multitude of activities including but not limited to fishing, boating, camping and nature viewing.

The Delaware River is unique in that it is free-flowing for its entire length (330 miles), which provides for un-impeded movement of migratory and resident fishes as well as other aquatic organisms. Further, the majority (152 miles; 77%) of the non-tidal Delaware River mainstem reaches have been designated part of the National Wild and Scenic Rivers system managed by the National Park Service: the Upper Delaware Scenic and Recreational River (UDPE); the Delaware Water Gap National Recreation Area (DEWA); and the Lower Delaware National Wild and Scenic River (LODE).

Given the relative proximity to major metropolitan areas, the Delaware River represents a significant water resource. One of the largest impacts upon the basin is the diversion of water from the upper Delaware River Basin for use in the New York City (NYC) metropolitan area. Water is diverted from the upper Delaware River Basin via three water supply dams located on the West Branch Delaware, East Branch Delaware and Neversink rivers. Management of these diversions and down basin water releases are linked to U. S. Supreme Court rulings in 1931 and 1954.

The Delaware River's connectedness among the four states necessitates a joint effort in the stewardship of the river's natural resources. In response to growing water quality and interstate issues, the Delaware River Basin Commission (DRBC) was formed in 1961 by President Kennedy and the governors of Delaware, New Jersey, Pennsylvania, and New York whom signed concurrent compact legislation into law for a unified approach for managing the river system without regard to political boundaries.

This management plan is a "living document" designed to guide future actions by the PFBC and aid other stakeholders in the identification of the information needed to gain a better understanding of these valuable resources. Ultimately it is the goal of this management plan to protect, conserve and enhance the aquatic resources of, and provide fishing and boating opportunities on the West Branch Delaware and Delaware rivers.

This management plan provides a description of the river and its watershed covering a range of topics. These issues have been combined in this plan to develop a holistic approach to addressing the system. Proposed management actions are listed within each Section of the plan and are organized in a manner that describes the West Branch Delaware and Delaware rivers aquatic resources in an increasingly detailed fashion beginning with the jurisdictions (Section 2.0), river basin features (Section 3.0) and river characteristics (Section 4.0). This is followed by discussions of river hydrology (Section 5.0), river habitats (Section 6.0), riverine biota (Section 7.0), fisheries (Section 8.0), human dimensions (Section 9.0), and a summary of the proposed management options (Section 10.0).

1.1 Mission, Vision and Goals

Mission

The mission of the Pennsylvania Fish and Boat Commission (PFBC) is ***"to protect, conserve, and enhance the Commonwealth's aquatic resources and provide fishing and boating opportunities."*** Statutory authority to address its mission is based on the Fish and Boat Code of 1980 [Title 30, PA Consolidated Statutes] with fishing and boating regulations set forth in Title 58 of the Pennsylvania Code.

Vision

Created in conjunction with the Commission's strategic plan, the vision of the Commission is to "expand its knowledge and expertise, protect and improve the quality of the Commonwealth's aquatic resources, expand and enhance safe boating and fishing opportunities, and recruit and retain individuals, families, and children as anglers, boaters, and stewards of the resource." The agency's goals are detailed in the Pennsylvania Fish & Boat Commission's Strategic Plan for July 2010 through 2015 (http://www.fishandboat.com/stplan.pdf).

1.2 River Management Plan Approach

This River Management Plan was initiated to aid in the development of a comprehensive, multidisciplinary approach to manage the West Branch Delaware and Delaware rivers and to better understand the complexity of issues affecting these systems. Understanding that the expertise and effort needed to advance the understanding of these systems far exceeds that of any individual agency or organization we aim to develop a dialogue for cooperation and management of these systems with the various stakeholder agencies, organizations, and institutions with interest in these resources. As a starting point, responsible parties, collaborative opportunities, and data gaps are identified to aid in prioritization of future directives and subsequent management activities.

The scope of this management plan encompasses the non-tidal mainstem waters of the Delaware River beginning at Trenton, NJ (RM 133.0) upriver to the confluence of the East Branch Delaware River and West Branch Delaware River just below Hancock, NY (RM 330.7); and the mainstem reaches of the West Branch Delaware River from its confluence with the East Branch Delaware River, just below Hancock, NY (RM 330.7) upriver to the border of Pennsylvania and New York (RM 7.5). For the purpose of this plan, all activities and issues outside of the respective non-tidal Delaware River and West Branch Delaware River proper will be addressed only as they relate to the respective rivers.

1.3 Sources of Information

Information included is this plan was primarily from Federal, Interstate, and State Agencies including, but not limited to:

- United States Environmental Protection Agency (EPA)
- United States Department of Interior, Bureau of U. S. Geological Survey (USGS)
- United States Department of Interior, Bureau of U. S. Fish and Wildlife Service (USFWS)
- United States Department of Interior, National Park Service (NPS)
- Delaware River Basin Commission (DRBC)
- Pennsylvania Department of Conservation and Natural Resources (DCNR)
- Pennsylvania Department of Environmental Protection (PA DEP)
- Pennsylvania Department of Transportation (PennDOT)
- Pennsylvania Game Commission (PGC)

Other sources of information in this plan included local, county, and municipal governments, non-government organizations, academic and research institutions, and reports submitted to resource agencies under conditions of permit requirements. All information in this plan, not otherwise credited to another institution or author, comes from information compiled or otherwise held by the Pennsylvania Fish and Boat Commission.

1.4 Public Process

The PFBC encourages public involvement and commentary pertaining to this management plan. Upon completion of the draft Delaware River Management Plan, two public information sessions were conducted in different parts of the watershed: the first session (March 2, 2011) was located in Easton, PA encompassing the middle and lower reaches of the Delaware River (Matamoras, PA/Port Jervis, NY to Morrisville, PA/Trenton, NJ); and the second session (March 3, 2011) was located in Matamoras, PA encompassing the upper Delaware River (Hancock, NY to Matamoras, PA/Port Jervis, NY) including the West Branch Delaware River. These served as an initial presentation of the document and provide an opportunity for public comment. A formal comment period was open upon completion of the public information sessions, closing April 30, 2011. Any commentary received after the formal open comment period was not considered for incorporation into the final plan. Given the anticipated nature of this plan as a “living” document, received commentary outside of the formal comment period will be assessed for inclusion to the existing content and or management options based on the perceived merits of the identified issues. This plan will be available through the PFBC website.

During the open public comment period, a total of 20 public comments and three agency comments were received. Topics of public comments were related to a variety of issues including water quality protection, water management from the New York City reservoirs (i.e., Flexible Flow Management Plan), dredging and fill activites, proposed power line projects, Shad-In-Schools, and fisheries management praticies for American shad, smallmouth bass, and muskellunge. The majority of received commentary centered on the Marcellus shale exploration. Specific concerns expressed relating to Marcellus shale development included the cumsuptive use of water resources from the Delaware River Basin and the potential negative impact on existing water quality and aquatic life. Changes were made to the text of the document for clarification based on the received comments. In addition, the opportunity was taken to alter the text where pending decisions were made since the draft of the document was released.

Additional written public commentary can be submitted through formal written format via PFBC website or postal mail to:

Daryl Pierce
Delaware River Biologist
Pennsylvania Fish and Boat Commission
Division of Fisheries Management
Delaware River
P. O. Box 155
Bushkill, PA 18324
dapierce@state.pa.us

1.5 Timeline

The development of the Large River Management Plans was initiated in July 2008 with final acceptance of the River Management Plan Outline in November 2008. Development of the initial draft of the River Management Plans commenced following acceptance of the outline with an anticipated completion date of December 31, 2009. Internal review of initial draft form of the River Management Plans is expected to be completed by February 28, 2011 and at that point the final draft River Management Plans will be released for public comment. Following closure of public comment period on April 30, 2011, all comments and amendments to the draft will be addressed. Presentation of the plan to the PFBC Commissioners is anticipated at the first quarterly meeting following closure of comment period. Implementation of the plan is targeted to begin following completion of presentation of the management plan to the Board of Commissioners as indicated under Goal 2, Item B of the Strategic Plan of the Pennsylvania Fish and Boat Commission.

Updates

It is anticipated, updates to this plan will occur on a regular schedule. Major updates of new information either from accomplished worked identified by the management options within this document or from outside sources are expected to occur on a five year cycle after the initial implementation date. However, it is understood that significant deviations from this plan may occur as major developments warrant.

2.0 Jurisdictions

Several federal and state resource agencies are responsible for the stewardship of the West Branch Delaware and Delaware rivers. Their jurisdictional authorities involve proposing, developing, and executing legislative actions and other measures that dictate stewardship and direct utilization of aquatic resources of the West Branch Delaware and Delaware rivers. In order for their stewardship to be effective, federal and state agencies must embrace cooperative planning and management with other governmental and non-governmental partners. This section summarizes jurisdictions of federal and state partners who must work collectively for the long-term sustainability of the West Branch Delaware and Delaware rivers aquatic resources. In an effort to insure aquatic resource protection the PFBC provides commentary and support as needed to agencies with regulatory authority beyond those of the PFBC as they pertain to the West Branch Delaware and Delaware rivers.

2.1 <u>Federal Jurisdictions</u>

Office of the Delaware River Master

The Office of the Delaware River Master (ODRM; http://water.usgs.gov/osw/odrm/index.html) was formed and maintained within the United States Geological Survey (USGS) as part of the 1954 Supreme Court Decree for administering provisions of the Decree relating to water releases from the New York City (NYC) reservoirs in the upper Delaware River basin. General and specific duties are explicitly listed on their web site (http://water.usgs.gov/osw/odrm/intro.html#background). As part of this duty, the ODRM is responsible for directing releases from the NYC reservoirs to maintain applicable target minimum flow of 1,750 cfs from September 16th to June 14th) as measured at the USGS Montague gaging station (RM 246.4; FFMP 2011). These flow targets represent a release schedule for maintaining a minimum basic rate of flow during normal conditions. The daily operations of the River Master are conducted by the Deputy River Master through a USGS field office in Milford, PA. The annual River Master report to the U. S. Supreme Court provides a detailed daily accounting of all diversions, flows and directed releases, demonstrating compliance with the Decree requirements.

National Park Service

The National Park Service (NPS) has been charged with the stewardship of three significant reaches of the Delaware River mainstem. The Upper Delaware Scenic and Recreational River (UPDE; http://www.nps.gov/upde/index.htm); the Delaware Water Gap National Recreation Area (DEWA; http://www.nps.gov/DEWA/index.htm); and the Lower Delaware National Wild and Scenic River (LODE; http://www.nps.gov/lode/index.htm) are all managed by the National Park Service under the National Wild and Scenic Rivers system. Together these National Recreation Areas encompass a total of 152 miles (77%) of the non-tidal reach of the Delaware River. The UPDE exists from Hancock, NY (RM 330) downriver to Millrift, PA (RM 285.4); however, all but 30 acres along the 73-mile UPDE is mostly privately owned. The UPDE was created with the inclusion of the upper Delaware River mainstem into the National Wild and Scenic Rivers system. Under this system the river must be protected in its free-flowing condition and that it must be managed for the benefit and enjoyment of present and future generations. To effect this protection the NPS-UPDE in coordination with local, state and federal agencies, developed an Upper Delaware River Management Plan (NPS 1986; http://www.nps.gov/upde/parkmgmt/planning.htm) that governs the stewardship of the UPDE.

The Delaware Water Gap National Recreational Area is part of the National Wild and Scenic Rivers system and includes nearly 70,000 acres along the 40-mile middle river corridor. The DEWA begins just above Milford, PA (RM 250.0) and continues downriver to just below Delaware Water Gap, PA (RM 209). This park was created in 1965 with the intent of providing recreational opportunities in conjunction with the proposed Tocks Island Dam Project (Taylor 1971). Authorized by Congress in 1962, the Tocks Island Dam Project had a proposed footprint of approximately 9,300 ha (23,000 ac) with the proposed impoundment stretching 59.5 km (37 mi) upstream reaching above Port Jervis, NY. The creation of the DEWA added another 19,000 ha (47,000 ac) to the project area. Due to strong local opposition and lack of funding the proposed Tocks Island Dam was not developed and subsequently, in 1978 the reach of river originally proposed for the reservoir was declared by Congress as part of the National Wild and Scenic Rivers system. The DEWA operates under their General Management Plan approved in 1987 (NPS 1987; http://www.nps.gov/dewa/parkmgmt/upload/DEWAGMPSummary1987.pdf). This Plan guides the overall management and use of the DEWA to ensure the perpetuation of the area's natural and cultural resources and the scenic setting for present and future public enjoyment. It is intended that this plan will also provide the foundation for subsequent detailed implementation plans, programs, and operations.

The creation of the Lower Delaware National Wild and Scenic Rivers National Park added a 38.9-mile section of the mainstem Delaware and approximately 28 miles of selected tributaries to the national system (http://www.nps.gov/lode/index.htm). Created November 1, 2000, the LODE linked the Delaware Water Gap (RM 209) and head of tide at Trenton, N.J. (RM 133.4). With the inclusion of the lower Delaware River, nearly (152 miles, 77%) all of the non-tidal reach of the Delaware River mainstem is protected under the National and Wild Scenic Rivers system. The Lower Delaware Wild and Scenic River Management Plan (NPS 2008; http://www.nps.gov/chal/sp/p07new3.htm) sets forth a vision for the use and management of the diverse resources in the river corridor in partnership with the National Park Service (http://www.nps.gov/ncrc/programs/pwsr/lowerdelaware_pwsr_sub.html). It is meant to be used and referred to by all levels of government, property owners and organizations that have an interest in the protection of the Lower Delaware River corridor. The Management Plan sets forth six major goals and recommends actions to maintain and improve the Lower Delaware River corridor, its tributaries and surrounding natural, historic and cultural resources. It provides for economic growth in a manner that does not adversely affect the region's resources. Each level of government would retain its existing level of authority and landowner rights are not jeopardized. Successful implementation of the Management Plan will require cooperation between all levels of government, individual landowners and related non-profit organizations. The Plan recognizes that local municipalities play a key role in implementing the suggested conservation measures.

The Appalachian National Scenic Trail is a more than 2,175-mile long footpath stretching through 14 eastern states from Maine to Georgia maintained as a partnership between the National Park Service (http://www.nps.gov/appa/index.htm) and Appalachian Trail Conservancy (ATC: http://www.appalachiantrail.org/). In Pennsylvania, the trail winds along the Blue Ridge Mountain Range, drops down into the town of Delaware Water Gap, PA and crosses the Delaware River on Interstate 80 in the DEWA Park. The Trail then continues in New Jersey along the Kittatinny Mountain Ridge line up to New Jersey's High Point State Park (http://www.state.nj.us/dep/parksandforests/parks/highpoint.html).

United States Fish and Wildlife Service

The U. S. Fish and Wildlife Service (USFWS; http://www.fws.gov/northeast/index.cfm) has recently designated the Cherry Valley National Wildlife Refuge (http://www.fws.gov/news/newsreleases/showNews.cfm?newsId=64739BB5-FC80-7E87-2E839AFC1479A309) as part of the National Wildlife Refuge system. The USFWS has established a boundary for the Refuge, encompassing 20,466 acres in two Pennsylvania counties (Monroe and Northampton) within which it may begin acquiring nationally significant habitat for wildlife. The USFWS will work to provide opportunities for wildlife-related recreation – such as hunting, fishing and bird watching – and ensure these activities are compatible with the management goals and mission of the refuge. The completed study, which includes the final environmental assessment and other establishing documents, can be found at http://www.fws.gov/northeast/planning/Cherry%20Valley/draftstudy/00_CVNWRStudy_PublicDraft_Coveretc.pdf (USFWS 2008). This Refuge borders the Delaware River within the DEWA at the point where Cherry Creek discharges into the Delaware River inclusive of Shawnee Island (a privately owned island) and the downriver DEWA park boundary.

2.2 <u>Pennsylvania Jurisdictions</u>

Pennsylvania Fish & Boat Commission

The Pennsylvania Fish and Boat Commission (http://www.fish.state.pa.us/mpag1.htm) is the state agency responsible for the management of aquatic resources along the shared border water with New York and New Jersey of the West Branch Delaware and Delaware rivers. Present day management includes angling regulations and law enforcement, habitat enhancement, management directed at protecting naturally reproducing fish stocks, and the use of cultured fish to provide recreational angling opportunities. Currently, the PFBC operates under a strategic plan for achieving the agencies mission in the stewardship of Pennsylvania's aquatic resources. This plan can be viewed on line at http://www.fish.state.pa.us/stplan.pdf. The shared border waters of the West Branch Delaware and Delaware rivers are encompassed by two Area Fisheries Regions, Area 5 (upper Delaware River) and Area 6 (lower Delaware

River) using the Lehigh River as the dividing point. Additionally, the PFBC maintains a biologist position dedicated solely to the West Branch Delaware and Delaware rivers.

Pennsylvania Game Commission

The Pennsylvania Game Commission (PGC) is the state agency responsible for the management of terrestrial wildlife, including many popular bird and mammal game species (http://www.pgc.state.pa.us/). Present day management includes monitoring wildlife populations, establishing laws and regulations, obtaining and improving habitat, assessing public expectations, and educating the public on wildlife issues. Currently, the PGC operates under a strategic plan for achieving the agencies mission in the stewardship of Pennsylvania's wildlife resources (PGC 2009). This plan can be viewed on line at http://www.portal.state.pa.us/portal/server.pt/document/737229/2009-2014_strategic_plan_pdf. Along the shared border waters of the West Branch Delaware and Delaware rivers, the PGC maintains two regional offices, the Southeast and Northeast Regional Offices, delineated by the Northampton/Monroe county line.

Pennsylvania Department of Conservation & Natural Resources

Established in 1995 when the former Department of Environmental Resources was split into two agencies, the Pennsylvania Department of Conservation and Natural Resources (DCNR) is responsible for maintaining and preserving 117 state parks and 2.1 million acres of state forest land, providing information on the state's ecological and geologic resources, and establishing community conservation partnerships with grants and technical assistance to benefit rivers, trails, greenways, local parks and recreation, regional heritage parks, open space, and natural areas (http://www.dcnr.state.pa.us/). The DCNR maintain numerous parks along the Delaware River (Table 2.1). Most notably are the many natural areas along the Delaware River corridor and the Delaware Canal State Park maintained in the lower Delaware River. Additionally, DCNR maintains several state forests along the middle and upper Delaware River. Currently, the DCNR operates under a strategic plan "*Shaping a Sustainable Pennsylvania – DCNR's Blueprint for Action*" for achieving the agencies mission in the stewardship of Pennsylvania's natural resources. Both the full plan (http://www.dcnr.state.pa.us/info/shapefuture/actionplanfinal.pdf) and a summary brochure (http://www.dcnr.state.pa.us/info/shapefuture/plansummarybrochure.pdf) can be viewed on-line. Along the shared border waters of the West Branch Delaware and Delaware rivers, DCNR maintains one regional office, the Eastern Regional Offices located near Lake Nockamixon in Bucks County.

Pennsylvania Department of Environmental Protection

Also established in 1995 when the Department of Environmental Resources was split, the Pennsylvania Department of Environmental Protection (PA DEP; http://www.depweb.state.pa.us/portal/server.pt/community/dep_home/5968) is responsible for protecting and preserving land, air, water, and energy resources through enforcement of

Pennsylvania's environmental laws. The PA DEP also fosters community development, environmental education, and encourages public involvement in environmental policy. Regional PA DEP offices within the West Branch Delaware and Delaware rivers reside in Wilkes-Barre (Northeast Regional Office) and Norristown (Southeast Regional Office). District PA DEP offices reside in Scranton, Pocono (Stroudsburg), Bethlehem, and Pottsville. These offices are all involved with administering environmental permitting and enforcement programs, as well as implementing surface and ground water quality and biological assessment and monitoring programs. In particular, PA DEP is responsible for collecting and analyzing samples for routine monitoring of contaminants in fish tissue used to promulgate and update fish consumption advisories issued for the Delaware River Basin.

2.3 Adjacent States & Interstate Commissions

New York Department of Environmental Conservation

The New York Department of Environmental Conservation, Division of Fish, Wildlife and Marine Resources (http://www.dec.ny.gov/about/634.html), is the state agency responsible for the aquatic resource management for the shared border water with Pennsylvania of the West Branch Delaware River and upper Delaware River mainstem downriver to Port Jervis, NY Specifically, the Bureau of Fisheries seeks to conserve and enhance New York State's abundant and diverse populations of freshwater fishes while providing the public with quality recreational angling opportunities. The shared border waters of the West Branch Delaware and Delaware rivers are encompassed by two Area Fisheries Regions, Regions 3 and 4. Management of the shared boundary waters between New York and Pennsylvania has been principally guided by their *Fishery Management Plan for the Upper Delaware Tailwaters*, which was implemented in 1992 (Sanford 1992).

New Jersey Department of Environmental Protection

The New Jersey Department of Environmental Protection, Division of Fish and Wildlife (http://www.state.nj.us/dep/fgw/), is the state agency responsible for the aquatic resource management for the shared border water with Pennsylvania of the middle and lower Delaware River mainstem, from approximately just below Port Jervis, NY downriver to Trenton, NJ Specifically, the Bureau of Freshwater Fisheries seeks the propagation, protection and management of the state's freshwater fisheries resources as well as promoting their recreational use. The shared border waters of the Delaware River is considered a separate Area Fisheries Region, although two other Regions (Upper and Lower) are responsible for the management of the Delaware River's tributaries.

Delaware River Basin Commission

The Delaware River Basin Commission (http://www.state.nj.us/drbc/drbc.htm) was formed in 1961 when President Kennedy and the governors of Delaware, New Jersey, Pennsylvania, and New York signed concurrent compact legislation creating a regional body with the force of law to oversee a unified approach to managing the river system without regard to political boundaries (DRBC 2007; http://www.state.nj.us/drbc/regs/compa.pdf). Members of the DRBC include the four basin state governors or their appointees and the Division Engineer, North Atlantic Division, U.S. Army Corps of Engineers, who serves as the federal representative. Commission programs include water quality protection, water supply allocation, regulatory review (permitting), water conservation initiatives, watershed planning, drought management, flood loss reduction, and recreation (DRBC 2009; http://www.state.nj.us/drbc/regs/watercode031109.pdf). The DRBC is funded by the signatory parties, project review fees, water use charges, and fines, as well as federal, state, and private grants. Currently, the DRBC operates under a management plan entitled *Water Resources Plan for the Delaware River Basin* (DRBC 2004; http://www.state.nj.us/drbc/basinplan.htm). As part of their management plan, the *2008 Delaware River State of the Basin Report* was generated offering a view of conditions for the Basin's landscapes and waters based on available information (DRBC 2008; http://www.state.nj.us/drbc/SOTB/index.htm).

Atlantic State Marine Fisheries Commission

The Atlantic States Marine Fisheries Commission (ASMFC) was formed by the 15 Atlantic Coast states in 1942 in recognition that fish do not adhere to political boundaries (http://www.asmfc.org/). The Commission serves as a deliberative body, coordinating the conservation and management of the states shared near shore fishery resources – marine, shell, and diadromous – for sustainable use. Member states are Maine, New Hampshire, Massachusetts, Rhode Island, Connecticut, New York, New Jersey, Pennsylvania, Delaware, Maryland, Virginia, North Carolina, South Carolina, Georgia, and Florida. Each state is represented by three Commissioners: the director for the state's marine fisheries management agency, a state legislator, and an individual appointed by the governor. Commissioners participate in the deliberations in the Commission's five main policy arenas: Interstate fisheries management, research and statistics, fisheries science, habitat conservation, and law enforcement. The one-state one-vote concept allows Commissioners to address stakeholder-resource balance issues at the state level. The Commission focuses on responsible stewardship of marine fisheries resources. It serves as a forum for the states to collectively address fisheries issues under the premise that as a group, using a cooperative approach, they can achieve more than they could as individuals. The Commission does not promote a particular state or a particular stakeholder sector. Specifically for fishes, the ASMFC manages costal species through the Commission's Interstate Fisheries Management Program (ASMFC 2003; http://www.asmfc.org/interstate.htm), and various Amendments and Addendums for specific managed species.

Delaware River Basin Fish and Wildlife Management Cooperative

The Delaware River Basin Fish and Wildlife Management Cooperative (DRBFWMC) is organized by unanimous consent of the directors of the fish and wildlife agencies of Delaware, New Jersey, New York, and Pennsylvania, and the regional offices of the U. S.

Fish and Wildlife Service, and the National Marine Fisheries Service. Originally formed in 1973 and later re-affirmed in 1997, the primary purpose of the Cooperative is to provide a forum for governmental agencies to discuss and provide direction for management of the fish and wildlife resources of the Delaware River Basin. Specifically, to coordinate research activities and the collection of scientific data; develop and implement fish and wildlife management plans; and review and comment on developing projects in the basin that could adversely affect interstate fish and wildlife populations. The DRFWMC operates via a Policy Committee that provides overall direction to a Technical Committee for fish and wildlife related matters in the basin that have interstate significance. Since its formation, representatives from DRBC and NPS have been included in the Technical Committee sessions, but are not voting members. This cooperative originated from the DRBC Fish and Wildlife Technical Assistance Committee formed by DRBC in 1961; however the DRFWMC is a separate entity from DRBC.

Upper Delaware Council

The Upper Delaware Council (UDC: http://upperdelawarecouncil.org/) was established in1988 as a private non-profit corporation representing a formal partnership of local, state, and federal governments and agencies to manage the Upper Delaware Scenic and Recreational River. The Council's existence evolved from special provisions in the 1978 National Parks and Recreation Act which designated the Upper Delaware River as a component of the National Wild and Scenic Rivers system (http://www.rivers.gov/index.html), and called for development of a management plan and a program providing for the coordinated implementation and administration of the plan. The primary purpose of the UDC is to provide the mechanism for implementation of the Upper Delaware Scenic and Recreational River Management Plan prepared by the Conference of Upper Delaware Townships in cooperation with the NPS, November 1986 (NPS 1986; http://www.nps.gov/upde/parkmgmt/planning.htm) and to oversee its administration on a continuing basis, utilizing the existing authority of its members. Thus, the UDC through its members retains local control of the upper Delaware River valley, alleviates the threat of eminent domain and excessive land acquisition, and protects the river through the cooperative effects of local individuals, governments and state and federal agencies. The UDC will, through its members, coordinate with the Delaware River Basin Fish and Wildlife Management Cooperative pertaining to issues of fish and wildlife management. Membership includes the New York towns of Hancock, Fremont, Delaware, Cochecton, Tusten, Highland, Lumberland, Deerpark; the Pennsylvania Townships of Berlin, Damascus, Lackawaxen, Shohola, Westfall; the State of New York, Commonwealth of Pennsylvania, Delaware River Basin Commission, and the National Park Service; of which DRBC and NPS are non-voting members. The PA townships of Buckingham and Manchester are also eligible for membership.

2.4 <u>Non-governmental Organizations</u>

Many watershed groups and local land conservancies are involved in protection and conservation of aquatic resources of the West Branch Delaware and Delaware rivers. Delaware River Basin Commission maintains a listing of organizations interested in protecting and monitoring the water shed resources in the Delaware River Basin (http://www.state.nj.us/drbc/watershedgroups.htm). Entities listed are primarily non-profit organizations and private clubs.

In early 2007, the National Park Service developed the non-profit Delaware River Greenway Partnership (DRGP; http://www.delrivgreenway.org/content/Welcome%21/Welcome%21%20Index.html) encourage river corridor protection and preservation as called for in the Wild and Scenic Lower Delaware River Management Plan through the coordination of the Lower Delaware Management committee. The purpose of the Lower Delaware Management Committee is to remind participating agencies of the plan goals, provide oversight and guidance to participating agencies, and through those agencies to other organizations. It does not to assume any regulatory functions. The functions of the committee include: prioritizing goals; setting timetables; providing education on river management actions; acting as a watch dog; encouraging other agencies to adopt the plan goals; tracking activity in the river corridor and acting as an information clearinghouse across political boundaries; providing technical assistance; and updating the plan (at least every 5 years). The committee membership includes representatives of the municipalities, watershed associations, counties, the DRBC, DRGP, the State of New Jersey (DEP), the Commonwealth of Pennsylvania, including the Department of Conservation and Natural Resources, DCNR, Department of Environmental Protection, PA DEP, and Pennsylvania Fish & Boat Commission, the Delaware & Lehigh Canal National Heritage Corridor Commission, and the National Park Service.

The Delaware Riverkeeper Network (DRN; http://www.delawareriverkeeper.org/), is a nonprofit membership organization established in 1988 upon the appointment of the Delaware Riverkeeper. The DRN's staff and volunteers work throughout the entire Delaware River Basin including portions of Pennsylvania, New Jersey, Delaware and New York. The DRN programs include: advocacy to protect water quality and habitat; awareness to action to organize local communities into activists to protect local streams; litigation and other legal action to enforce environmental laws; monitoring by volunteers along the entire length of the river; and restoration to provide communities the expertise, community training and organizing needed to restore damaged streams and waterway ecosystems. The DRN maintains a pollution hotline (1-800-8DELAWARE) for citizens to report pollution in order to help take action necessary to put a stop to the harm.

The Nature Conservancy (TNC; http://support.nature.org/site/PageServer?pagename=resolution_hgg&gclid=COeu4pacsKYCFQY65QodOT8Oow) is a well recognized international environmental group. Their mission is to preserve the plants, animals and natural communities that represent the diversity of life on Earth by protecting the lands and waters they need to survive. To this end, TNC has been active within the Delaware River Basin accomplishing significant habitat protection in the upper Delaware River and associated watersheds. Further, TNC has been directly involved in the development of the Flexible Flow Management Program (FFMP 2001, 2008) while chairing the DRBC's Sub-committee for Ecological Flows (SEF) for several years.

Several angler organizations are active in the protection and management of the West Branch Delaware and Delaware rivers. Friends of the Upper Delaware River (FUDR), local chapters of Trout Unlimited (TU), local chapters of Muskies Inc, and the Delaware River Shad Fisherman's Association (DRSFA) all contribute significantly to the stewardship of the Delaware River Basin.

2.5 Management Options

Priority 1: (on-going activities or recommendations to be implemented in first year of management plan).

- Continue to maintain open communication with other federal and state resource management agencies and remain active in the Delaware River Basin Fish and Wildlife Management Cooperative for the vetting of interstate fisheries issues.

Priority 3: (recommendations with implementation date in years 4 -5 of management plan)

- Identify opportunities for combining resources with other governmental agencies to maximize the ability for field activities, while reducing the associated cost.

Table 2.1. Listing of public lands within Pennsylvania along the West Branch Delaware and Delaware rivers. DCNR = PA Dept. Conservation and Natural Resources; NCP = Northampton County Parks; BCP = Bucks county Parks; PAHMC = PA Historical and Museum Commission; NPS = National Park Service.

Public Land	Agency	Web address URL
West Branch Delaware River		
State		
State Game Lands 299	DCNR	http://www.portal.state.pa.us/portal/server.pt/community/state_game_lands/11363
Ball Eddy Launch	PFBC	
Delaware River		
Federal		
Upper Delaware Scenic and Recrational River	NPS	http://www.nps.gov/upde/index.htm
Delaware Water Gap National Recreation Area	NPS	http://www.nps.gov/dewa/index.htm
Lower Delaware National Wild and Scenic River	NPS	http://www.nps.gov/lode/index.htm
State		
Delaware Canal	DCNR	http://www.dcnr.state.pa.us/stateparks/parks/delawarecanal.aspx; http://www.dcnr.state.pa.us/stateParks/parks/delawarecanal/delawarecanal_mini.pdf
Delaware State Forest	DCNR	http://www.dcnr.state.pa.us/forestry/stateforests/delaware/index.htm
Giving Pond Recreation Area	DCNR	http://www.dcnr.state.pa.us/stateparks/parks/delawarecanal.aspx
Nockamixon Cliffs Natural Area	DCNR	http://www.dcnr.state.pa.us/stateparks/natural/naturalareas.aspx
Virginia Forrest Recreation Area	DCNR	http://www.bucksviews.com/Destinations/DelawareCanal/VirginiaForrestArea/virginia_forrest.htm
Loors Island	DCNR	http://www.dcnr.state.pa.us/stateparks/natural/naturalareas.aspx
Whippoorwill Island	DCNR	http://www.dcnr.state.pa.us/stateparks/natural/naturalareas.aspx
Old Sow Island	DCNR	http://www.dcnr.state.pa.us/stateparks/natural/naturalareas.aspx
Raubs Island	DCNR	http://www.dcnr.state.pa.us/stateparks/natural/naturalareas.aspx
Hendrick Island	DCNR	http://www.dcnr.state.pa.us/stateparks/natural/naturalareas.aspx
State Game Lands 56	DCNR	http://www.portal.state.pa.us/portal/server.pt/community/state_game_lands/11363
State Game Lands 209	DCNR	http://www.portal.state.pa.us/portal/server.pt/community/state_game_lands/11363
State Game Lands 316	DCNR	http://www.portal.state.pa.us/portal/server.pt/community/state_game_lands/11363
Damascus Launch	PFBC	
Washington Crossing Historical Park	**PAHMC**	**http://www.ushistory.org/washingtoncrossing/**

Table 2.1. Listing of public lands within Pennsylvania along the West Branch Delaware and Delaware rivers. DCNR = PA Dept. Conservation and Natural Resources; NCP = Northampton County Parks; BCP = Bucks county Parks; PAHMC = PA Historical and Museum Commission; NPS = National Park Service.

Public Land	Agency	Web address URL
County/Municipal		
Doe Hollow	NCP	
Bowman's Hill Wildflower Preserve		
Frost Hollow Overlook	NCP	
Hal Clark Park		
Wi-Hit-Tuk County Park	NCP	http://www.northamptoncounty.org/northampton/cwp/view.asp?a=1530&q=620749#Parks
Scott Park Access Area		
Prahls Island County Park		
Theodore Roosevelt Re. Area	NCP	
Fry's Run Park	NCP	http://www.northamptoncounty.org/northampton/cwp/view.asp?a=1530&q=620749#Parks
Hugh Moore Park	NCP	http://www.canals.org/Visitors/Hugh_Moore_Park
Riverside Park	NCP	
Mount Jack County Park	NCP	
Tinicum County Park	**BCP**	**http://www.buckscounty.org/government/departments/ParksandRec/Parks/Tinicum.aspx**

3.0 River Basin Features

Landscape features of a drainage basin, both natural and anthropomorphic, impact the basic form and function of the basin. Often, influences are the synergistic effects of multiple features that define the overall characteristics of the river system. Natural influences derived from the physical basin shape such as catchment basin size and topographic features direct the rivers' hydrologics and subsequently nutrient and sediment transportation. The underlying geological formations can significantly influence a rivers' water chemistry, particularly if the rivers course or tributaries run through limestone formations originating from ancient marine fossils. Impacts of humans are also strongly influential on the form and function of a river. The creation of the Delaware Canal system certainly changed the Delaware River flood plain and hydrologic input into the Delaware River from tributaries. Resource extraction (e.g., natural gas, water withdrawal), land use, and urban development place additional strain and possibly completely change a river' characteristics.

3.1 Basin Geology

The 2008 Delaware River *State of the Basin* report (DRBC, 2008; http://www.state.nj.us/drbc/SOTB/index.htm) provides a brief overview of the geology of the Delaware River Basin; however a more complete review is discussed by Schultz (1999). Briefly, the non-tidal reach of the Delaware River is within four of the five physiographic provinces that comprise the basin including Appalachian Plateau, Ridge and Valley, New England, and Piedmont (Figure 3.1). The upper reaches of the Delaware River, above Port Jervis, NY, but within Pennsylvania, is underlain by non-marine sandstone, siltstone, shale and mudstone principally from Catskill and Trimmers Rock formations. Below Port Jervis, NY to approximately just below the Delaware Water Gap, PA sandstone, shale, siltstone, dolomite, felsic gneiss, quartzite and malfic gneiss become prevalent from a variety of formations (Bloomsburg, Shawagunk, Maritinsburg, Mahantango, Rickenbach, Allentown, Hardystone, Leithsville and Hornblende gneiss formations) within the Ridge and Valley and New England provinces. Below the Delaware Water Gap, PA, the underlying geology is principally sandstone, mudstone, siltstone, sand, gravel, diabase, felsic gneiss and malfic gneiss of various formations (Brunswick, Wissehickon, Stockton, Chickies, Lockatong formations, Diabase, Trenton Gravel) within the Piedmont province (Figure 3.2).

3.2 History

General History of Human Use

The Delaware River Basin is rich with cultural history. Prior to European settlement it is estimated that 30 to 40 Native American Lenape communities existed in the Delaware Valley; generally recognized forming three divisions Minisi, Unami, and Unalachtigo (http://www.newhopepa.com/delawareriver/Lenape2.htm). Many of their communities were located along the banks of the Delaware, which the Lenape called Lenapewihittuk. Captain Samuel Argall, however in 1610, gave the name "Delaware" upon his discovery of a large bay while exploring the America coast in honor of Sir Thomas West, Third Lord de la Warr and the first governor of the Virginia. With the onset of European settlement, conflicts arose over the land and gradually the native tribes were displaced and diminished by the mid-eighteenth century.

Since European settlement the Delaware River has undergone substantial change. One of these legacies is a network of canal paths, which acts as a reminder of the nineteenth century when these canals were established to aid in the transportation of anthracite coal from the Lehigh River region to industrial markets in Trenton, NJ, Philadelphia, PA, New York, and elsewhere. To date, most of these canals form parts of state parks. Author Zane Grey maintained a house on the Delaware River near the confluence of the Lackawaxen River, where he penned numerous novels. The historical significance of the lower Delaware River has been recognized through the 1988 Congressional designation of the Delaware and Lehigh Navigational Canal National Heritage Corridor and the designation of twenty-nine National Historic Districts and eight National Historic Landmarks. Further, the Crossing of the Delaware by General Washington and his troops on Christmas Eve (1776) prior to the Battle of Trenton is an American iconic event, which is reenacted to this day. Today, the historic treasures and scenic beauty of the Delaware River corridor support a thriving “eco-tourism” economy. The Delaware River Valley’s proximity to the greater New York City metropolitan area in the north and Philadelphia and Washington D.C. to the south provide these populations with essential recreational opportunities.

Major Impacts

The industrialization and urbanization of lands and the resultant water quality degradation continues to impact the Delaware River Basin. The canal/lock system, built in the 1820’s, dramatically affected river flow and aquatic communities. Remnants of this system are still in place. As the coal and steel industries grew, degradation of the Lehigh River, a major tributary to the Delaware River, occurred in addition to acidic mine drainage from coal mines in the upper Lehigh River Basin. Industrial pollution was finally recognized as an environmental disaster and since the passage of the Clean Water Act in 1972, water quality in the Lehigh and Delaware river basins continues to improve. One of the most significant impacts on the West Branch Delaware and Delaware rivers was the building and subsequent management of water from the New York City water supply reservoirs (Cannonsville on the West Branch Delaware River, Pepacton on the East Branch Delaware River, and the Neversink on the Neversink River) to support the New York City metropolitan area. Reservoir releases from these supply dams directly influence the aquatic community through regulated reservoir releases.

3.3 <u>Socioeconomic Profile</u>

Population Centers

Several sizable municipalities, representing over 7.7 million people, exist along the West Branch Delaware River and non-tidal Delaware River (DRBC 2008). The majority (78%) of the population within the Delaware River Basin resides in the lower region including the Philadelphia, PA metropolitan area. Further, the Delaware River Basin is within a relatively convenient drive from the metropolitan areas of New York City, Baltimore, Maryland and Washington D.C. Principal city population areas in the non-tidal Delaware River include: Hancock, NY, Callicoon, NY, Narrowsburg, NY, Matamoras, PA, and Port Jervis, NY in the upper reaches; Milford, PA, Belvidere, NY, Easton, PA., and Phillipsburg, NJ in the middle reaches; and New Hope, PA, Lambertville, NJ and Trenton, NJ in the lower reaches (Figure 3.3).

Major Industries/Sources of Employment

Major industries within the Pennsylvania portion of the Delaware River Basin principally include agriculture, tourism, and light industry. Agriculture is prevalent throughout the basin, but is more prominent in the upper and middle reaches of the Delaware River. The U. S. Department of Agriculture indicated the top agriculture commodity in Pennsylvania is dairy products (http://www.classbrain.com/artstate/publish/article_721.shtml).

Historically, manufacturing and extractive industries (e.g., coal and lumber) were primary industries within the Delaware River Basin. In the early part of the century, coal extracted from the headwaters of the Lehigh River and transported downriver was the back bone of the local economy. In years past the boroughs of Bethlehem and Allentown were world renowned for their steal industry. However in more recent years these cities are refocusing on attracting and supporting a lager tourism component. Bluestone quarrying and lumbering, particularly in the upper reaches of the Delaware River continue to support local economies. In more recent times, manufacturing has declined but with the economical extraction of natural gas from Marcellus shale is set to become a major industry in the upper Delaware River reach.

Tourism is a significant economic influence along the West Branch Delaware and Delaware rivers. Maharaj et al. (1998) estimated that the guide industry in the upper Delaware River was approximately $17.7 million in local business revenue in 1996. Many rafting companies exist throughout the length of the Delaware River for one-day and multiple day excursions however a dollar value to this industry is currently un-available. Many of the communities in the upper Delaware River cater to these industries. Further, the majority of the Delaware River is within National Recreational Areas (i.e., the Upper Delaware Scenic and Recreational River, Delaware Water Gap National Recreational Area, and Lower Delaware National Wild and Scenic River) that draw numerous tourists for outdoor activities along the Delaware River, collectively annually hosting 5.25 million visitors. Historical and cultural events are also popular tourist attractions. Washington's Crossing and Bowman's Hill Tower in the lower Delaware River are popular historical landmarks. The artistic communities in the lower Delaware are highly popular, particularly in the New Hope, PA - Lambertville, NJ region.

Regional and Local Vehicular Access

Primary roads that provide extensive access to the Pennsylvania shoreline of the West Branch Delaware River include Winterdale Road (T4014) from State Route (SR) 0191 to Balls Eddy, PA and Penn York Road, which continues along the river above Balls Eddy, PA. A variety of U. S. routes and local township roads run along the Pennsylvania shoreline in the upper Delaware River and include, SR 0191, River Road, SR1016, Damascus Rd (SR 1004), SR 1002, SR1017, SR 1014 and SR1017. The middle reach of the Delaware River is accessed principally via US Route 209, SR 0611 and local access roads within the Delaware Water Gap National Recreational Area. Below Easton, PA, immediate access to the non-tidal reaches of the river include SR 0611 and SR 0032. Interstates 84, 80, 78 and 95 all cross the Delaware River Basin at some point along their lengths (Figure 3.4).

3.4 <u>Basin Land Uses</u>

Land Use

The 2008 Delaware River *State of the Basin* report (DRBC, 2008; http://www.state.nj.us/drbc/SOTB/index.htm) summarizes land uses within the Delaware River Basin. At that time 55% of the basin landscape was dominated by forest cover, 26% was in agricultural use, while developed land accounted for nearly 15% (Figure 3.5). Wetlands, accounted for only 4.4% of the landscape, but the *State of the Basin* report suggested that this number may have under-represented the full extent of wetlands due to extensive forest canopy which confounded the identification of wetland edge. Further, the *State of the Basin* stated that land use was regionally variable with the upper and middle reaches being dominated by forested habitat as compared to the lower reach (below Easton , PA) where a higher percentage of developed land (agriculture and metropolitian) and wetlands tended to dominate (DRBC 2008).

Brownfield and Land recycling

A total of 115 brownfield revitalization projects and 4,764 land recycling projects occur in the Pennsylvania portion of the Delaware River Basin (Figure 3.6). The Land Recycling Program encourages the recycling and redevelopment of old industrial sites. It sets standards, by law for the first time, that are protective of human health and the environment, but which consider future use (PA DEP 2009). This program is managed by the PA DEP, Bureau of Waste Management, Office of Community Revitalization and Local Government Support.

Municipal Waste, Captive Hazardous Waste, and Commercial Hazardous Water Operations

A total of 879 recognized municipal waste operations, 365 captive hazardous waste operations, and 17 commercial hazardous waste operations are located within the Pennsylvania portion of the Delaware River Basin (PA DEP 2009; Figure 3.7). These activities are overseen by the PA

DEP, Bureau of Waste Management, Municipal Waste Program and Hazardous Waste Program.

Superfund is the federal government's program to clean up the nation's uncontrolled hazardous waste sites. On the National Priority List (http://www.epa.gov/superfund/sites/index.htm) under the Comprehensive Environmental Response Compensation and Liabilility Act, there are two superfund sites that are currently listed within the Delaware River Basin (Cortese Landfill and DeRewal Chemical Company). Numerous other superfund sites within the Delaware River Basin, mostly within Pennsylvania, have either been remediated or are in the final stages of remediation.

Abandoned and Active Mines

Mining operations, particularly for quarry stone are prevalent throughout the Pennsylvania portion of the Delaware River Basin (Figure 3.8). Numerous industrial mining operations, genrally quarry surface mining, are active (N = 526) and another 77 have reclamination completed. Coal extraction, typically by deep shaft mining, occurs principally in the upper drainage of the Lehigh and Schuylkill rivers within the Delaware River Basin (Figure 3.8). Abandoned mine management and reclamations are overseen by the PA DEP, Bureau of Abandoned Mine Reclamation (BAMR) and active mining are under the oversight of the PA DEP, Bureau of District Mining Operations. There are currently 218 mines that are in varying degrees of activity, 20 that have been reclaimed, and another two abandoned mines in the Delaware River Basin.

Public Lands

Historical rulings from the Pennsylvania Supreme Court in *Shrunk v. Schuylkill Navigation Company* in 1826 defined the great rivers of Pennsylvania to be the Ohio, Monongahela, Youghiogheny, Allegheny, Susquehanna, and its north and west branches, Juniata, Schuylkill, Lehigh, and Delaware as public waters (http://www.fishandboat.com/water/public/faq_public_waters.htm). The states of Pennsylvania, New Jersey, and New York, as well as local municipalities maintain public lands through the establishment of parks, forest and game lands and other wildlife and recreational holdings along the non-tidal Delaware River reaches (Table 2.1; Figure 3.9). Stewardship of state forests and recreational areas are maintained by the DCNR in Pennsylvania, New York Department of Environmental Conservation (NYDEC) in NY, and Department of Environmental Protection in NJ. The majority of the Delaware River is encompassed in the UPDE, DEWA, and LODE National Park Service National Wild and Scenic Rivers system; however, in the UPDE and LODE most of the actual river frontage by on both shorelines is privately held.

Canals

The Delaware River Canal begins at the confluence of the Lehigh River at Easton, PA and extends downriver to Bristol, PA. Designated a National Historic Landmark, and listed on the

National Register in 1976 the canal represents the legacy of commercial bulk transport, principally coal to market. Today, a 60-mile stretch between Easton and Morrisville, PA forms the Delaware Canal State Park (http://www.dcnr.state.pa.us/stateparks/parks/delawarecanal.aspx) operated by Pennsylvania Department of Conservation and Natural Resources. This park has recently been the focus of restoration after severe damage from the 2005, 2006, and 2007 floods (http://www.dcnr.state.pa.us/news/resource/res2008/08-0827-delawarecanalsp.aspx). Flood damage has rendered parts of the canal unusable. To support concession barge rides, portions of the canal are seasonally flooded via pumping of mainstem water at Center Bridge (SR 0263; RM 151.9) above New Hope, PA.

The Delaware and Raritan Canal is a historical canal system on the New Jersey side of the Delaware River. This canal begins just above the Lumberville, PA wing dam and follows along the Delaware River to Trenton, NJ forming a part of New Jersey's state park system (http://www.dandrcanal.com/park_index.html). As per the 1954 Supreme Court Decree, a total of 100 mgd is diverted from this canal as an out-of-basin water supply.

3.5 Resource Extraction

Resource extraction is a phrase that is referring to the removal of natural commodities (e.g., coal) from a river basin. In the context of this management plan for the mainstem waters of the West Branch Delaware and Delaware rivers, resource extraction is limited to that which can directly influence mainstem waters, rather than expanding into issues pertaining to major tributaries (e.g., Lehigh River).

Dredge and Fill Activities

The West Branch Delaware and Delaware rivers do not have dredge and fill activities for resource extraction. The Delaware River Basin Fish and Wildlife Management Cooperative (DRBFWMC) of which PFBC is a charter member maintain a white paper that provides guidance on seasonal restrictions of in-water improvements (DRBFWMC, 1992, 2010). Construction and maintenance operations contracted by the USACOE mainly occur in the navigation canals and anchorages in the tidal reaches of the Delaware Estuary. Thus, most of the species for consideration of restrictive dredge windows are estuarine oriented (e.g., blue crab, sand bar shark, horseshoe crabs) or migratory fishes (e.g., sturgeon, American shad). Pertaining to fishes within the non-tidal Delaware River reaches, the updated white paper (DRBFWMC, 2010) provides detailed seasonal restrictions from the head of tide upriver to the confluence of the East Branch Delaware and West Branch Delaware rivers in a series of three zones. Construction and maintenance restriction windows were structured for the non-tidal Delaware River principally for the protection of gamefishes, including critical time periods for American shad, sunfishes and salmonids spawning and nursery grounds.

Oil and Gas (Marcellus shale)

The northeastern region of Pennsylvania has recently received new interest for drilling targeting natural gas found in the Marcellus shale formation. This formation underlies approximately 36 percent of the Delaware River Basin (Figure 3.10). Given the increasing demands for fossil fuels, coupled with new horizontal drilling and extraction methods, have resulted in a dramatic boom of interest in mining the Marcellus shale deposits.

Extraction methods require large amounts of fresh water to fracture the formation to release the natural gas. A portion of water used in the extraction process is recovered, but this "frac water" includes a mixture of chemicals that are added to the water to facilitate the extraction process, as well as brine and other contaminants released from the formation. This frac water requires significant treatment efforts before being released back into the environment. Any surface or ground water diverted for support of Marcellus shale development is considered a consumptive out-of-basin diversion. Currently, approximately 10-15% of flow back the water from the frac process is recovered from the Marcellus shale formation. Natural gas development companies have begun recycling a portion of this water to be used in the next frac process to minimize treatment of flow back waters.

Under the authority granted to the DRBC by their compact, the DRBC is mandated to maintain the current water quality for the Delaware River Baisn under their Special Protection Waters program. The DRBC issued a determination (DRBC 2009; http://www.state.nj.us/drbc/EDD5-19-09.pdf) notifying natural gas extraction project sponsors that they may not commence any natural gas extraction project located in shale formations within the drainage area of the basin's Special Protection Waters without first applying for and obtaining their approval. This determination was extended on June 14th, 2010 by DRBC Executive Director to include exploratory wells (DRBC 2010; http://www.state.nj.us/drbc/SupplementalEDD6-14-10.pdf) with the exception of those already granted by state drilling permits. This extension was amended July 23, 2010 to allow for the continuation of development of two Hess Corporation exploratory vertical wells located in Wayne County, Pennsylvania that were in the final stages of permitting under the PA DEP at the time of the June 14th, 2010 determination (DRBC 2010; http://www.state.nj.us/drbc/AmendedSuppEDD072310.pdf). Further, at the May 5th, 2010 public business meeting, DRBC Commissioners approved staff for pursuing the development of draft natural gas regulations with the expectation for public commentary by the end of summer 2010. DRBC does not intend to consider natural gas well pad applications till these draft regulations have been formally adopted.

Within Pennsylvania, regulation of natural gas for the development of the Marcellus shale is provided by the PA DEP; http://www.dep.state.pa.us/dep/deputate/minres/oilgas/new_forms/Marcellus/Marcellus.htm) and DRBC. The PFBC, Division of Environmental Services, provides commentary to both agencies with regard to Marcellus shale development impacts to trust species under the PFBC. As the Marcellus shale development continues, it is anticipated that requests for surface water will increase. Prior to DRBC's Executive Director Determination (DRBC 2009, 2010a, 2010b) a proposal for water withdrawal for Marcellus shale development was reviewed by DRBC (DRBC Docket D-2009-20-1). It was proposed by Chesapeake Appalachia, LLC for withdrawal up to 1.0 million gallons per day, from the West Branch Delaware River Cutrone Withdrawal site, near Buckingham Township, Wayne County, Pennsylvania. In October 2009, Chesapeake Appalachia, LLC rescinded its application for approval of a surface water withdrawal project. Docket D-2009-13-1was approved on July 14, 2010 for the water withdrawal (0.7 mgd) from the West Branch Lackawaxen River in Mount Pleasant Township, Wayne County, Pennsylvania, by Stone Energy Corporation (DRBC 2010c; http://www.state.nj.us/drbc/dockets/2009-013-1.pdf). The docket does stipulate the Stone Energy cannot withdrawal water from the site until they receive a separate DRBC approval for the natural gas well pad. An additional water withdrawal for gas drilling is now being considered by the DRBC (DRBC 2010g; http://www.state.nj.us/drbc/dockets/D-2010-022-1.pdf). Docket 2010-022-1 is a request from XTO Energy to withdrawl 0.25 mgd from the Oquaga Creek, tributary to the West Branch Delaware River (confluence located in Deposit, NY).

Presently, the DRBC has released draft regulations pertaining to their role in regulating natural gas drilling activities related to development of Marcellus shale wells under the authority of their 1961 compact (DRBC 2010e; http://www.state.nj.us/drbc/naturalgas-draftregs.pdf). The DRBC envisions three principle roles concerning their involvement of regulating Marcellus shale development: 1) water diversion; 2) well pad siting; and 3) wastewater disposal all as a new Article 7 in their Water Quality Regulations. Briefly, DRBC is concerned with water withdrawals having substantial water quality impacts due to their high intermittent daily withdrawal volume. Consequently, DRBC requires that water used for natural gas development projects must come from water sources that have been approved by the Commission for use for natural gas development. The requirements for approval are designed to protect minimum stream flows, provide a record of water transfers and otherwise ensure that water resources are not adversely affected. The DRBC seeks for minimize impacts to water resources by establishing well pad siting and planning requirements (i.e., Natural Gas Development Plan - NGDP). The envision of using the NGDP is to determine, minimum setbacks from water bodies, wetlands, surface water supply intakes and water supply reservoirs at distances specified in the regulations, and from occupied homes, public buildings, public roads, public water supply wells, and domestic water supply wells as provided by regulations of the state in which the well pad is located. Finally any wastewater treatment facility will need to obtain approval from the Commission for accepting wastewater produced by natural gas development.

The proposed draft DRBC regulations also make two other key provisions. The first is aimed for providing a streamlined process for natural gas developments under an “approval by rule” (ABR), anticipated to take less than 30 days. Numerous criteria will need to be addressed for consideration of eligibility to this process (DRBC 2010e). Further, the DRBC requires financial assurance for the plugging, abandonment and restoration of natural gas wells and the remediation of any pollution from natural gas development activities in the amount of $125,000 dollars per natural gas well (DRBC 2010e). Copies of the full draft regulations or an “At-a-glance” fact sheet (http://www.state.nj.us/drbc/naturalgas-draftregs-factsheet.pdf) can be viewed on-line. Beginning Dec 9th, 2010, the DRBC initiated a written comment period for soliciting public input pertaining to these proposed regulations (http://www.state.nj.us/drbc/newsrel_naturalgas120910.htm). This comment period was closed April 15, 2011. The DRBC is currelty in the process of reviewing received public commentary and redressing their draft natural gas development regulations.

The development of the Marcellus shale formation has created conflicting view points of the impacts of the industry upon the Delaware River Basin. Certainly, substantial social pressure for the continuance of the Marcellus shale development was created by the potential for large montery wealth to be gained from the proceeds of extracted gas for leased access rights from individual land-holders. Yet, the direct impacts of the Marcellus shale development for both the tributaries and mainstem Delaware River remain unknown. Reviews of the the potential dedgradation of the Delaware River Basin have been offered. Silldorff (2010), Anderson and Kreeger (2010), and Jackson and Sweeney (2010); all suggesting the cumulation of individual risks associated with the Marcellus shale development potentially led to substantial negative impacts to aquatic communties. These impacts are not necessarilty limited to environmental concerns but can pose significant human health risks (Volz 2011). In analysis of violations within Pennsylvania, Volz (2011) identified a strong probabililty that any well drilled will have a pollution violation, and that the probabilility increases with additional exploratory wells drilled into the Marcellus shale.

Given the potential for substantial development of the Marcellus shale formation there is a critical need for robust monitoring of aquatic communites within the West Branch Delaware and Delaware rivers. Ideally, datasets would characterize both the pre- and post-Marcellus shale development baseline aquatic communities existing in the Delaware River Baisn; potentially allowing for direct comparions for identifying any measurable adverse effects of the Marcellus shale development. Some baseline aquatic community data is available for the West Branch Delaware and Delaware rivers offering insight to existing condtions of various components of the aquatic community. These datasets are discussed in further detail later in this document; however, most of the time-series available are synoptic surveys and do not offer insight to long-term population trends. The development of aquatic community monitoring typically requires a lengthy developemtal process and are inhibited by capital requirements in both staff and monetary resources. The U.S. EPA has identified seven case studies to assess the potential impacts of hydraulic fracturing on drinking water resources (http://water.epa.gov/type/groundwater/uic/class2/hydraulicfracturing/index.cfm). Three of the case studies will include development of Marcellus shale formations located in western Pennsylvania. It is anticipated initial study results will be available by late 2012.

Commercial sand and gravel dredging

There are no commercial sand and gravel dredging activities within the West Branch Delaware River and non-tidal reaches of the Delaware River.

Coal extraction

Within the West Branch Delaware River and Delaware rivers there are no coal mining activities located within the flood basin of the mainstem waters. However, some coal extraction occurs within the Delaware River Basin and acid mine drainage is present in the tributaries to the Delaware River, particularly the Lehigh River (White Haven to Lehighton) and Schuylkill River (headwater region) drainage basins (Kocher et al. 2000).

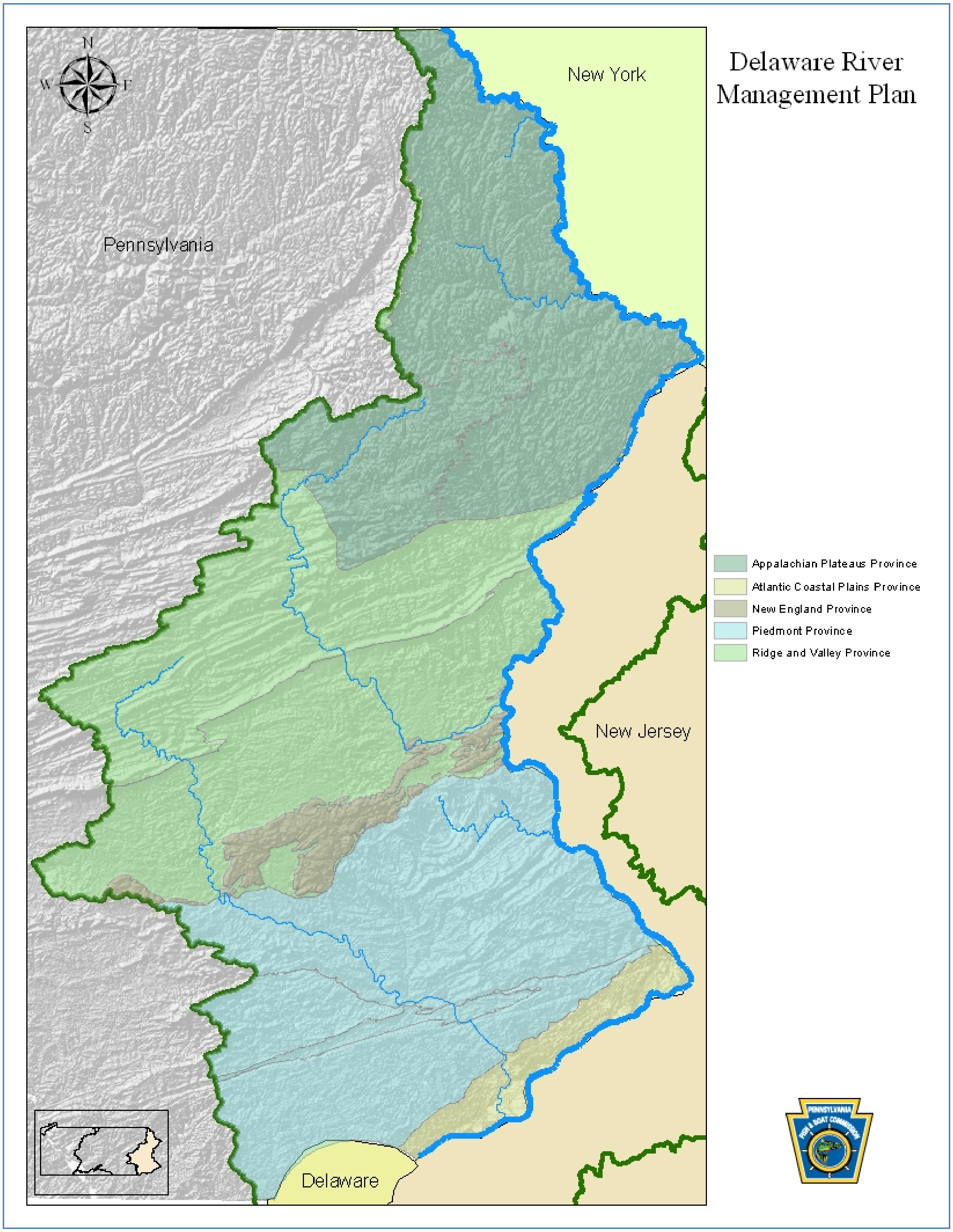


Figure 3.1. Physiographic provinces within the Pennsylvania portion of the Delaware River Basin.

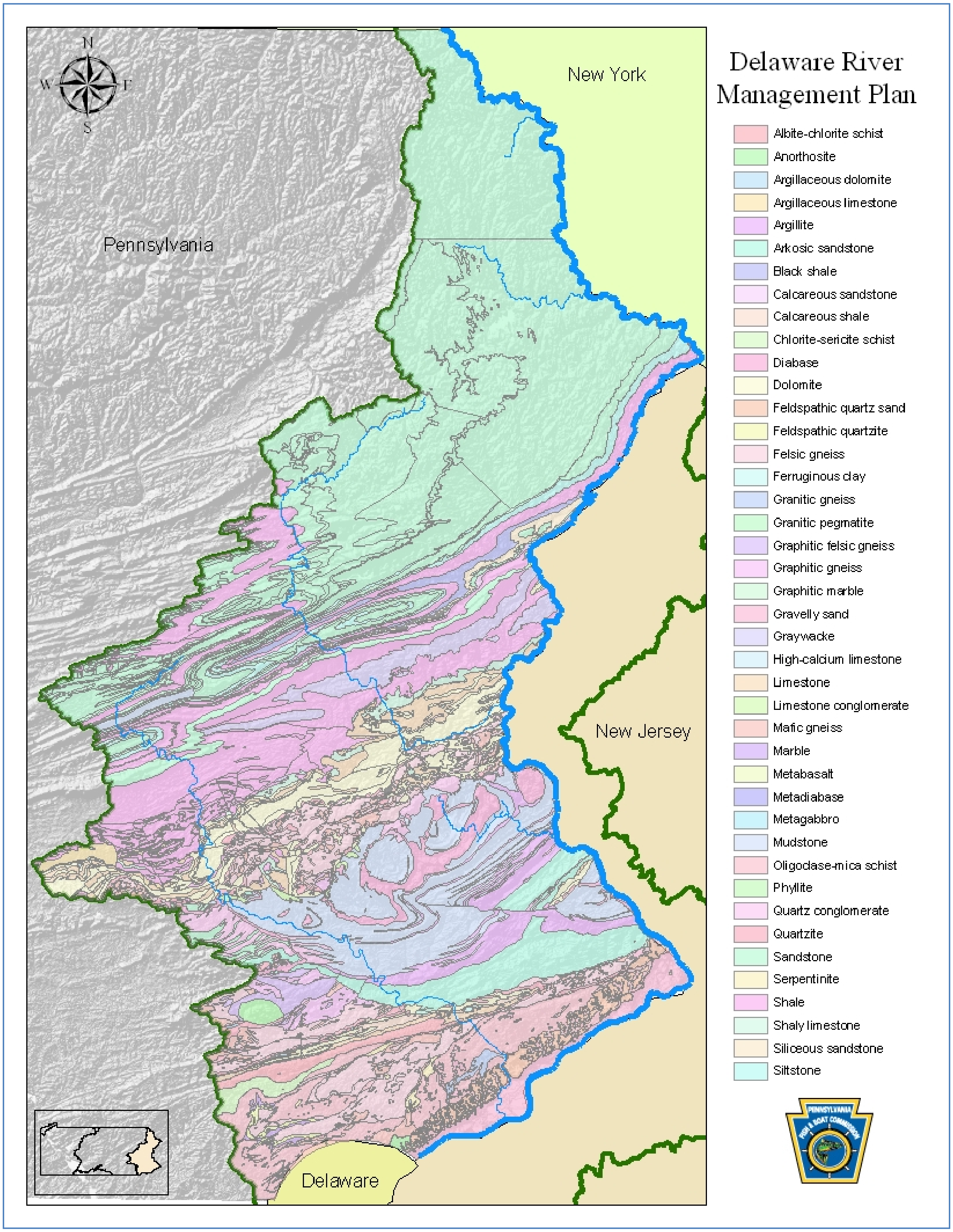


Figure 3.2. Lithology (rock type) within the Pennsylvania portion of the Delaware River Basin.

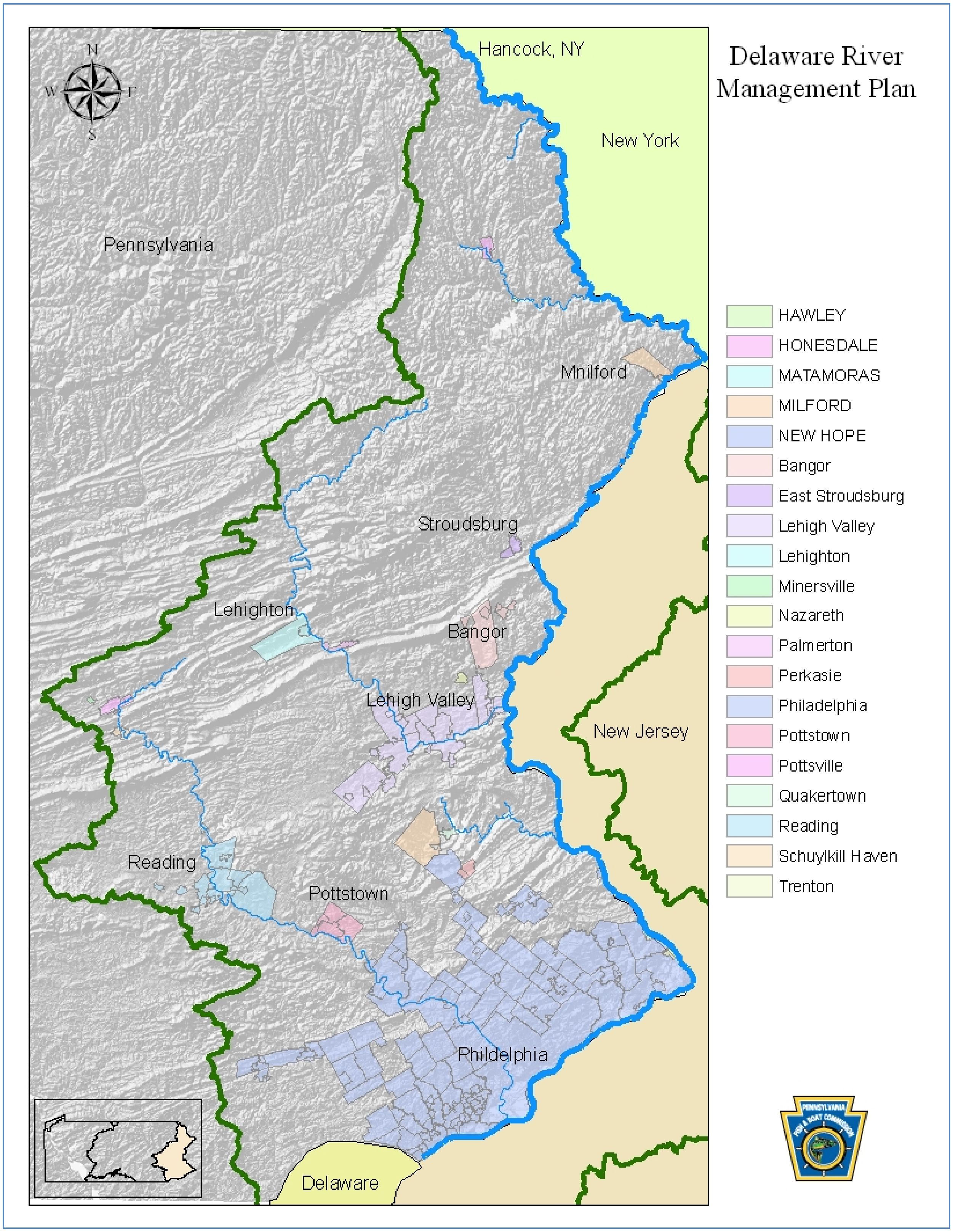


Figure 3.3. Major boroughs within the Pennsylvania portion of the Delaware River Basin.

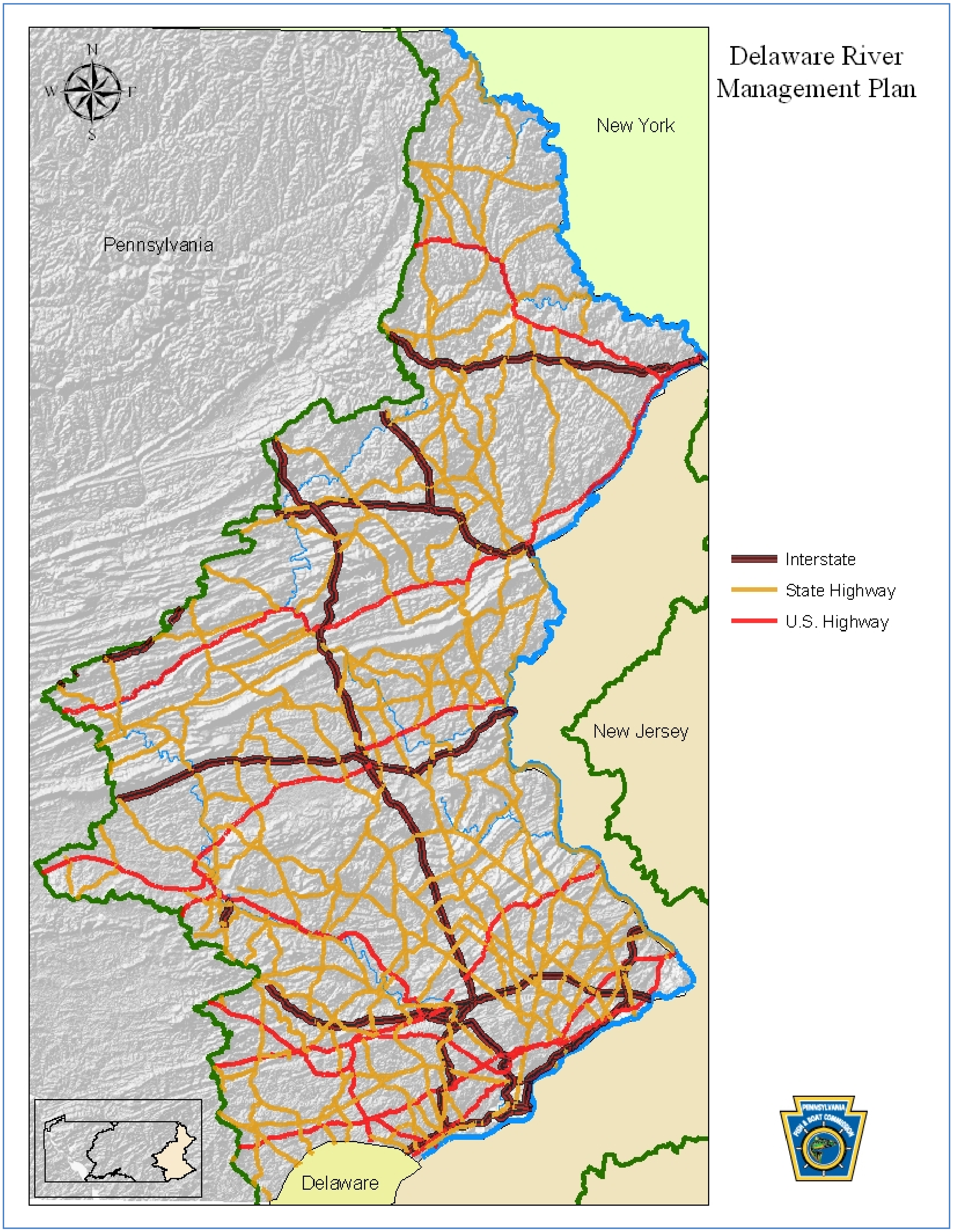


Figure 3.4. Interstate, U. S. highways, and State highways located within the Pennsylvania portion of the Delaware River Basin.

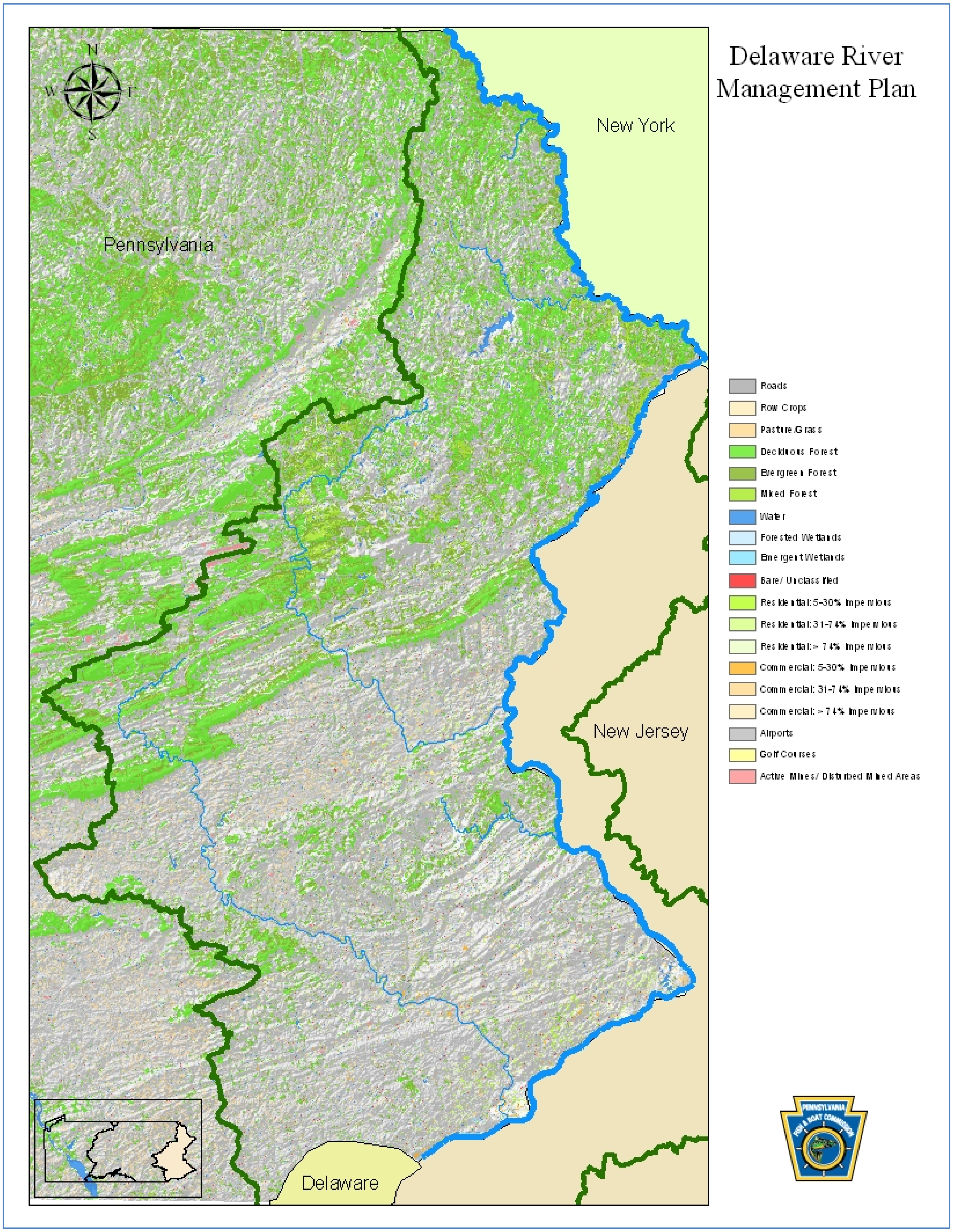


Figure 3.5. Land use patterns in the Pennsylvania portion of the Delaware River Basin based on Anderson et al. (1979).

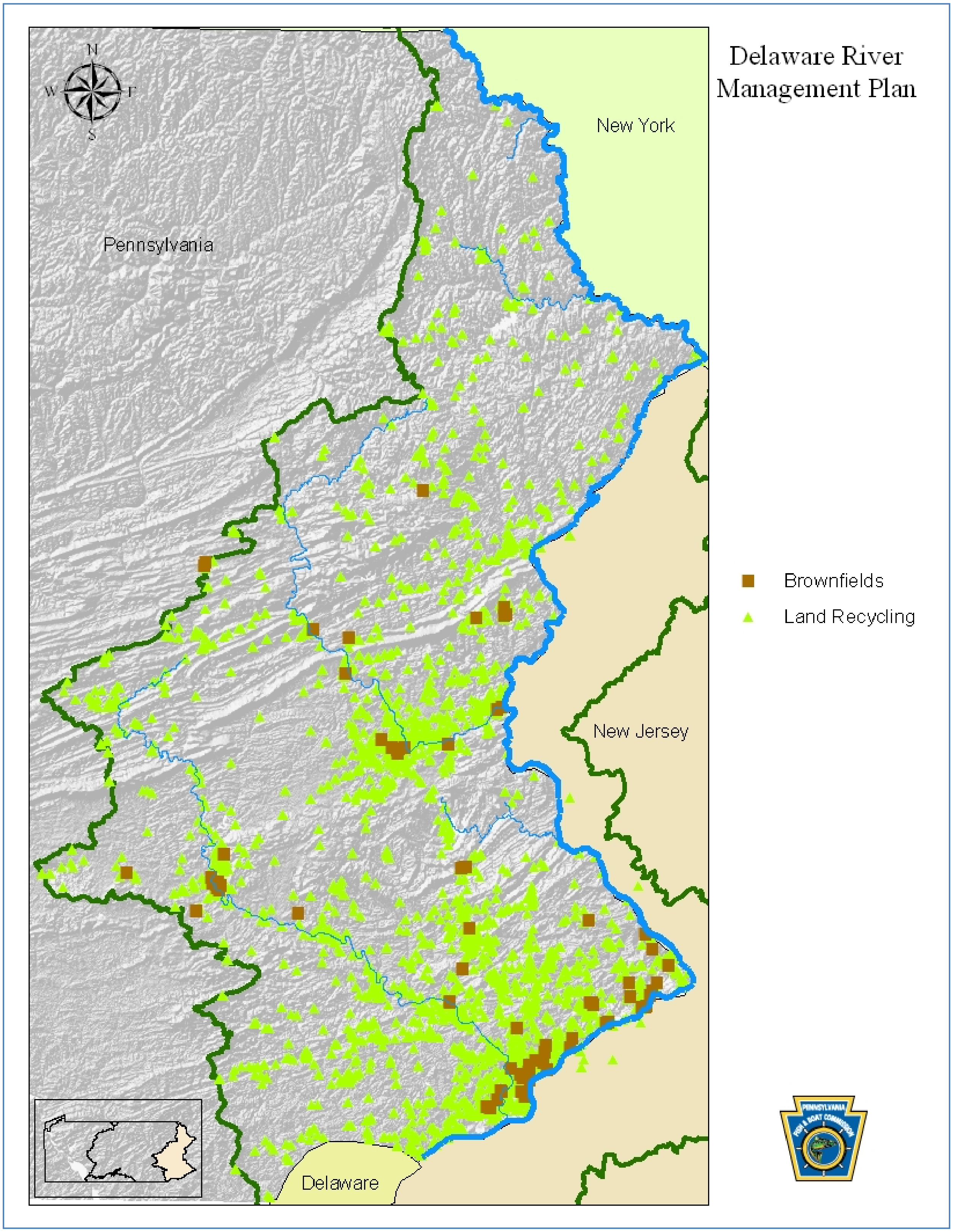


Figure 3.6. Brownfield revitalization and land recycling projects located within the Pennsylvania portion of the Delaware River Basin.

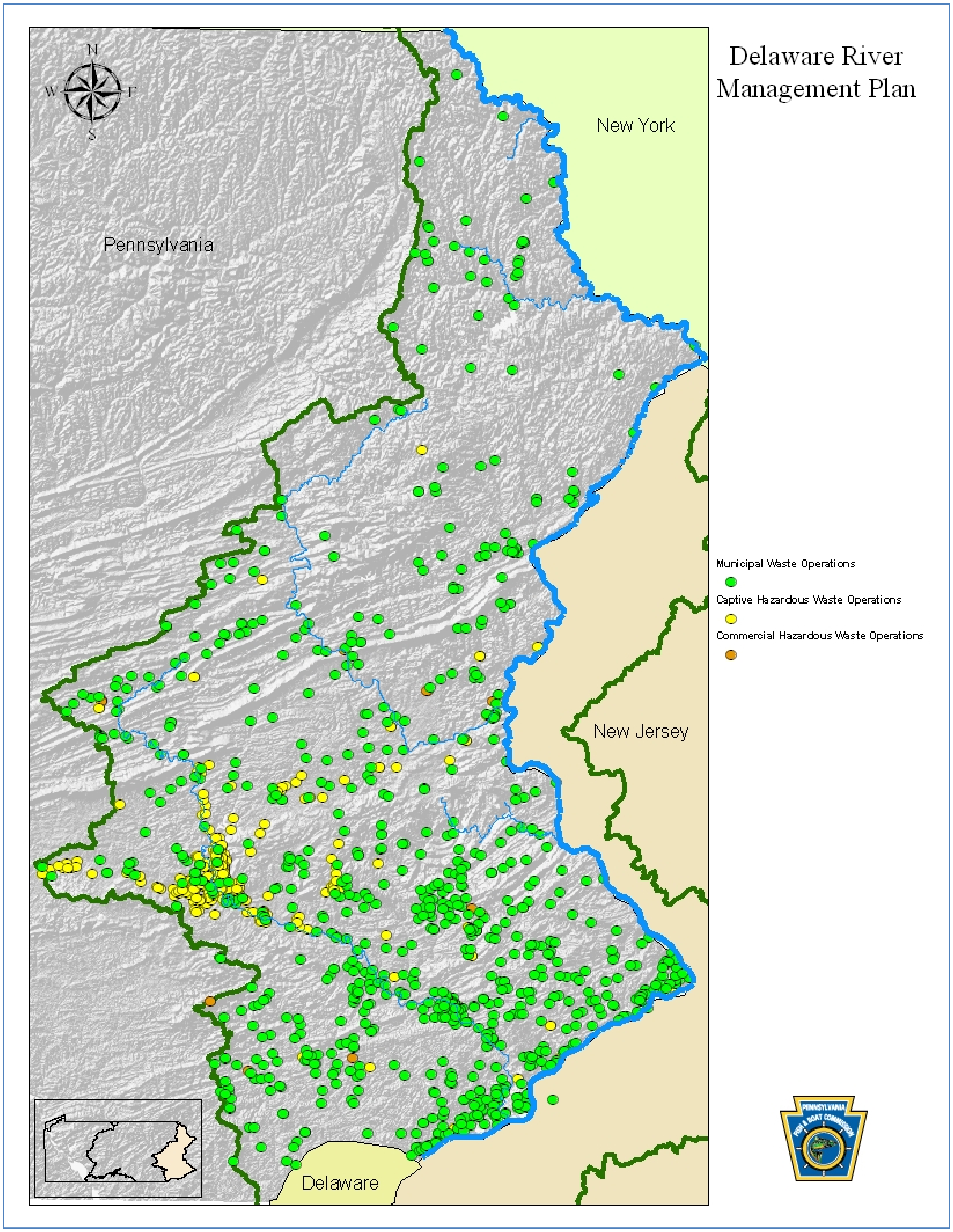


Figure 3.7. Municipal waste, captive hazardous waste, and commercial hazardous waste operations located within the Pennsylvania portion of the Delaware River Basin.

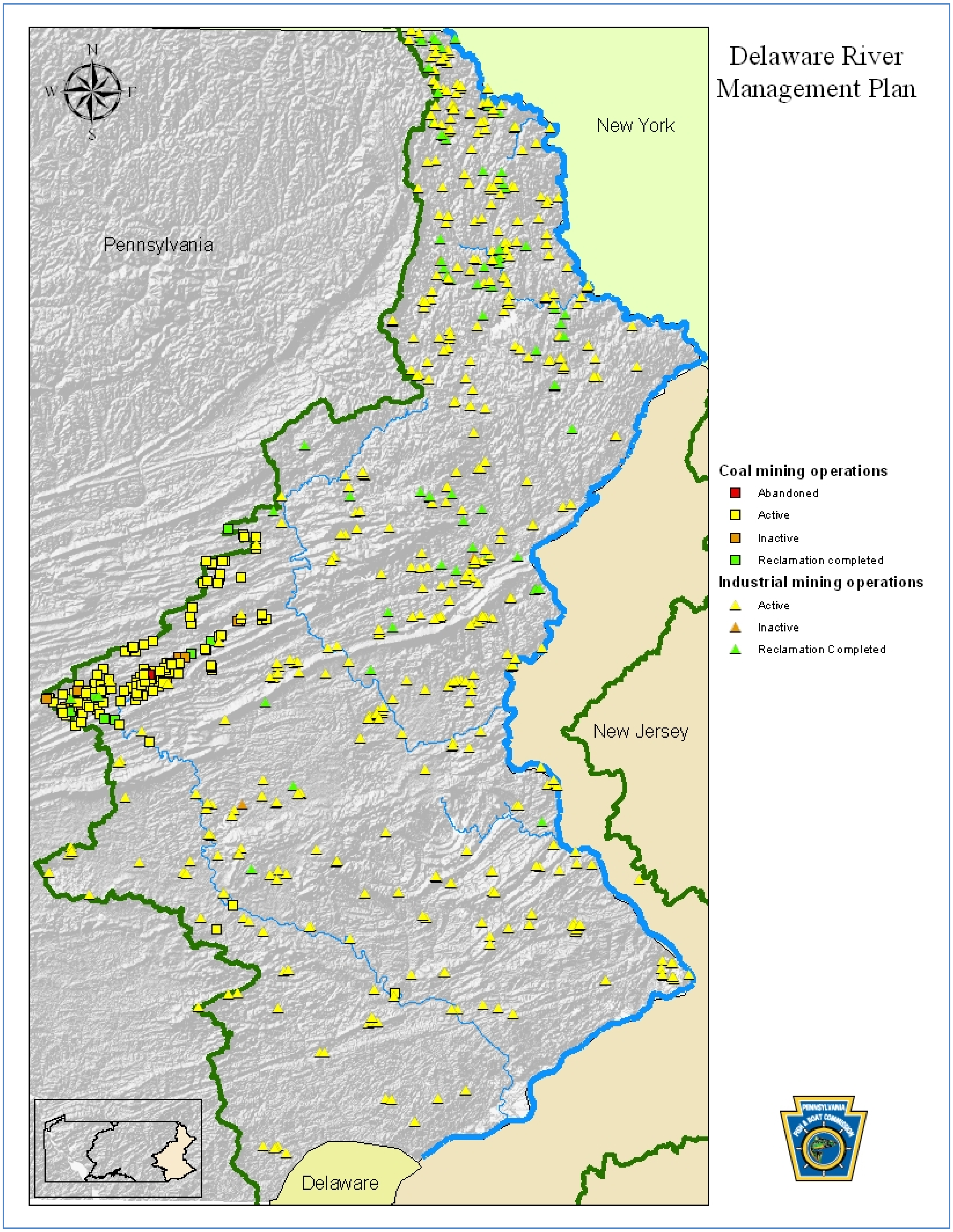


Figure 3.8. Coal mining and industrial (principally quarrying) operations located within the Pennsylvania portion of the Delaware River Basin.

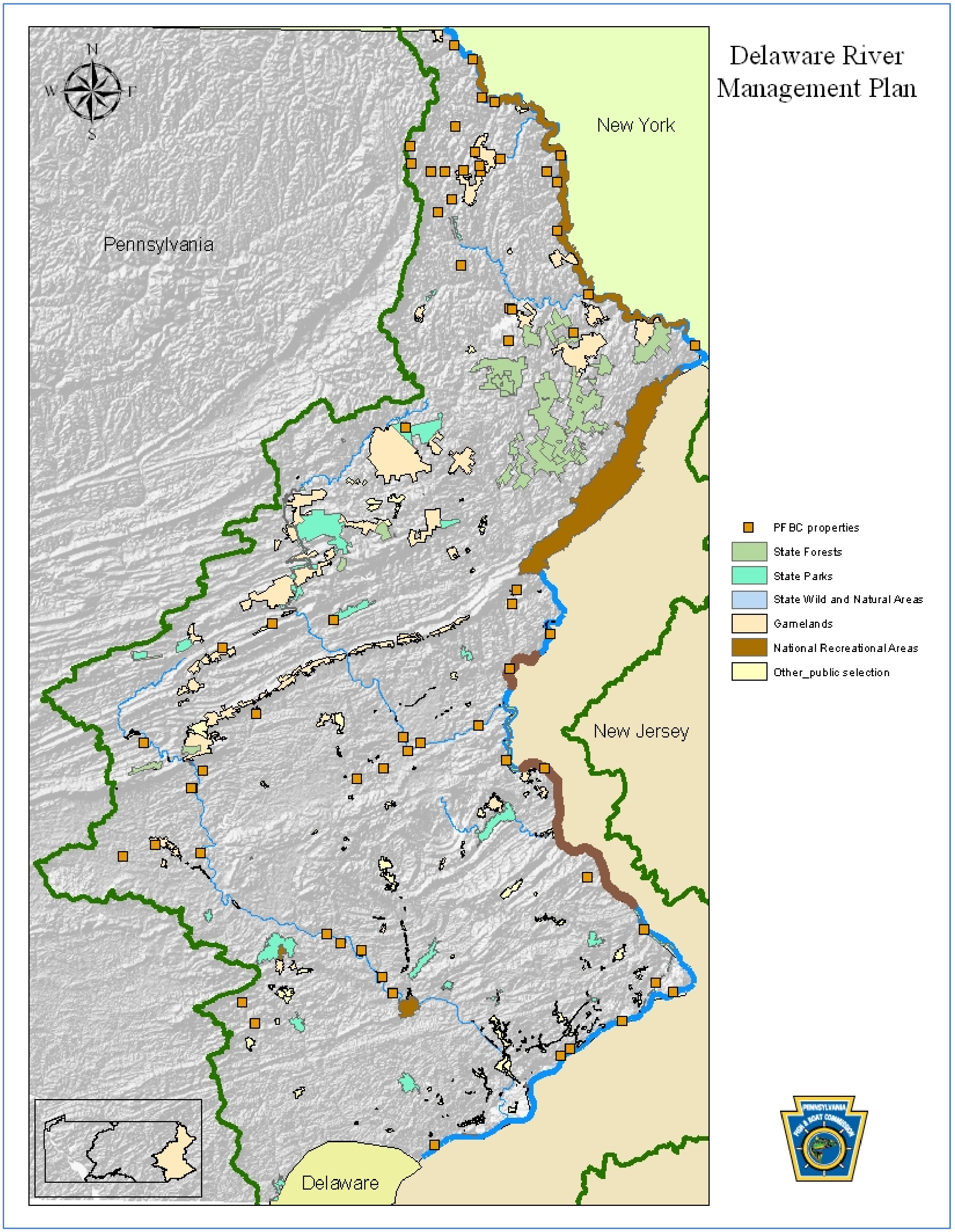


Figure 3.9. Public lands located within the Pennsylvania portion of the Delaware River Basin.

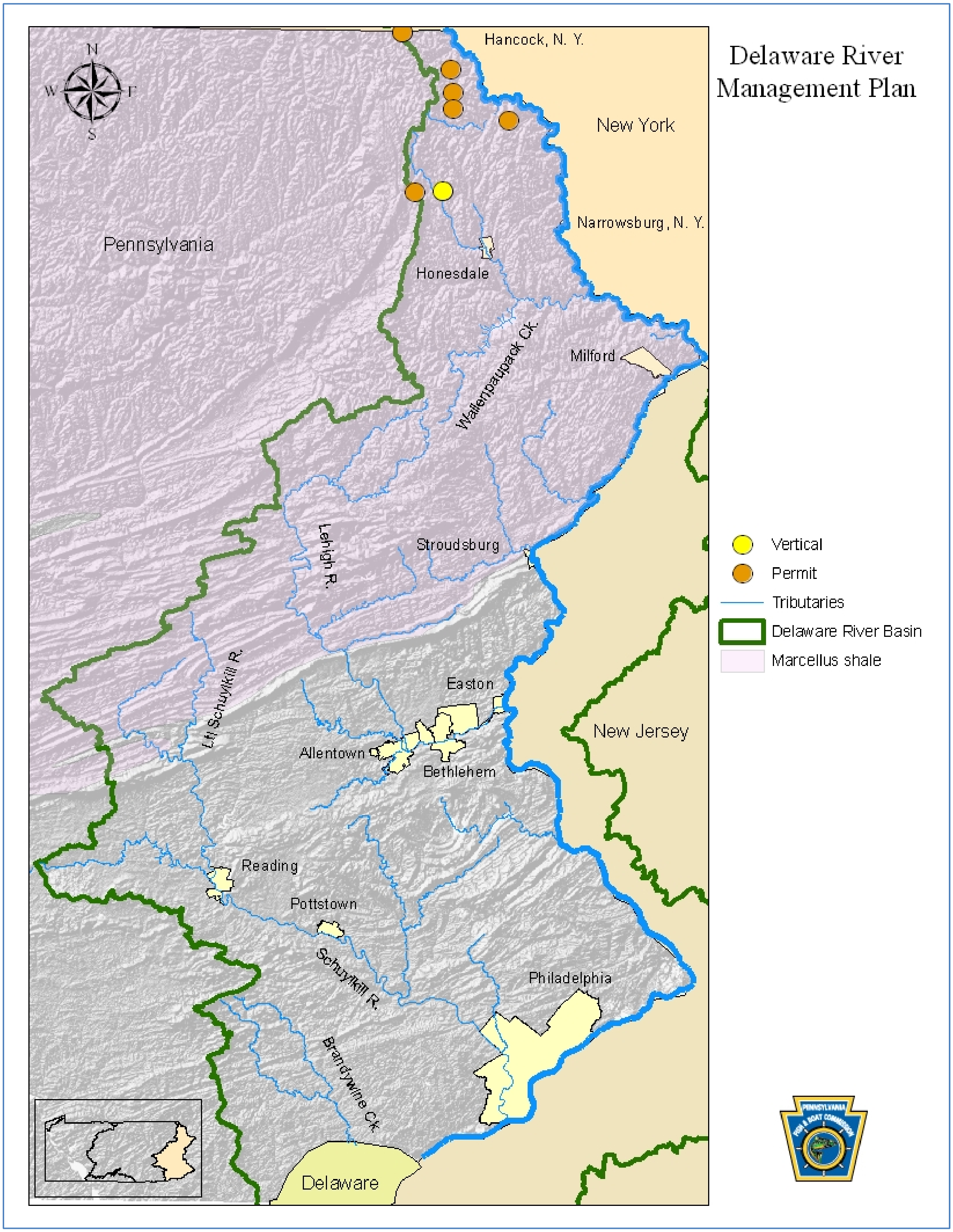


Figure 3.10. Oil and gas well locations located within the Pennsylvania portion of the Delaware River Basin.

4.0 River Characteristics

The West Branch Delaware and Delaware rivers are defined by its natural physical characteristics and by the legacies of human settlement and use. Flows in the West Branch Delaware and Delaware rivers are variable and dependent on precipitation, base ground water flows and the manipulation of flow regimes from storage dams located within the system. One of the principal determinates of river flow is the physical basin topography through which the West Branch Delaware and Delaware rivers mainstems traverse. A series of measurements are used to characterize river flows in general terms to give an understanding of the physical basin and allow for simple comparision between river basins.

4.1 Catchment Area

The Delaware River Basin drains 12,765 square miles (mi^2; 33061 square kilometers) across portions of four states: Pennsylvania, New Jersey, New York, and Delaware (Figure 4.1). Within the Commonwealth of Pennsylvania the basin drains 6,458.8 mi^2 (16,728.4 km^2) or approximately 50.3% of the basin (Sloto and Buxton 2007). The remainder of the basin is in New Jersey (23.3%), New York (18.5%) and Delaware (7.9%). The Delaware River Basin drains all or parts of 17 of the 67 Pennsylvania counties (Figure 4.1).

4.2 Basin Topography

The topography of the West Branch Delaware and Delaware rivers are characterized by its traverse from headwaters in the Catskill Mountains through the Blue Mountain and Kittatinny Mountain Ranges to the Atlantic coastline between the States of New Jersey and Delaware (Figure 4.2). The non-tidal reach is defined as the point where tidal influences from the Atlantic Ocean are not evident. Above this point, the Delaware River is characterized as a freshwater river system; and below, the Delaware River while initially predominately freshwater, is subject to tidal influences, and increasingly estuarine and oceanic waters, as proximity to the Atlantic Ocean increases. This point of change between tidal and non-tidal reaches of the Delaware River mainstem has been accepted to occur at a fall near Trenton, NJ (RM 133.4) approximately 0.6 miles above the U.S. 1 Highway Bridge.

West Branch Delaware River

The West Branch Delaware River originates in the northern Catskills Mountains within the State of New York and remains wholly within New York for most of its length. The lower most 7.9 miles of the West Branch Delaware River is a shared political border between the State of New York and the Commonwealth of Pennsylvania. From the state border, the West Branch Delaware River generally flows in southeast direction, descending approximately 40 ft in elevation to its confluence joining the East Branch Delaware River forming the Delaware River just south of Hancock, NY.

Delaware River

The Delaware River is formed just south of Hancock, NY by the joining of the East Branch Delaware and West Branch Delaware rivers. From the confluence to Port Jervis, NY, the Delaware River forms a political boundary between the State of New York and Pennsylvania. Below this point the remainder of the non-tidal Delaware River is shared between Pennsylvania and New Jersey.

The Delaware River can be divided into three general reaches the upper, middle and lower for regional referencing. The upper reach encompasses the Delaware River from the confluence of the East Branch Delaware and West Branch Delaware rivers just below Hancock, NY (RM 330.7), to Port Jervis, NY (RM 254.7). The middle reach flows from Port Jervis, NY (RM 254.7) downriver to Easton, PA (RM 183.6) and the lower reach extends from Easton, PA (RM 183.6) downriver to the head of tide at Trenton, NJ (RM 133.4).

From the confluence of the East Branch Delaware and West Branch Delaware rivers, the upper reach generally flows in a southeasterly direction. The majority of this reach is contained within the Upper Delaware Scenic and Recreational River (UPDE) National Scenic River system maintained by the National Park Service. The topography is characterized by a relatively narrow floodplain as the Delaware River winds through a valley framed on either bank by steep mountains. The river descends 460 feet from an elevation of 880 feet at Hancock, NY to 413 feet at Port Jervis, NY. The ridge tops generally rise to 1,400-1,600 feet, with highest peaks reaching above 1,740 feet.

The middle reach of the Delaware River (Port Jervis, NY – Easton, PA), primarily flows through the Delaware Water Gap National Recreational Area. At Port Jervis, NY the river begins a southwesterly flow through the Water Gap then turns back to a southeasterly flow just north of Belvidere, NJ before returning to southwesterly direction toward Easton, PA. This reach of the river descends 272 feet from 413 feet at Port Jervis, NY to 141 feet at Easton, PA. for most of the middle reach, the river runs between two mountain ridge lines as part of the Kittatinny Range before the Water Gap, then cuts between the Blue Mountain and Kittatinny Ranges. Mountain elevations vary from 700 to over 1,500 feet on both sides of the river; however, ridge lines tend to be slightly lower on the Pennsylvania side (700 - 1,200 feet). The river does take a severe turn to the northeast at the Wallpack Bend as it cuts through the Godfrey Ridge, after which the river returns to a southwesterly heading.

The lower reach of the Delaware River (Easton, PA – Trenton, NJ) flows through some of the more highly urbanized areas of the river. This reach of the river is a transition zone where both natural and anthropogenic changes to water quality occur. Significant limestone bands influence the water quality of the river and tributary streams. At Easton, PA, two major tributaries that drain urban landscapes enter the river (Lehigh River and Bushkill Creek). This reach of the river again turns southeasterly flow to Trenton, NJ, decending the remaining 141 feet from Easton to the head of tide through a valley flanked by hills and in places by cliffs, of which the Nockamixon Rocks are most notable (3 miles long, reaching heights of 200 feet). The river below

Riegelsville, PA is characterized by a narrowing of the watershed. With the exception of Tohickon Creek, tributaries to this reach are very small.

4.3 Channel Dimensions

Channel dimensions are intended to characterize the river's basic physical dimensions. These give a sense of the average expected capacity of the river in terms of the volume and flow patterns.

Stream Order

Rivers have been traditionally ranked by a classification system known as stream order (Strahler 1957). This system is based on tributary input. A first order classification can be characterized as having a year-round flow but no tributary input and are commonly referred to as headwater streams. When two first order waters flow together the resulting mainstem stream is reclassified as a second order water; if two second order mainstem streams flow together they form a third order, and so on. At the northern state border, the West Branch Delaware River enters as a fifth order stream, and remains at this classification to its confluence with the East Branch Delaware River. With the joining of the East Branch Delaware and West Branch Delaware rivers, the Delaware River headwaters at Hancock, NY is classified as a sixth order stream. The Delaware River classification increases once before entry into the Delaware Estuary with the confluence of the Lackawaxen River (RM 277.7), at Lackawaxen, PA.

Length

The length of the West Branch Delaware River for the shared border waters between New York and Pennsylvania is a total of 7.9 (12.8 km) from the confluence of the East Branch Delaware and West Branch Delaware rivers upriver to the border of New York and Pennsylvania. The Cannonsville Dam is located in New York, 10.1 miles upriver from the Pennsylvania - New York border. Above the Cannonsville Dam, the West Branch extends an additional 90 miles (144 km) to its head waters in the Catskill Mountains.

The Delaware River is a free-flowing river for 330 miles beginning at the confluence of the East and West Branches (RM 330) downriver to the entrance of the Delaware Bay. The non-tidal reach is 197 mi long from headwaters at Hancock, NY to the head of tide in Trenton, NJ (RM 133).

Width

Both the West Branch Delaware and Delaware rivers reaches are classified as large rivers based on PFBC categorization of average river widths exceeding 30 m (99 ft; Table 4.1). Average width for the shared border waters of the West Branch Delaware River is 71.1 m (223.3 ft). The Delaware River can be genralized as a wide, shallow river. Average widths, range from 108.4 m (355.7 ft) to 127.4 m (418.0 ft) in the upper reaches, above Port Jervis, NY to 176.7 m

(580.0 ft) to 182.3 m (598.1 ft) in the lower reaches, below Easton, PA. River widths in the West Branch Delaware River and Upper Delaware River have been extensively characterized by Bovee *et al*. (2007).

Gradient

Stream gradient, defined as the drop in elevation per unit length of channel, affects stream velocity and the availability of habitat types (Murphy and Willis 1996). Geomorphic characteristics like stream gradient influence the availability and diversity of habitats within watersheds and consequently influence the composition of the fish community as well as fish species abundance in a particular watershed or river reach (Lanka *et al.* 1987). The West Branch Delaware and Delaware rivers undergo significant drops in elevation over their entire length from northeastern Pennsylvania to the head of tide at Trenton, NJ (Figure 4.3). Specific reaches throughout the Delaware River produce Class II rapids during spring runoff. Elevation change for the shared border waters of the West Branch Delaware River is approximately 0.9 m/km (5.0 ft/mi) from 920 ft elevation at the state border of Pennsylvania and New York to 880 feet elevation at the confluence of the East Branch Delaware and West Branch Delaware rivers, just south of Hancock, NY in a pool local citizens termed Junction Pool. From Junction Pool, the Delaware River undergoes slightly greater changes in gradient above Port Jervis, NY, ranging from 0.6 m/km (3.5 ft/mi) to 1.4 m/km (7.7 ft/mi), after which the river steadily drops at a slightly less steep gradient (0.5m.km to 1.1 m.km) to mean sea level at the head of tide in Trenton, NJ.

4.4 <u>Channel Morphology</u>

Channel morphology is used to describe the shapes of the river and how they change over time. The morphology of a river channel is a function of a number of processes and environmental conditions, including the composition and erodibility of the bed and banks; vegetation and the rate of plant growth; availability of sediment; the size and composition of the sediment moving through the channel; the rate of sediment transport through the channel and the rate of deposition on the floodplain, banks, bars, and bed; and regional aggradation or degradation due to subsistence or uplift.

Valley Width

Valley width, the width of the river channel and its flood-prone riparian border provides an estimation of the potential expansion of flooding once the river over tops its banks. Information relating to valley width has been defined by the National Oceanic and Atmosphere Administration, National Weather Service (NWS) in terms of flood stage based on the expected frequency of occurrence of a magnitude of an event (i.e., a 100 year flood stage). This information is utilized by NWS in the Advanced Hydrologic Prediction Service (AHPS) forecasts that can be accessed through the Internet at http://water.weather.gov/ahps2/glance.php?wfo=phi&gage=tksn4&riverid=203940&view=1,1,1,1,1,1&toggles=10,7,8,2,9,15,6.

Meander Pattern/Sinuosity

A meander is a bend in a sinuous watercourse. A meander is formed when the moving water in a river erodes the outer banks and widens its valley, which can eventually form into a series of alternating erosion/deposition forming various bends and turns in the mainstem that can be categorized into general types (i.e., meander pattern).

Sinuosity is a measure of deviation of a path length from the shortest possible path and provides a numerical classification of channel meander (*i.e.* number of bends over a given length) and is described by a ratio of channel length to the valley length (Murphy and Willis 1996). We are unaware of any available information pertaining to meander patterns and sinuosity for the West Branch Delaware and Delaware rivers reaches.

Degree of Confinement

Confinement of a river channel typically refers to the ability of a rivers banks for restricting water to remain within its' channel. We are unaware of any available information pertaining to the degree of confinement for the West Branch Delaware and Delaware rivers reaches.

Degree of Entrenchment/Incision

The concept of entrenchment or incision refers to the depth a river has cut downward through its riverbed, such as sediment or bedrock. Generally, the river begins at one elevation and incises downward through its bed while leaving its floodplain behind (higher). We are unaware of any available information pertaining to the degree of confinement for the West Branch Delaware and Delaware rivers reaches.

Table 4.1. Gradient, average river widths and Chapter 93 designations for the mainstems of West Branch Delaware and Delaware rivers.

Section	River Mile	Gradient		Width		Chapter 93
		m/km	ft/mi	m	ft	
West Branch Delaware River						
1	0-7.9	0.9	5.0	71.1	223.3	CWF & MF
Delaware River						
1	312.6 - 330.7	1.4	7.7	108.4	355.7	CWF & MF
2	289.0 – 312.6	0.6	3.5	120.8	396.3	CWF & MF
3	277.7 – 289.0	1.1	6.4	119.9	393.4	WWF & MF
4	250.0 – 277.7	0.9	5.1	127.4	418.0	WWF & MF
5	209.5 – 250.0	0.7	3.9	137.1	450.0	WWF & MF
6	186.6 – 209.5	1.1	5.7	137.1	450.0	WWF & MF
7	157.0 – 183.6	0.6	3.1	176.7	580.0	WWF & MF
8	133.7 – 157.0	0.5	2.5	182.3	598.1	WWF & MF

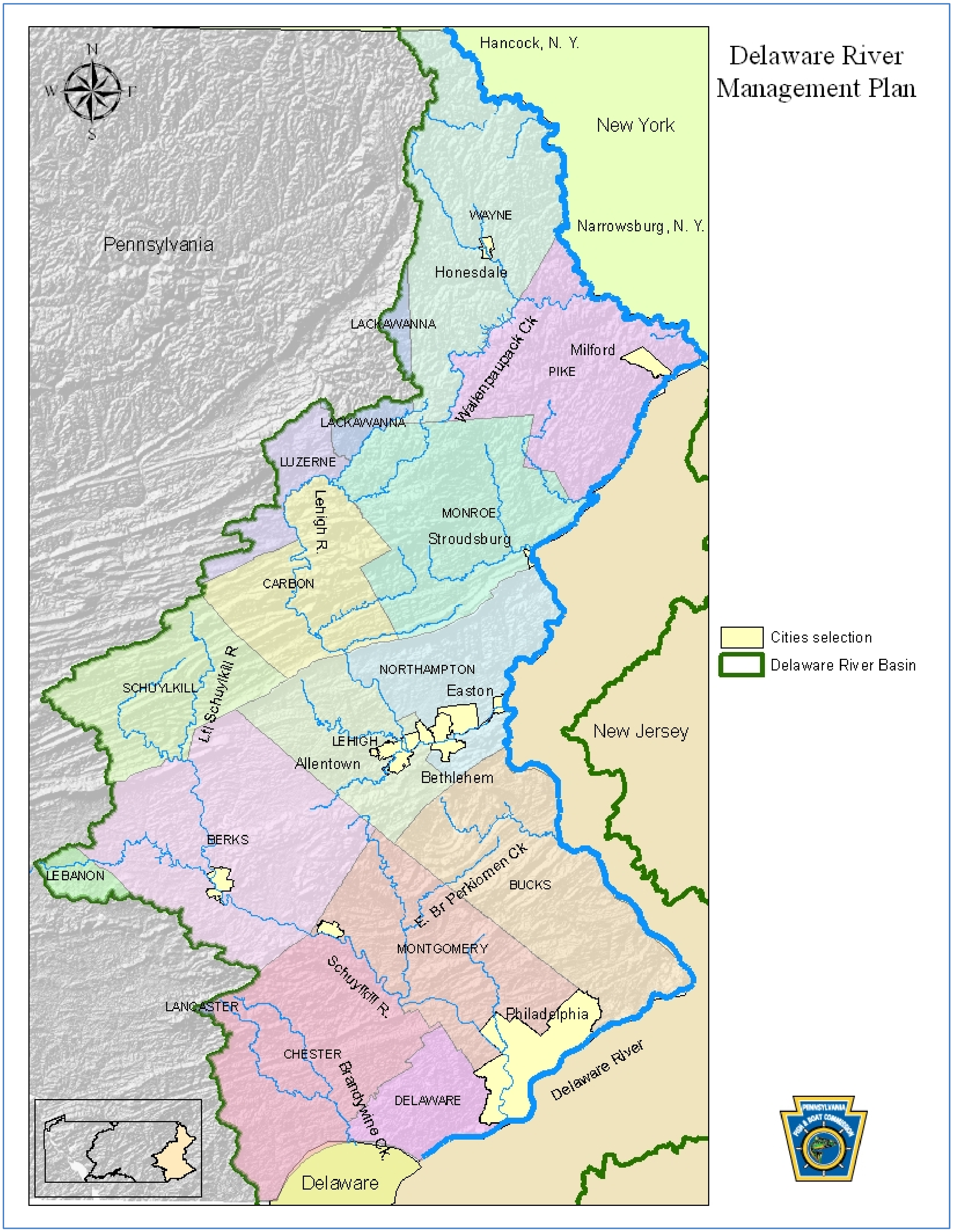


Figure 4.1. Pennsylvania counties within the Delaware River Basin.

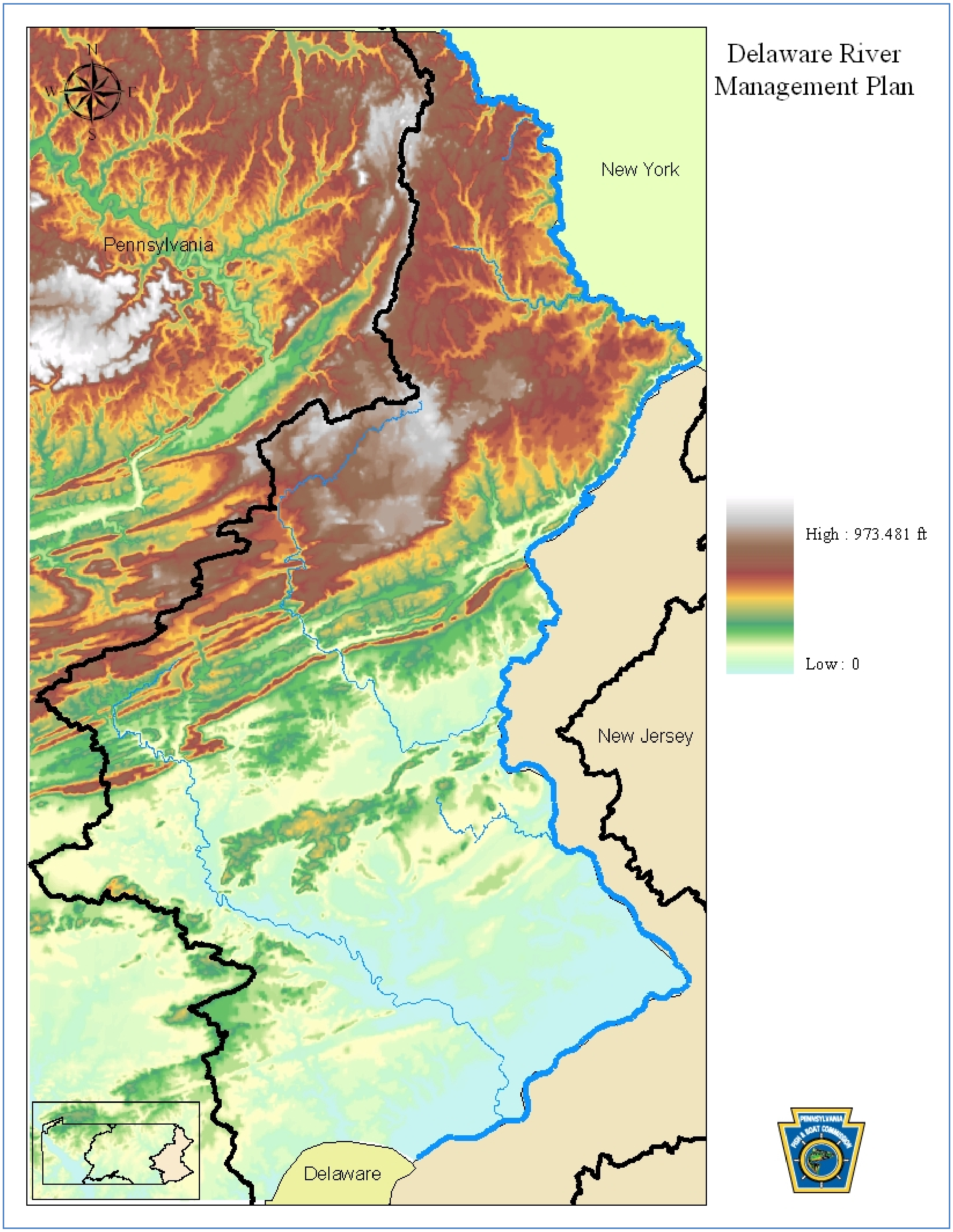


Figure 4.2. Topography within the Pennsylvania portion of the Delaware River Basin.

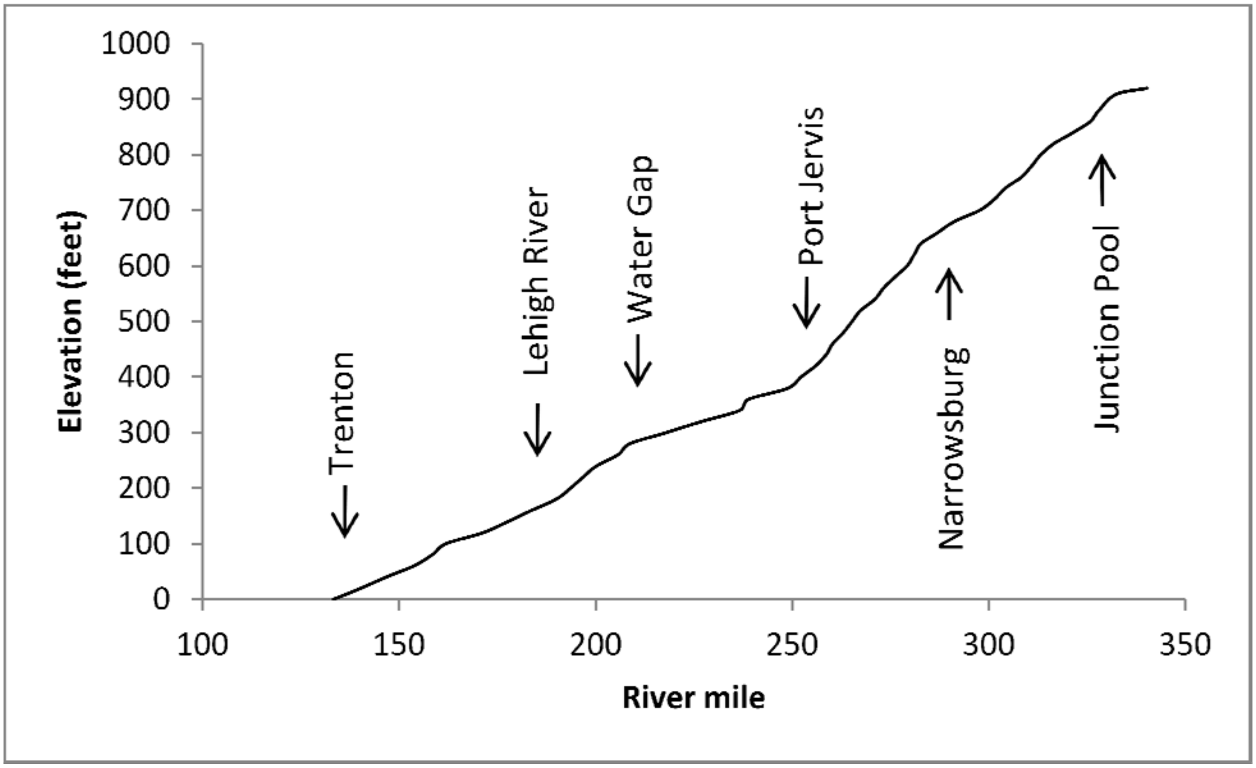


Figure 4.3. Illustration of elevation (USGS contour crossings) to river miles for the West Branch Delaware and Delaware rivers. Note, that the head of tide at Trenton, NJ has been defined as zero (0) elevation by USGS. The Delaware River begins at Junction Pool with the joining of the East Branch Delaware River and West Branch Delaware River, just below Hancock, NY.

5.0 River Hydrology

The hydrology of the West Branch Delaware and Delaware rivers vary over their lengths. Within Pennsylvania the West Branch Delaware River is un-impounded, but flows are directly influenced by releases from Cannonsville Reservoir a water supply impoundment for the New York City (NYC) metropolitian area. Cannonsville Reservoir is located 10.5 river miles upriver from the Pennsylvania – New York border. The mainstem of the Delaware River is free flowing from the confluence of the East Branch Delaware River and West Branch Delaware River to Delaware Bay. The Delaware River above Callicoon, NY including the West Branch Delaware River, function as a tailwater to the collective water releases from NYC reservoirs on the West Branch Delaware River (i.e., Cannonsville Reservoir), and East Branch Delaware River (i.e., Pepacton Reservoir). The PFBC provides comment on hydrologic issues related to the West Branch Delaware and Delaware rivers through resource agencies tasked with managing these issues such as the Delaware River Basin Commission, and Pennsylvania Department of Environmental Protection.

Starting in 1976, a comprehensive study was conducted to identify and resolve water resource problems in the Delaware River Basin. The result was the "*Level B Study*" issued in 1981 by DRBC (DRBC 1981) that provided comprehensive findings including resource conditions and recommendations for management. In 1999, a process was begun to develop a new and unifying vision for water resource management. The result of this effort was the *Water Resources Plan for the Delaware River Basin.* Unveiled in 2004 (DRBC 2004; http://www.state.nj.us/drbc/basinplan.htm), this plan presented a direction for integrated water resource management by acknowledging the connection between land and water and valuing aquatic habitat protection in the course of ensuring adequate flows and supplies for human needs. This plan represents the current thought process and management objectives for water resource management in the Delaware River Basin. The 2008 Delaware River State of the Basin report (DRBC 2008; http://www.state.nj.us/drbc/SOTB/index.htm) serves as a companion to the *Level B Study* and provides a benchmark of current conditions for gauging progress towards the goals of the *Water Resources Plan for the Delaware River Basin*. Within the DRBC 2008 State of the Basin report are overviews of the topics listed in this section. It is not the intent of the PFBC for this management plan to supplant the DRBC Water Resources Plan, but to provide a companion document addressing management of aquatic biological resources. Currently the DRBC has released its strategic plan (http://www.state.nj.us/drbc/WRP2010-2015.pdf) covering fiscal years 2010 through 2015 to address the goals of the Key Result areas of the *Water Resources Plan for the Delaware River Basin* (DRBC 2004, 2010d).

The DRBC (2009) provides and annual report of the hydrologic conditions in the Delaware River Basin. This report covers the meteorological events and uses of water within the basin. The most current report (2008) can be obtained at http://www.state.nj.us/drbc/08hydro/report.pdf. Further, the U.S. Geological Survey, Office of the River Master provides reports summarizing hydrologic conditions in the upper Delaware River Basin as per conditions entailed in the 1954 Decree. The most current monthly status report (USGS 2010) can be obtained at http://water.usgs.gov/osw/odrm/monthly.html, along with recent archived monthly reports.

5.1 Hydrologic Regime

Ground Water

Ground-water availability within the Delaware River watershed was recently assessed by the USGS in cooperation with the DRBC (Sloto and Buxton 2007). Using a watershed-based approach, the authors identified 147 watersheds comprising the Delaware River Basin. One hundred and nine watersheds were underlain with fractured rocks, based on lithology and physiographic province. Average annual base flow for these watersheds ranged from 0.313 to 0.915 million gallons per day per square mile for the 2-year-recurrence interval to 0.150 to 0.505 million gallons per day per square mile for the 50-year-recurrence interval. The remaining watersheds were underlain by unconsolidated surficial aquifers consolidated from surficial geology and land use. Average annual base flow for these watersheds ranged from 0.465 to 1.169 million gallons per day per square mile for the 2-year-recurrence interval to 0.178 to 0.670 million gallons per day per square mile for the 50-year-recurrence interval.

The DRBC established in 1980 a ground water protection area in southeastern Pennsylvania (http://www.state.nj.us/drbc/regs/gwpa.pdf; DRBC 1999). This protection area takes in 1,200 square miles and includes 127 municipalities within the Neshaminy Creek Watershed and portions of the Brandywine Creek, Perkiomen Creek, and Wissahickon Creek basins. The goal is assure the effective management of water withdrawals to avoid depletion of streamflow and ground water and to protect the quality of that water, assure that ground-water withdrawals are consistent with DRBC policies, to protect the rights of present and future users of water resources, and to provide a mechanism to more accurately plan and manage water resources.

River Discharge

The West Branch Delaware and Delaware rivers undergo changes of hydrologic regimes over the length of the non-tidal reaches due to topographical influences (Figure 4.2). The upper reaches are relatively high gradient that have frequent areas of riffles and rapids with relatively small pools. The middle reach of the river supports fewer riffles and rapids while the frequency of longer runs and larger pools increases. The lower reach of the Delaware River is exemplified by wide shallow runs with some occurrence of shallow riffles. Discharge typically follows seasonal variations with elevated discharge conditions in fall through middle spring and decreasing to relatively low flow conditions by late spring through early fall (Appendix A). Elevated discharge during the fall months typically originates from the passing remnants of tropical storms or Nor'easters. While discharge is related to precipitation experienced within the upper basin, operational releases from various dams, particularly the NYC water supply dams, located on major tributaries can also have a significant impact on river discharge.

West Branch Delaware River

The flow pattern for the West Branch Delaware River is directly dependent on reservoir releases from the NYC Cannonsville Dam. Similarly, the hydrology of the entire upper Delaware River system is largely dependent on releases of water from NYC water supply reservoirs, including Cannonsville, located on the West Branch Delaware River, Pepacton, located on the East Branch Delaware River, and Neversink, located on the Neversink River. These releases are highly regulated, following a series of set conditions described by the current plan – Flexible Flow Management Plan (FFMP 2011; http://water.usgs.gov/osw/odrm/documents/ffmp_ost_052511_final.pdf). This plan represents a temporary agreement for one year (June 1, 2011 through May 31, 2012). Generally these releases are for meeting the needs of multiple purposes one of which is for the protection of coldwater aquatic communities in the dams' tailwaters. These releases are also directed, if necessary, to maintain a minimum target flow of 1,750 cfs as measured at the United States Geological Survey gage station located at Montague, NJ. Due to the eccentricities of precipitation driven flow patterns and the need for accurate forecasting for anticipating rainfall input the West Branch Delaware River occasionally exhibits abnormal variations that can significantly dewater its channel such that the river flow dramatically swings from low to high and back again. This was evident in mid-September, 2008, when releases from the NYC Cannonsville Dam were reduced due in anticipated precipitation from a forecasted tropical storm. Unfortunately, the amount of precipitation was not realized, coupled with the reduced release form the Cannonsville Reservoir produced a significant dewatering of the West Branch Delaware River until corrections were accomplished to increase reservoir releases. A significant step forward to improve forecasting probability of reservoir refill is currently being under taken by NYC Department of Environmental Protection in the development of the Operations Support Tool (OST; NYC 2010). This is a state-of-the-art forecast-driven simulation/analysis decision support system that will provide the city's operators and managers with probabilistic predictions of future system status based on simulated scenarios inclusive of the entire NYC water supply system (i.e., Delaware, Catskill and Croton systems)

River flow patterns can be characterized by flow duration curves, which describe the percent of time during a period-of-record river discharge was equaled or exceeded a given rate (cfs). The USGS, through various partnerships, maintains two gage stations in the West Branch Delaware River, both of which are located above the New York – Pennsylvania border including, Stilesville (01425000) and Hale Eddy (01426500), to monitor river discharge (Figures 5.1 and 5.2). Given the rigorous management of releases from NYC's reservoirs, flow duration curves suggest prior to the building of the Cannonsville Dam, flow rates equaled or exceeded 100 cfs over 83.3% and 92.1% of the period-of-record at Stilesville and Hale Eddy gages, respectively (Figures 5.1 and 5.2). During the time period encompassing Cannonsville Dam becoming operational (1963) up to the implementation of the 2007 FFMP, management of releases tended to sustain flows equaled or exceeding 100 cfs during less time in the period-of-record (64.2%) at the Stilesville gage or generally mimic historical flows at the Hale Eddy Gage. With the implementation of the FFMP however, managed flows appear to provide some benefit for sustaining a relatively higher discharge for a greater percentage time, particularly at the Hale Eddy gage, which did not fall below 100 cfs (Figures 5.1 and 5.2).

Examination of monthly mean flows does illustrate a typical seasonal cycle, with high flows in springtime months, tapering to relatively lower flows during late summer (Appendix A). Annual mean discharge at Stilesville and Hale Eddy based on daily records of the period of record is 651 cfs (1952 to 2009) and 961 cfs (1912 to 2010), respectively. The illustration of flows during the FFMP water management (Oct. 1, 2007 to Sept. 30, 2008) years shows seasonal cycle with spring time highs; however, a "yo-yo" effect occurred at the end of April when water flow was cut from 250 cfs on April 27th to 72 cfs on 30th and then increased to 211 cfs by 2nd. These fluctuations were the result of following the FFMP and were required to address procedural changes between storage zones. Adjustments were made for 2009 season to avoid a recurrence of these events.

Establishment of a base flow is ambiguous for the West Branch Delaware River, given the high degree of manipulation from reservoir releases as per the FFMP (FFMP 2007, 2008, 2011). However, Sheppard (1983) and Sanford (1992) suggested that a 225 cfs flow at the Hale Eddy gage would be sufficient for protecting trout species. Late spring through summertime monthly mean flows examined under the first year of the FFMP (Oct 1, 2007 to September 30, 2008), ranged from of 200 cfs to 1,000 cfs at both Stilesville and Hale Eddy gages. The recommendation by NYDEC and PFBC (2010) is to increase flow from 80 to 150 cfs in fall/winter and 260 to 500 cfs in the summer to provide for improved river habitat conditions. Based on the flow duration curves for the USGS Hale Eddy gage, during the FFMP management program, 225 cfs was equaled or exceeded 97.1% and the 500 cfs was exceeded 65.2% of the period–of-record (Figure 5.2).

Over the many years of monitoring river discharge in the West Branch Delaware River, there have been major flood events. Since initiation of monitoring in 1952 at the USGS Stilesville gage, the record maximum peak discharge recorded was during the infamous June 2006 flood (27,700 cfs on June 28, 2006). Only during two other springtime floods in 1977 (10,100 cfs) and 1986 (12,500 cfs) did river flow exceed 10,000 cfs. At the USGS Hale Eddy gage location record maximum peak discharge was 35,200 cfs also on June 28, 2006. Flow at the Hale Eddy gage exceeded 20,000 cfs on numerous occasions most notably prior to the completion of the Cannonsville Dam including: winter 1925 (20,500 cfs); spring 1914 (21,000 cfs), 1936 (22,300), 1940 (20,000 cfs), 1948 (24,500 cfs), and 2005 (20,400 cfs); and fall 1938 (22,400). Minimum flows occurred during the drought-of-record (1961-1966) when annual river flow declined to 87.3 cfs at Stilesville and 203 cfs at Hale Eddy gages, respectively in 1965.

Delaware River

River flow for the Delaware River is free flowing throughout its entire length, but can be strongly influenced by human endeavors. The Delaware River reach (confluence East Branch Delaware River and West Branch Delaware River downriver to Callicoon, NY), is considered as part of the NYC Cannonsville and Pepacton dam's tailwaters for maintaining self-sustaining trout populations above Callicoon, NY (RM 302.7). Further, the three NYC reservoirs (i.e., Cannonsville, Pepacton, and Neversink) are collectively managed to maintain minimum flow objectives as measured at the United States Geological Survey gage station (RM 246.4) located at Montague, NJ located 7.2 river miles downriver of Port Jervis, NY (FFMP 2011). Operational releases from the NYC dams and other flood control and hydroelectric dams within the basin have some impact on flow conditions within the middle (Port Jervis, NY downriver to Easton, PA) and lower Delaware River (Easton, PA downriver to Trenton, NJ). The DRBC Water Code provides regulations for sustaining minimum streamflow objectives at the USGS gaging station (01463500) located in Trenton, NJ (RM 134.3) during normal and drought conditions for maintaining the salt front interface between fresh and estuarine waters (DRBC 2008).

The USGS, through various partnerships, maintains a series of gage stations in the non-tidal reach of the Delaware River for monitoring river discharge. Four gage stations are located in the upper Delaware River (i.e., Lordville 01427207, Callicoon 01427510, Lackawaxen 01428500 and Port Jervis 01434000), three gage stations are located in the middle mainstem reach (Montague 01438500, Water Gap 01440200, and Belvidere 01446500), and two are located in the lower mainstem reach (Riegelsville 01457500 and Trenton 01463500) used for daily monitoring of river discharge. Daily flow discharge for these gage stations are publically available, however the duration of the period-of-record is dependent on the gage.

Generation of flow duration curves for each of the gage stations provides understanding of flow frequencies (i.e., percentage of time in the period-of-record that equaled or exceeded a given rate). Not unexpectedly, total discharge increases at the downriver gages due to the relative increase of tributary input. In the upper Delaware River reach, flow duration curves at the Lackawaxen and Port Jervis gage stations provide an understanding of flow prior to the building and subsequent management of reservoir releases from the Cannonsville and Pepacton reservoirs given the longer period-of-record (Figures 5.3 and 5.4). Prior to managed reservoir releases (Oct. 1940 to Oct. 1954) flow rates at the Lackawaxen and Port Jervis gage stations equaled or exceeded 1,000 cfs for 73.2% and 89.5% of the period of record, respectively. Whereas during the managed water years (Oct. 1952 - Oct. 2007) up to the implementation of the FFMP, flow rates were improved for supporting slightly higher flows for a longer duration relative to pre-reservoir releases as measured at these two gage stations (Figures 5.3 and 5.4). This improvement of FFMP managed (Oct. 2007 – present) flow over the collective prior release programs (Oct. 1952 – Sep. 2007) was evident at the Lordville and Callicoon gages also located within the upper Delaware River (Figures 5.5 and 5.6). For example, at the Callicoon gaging station (USGS 01427510) a flow rate of 1,000 cfs is equaled or exceeded 94.1% of the period-of-record during the FFMP water management years (Figure 5.6). Mean seasonal highs occurred during the late winter and spring months with summer flows approaching or relative low flows (Appendix A). Annual mean flows were 3,079 cfs, 2,919 cfs, 3,351 cfs, and 5,266 cfs at the Lordville, Callicoon, Lackawaxen, and Port Jervis USGS gage stations, respectively. Calculated mean flows were inclusive of the entire period-of-record specific to each gage station, which encompasses differing time period durations. Examination of flows under the first year of the FFMP suggests that at times flows were lower than mean flow, particularly during the late spring months.

In the middle reach of the Delaware River, river discharge is monitored at three locations including Montague, Water Gap, and Belvidere USGS gage stations. Daily flow data exists at the Montague and Belvidere gages to generate flow duration curves for characterizing flows prior to management of reservoir releases from the NYC Cannonsville, Pepacton and Neversink reservoirs (Figures 5.7 and 5.8). Monitoring of river discharge at the Water Gap station was implemented and subsequently discontinued during the reservoir release programs prior to the initiation of the FFMP (Figure 5.9). Flow duration curves base on the pre-reservoir releases at Montague (1939-1953), indicated that flow was sustained at or exceeding 1,750 cfs, as established by the 1954 U.S. Supreme Court Decree, for 83.2% of the period of record. Since the implementations of the reservoir release programs, flows have improved in sustaining the Montague target. As observed in the upper Delaware River, river discharge is seasonal with higher flows in the fall through winter, and relatively lower flows during the summer months (Appendix A). Annual mean flows were 5,844 cfs, 6,208 cfs, and 7,998 cfs as measured for the period of record at Montague, Water Gap, and Belvidere gage stations, respectively.

In the lower reach of the Delaware River, river discharge is currently only monitored at one USGS gage station (i.e., Trenton, N.J. Figure 5.10). Two historical data sets for river discharge however are available for gages maintained by the USGS including Riegelsville (Oct. 1906 to Sep. 1971) and Lambertville (Oct. 1897 to Sep. 1906; Figures 5.11 and 5.12, respectively). For both the Trenton and historical Riegelsville data sets, the reservoir release programs collectively (1953-1971), prior to the FFMP, appear to nearly mimic the pre-reservoir conditions (Figures 5.10 and 5.11, respectively). Flows equaled or exceeded 3,000 cfs at the Trenton gage for 87.9% during pre-reservoir releases, and 92.3% during the reservoir releases prior to FMFP implementation (Oct. 1953 – Oct. 2007). Since the implementation of the FFMP (i.e., Oct. 2007), flows are maintained at or above 3,000 cfs for 97.7% of the period of record (Oct. 2007 – present day) at the Trenton gage. Annual mean flows were 10,802 cfs, 14,133 cfs, and 11,911 cfs as measured for the period of record at Riegelsville, Lambertville, and Trenton gage stations, respectively.

Establishment of base flow conditions within the non-tidal reaches of the Delaware River is problematic for similar reasons as establishing base flows in the West Branch Delaware River. The non-tidal Delaware River is influenced by reservoir releases from NYC and other dams throughout its entirety. This is particularly true for the upper Delaware River reach upstream of the USGS Montague gage station (01438500; RM 246.4) where a minimum flow target (1,750 cfs) is maintained by the Office of the River Master as per the current FFMP (FFMP 2011). The manipulation of flow for the maintenance of the salt front below Trenton, New Jersey further confounds the identification of baseline flows in the middle and lower reaches of the Delaware River (DRBC 2008). A minimum flow objective during “normal” conditions is 3,000 cfs; whereas this flow objective decreases accordingly to 2,700 cfs during drought warning, and to 2,500 – 2,900 cfs under drought conditions, depending with time of year and location of salt front.

The occurrence of peak flows have been well documented at the various USGS gage stations within the Delaware River. Since initiation of monitoring, maximum peak discharge was recorded of 38,100 cfs (Oct. 2010), 127,000 cfs (June 2006), 140,000 cfs (June 2006), and 163,000 cfs (Aug. 1955) in the upper Delaware River at the Lordville, Callicoon, Lackawaxen, and Port Jervis gages respectively. River discharge was exceptionally high in other years, particularly during June 2006 (21,700 cfs) at Lordville, the spring time flood in 2005 measured at Callicoon (94,700 cfs) and Lackawaxen (104,000 cfs); and March 1936 (113,000 cfs) and

August 1955 (163,000 cfs) at Port Jervis. Further down river, maximum discharge was 187,000 cfs (Aug. 1955), 211,000 (June 2006) at the Montague, and Belvidere gages in the middle Delaware River; and 228,000 cfs (Mar. 1936) and 279,000 cfs at the Riegelsville and Trenton gage stations in the lower Delaware River, respectively.

Minimum flows occurred principally during the drought-of-record (1961-1966) when annual river flow declined to 1,383 cfs, 2,140 cfs, 2,422 cfs, 3,156 cfs, and 4,976 cfs at Lackawaxen, Port Jervis, Montague, Belvidere, and Trenton gages, respectively in 1965. Periods of annual mean low flows were also experienced in other years most notably in 1930-’31 (Port Jervis: 3,554 cfs; Belvidere: 5,166 cfs; Trenton: 7,618 cfs) the previous acknowledge drought-of-record prior to the 1961-1966 experience. Further, in numerous years, annual mean flows were relatively depressed but for a short duration dependent on metrological conditions. Annual mean flows were not as adverse in these other years as experienced in 1965, but daily flows did occasionally decline to the same level as experienced during the drought-of-record. Drought emergencies were declared by the DRBC in 1999 (http://www.state.nj.us/drbc/drght7.htm) and 2001-2002 (http://www.state.nj.us/drbc/02chronology.pdf).

Hydrologic Modeling

Hydrologic modeling of the Delaware River Basin has been the focus in past years for two principal objectives: reservoir release management from the New York City water supply dams (http://water.usgs.gov/osw/odrm/daily_flow_model.html); and flood analysis (http://www.state.nj.us/drbc/Flood_Website/floodanalysismodel.htm). In 1981, recognizing the need to a more accurate and effective means of quantitatively comparing alternative operating plans for major reservoirs in the Delaware River Basin; the Philadelphia District U.S. Army Corps of Engineers contracted the development of a daily flow model for the reservoirs. The original incremental inflow file (i.e., input data sets) was developed for the 50-year period from October 1927 to September 1977. This model was modified several times in the 1980’s to reflect reservoir operating curves (i.e., NYC and Merrill Creek Reservoir). Modifications continued in the 1990’s by the extension of the incremental inflow file extended through water year 1987. Then in 2002, as part of a flow management study for the DRBC, HydroLogics, Inc. developed a new version of the daily flow model under the trade name Operational Analysis and Simulation of Integrated Systems (OASIS). The OASIS model was programmed to use the same incremental inflow file that was used to drive the original daily flow model. Additionally, in 2002, PPL Generation, LLC, added features to the official DRBC OASIS version of the daily flow model, which provided for modeling of Lake Wallenpaupack operations. Features to the OASIS were added by DRBC in 2004 to improve representation of New York City operations and to evaluate alternative reservoir releases programs in support of fisheries in the dam tailwaters. The current version of the OASIS model includes most of the features of the interim reservoir releases programs agreed to by the Decree Parties. The current version of OASIS is commercially available from HydroLogics, Inc. and as such, has allowed various independent organizations the ability to investigate various flow regimes for the upper Delaware basin.

Two cornerstone studies by Sheppard (1980, 1983) modeled the upper Delaware River flow as an indicator of available in-river fish habitat relative to flow. Sheppard (1980, 1983) used the USFWS/USGS Physical HABitat SIMulation System (PHABSIM) to calculate available habitat values for various fish species and life stages as a function of stream discharge. The original version of PHABSIM involved two major components: 1) one dimensional stream hydraulics model; and 2) life stage-specific habitat requirements. Field measurements of depth, velocity and substrate are taken at specific sampling points (cells) on a cross section of the river. Models were then used to predict depths and velocities at flows different from those measured. Habitat suitability indices for each habitat attribute (depth, velocity, and substrate) were then developed for each species and life stage of interest, based on scientific literature and expert opinion. For each species or life stage of interest, the area of each river cell was weighted with a value between 0 and 1 for each of the habitat suitability indices. The weighted values for all cells are then summed yielding a total estimate of weighted usable habitat. Estimates of weighted usable habitat were made for a range of discharges and the relationship between discharge and habitat was graphed. A thermal-stress day was defined as a day when the maximum water temperature equals or exceeds 75^{o}F and/or the water temperature equals or exceeds 72^{o}F for an entire 24-hour period (Sheppard 1980). This became the basis for thermal target objectives in the management of reservoir releases and provided a means in which to measure the frequency of occurrence of environmentally stressful conditions. Sheppard (1983) further developed fish habitat - flow relationships for brown trout, which suggested flows of 75-100 cfs to 300-350 cfs were required to obtain the maximum usable spawning habitat in the West Branch Delaware River below Stilesville, NY. Habitat-flow curves also indicated that 250-300 cfs flows at Hale Eddy, NY were necessary to maximize the amount of juvenile brown trout habitat; and flows of 150-300 cfs were required to maximize adult brown trout habitat in the West Branch Delaware River. A release of 225 cfs at Hale Eddy, NY was recommended to protect aquatic communities, particularly fish, during all types of hydrologic conditions.

The discharge of water from the NYC reservoirs during the time period from 1997-1999 is commonly known as "Experimental flows" program. In an effort to evaluate the efficacy of the management of water discharge during the Experimental flow, Elliot (2001) provided a comprehensive overview of releases and their potential influence on the trout population in the upper Delaware River. Study findings suggested that in general the West Branch Delaware River typically experienced cooler summer water temperatures and fewer low flow events than the East Branch Delaware River or Delaware River mainstem (Hancock, NY to Hankins, NY). It was also determined that a relatively small percentage (8.3%) of the monthly average flows in the West Branch Delaware River were below suitable habitat flows as defined by Sheppard (1983). The West Branch Delaware River supports a consistent trout biomass with a relatively successful and well distributed fishery; however, the variability within the system precluded a clear understanding of the cause-and-effect of the reservoir releases upon trout biomass.

In 2004, the Decree Parties and the DRBC commissioned a study to further determine flow requirements and to compare the predicted effects of alternative flow regimes on species of interest (Bovee et al. 2007).This second study developed a three-dimensional bed topography combined with the River2D model (i.e., a 2- dimensional hydraulic simulation) to predict water depths and velocities at various flows for quantifying habitat requirements of selected species and species guilds versus discharge relationships. Suitable depth and velocity ranges for target organisms were defined with a group of experts (Bovee *et al*. 2007). Target organisms included trout incubation, spawning, juvenile, and adult habitat; American shad spawning and juvenile habit; shallow-fast guild habitat to represent riffle-dwelling species; and shallow-slow guild habitat to represent young-of-year habitat for virtually all species as well as species found primarily in slack water areas. Outputs from the River2D model were combined with target organisms' preferred depth and velocity ranges to estimate the area suitable for each target organism over a range of flows. A mesohabitat layer that mapped hydromorphic units such as pools, riffles, and pool tailouts was used to further refine the estimates of suitable habitat area. Habitat persistence for brown trout spawning and incubation, and dwarf wedgemussel patches were also included in the analysis. Outputs were expressed as hectares of total habitat for a given stream segment. Habitat area versus flow for each species/guild is provided by Bovee *et al.* (2007), providing a metric similar to that provided by the initial PHABSIM study. The resulting Decision Support System (DSS) uses projected reservoir releases and OASIS model outputs to evaluate impacts on habitat metrics in selected locations for the East Branch Delaware, West Branch Delaware, Neversink, and Delaware rivers. The DSS model is considered to have a precision of ±10% and outputs from the DSS are affected by the quality and accuracy of OASIS model and meteorological inputs. Both the Sheppard (1983) and Bovee et al. (2007) habitat flow relationships are for the most part complimentary and form a strong basis to manage flows to benefit resident fish communities.

Recently, the Nature Conservancy has written a report characterizing the hydrologic impacts of NYC's reservoir releases (1954-2008) to the upper Delaware River tailwaters (Moberg et al. 2010). Findings were addressed by partitioning historical river discharge into generalized categories: pre-reservoir period (prior 1953), construction period (1953 – 1966); initial operation (1967-1984); reservoir release program (1985 – 2007) and FFMP (2007 to present); then subsequently contrasting flows based on a series of four questions. Briefly, 1) has water regulation changed flow patterns? 2) Did the water management in later release programs result in changed flow patterns compared to initial reservoir operations? 3) Is any impact of FFMP on flow detectable? and 4) How do multi-purpose releases impact rate-of-change downstream under FFMP. The authors characterize study findings by effects on tributaries (i.e., East Branch Delaware and West Branch Delaware rivers) and the Delaware River mainstem. In short study findings were complex given the continued evolution of management reservoir releases (Moberg *et al.* 2010). In relation to the first question, the authors suggest that median flows in the tributaries has been moderately to greatly decreased immediately below the NYC reservoirs, in addition to the timing, frequency and duration of flows. Further the authors suggest effect of winter reservoir regulation on winter and fall monthly median flows can potentially be traced downstream to Trenton, N.J., and heavily impacted by maintaining Montague minimum flow target. The contrast between the initial operation period to later reservoir release management practices as per the authors second question, suggest monthly median flows during winter greatly increased whereas monthly median flows during spring moderately decreased in both the East Branch Delaware and West Branch Delaware rivers. Pertaining to the third question regarding any perceived improvement of FFMP over past release programs, the authors concluded that monthly median flows under the FFMP more closely mimicked pre-reservoir monthly median statistics and successfully reintroduced seasonal flow variations, particularly on the East Branch Delaware and Neversink rivers, lacking in past release programs. The authors, suggest FFMP impact on rate-of-change downstream of the Cannonsville Reservoir (i.e., West Branch Delaware River) was significant and linked to reservoir operations from directed releases for maintaining the Montague and Trenton flow targets.

The NYDEC Division of Fish, Wildlife & Marine Resources and PFBC (PFBC 2010; http://www.fish.state.pa.us/water/rivers/delaware/dela_flex_flow.pdf) developed a white paper position on recommended reservoir releases from the NYC dams for the protection of the tailwater coldwater aquatic community. The white paper details an optimal release schedule from a fisheries management perspective with water avaialbe following 75th percentile of NYC diversions. River reaches influenced by this position paper include the East Branch Delaware and West Branch Delaware rivers, and the upper Delaware River mainstem downriver to Callicoon, N.Y. and the Neversink River. The goal is to best manage water not diverted by NYC water supply use, establish a series of protection levels, and enhance the tailwaters coldwater aquatic community, which declines relative to the distance from NYC dams' outflow. The recomandations call for greater support of river flows during non-drought reservoir storage conditions in the NYC reservoirs and address both year-round habitat and summer water temperature protection. Inherent within these protection levels is the stabilization of a transitional zone changing from a well established coldwater aquatic community in the West Branch Delaware River to a warmwater community below Callicoon, NY.

The New Jersey Department of Environmental Protection is pursuing the reassessment of safe yield from the Delaware River Basin (http://www.state.nj.us/drbc/RFAC121410_brand.pdf; http://www.nj.gov/dep/watersupply/doc/analysisnycreservoir.pdf). Their goal is to reassess the quantity of water available when derived from a conjunctive use, safe yield based operating plan using realistic demand conditions to optimize reservoir operations for sustainable water uses for all parties. Ideally a realistic safe yield, should provide and protect water supply and water quality, downriver aquatic ecology, enhance flood mitigation, ensure salinity repulsion, and restore equality of water apportionments during the drought of record.

The NYC Department of Environmental Protection is developing a comprehensive decision support tool for improving their water operations and planning (NYC 2010; http://water.usgs.gov/osw/odrm/documents/OST_White_Paper.pdf). The resultant computer model, termed Operations Support Tool (OST), is envisioned to provide direct input on the management of water collectively from the Delaware, Catskill, and Croton systems. This system is a forecast-driven simulation and analysis tool to provide probabilistic predictions of future system operations based on a series of priorities and conditions. Thus from a broader perspective, the OST will serve to simulate the possibility for achieving multiple and possibly competing objectives in relation to impacts (positive and negative) from various operating strategies. The principle objective for which the NYC water system is managed is water supply reliability. Other objectives are concerned with water quality reliability, downriver ecosystems and economic considerations in operating the water system. Once completed, the intent is for the OST to supplant the NYC OASIS-W2 model currently being used for managing NYC water supplies. This operating system has been suggested as a substitiue for a safe yield reassessment.

The DRBC maintains an active Flood Advisory Committee whose primary objectives are to assess, evaluate, and recommend improvements in the basin's flood warning system. This committee was created and later amended by DRBC resolutions 2000-8 (DRBC 2000; http://www.state.nj.us/drbc/Res2000-8.htm) and 2006-3 (DRBC 2006; http://www.state.nj.us/drbc/Res2006-3.pdf), respectively. Under this committee, the DRBC actively pursues the development of flood models (http://www.state.nj.us/drbc/Flood_Website/FloodAnalysisModel/index.htm) to potentially minimize flood damage experienced by downriver communities in the lower reach of the Delaware River. Resolution number 2006-20 (DRBC 2006; http://www.state.nj.us/drbc/Flood_Website/Res2006-20.pdf) authorized and directed DRBC to accept funds from basin states to be used to develop a model for evaluating the potential for reservoirs throughout the basin to be used to mitigate flooding on the Delaware River and its tributaries. The USGS is the lead agency working with the U.S. Army Corps of Engineers Hydrologic Engineering Center and the National Weather Service to develop the model for DRBC.

Results from the computer model that was developed indicated that operational changes to the reservoirs alone would not substantially reduce downriver flooding from storms similar to those of September 2004, April 2005, and June 2006 (DRBC 2009). A series of model simulations were used to predict river stages at nine NWS flood forecast points downriver for six-hypothetical pre-event reservoir conditions for each of the three aforementioned storm events. Model predictions indicated that even with the three NYC reservoirs empty proceeding each storm event, river elevations would still have reached or exceeded flood stage at all but three (Hale Eddy, NY in 2005, Harvard, NY in 2004/205, and Bridgeville, NY in 2006) of the nine locations included in the forecast simulations. Simulations with hypothetical pre-event voids in the NYC reservoirs, also indicated river elevations would have reached or exceeded flood stage for all but two (Harvard in 2004 at pre-event 10 or 20 percent void; Bridgeville in 2006 with a 20 percent void) forecast locations. Interestingly, of the thirteen reservoirs included in the simulation, Prompton Reservoir (West Branch Lackawaxen River), General Edgar Jadwin (a dry dam on Dyberry Creek, a tributary to the Lackawaxen River), F.E. Walter Reservoir (Lehigh River), Beltzville Lake (Pohopoco Creek, a tributary to the Lehigh River), and Merrill Creek Reservoir (Merrill Creek, NJ) did not spill during any of the three storm events and cannot provide further flood mitigation with additional pre-event void space (Figure 5.13). Model results do not support claims that spills from reservoirs are the root cause of downriver flooding. Pervasive out-of-bank flooding would still have occurred (DRBC 2009). Further while pre-event voids may potentially reduced peak flood crests, the amount of reduction is highly dependent upon the characteristics of the storm event (precipitation intensity, duration and timing) river location (distance downriver from reservoir, and local topography and geomorphology of the river channel. Simulations also suggested dedicated pre-event voids would not eliminate flooding and year-round twenty percent voids would reduce the reliable yield of NYC reservoirs and double drought frequency as modeled with historical inflow records and current water management constraints.

Flood analysis model simulations and associated studies have provided guidance for future direction pertaining to flood mitigation in the mainstem Delaware River (DRBC 2009; http://www.state.nj.us/drbc/newsrel_model121509.htm). No one set of measures will eliminate flooding along the Delaware River, rather the Interstate Flood Mitigation Task Force recommends a combination of measures to improve the basin's resiliency (i.e., prepare for and recover from flooding) to flood events. The DRBC will continue to purse implementation of all six recommended Task Force priority management areas in framing a multi-year Flood Mitigation Action Plan including: preservation/restoration of floodplains where possible; flood preparation; protection of citizens from flood hazards; prevention of adverse impacts and unwise uses in floodplains; prevention of adverse impacts from development and redevelopment; and acknowledgement of the value of structural flood control measures (DRBC 2009; http://www.state.nj.us/drbc/newsrel_model121509.htm).

Material Transport

Riverine waters carry or "transport" materials, typically categorized in two general forms, suspended load and bedload. A suspended load are those materials that are small particles (e.g., fine –grain clays and silts) that can remained suspended within the water column. As river velocities decreases, it reaches a point when the force of water is not great enough to keep sediment up in the water column and particles begin to be deposited (i.e., sedimentation). Bedloads represent the more coarse (e.g., coarse-grain sands, gravel, cobble, and boulder sized materials) materials that are too large to become suspended in the water column; however, they can get pushed downstream along the river's bottom dependent on the force of water. We are unaware of any information available pertaining to sediment and bedloads in shared border waters of the West Branch Delaware River. Limited information is available about suspended sediment discharge from two USGS gages maintained at Water Gap (USGS 01440200; Oct. 1963 – Sep. 1972) and Trenton (USGS 01463500; Oct. 1948 – Sep. 1982) through the National Water Interface System (Figures 5.14 and 5.15, respectively). Suspended sediments discharge was assessed as tons per day and milligrams per liter. At the Water Gap gage, peaks of suspended solid discharge (tons/day and mg/l) occurred during the winter through mid-summer months approximately corresponding to increased flow discharge. Small quantities of suspended sediments were discharged during the mid-summer months to mid-fall months. At the Trenton gage, peaks in suspended sediments were consistent throughout the year and were weakly correlated with peaks of flow discharge.

Tributaries

Flows in the West Branch Delaware and Delaware rivers, are the cumulative effects of flow from the tributaries. A multitude of tributaries ranging from small first order headwater streams to large seventh order tributaries discharge into the West Branch Delaware and Delaware rivers. These tributaries carry surface run-off combined with ground water inputs and can have profound impacts on the water quality of the rivers depending upon their size and the land use practices within the watersheds that they drain. The Delaware River Basin within Pennsylvania is composed of 22 major subbasins (Figure 5.16).

West Branch Delaware River

Tributary discharge into the shared border waters of the West Branch Delaware River is generally limited to first and second order streams. Balls Eddy Creek and Shehawken Creek are the major inputs into the West Branch Delaware River from Pennsylvania. Most of the river flow is directly from reservoir releases from the New York City Cannonsville Dam and other tributaries located above the Pennsylvania – New York state line. From New York below the state border, Travis Brook and Sands Creek discharge into the West Branch Delaware River. Most of these tributaries discharging in to the West Branch Delaware River are generally poorly buffered, but can support robust trout populations. Further, trout are known to migrate into these tributaries during spawning runs, such that many of these tributaries support young-of-the-year (YOY) trout production.

Delaware River

Tributary discharges into the non-tidal Delaware River mainstem are from first to seventh order streams. On the Pennsylvania side of the river, the Lackawaxen River in the upper reach (Hancock, NY downriver to Port Jervis, NJ) , the Lehigh River in the middle reach (Port Jervis, NJ downriver to Easton , PA), and the Tohickon Creek in the lower reach (Easton, PA down river to Trenton, NJ) provide the greatest volume of discharge. Basket Creek, Callicoon Creek, Mongaup River, Neversink River (impounded for NYC water supply) in New York are the principal tributaries in the upper reach of the Delaware River. Tributary inputs from the State of New Jersey, Flat Brook and Pequest River are the major contributors in the middle reach with Musconetcong River and Assunpink Creek in the lower reach.

5.2 Flow Modifications

The Delaware River represents the single longest free flowing river in the eastern United States. However, river flows have been substantially influenced by mankind over the last century. In the West Branch Delaware and upper Delaware rivers, flow can be dramatically influenced by operational procedures of the three New York City water supply dams as per the agreed upon past reservoir release programs and the current FFMP (FFMP 2007, 2008, 2011). Further downriver, several major dams exist on tributaries for various purposes, principally flood control and hydroelectric generation (Table 5.1; Figure 5.13). While flow regulation is not within the authority of the PFBC, the PFBC does provide support and commentary as needed to regulatory agencies pertaining to evaluation of flow regimes and hydrological modeling of the West Branch Delaware and Delaware rivers. Further, the PFBC continues to strongly advocate for returning and maintaining its waterways as free-flowing and has been actively pursuing means for defunct dam removal.

Impoundments

West Branch Delaware River

River flow on the West Branch Delaware River is heavily modified and regulated by reservoir releases from the NYC Cannonsville Dam by the FFMP (FFMP 2007, 2008, 2011). Specifically, the shared border water of the West Branch Delaware River between Pennsylvania and New York remains free of impoundments, however; the Cannonsville Dam is located 18 river miles upriver on the West Branch Delaware River from the confluence with the East Branch Delaware River. Thus, the shared border waters of the West Branch Delaware River are completely encompassed by Cannonsville tailwaters. The main purpose of this dam is to supply water to NYC. Currently, minimum target flow of 1,750 cfs at Montague (RM 246.4) is enforced by the Office of the River Master (FFMP 2007, 2008, 2011), and a 3,000 cfs flow objective at the Trenton under "normal" conditions gage as per DRBC Water Code (DRBC 2009; http://www.state.nj.us/drbc/regs/watercode031109.pdf).

Delaware River

The entire 330 river miles of the non-tidal mainstem Delaware River remains free flowing. Two wing dams, Lumberville (RM 155.9) and Lambertville (RM 147.9), exist in the lower reaches of the mainstem, below Easton, PA. The first is from the wing dam at Bulls Island, which supplies water to the Delaware and Raritan Canal (RM 156.2) for consumptive use by New Jersey. This out-of-basin consumptive use is part of the 1954 Supreme Court Decree that allows for a withdrawal of up to 100 mgd to supply water to the New Jersey side of the New York City metropolitan region. The second diversion in the lower reach of the non-tidal Delaware River is a non-consumptive in-basin diversion for maintaining the Delaware Canal on the Pennsylvania side just above New Hope, PA. The DCNR seasonally pumps water from the mainstem at Center Bridge (SR 0263, RM 151.9) into the Delaware Canal to keep the canal full from spring to fall. All pumped water, less evaporation, is returned back into the Delaware River via sluice gates. The amount of water and timing of water diverted into the Delaware Canal varies from year to year as a result of periodic damage and subsequent repairs to the canal resulting from spring flood events. A major multi-purpose dam was planned at Tocks Island (RM 217.2) principally to support municipal water supply, hydroelectric generation, flood control, and recreation. This highly controversial project was never completed and the lands acquired for the project were incorporated into the Delaware Water Gap National Recreational Area.

Flow in the mainstem of the Delaware River can be affected by several major dams located within tributary drainages. Currently there are eleven major dams located within the non-tidal reach of the Delaware River. Included in these eleven dams are the three NYC water supply dams (Table 5.1), Lake Wallenpaupack owned by Pennsylvania Power & Light (PPL) and Rio Reservoir owned by Alliance Energy. Both Lake Wallenpaupack and Rio Reservoir are operated for hydro-electric generation and are taken into account in the determination of directing releases for meeting river flow targets at the Montague gage. Most of the other Dams within Pennsylvania are owned by either the U.S. Army Corps of Engineers or the Pennsylvania

Department of Conservation and Natural Resources and are operated for flood control and recreation (Table 5.1; Figure 5.13).

Water Regulation

Water releases from the upper Delaware River Basin reservoirs have been actively managed at some level for several decades. A historical review is available from the Office of the River Master website at http://water.usgs.gov/osw/odrm/releases.html. In 1931, the U. S. Supreme Court issued a decree authorizing NYC to divert an average of up to 440 million gallons of water per day (mgd) from the Delaware River headwaters to its water supply system in the Hudson River basin. The 1931 decree was amended and superseded by the 1954 U. S. Supreme Court ruling ("Decree") increasing the allowable diversion by NYC up to 800 mgd from its three Delaware River Basin reservoirs, upon completion of the Cannonsville Dam on the West Branch Delaware River. Further, New York City was required to release from its three upper basin reservoirs into the Delaware River a sufficient quantity of water to meet a flow objective of 1,750 cubic feet per second (cfs) as measured at the United States Geological Survey gage station (gage 01438500) located at Montague, NJ (RM 246.4), in order to ensure adequate streamflows downriver. The Decree also authorized the State of New Jersey to continue its existing out-of-basin diversion via the Delaware-Raritan Canal system, of up to an average of 100 mgd without providing compensating releases. Finally, the position of the Delaware River Master under the USGS was created by the Decree for ensuring that the provisions of the Decree are met and to provide an account of all diversions through an annual report to the U.S. Supreme Court.

The formulation of the DRBC created an entity joining the federal government and boundary states as equal partners in river basin planning, development, and regulation. Parties to the Decree include governors from the four basin states and the mayor of NYC ("Decree Party"); whereas members of the DRBC include governors of the four basin states and a federal representative. The DRBC has the authority to allocate waters of the Delaware River Basin to and among States and their political subdivisions and impose conditions, obligations and release requirements; but the DRBC may not without unanimous consent of the Decree Party diminish or otherwise adversely affect diversions, compensating releases and other provisions in the 1954 decree ruling.

The DRBC maintains several Advisory Committees (http://www.state.nj.us/drbc/advisory.htm#flow) for providing a forum for the exchange of information and viewpoints on a variety of issues. The history of the series of advisories committees pertaining to the 1954 Decree can be found at http://www.state.nj.us/drbc/RFAC_Bylaws_022306.pdf (DRBC 2006). A technical Task Group, including all the parties to the 1954 U.S. Decree, was originally formed in 1967 (Resolution 67-4) to reevaluate the adequacy of water supply resources of the Delaware River Basin. Resolution 83-6 continued the functions of the Task Group and renamed the committee as the Flow Management Technical Advisory Committee (FMTAC) for providing technical support for the implementation of the "Good Faith" Recommendations. The function of FMTAC was to follow through with the Good Faith Recommendations pertaining to water resource planning during droughts and the planning of additional water supply storage, if needed, to maintain flow objectives on the river.

Resolution No. 2005-18 reconstituted the FMTAC as the Regulated Flow Advisory Committee (RFAC). It clarified the RFAC's scope to include the regulated streams below Cannonsville, Pepacton, Neversink, Merrill Creek, Blue Marsh, F. E. Walter, Beltzville and Nockamixon reservoirs, Lake Wallenpaupack and the hydropower reservoirs in the Mongaup River. The RFAC was charged with: advising the Commission about regulated flows and potential changes to the Water Code; providing a forum for public discussion; disseminating accurate scientific information; and increasing understanding of operational and legal constraints and opportunities.

Resolution No. 2003-18 formalized a process for developing and evaluating the feasibility of achieving flow targets to address instream flow and freshwater inflow requirements for aquatic ecosystems in the Delaware River Basin, including the Delaware Bay. It also established a Subcommittee on Ecological Flows (SEF) to assist the DRBC's RFAC in developing scientifically-based ecological flow requirements for the maintenance of self-sustaining aquatic ecosystems. Currently, the chairman of SEF is held by staff in the PFBC. The purpose of the SEF is to: assist in developing scientifically-based ecological flow requirements; provide regular progress reports to the RFAC; and work with the DRBC's RFAC and the Water Management Advisory Committee (WMAC) in a collaborative way. Membership of the SEF includes at least one member of RFAC who is a Decree Party member and at least one member of the WMAC who is not a Decree Party member.

Water supply for New York City is diverted from three reservoirs within the upper Delaware River Basin. The dams creating these reservoirs are located on the East (Pepacton) and West (Cannonsville) Branches Delaware rivers, and the Neversink River (Table 5.1; Figure 5.13). Construction of these dams was completed between 1953 and 1963. By 1967, the Cannonsville Reservoir, the last of the Delaware River storage reservoirs had filled and NYC was allowed a cumulative diversion of up to 800 mgd. However, releases from Cannonsville Dam provide most of the water to meet the flow target mandated by the Decree.

Since the mid-1970s the Parties to the 1954 Decree, working in conjunction with the DRBC, have enacted a series of programs aimed at improving ecological conditions downstream of the NYC Delaware Basin reservoirs (http://www.state.nj.us/drbc/nycreservoirs_docketinfo.htm). The DRBC provides an online listing of these revisions and resolutions related to Docket Number D-77-20 (http://www.state.nj.us/drbc/Reservoir_NYC/List-Res-reD-77-20CP_032609.pdf). These programs have been adopted with the unanimous agreement of the Decree Parties and began in 1977 with an Experimental Program (DRBC, 1977; Docket D-77-20; http://www.state.nj.us/drbc/Reservoir_NYC/D-77-20.pdf) that was extended by eight DRBC resolutions through 1983. The Good Faith Recommendations (DRBC, 1982; http://www.state.nj.us/drbc/regs/GoodFaithRec.pdf) comprise a set of consensus recommendations for interstate water management. From this set of recommendations, Resolutions 83-13, 84-7, and 88-22 (Revised) were codified in the DRBC Water Code, generally known as the reservoir drought operating plans. Codified in 1983, DRBC Docket D-77-20 CP (Revised), also referred to as Revision 1 (DRBC, 1983; http://www.state.nj.us/drbc/Reservoir_NYC/D-77-20CPRev.pdf) reached further understandings with respect to fishery management below the three NYC reservoirs. During subsequent years, modifications deviating from DRBC Docket D-77-20 CP, were temporary unanimous agreements by the Decree Party and not formally adopted in DRBC water code (DRBC 1983, 1999, 2002, 2003, 2004, 2006). There revisions are referred to by numerical order as new agreed medications were achieved (i.e., revisions 2 - 9). The goal of these revisions has been to balance the storage ability of the reservoirs with the need to improve the river's ability to support a cold-water fish community in the upper Delaware River while maintaining adequate water supplies to NYC and New Jersey through the diversions authorized by the 1954 Decree.

Beginning on October 1st, 2007, Flexible Flow Management Program (FFMP) was implemented. The FFMP is a framework for managing diversions and releases from New York City's Delaware River basin reservoirs for multiple objectives including water supply, minimum flow objectives, conservation releases for the protection of the tailwaters fisheries, drought management, mitigating the impacts of flooding, mainstem habitat requirements and salinity repulsion. The full text of the original FFMP may be viewed at http://water.usgs.gov/osw/odrm/document_archive/FFMP_original.pdf (FFMP 2007). Following the initial year of implementation the original version was modified twice since (FFMP 2008; http://water.usgs.gov/osw/odrm/documents/FFMP_FINAL.pdf; FFMP 2011; http://water.usgs.gov/osw/odrm/documents/ffmp_ost_052511_final.pdf), to its current state. This adaptive program provides opportunity to modify release rates as new circumstances arise. Faced with the possibility of a short-term closure of the Roundout West Branch Tunnel for maintenance purposes, the basin states and the City of New York developed and agreed to a temporary supplemental release program to make best use of excess water that may be available in the reservoirs (http://water.usgs.gov/osw/odrm/documents/Agreement_Temporary_Releases_Program_2010_RWBT_Shutdown.pdf). This modification adds to previously established release rates by estimating near-term water availability, including predictions of reservoir storage conditions that result from the tunnel shutdown.

The FFMP works on a series of management curves and anticipated storage availability that direct flow releases from the three NYC reservoirs. Conservation releases designed for protection of the ecology in the tailwaters below the NYC reservoirs are made under the Habitat Protection Program (HPP) in accordance with operational curves and reservoir storage. Water available for supporting the HPP is based on a series of five defined water curves (L1, L2, L3, L4, and L5). The L1 curve is principally used for spill mitigation in the refilling of the reservoirs from the snow pack melt-off and springtime precipitation events. The curves L3, L4, and L5, representing Drought Watch, Drought Warning, and Drought Emergency, respectively, are principally responsible to flow release management during water shortages. The DRBC has authority under their Water Code for directing reservoir releases from impounded waters (e.g., Francis E. Walter, Prompton, Beltsville, Blue Marsh, Nockamixon, Lake Wallenpaupack, and Mongaup) as necessary, to complement drought management operations of the NYC reservoirs during drought periods. Reservoir operations within these three zones are undesirable by all those involved. The majority of the reservoir releases are managed under the L2 curve. It is generally desirable by those involved with the Decree Party to operate within the L2 curve. Releases from NYC's reservoirs during L2 conditions area are premised on available water storage and calendar date under the Habitat Protection Program provisions. A series of tables provides guidance on resultant outflows above the base releases when assessment by NYC's OST determines that additional waer is available without undue risk to water supply. The NYDEC-PFBC white paper recommends improved releases for fisheries under L2 to be the same as L1 and range from 150 cfs in fall-winter to 525 cfs in summer from Cannonsville Reservoir (PFBC 2010; http://www.fish.state.pa.us/water/rivers/delaware/dela_flex_flow.pdf).

The maintenance of a minimum flow target at the USGS Montague gage station (01438500) located 7.2 river miles downriver of Port Jervis, NY is an integral mandate of the current FFMP (FFMP 2011). The three NYC reservoirs (i.e., Cannonsville, Pepacton, and Neversink) are collectively managed to maintain a minimum target flow of 1,750 cfs. It is the responsibility of the USGS Office of the River Master for overseeing and directing reservoir releases from the NYC reservoirs for the maintaining of the minimum flow at Montague. Additionally, the Pennsylvania Power and Light (PPL) provide the ODRM with forecasts of anticipated daily releases from Lake Wallenpaupack power generation station. Water from these releases enter the Delaware River mainstem from the Lackawaxen River (RM 277.7) located 31.2 miles up-river of the Montague gage. These releases are then accounted for by the ODRM when scheduling daily releases form NYC's reservoirs to meet the Montague flow target. The current FFMP (2011) and DRBC Water Code provide regulations for sustaining minimum streamflow objectives at the USGS Trenton gaging station (01463500) located in Trenton, NJ (RM 134.3) during normal and drought conditions for maintaining the salt front (DRBC 2008). A minimum flow objective during "normal" conditions is 3,000 cfs; whereas this flow objective decreases accordingly to 2,700 cfs during drought warning, and to 2,500 – 2,900 cfs under drought conditions, depending with time of year and location of salt front.

It is anticipated that the FFMP will provide the framework for managing reservoir releases in the near-future. Provisions within the FFMP are to be the current temporary agreed upon operating procedures until the Year 2012 (FFMP 2011; http://water.usgs.gov/osw/odrm/documents/ffmp_ost_052511_final.pdf). If an agreement to extend or modify the existing FFMP is not achieved by May 31st, 2012 then operational releases from the NYC reservoirs will revert back to the last permanent plan in the DRBC Water code, Docket D-77-20 CP (i.e., Revision 1). Releases under the FFMP or succeeding document will continue to be modified as further experience is gained. The one year temporary FFMP agreement (FFMP 2011) has incoperated in part release recommendations in the joint NYDEC-PFBC white paper (PFBC 2010; http://www.fish.state.pa.us/water/rivers/delaware/dela_flex_flow.pdf) and NYC OST procedures (NYC 2010; http://water.usgs.gov/osw/odrm/documents/OST_White_Paper.pdf).

5.3 Water Quality

The quality of water is essential for supporting aquatic needs and human endeavors. Water must be suitable for use as drinking water and to support recreational, industrial and agricultural activities, while remaining suitable for fish and wildlife. Within Pennsylvania the PA DEP is the regulatory agency responsible for developing and enforcing water quality standards. Further, the formation of the DRBC in 1961 gave regulatory authority in all facets of water resource management, including water quality for the Delaware River to the DRBC. As such, the PFBC has and continues to provide commentary as needed to PA DEP and DRBC pertaining to maintaining and improving water quality criteria for the West Branch Delaware and Delaware rivers. The PFBC also is an active member in the DRBC Sub-committee for Ecological Flows (SEF).

Since its inception, the DRBC has been actively addressing water quality issues. In 1967 the DRBC adopted water quality standards for dissolved oxygen and new bacteria standards for recreational use. In 1968, approximately 90 municipal and industrial discharges were given waste load allocations, which served as a prototype for complex water pollution control. In 1972, the Federal Water Pollution Control Act required permitted discharge, provided construction funds, and added enforcement and other incentives to ensure implementation of water pollution control efforts.

One of the primary goals of the DRBC is the monitoring and regulation of water quality in the Delaware River Basin. Regulations for the protection of the Delaware River and its tributaries are detailed in the DRBC Water Code (DRBC 2009; http://www.state.nj.us/drbc/regs/watercode031109.pdf). For the non-tidal reaches of the Delaware River the DRBC Water Code defines reach-wide existing water quality (EWQ) criteria for the upper (Upper Delaware Scenic & Recreational River), middle (Millrift, PA downriver to southern terminus of the Delaware Water Gap National Recreation Area) and site-specific monitoring stations for the lower (southern terminus of DEWA downriver to Trenton, NJ) reaches of the Delaware River.

In 1992 the DRBC adopted the special protection waters (SPW) program designed to protect the high water quality of the portions of the river that had been designated as part of the National Wild and Scenic River system. These regulations aim to maintain existing water quality when it is improved beyond existing water quality criteria. The SPW regulations were adopted in 1992 for point source discharges and later amended in 1994 to include non-point source pollutant loadings and were initially applied to a 121-mile stretch of the Delaware River from Hancock, NY downstream to the Delaware Water Gap (http://www.state.nj.us/drbc/spw.htm). This corridor includes the two reaches of the river federally designated as "Wild and Scenic" as well as an eight-mile reach between Millrift, PA and Milford, PA. In 2000, federal legislation added key reaches of the lower Delaware River to the National Wild and Scenic Rivers system. Subsequently, based on extensive surveys, the DRBC temporally designated the lower Delaware River (RM 209.5 to 133.4) as SPW in 2005 (http://www.state.nj.us/drbc/Res2005-2-LDspw.pdf; DRBC 2005) and permanently adopted as SPW in 2008 (http://www.state.nj.us/drbc/Res2008-9-LDspw.pdf; DRBC 2008).

The DRBC SPW regulations take a watershed approach to antidegradation of water quality and have associated with them a variety of specific pollution prevention and reduction requirements driven by a “no measurable change” policy toward water quality. Designated reaches of SPW fall into two categories: Outstanding Basin Waters and Significant Resource Waters. Through requirements made in the docket (permit) review process, policies provide an upfront approach to reducing or eliminating new pollutant loadings for the purpose of maintaining EWQ in designated waters. This is accomplished, in part, by looking at the cumulative impacts of point and non-point sources as they may affect the designated waters, either through direct discharge or through tributary loading. EWQ is defined as “the actual concentration of a water constituent at an in-stream site or sites, as determined through field measurements and laboratory analysis of data collected over a time period determined by the DRBC to adequately reflect the natural range of the hydraulic and climatologic factors which affect water quality” (DRBC Water Code: DRBC 2009; http://www.state.nj.us/drbc/regs/watercode031109.pdf). The reaches that were designated as Outstanding Basin Waters included the Upper Delaware River Scenic and Recreational Park (RM 330.7 to 258.4), the Middle Delaware Scenic and Recreational River (RM 250.1 to 209.5) and the Delaware River (RM 258.4 to 250.1).

The DRBC and National Park Service’s Scenic Rivers Monitoring Program and the Lower Delaware Monitoring Program combine to monitor water quality of the entire 197-mile non-tidal length of the Delaware River. Similarly, the Delaware River Biomonitoring Program (http://www.state.nj.us/drbc/BioQAPP06-07.pdf) is responsible for biomonitoring and biocriteria development for the non-tidal portion of the Delaware River. Collected data suggest the Delaware River exhibits periods of oxygen super-saturation and high pH most likely related to excessive aquatic plant growth linked to elevated nutrient levels. This is especially evident during periods of stable and low flow. Results from the DRBC Delaware River study (DRBC 2004a, 2004b) indicate that existing water quality exceeds criteria levels, with the exception of bacteria. Existing water quality parameters in the lower Delaware River reach showed 94% of the sites were better than criteria. Seventy-four percent (74%) were better at all times, 20% met criteria approximately 90% of the time, and 6% never met criteria. For most sites and parameters, existing water quality based targets in the lower Delaware River would provide protection for maintenance of existing good water quality. Enterococcus bacteria concentrations are the single major problem. Fecal coliform and *E. coli* bacteria concentrations were problematic during storms. Phosphorus concentrations were relatively high but did not render the lower Delaware River reach unsuitable for aquatic life use. In addition, the DRBC (Limbeck and Smith, 2007) completed a pilot study in 2005 for a periphyton monitoring network (http://www.state.nj.us/drbc/Periphyton_pilotstudy0307.pdf). They concluded that eutrophication due to high nutrient concentrations may be problematic in the lower non-tidal portion of the Delaware River. The Delaware River generally possesses a diatom community characteristic of high water quality and high biological integrity. The northern Delaware River diatoms are more indicative of oligotrophic conditions, and below the Lehigh River, the diatoms were more representative of eutrophic conditions.

The primary producers including periphyton, phytoplankton and macrophytes are driven by nutrient loading and have the potential to affect water quality. The periphyton community dominates at most times over phytoplankton and macrophytes in terms of biomass (Santoro and Limbeck 2008). Phytoplankton may be significant at times, particularly in large, warm, slow-flowing pools with sufficient retention time for development. Macrophytes are uneven in distribution, but may also become very significant throughout the Delaware River in terms of biomass during extended periods of low flow. However, throughout the seasons, periphytons are always present in sufficient quantity to drive daily dissolved oxygen and pH water quality patterns. During periods of low flow, all three groups may contribute significantly to wide daily swings in dissolved oxygen and pH, and violations of water quality standards are increasingly likely during low flow periods (Santoro and Limbeck 2008).

The non-tidal Delaware River may be characterized by its nutrient chemistry into three major reaches based on a nutrient load strategy (Santoro and Limbeck 2008; http://www.state.nj.us/drbc/DRBC-NutrientStrategy042508.pdf). The upper Delaware River from Hancock, NY to Port Jervis, NY, is generally nutrient-poor (TP<30 µg/l), cold, shallow, and fast-flowing. The middle Delaware River, from Port Jervis, NY to Easton, PA, is slightly higher in nutrient concentrations (TP 30-80 µg/l), warmer, with more extensive pools and shorter riffles. The lower Delaware River, from the Delaware Water Gap to the Lehigh River confluence, resembles the middle Delaware but with slightly higher nutrient concentrations and distinct limestone influences. Below the Lehigh River and extending to Trenton, NJ, the lower Delaware River is relatively high in nutrient concentrations (TP>100 µg/l), warm, with very long pools, fewer riffles.

The Tri-State Water Management Plan (DRBC; http://www.state.nj.us/drbc/tristate.htm) is designed to preserve and protect the designated Special Protection Waters of the middle Delaware River while insuring that the growth desired by municipalities can occur in this area. The area defining the boundary of the work plan is the 300-square-mile drainage area surrounding an 8.5-mile stretch of river just north of the DEWA up to the southern edge of the UPDE. This stretch of river borders Pennsylvania, New Jersey, and New York. The project authorities include the DRBC, National Wild and Scenic Rivers Act, and DEWA through their general management plan.

The Delaware River Basin National Water-quality Assessment Program (NAWQA) study headed by the USGS is a multi-district effort to collect samples of water, suspended and bed sediment, biologic tissues, and aquatic communities (http://nj.usgs.gov/nawqa/delr/index.html). Within the Delaware River Basin assessments for water quality through the NAWQA was initiated in 1997. The water quality conditions in the Delaware River Basin have been summarized from sampling conducted from 1998-2001 (Fischer 2004; http://pubs.usgs.gov/circ/2004/1227/pdf/circular1227.pdf). Survey results, indicated that the Delaware River Basin is significantly affected by human activities related to agriculture and urbanization; but many nutrients, pesticides, and volatile organic compounds, while detected, were low and rarely exceeded guidelines or standards for drinking-water quality or aquatic-life protection. The authors determined that the major influences on streams and rivers were: runoff and point-source discharges from agricultural and urban areas; persistence of contaminants associated with past agricultural, urban, industrial and mining activities; and impoundments and diversions of water. Major influences on ground water included: use of nutrients, pesticides, and volatile organic compounds, in urban and agricultural areas; physical properties of soils and aquifers and chemical properties of contaminants; and naturally occurring radon and arsenic. Further, through the NAWQA program, USGS has produced a series of reports for characterizing PCB contaminations (Riva-Murray *et al*.; 2003; http://ny.water.usgs.gov/pubs/wri/wri014066/wrir01-4066.pdf); and mercury and methylmercury contaminations in selected tributaries of the Delaware River (Brightbill, *et al*. 2004; http://pubs.usgs.gov/wri/wri03-4183/wrir03-4183.pdf).

The U. S. Environmental Protection Agency (EPA) maintains a data repository (STORET: http://www.epa.gov/storet/) for water quality, biological and physical data collected by water resource management groups across the country. The intent is to provide publically accessible data for re-use in analysis. Specific water quality data pertaining to the Delaware River Basin can be retrieved from this online web service.

Water Quality Protections

Protection for the quality of water within the West Branch Delaware and Delaware rivers is monitored and regulated by various agencies of the shared border waters including the DRBC, the PA DEP, the New Jersey Department of Environmental Protection, and the New York Department of Environmental Conservation.

DRBC Water Quality Zones

The DRBC Water Code (DRBC 2009; http://www.state.nj.us/drbc/regs/watercode031109.pdf), Resolution Number 67-7, allows for the division of the Delaware River and Bay and their tributaries into zones. These zones are designed to facilitate the management of surface water quality and reporting of integrated Water Quality Assessment 305(b) reports as required by the 1972 Clean Water Act. The intent of the 305(b) reports is to provide an assessment of waters in the Delaware River for support of various designated uses and indentify impaired waters that do not meet DRBC Water Quality Regulations. A single zone (W1) was defined for the West Branch Delaware River; whereas a series of five zones (1A – 1E) were differentiated in the Delaware River. The designated use for zone 1A (RM 289.9-330.7) differs from the remaining zones (i.e., 1B: RM 254.7 – 289.9; 1C: RM 217.0 - 254.7; 1D: RM 183.6 – 217.0; and 1E: RM 133.4-183.6), such that waters in 1A are more protected than the further downriver zones.

The findings of the DRBC 2010 Integrated Assessment (DRBC 2010f; http://www.state.nj.us/drbc/10IntegratedList/FinalReport.pdf) identified several designated uses that were not supported in the non-tidal Delaware River. The designated use for "Drinking Water" was supported in zones 1A, 1B, and 1D, but not I 1C, and 1E, due to the exceedance of arsenic levels beyond EPA recommended criteria. This exceedance is currently under review by

DRBC. The designated use “Aquatic Life” was not supported in all zones. This was determined by the exceedance of various chemical criteria including aluminum (zones 1A-1E), pH (zone 1A, 1B, 1E), alkalinity (1E), and biological assessment criteria (zone 1E). Recreation uses were supported in all zones.

Chapter 93 Designations

In Pennsylvania, the quality of waterways is protected under the Pennsylvania Code Title 25 Environmental Resources, Chapter 93 Designations (http://www.pacode.com/secure/data/025/chapter93/chap93toc.html). The water quality of the shared border waters of the West Branch Delaware River and the upper reaches of the Delaware River to the confluence with Peggy Run near Narrowsburg, NY (RM 289.0), are protected by the Cold Water Fishes (CWF) and Migratory Fishes (MF) designations. The CWF designation as defined in 25 PA Code, Chapter 93 is the *“Maintenance and/or propagation of fish species including the family Salmonidae and additional flora and fauna which are indigenous to a cold water habitat”*; and the MF is defined as: *“Passage, maintenance and propagation of anadromous and catadromous fishes and other fishes which ascend to flowing waters to complete their life cycle”*. The remaining reach of the non-tidal Delaware River mainstem from Peggy Run (RM 289.0) downriver to Trenton, NJ is regulated under the Warm Water Fishes (WWF) and MF designations. The WWF designation as defined in 25 PA Code, Chapter 93 is the: *“Maintenance and propagation of fish species and additional flora and fauna which are indigenous to a warm water habitat”*. As Delaware River Basin water quality continues to improve the WWF designation does not account for higher levels of protection. The majority of the Delaware River resides under the WWF designation allowing some higher quality fish populations to be under protected. Water quality regulations under 25 Pa Code, Chapter 93 however, may be superseded and/or supplemented by criteria defined by the DRBC Water Code (DRBC 2009; http://www.state.nj.us/drbc/regs/watercode031109.pdf) for water quality criteria pertaining to their zones 1A through 1E (i.e., non-tidal Delaware River mainstem). Note in the 25 PA Code, Chapter 93 listing of protection for the shared border waters of the West Branch Delaware River, exemptions and/or supplemental criteria to 25 PA Code, Chapter 93 would reference DRBC zone 1A rather than zone W1.

Water Quality Temperature Regime

Water temperature represents one of the most basic and important parameters pertaining to water quality for supporting aquatic life in a system. Within the West Branch Delaware River and non-tidal Delaware River these parameters are continuously monitored at selected in-river gage stations maintained by the USGS (http://pa.water.usgs.gov/). Additional monitoring is accomplished by synoptic surveys, principally in recent years by the DRBC Biomonitoring program (http://www.state.nj.us/drbc/BioQAPP06-07.pdf).

One overriding impact to the Delaware River with regards to water temperature is the management of NYC reservoir releases for sustaining an artificial coldwater aquatic system. The upper Delaware River including the East Branch Delaware River and West Branch

Delaware River and the mainstem Delaware River downriver to Callicoon, NY, are characterized as the tailwaters of the NYC Cannonsville (West Branch) and Pepacton (East Branch) reservoirs. Thus, the observed water temperatures within this reach are strongly directed by the governing release management program, currently the FFMP (FFMP 2008). The downriver influence of thermally manipulating river waters, particularly in the Delaware River mainstem is rapidly mitigated by several factors, particularly tributary and solar influences.

West Branch Delaware River

One of the objectives for managing Cannonsville reservoir releases is the maintenance of a coldwater tail race. Water temperatures in the West Branch Delaware River are continuously monitored at the USGS gage station, Hale Eddy, NY (USGS 01426500), which is located upriver of the shared border reach between New York and Pennsylvania and at Hancock, NY (USGS 01427000). Temperature duration curves from the period-of-record (i.e., Oct. 2007 to present) of daily data during the FFMP for these two gages indicate that water temperatures never equaled or exceeded 68 ^{o}F (20 ^{o}C) at the Hale Eddy gage but did equal or exceed 68 ^{o}F 0.2% of the period-of-record at the Hancock gage (Figures 5.17 and 5.18, respectively). Overall, water temperatures with respect to trout tolerances (able to promote optimal trout growth and survival) generally remained within acceptable limits under the FFMP. Historically, during reservoir releases not managed under the FFMP, water temperatures have exceeded 68 ^{o}F for 0.4% (Hale Eddy: Oct. 1963 – Oct. 2007) and 0.7% (Hancock: Jun. 1996 – Oct. 2007) of the period-of-record at both gage locations.

Water temperatures in the West Branch Delaware River are subject to significant seasonal variation; however, seasonal temperatures peaks are atypical in that they occur during the late summer months (Appendix B). At the Hale Eddy gage, average low water temperatures range between 32.9 to 35.6 ^{o}F (0.5 to 2.0 ^{o}C) during the winter to average highs between 54.5 and 59.9 ^{o}F (12.5 to 15.5 ^{o}C) during early summer and fall. Average summer water temperatures range between 51.6 to 58.1 ^{o}F (10.9 to 14.5 ^{o}C). Downriver at the Hancock, N.Y. gage, average low water temperatures ranged from between 32.7 to 40.8 ^{o}F (0.4 to 4.9 ^{o}C) during the winter to summer high water temperatures between 55.4 to 62.9 ^{o}F (13.0 to 17.2 ^{o}C). The trend of decreasing summer water temperature is the result of managed reservoir releases from the NYC Cannonsville Dam hypolimnion to keep the tailwaters suitable for cold water species. Further, observed water temperatures at both the Hale Eddy and Hancock gages exceed 25 PA Code, Chapter 93 seasonal criteria, typically during late spring and in fall months.

Delaware River

Within the upper reach of the Delaware River, the thermal influences from the NYC Cannonsville and Pepacton Reservoirs are mitigated by tributary input. These tributary inputs change the mainstem from a coldwater aquatic community to a warm water aquatic community. It is generally recognized that thermal influence from the NYC reservoir releases are exhausted within the upper Delaware River; however, the actual downriver extent varies annually and is dependent on seasonal conditions. Thus, water temperatures within the upper reach of the

Delaware River exhibit a significant latitudinal warming trend during summer months at the farther downriver gages relative to the most upriver gage at Lordville, NY. The 25 PA Code, Chapter 93 designations recognize these latitudinal gradients such that reaches above Narrowsburg, NY are protected under the CWF criteria and reaches below Narrowsburg are protected under the WWF criteria.

Water temperatures are continuously monitored at a series of gage stations along the entire length of the Delaware River by the USGS along with various partners. The period-of-record for daily temperature measurements is varied amongst the different gage locations. These gage stations include: Lordville (USGS 01427207), Callicoon (USGS 01427510), Lackawaxen (USGS 01428500), Barryville (01432160) and Pond Eddy (USGS 01432805) within the upper Delaware River; Water Gap (USGS 01440200) within the middle Delaware River; and Point Pleasant (USGS 01460200) and Trenton (USGS 01463500) in the lower Delaware River.

In consideration to the maintenance of an artificial coldwater community within the upper Delaware River, temperature duration curves demonstrated an increasing exceedance of 68 ^{o}F (20 ^{o}C) the further removed from the NYC reservoirs. For example, during management of reservoir releases under the FFMP (Oct 2007 – present), temperatures equaled or exceeded 75 ^{o}F (24 ^{o}C) 0.9% and 4.7%, of the period-of-record at the Lordville and Callicoon gages, respectively (Figures 5.19 and 5.20). The 75 ^{o}F (24 ^{o}C) daily maximum water temperature is based on the "thermal stress day" concept developed by Sheppard (1983). A thermal stress day occurs when the maximum daily water temperature equals or exceeds 75 ^{o}F (24 ^{o}C) and/or the minimum daily water temperature equals or exceeds 72 ^{o}F (22 ^{o}C) for an entire 24-hour period. Trout mortality becomes a concern if these conditions persist for a period of several consecutive days and trout are unable to move to cooler water refugia. This threshold is intended to serve as an indicator of where maximum water temperatures may be a limiting factor for trout populations.

Seasonal trends of water temperatures at the Lordville, NY and Callicoon, NY gages were more characteristic of the classic winter lows/summer peaks (Appendix B). Winter low water temperature averages were between 32.1 to 36.1^{o}F (0.1 to 2.3 ^{o}C) at Lordville and 32.3 to 34.1 ^{o}F (0.2 to 1.2 ^{o}C) at Callicoon; whereas average summer high water temperatures ranged between 64.4 to 72.1 ^{o}F (18.0 to 22.3 ^{o}C) at Lordville and 64.4 to 74.1 ^{o}F (18.0 to 23.4 ^{o}C) at Callicoon. The decrease of water temperature at the Lordville gage in August reflects cold-water releases from the NYC reservoirs to offset warming during the hottest portion of the summer.

Water temperatures within the Delaware River above Callicoon, NY exceed 25 PA Code, Chapter 93 criteria. Approximately 45% of the period-of-record (Oct. 2007 to present) during the FFMP reservoir release management have water temperatures exceeding 25 PA Code, Chapter 93 criteria at both the Lordville, NY and Callicoon, NY gages. Seasonally water temperatures generally remain at or below 25 PA Code, Chapter 93 criteria for CWF at the Lordville gage, except during the early to mid-summer months, when water temperatures exceed criterion. At the Callicoon gage, water temperatures tend to exceed 25 PA Code, Chapter 93 CWF criteria from late spring through mid-fall. Currently, New York Department of Environmental

Conservation (NYDEC), Division of Fish, Wildlife & Marine Resources and PFBC (PFBC 2010; http://www.fish.state.pa.us/water/rivers/delaware/dela_flex_flow.pdf) have finalized a white paper position on recommended reservoir releases from the NYC dams for the protection of the tailwater coldwater aquatic community. One of the goals of this white paper is to stabilize river flows such that a series of protection levels for enhancing the coldwater community which declines relative to the distance from NYC dams' outflow. Inherent within these protection levels is the stabilization of a transitional zone changing from a well established coldwater aquatic community in the West Branch Delaware River to a warmwater community below Callicoon, NY. For proper characterization of ambient conditions, it is necessary for additional continuous water temperature monitoring within the upper reach of the Delaware River above Callicoon, NY in defining the anticipated transition zone.

The Delaware River below Callicoon, NY is traditionally considered to be beyond the thermal influence of the NYC reservoir releases and, as such, is considered to support a warmwater species community. Temperature duration curves for the remaining gages in the upper, middle and lower reaches of the Delaware River suggest an increasing latitudinal trend of warmer water. For example, water temperatures exceeded 70 ^{o}F (21 ^{o}C) 20.0%, 18.3%, 20.5%, 28.2%, 54.6%, and 27.5% of the period-of-record at the Lackawaxen (Oct. 1975 – present), Barryville (Mar. 1975 – Dec. 2010), Pond Eddy (Oct. 1973 – Dec. 2010), Water Gap (Mar. 2004 – Sep 2005), Point Pleasant (May 2000 – present), and Trenton (Oct. 1965 – Oct. 1995) gages respectively (Figures 5.21 – 5.26, respectively).

Seasonal trends of water temperature follow traditional expected patterns with winter lows increasing to peaks of high temperature during the summer (Appendix B). Winter low water temperature averages range between 32.5 to 33.9 ^{o}F (0.3 to 1.1 ^{o}C) at Lackawaxen, 32.5 to 34.1 ^{o}F (0.3 to 1.2 ^{o}C) at Barryville, 32.5 to 33.9 ^{o}F (0.3 to 1.1 ^{o}C) at Pond Eddy, 32 to 44.4 ^{o}F (0.0 to 6.9 ^{o}C) at Water Gap, 36.6 to 46.4 ^{o}F (2.6 to 8.0 ^{o}C) at Point Pleasant, and 34.1 to 39.0 ^{o}F (1.2 to 3.9 ^{o}C) at Trenton. Average summer high water temperatures range between 66.9 to 77.0 ^{o}F (19.4 to 25.0 ^{o}C) at Lackawaxen, 65.3 to 76.1 ^{o}F (18.5 to 24.5 ^{o}C) at Barryville, and 65.3 to 76.6 ^{o}F (18.5 to 24.8 ^{o}C) at Pond Eddy, 62.4 to 76.8 ^{o}F (16.9 to 24.9 ^{o}C) at Water Gap, 65.8 to 80.6 ^{o}F (18.8 to 27.0 ^{o}C) at Point Pleasant and 68.3 to 80.7 ^{o}F (20.2 to 27.1 ^{o}C) at Trenton. At the Lackawaxen, Barryville, Pond Eddy, and Trenton gages, water temperatures remain well below 25 PA Code, Chapter 93 WWF criteria throughout the year. Water temperatures exceeded the 25 PA Code, Chapter 93 WWF criteria 54% of the period of record (Mar. 2004 – Sep 2005) at Water Gap and 20% of the period-of-record (May 2005 – present) at the Point Pleasant gage. These exceedances are most likely related to the combination of a limited period-of-recorded (1 year) at the Water Gap and the unusually warm summer of 2005.

The need exists for continuous monitoring of water temperature at more stations within the middle and lower reaches of the Delaware River. Currently, determination of ambient conditions relies on synoptic collections as part of the DRBC monitoring programs. This limited information precludes the ability to fully examine temporal and latitudinal variations in water temperatures. Better characterization of ambient conditions will lead to a better understanding of river conditions required to support aquatic life.

A potentially significant influence on water temperatures in the Delaware River may originate from the Lackawaxen River (RM 277.0). Beginning in 2010, Pennsylvania Power and Light (PPL) as part of their Federal Energy Regulatory Commission (FERC) re-licensing agreement are managing reservoir releases from Lake Wallenpaupack for supporting a cold-water tailrace fishery in the lower reaches of the Lackawaxen River (PPL 2002; http://www.pplweb.com/NR/rdonlyres/4CA38158-CC9A-4F76-AA84-D7DF48293854/0/relicensing_application.pdf). It is anticipated that the influence of the cold-water (not exceeding 77 ^{o}F (25 ^{o}C)) will only extend downriver approximately 6.0 miles (river miles 4 through 10) and thus, will not reach the Delaware River. However, flow augmentation has occurred for only a single year, during a relatively dry summer, and it is believed that the potential exists for the affects from these releases to continue into Delaware River mainstem, particularly during years that experience either cooler than average summer temperatures, higher than average flows or a combination of both.

Non-point Source Inputs

Within the Delaware River Basin the DRBC regulates point source pollutants. The 2008 Delaware River and Bay Integrated List Water Quality Assessment Report (DRBC 2008; http://www.state.nj.us/drbc/08IntegratedList/EntireReport.pdf) summarizes non-point source pollution monitoring by the DRBC. Briefly, the DRBC regulates non-point pollution as part of the anti-degradation requirements of SPW. Under the DRBC SPW regulations, all new or expanded discharges to the drainage areas of SPW must submit for approval a Non-point Source Pollution Control Plan with their application. The plan must control the new or increased non-point source loads generated within the portion of the project's service area that is also located within the drainage area of SPW. The plans must document the best management practices to be applied to the project site. Non-point pollution from runoff of developed areas in SPW may not be subject to antidegradation constraints if they are associated with an existing, nonexpanding facility, such as a wastewater treatment plant that is not expanding its service area. Non-point sources of polychlorinated biphenyls (PCBs) may also be regulated on a project-specific basis by Pollutant Minimization Plans (PMPs) that the DRBC has begun to require. These PMP's are intended to reduce PCB loadings into the Delaware River.

Point Source Inputs

Within the Delaware River Basin the DRBC regulates point source pollutants. The 2008 Delaware River and Bay Integrated List Water Quality Assessment Report (DRBC 2008; http://www.state.nj.us/drbc/08IntegratedList/EntireReport.pdf) summarize point source pollution monitoring by the DRBC. Briefly, the DRBC uses a variety of programs to regulate point source pollutant loadings that would impact the Delaware River. These consist of docket review, pollutant allocations including PMP, Special Protection Water regulations, and basin-wide minimum treatment standards and interstate cooperative agreements. As per the DRBC compact, all point source discharges must be reviewed and approved by the Commission. The DRBC maintains cooperative agreements with all four basin states, which provide that all

NPDES permits for projects that lie within the basin must comply with both the DRBC standards, as well as the state standards.

Abandoned Mine Drainage

The West Branch Delaware River and non-tidal Delaware River mainstem are not directly degraded by abandoned mine drainage (AMD). Within the drainage basin however, several tributaries are known to be impacted, particularly in the Lehigh River drainage from Luzerne and Carbon counties in Pennsylvania. However, these degradations are mitigated before tributary waters enter the mainstems of the West Branch and Delaware rivers. Refer to the PFBC Lehigh River Management Plan for more information pertaining to AMD in the Lehigh River drainage (PFBC 2007; http://www.fishandboat.com/newsreleases/2007/lehigh_fm_plan.htm).

Metals

The Palmerton Natural Resource Trustee Council (2007) reported that the Palmerton Zinc Pile Superfund Site had contaminated the lower Lehigh River sediment with zinc and cadmium. This site has been identified as a point source for metals that are transported to the Delaware River at Easton, PA.

Wastewater Treatment

In Pennsylvania, the governing agency for wastewater treatment is the PA DEP. Wastewater treatment is regulated under Pennsylvania Code Chapter 95 (http://www.portal.state.pa.us/portal/server.pt/gateway/PTARGS_0_753913_0_0_18/chapter_95_wastewater_treatment_requirements_sep09.pdf).

Stormwater Management

Stormwater management is the control of runoff as close as possible to its point of origin. The purpose is to provide for infiltration and prevent the worsening of downstream flooding. There are many techniques for stormwater management, including natural landscaping, eliminating lawn mowing in flood plains and stream buffers, diverting gutter downspouts to lawns instead of driveways, and use of porous paving. The objective is to slow runoff and allow maximum time for infiltration. The retrofitting of stormwater controls in urban areas is an especially difficult problem since many areas are nearly 100% impervious. Stormwater management for the Delaware River is handled by the individual basin state’s regulatory agencies. For Pennsylvania, the governing agency is the PA DEP under the Bureau of Watershed Conservation Stormwater Management Program (http://www.depweb.state.pa.us/watershedmgmt/cwp/view.asp?a=1437&q=518682).

5.4 Management Options

Priority 1: (on-going activities or recommendations to be implemented in first year of management plan).

- Continue to coordinate with PA DEP, DRBC, Decree Party, and other associated agencies for managing reservoir releases from the NYC water supply dams that best protect/promote aquatic communities in the Delaware River Basin.

- Pursue further refinement of the NYDEC-PFBC white paper recommendations for flow recommendations to support the existing coldwater fishery in the West Branch Delaware River and upper Delaware River by using the existing hydrologic modeling tools to further explore alternative reservoir releases to improve the protection of the aquatic coldwater and downriver communities.

Priority 2: (recommendations with implementation date in years 2-3 of management plan)

- Coordinate with PA DEP through the PFBC, Bureau of Fisheries, Division of Environmental Services to develop fishery measures for high quality, warmwater fishery criteria for inclusion in PA Code, Chapter 93 as identified under Goal 2, Item H of the PFBC Strategic Plan.

Priority 3: (recommendations with implementation date in years 4-5 of management plan)

- Coordinate with partner agencies to determine the feasibility of installation of water quality monitoring stations in the upper Delaware River Basin above Callicoon, N.Y. to assess the extent of spatial and temporal patterns of the coldwater tailrace in the upper Delaware River.

Table 5.1. Major dams and locations within the Delaware River Basin.

Dam	Tributary Drainage	Owner	Purpose	Construction	Storage
		New York			
Cannonsville	WBDR	New York City	Water Supply	1963	96
Pepacton	EBDR	New York City	Water Supply	1954	140
Neversink	Neversink R.	New York City	Water Supply	1953	35
Rio Reservoir	Mongaup R.	Alliance	Hydro-electric		15
		Pennsylvania			
Lake Wallenpaupack	Lackawaxen R.	PPL	Hydro-electric	1926	30
General Edgar Jadwin	Dyberry Creek	ACOE	Flood control	1948	
Prompton	W. Br. Lackawaxen R.	ACOE	Flood control	1960	
Francis E Walter	Lehigh R.	ACOE	Flood control	1961	11
Wild Creek Reservoir			Water supply		
Penn forest Reservoir			Water Supply		
Beltsville	Pohopoco Creek	ACOE	Water supply; Recreation; Flood control	1971	13
Nockamixon	Tohickon Ck.	PADCNR		1968	
Green Lane	Schuylkill R.		Water Supply		
Still Creek Reservoir	Schuylkill R.		Water supply		
Ontelaunee Reservoir	Schuylkill R.		Water Supply		
Lake Galena	Schuylkill R.		Water Supply		
Blue Marsh	Schuylkill R.	ACOE	Water supply; Recreation; Flood control	1977	6.5
Geist			Water Supply		
Marsh Creek	Brandywine Ck.	ACOE	Multipurpose		4.0
Chamber Lake	Brandywine Ck.		Multipurpose		
		New Jersey			
Hopatcong Lake					
Merrill Creek	Merrill Ck.	Merrill Creek	Private		16

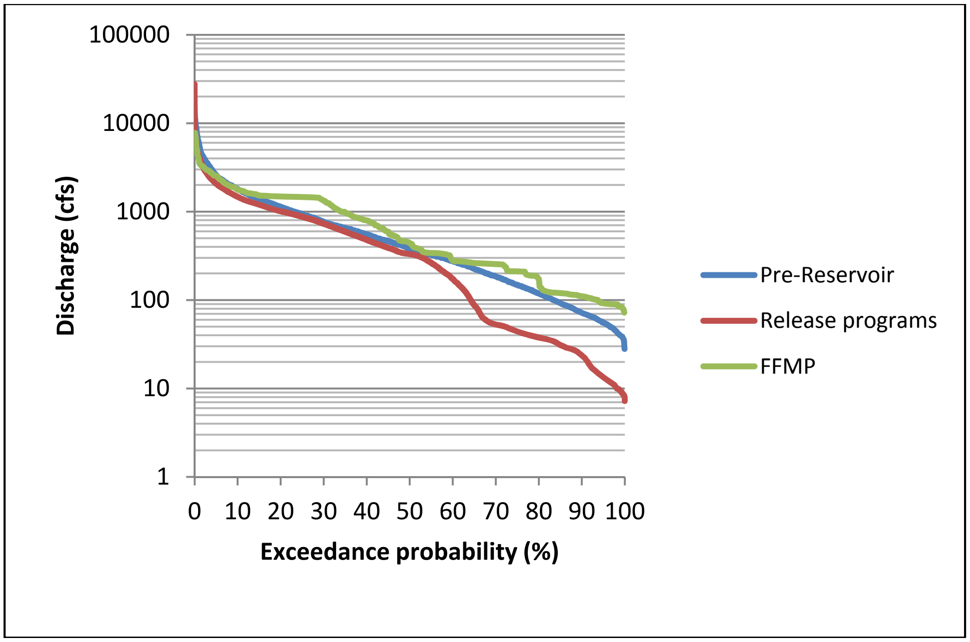


Figure 5.1. Flow duration curve for river discharge at Stilesville, NY (USGS 01425000) in the West Branch Delaware River for the period of record from August, 1952 – September, 2009. Pre-reservoir: August, 1952 – September, 1963; Release programs: September, 1963 – September, 2007; and FFMP: October, 2007 – September, 2009.

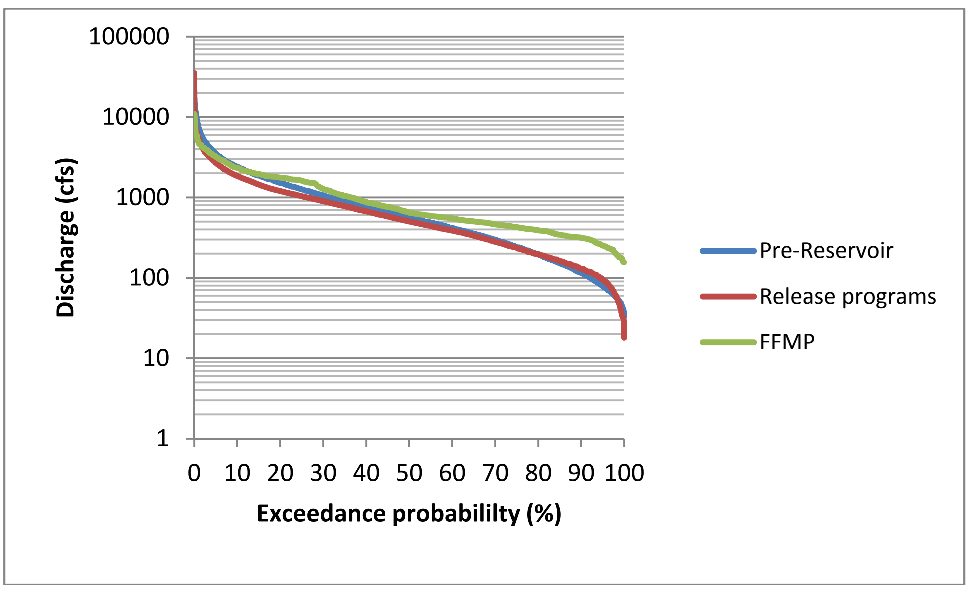


Figure 5.2. Flow duration curve for river discharge at Hale Eddy, NY (USGS 01426500) in the West Branch Delaware River for the period of record from August, 1952 – December, 2010. Pre-reservoir: August, 1952 – September, 1963; Release programs: September, 1963 – September, 2007; and FFMP: October, 2007 – December, 2010.

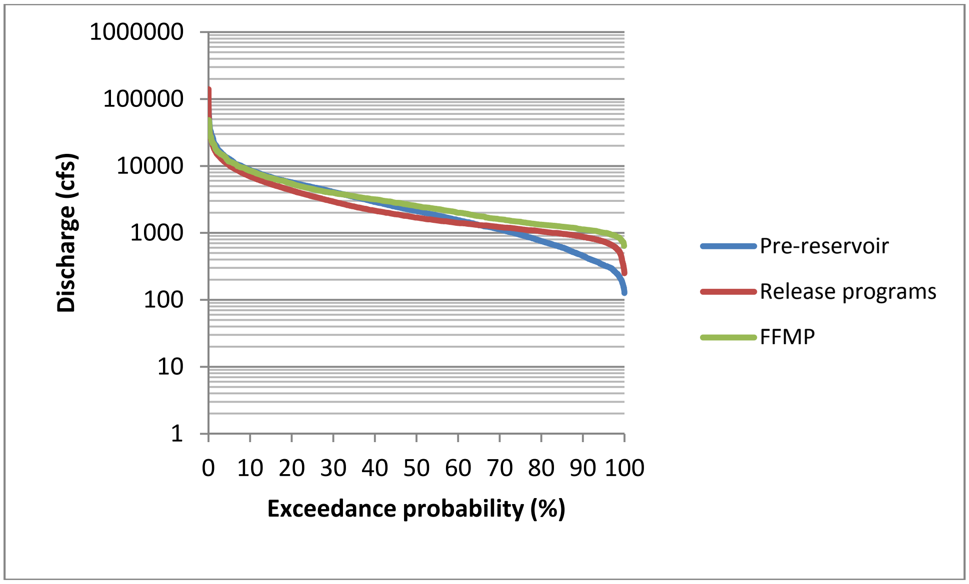


Figure 5.3. Flow duration curve for river discharge at Lackawaxen, PA (USGS 01428500) in the Delaware River for the period of record from October, 1940 – December, 2010. Pre-reservoir: October, 1940 – September, 1954; Release programs: September, 1954 – September, 2007; and FFMP: October, 2007 – December, 2010.

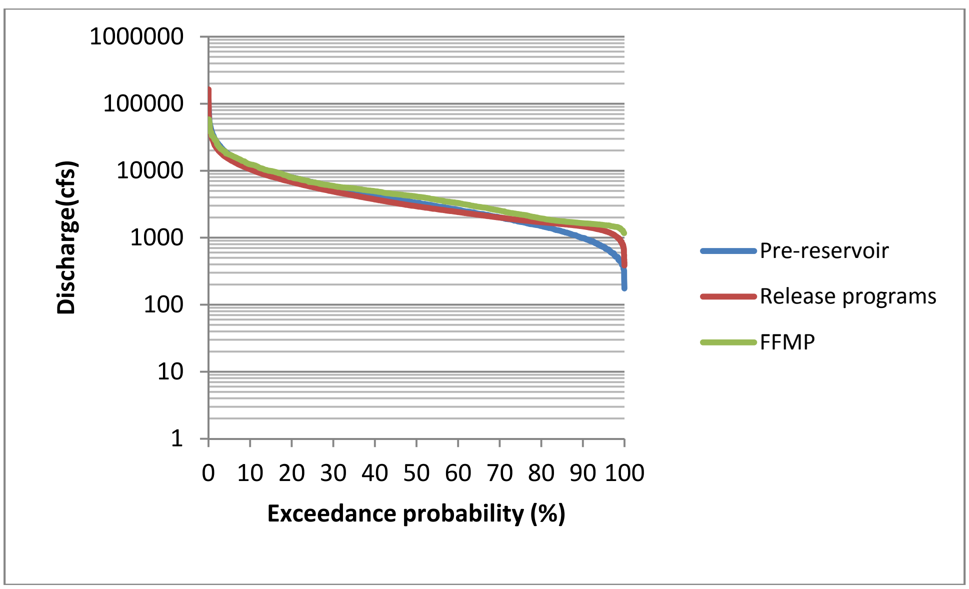


Figure 5.4. Flow duration curve for river discharge at Port Jervis, NJ (USGS 01434000) in the Delaware River for the period of record from October, 1904 – December, 2010. Pre-reservoir: October, 1904 – September, 1954; Release programs: October, 1954 – September, 2007; and FFMP: October, 2007 – December, 2010.

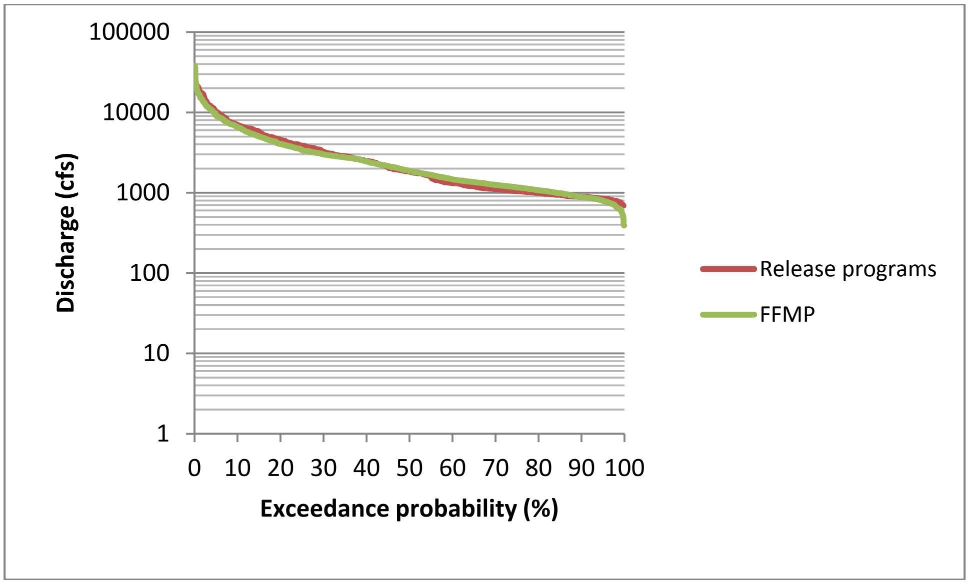


Figure 5.5. Flow duration curve for river discharge at Lordville, NY (USGS 01427207) in the Delaware River for the period of record from October, 1904 – December, 2010. Release programs: July, 2006 – September, 2007; and FFMP: October, 2007 – December, 2010.

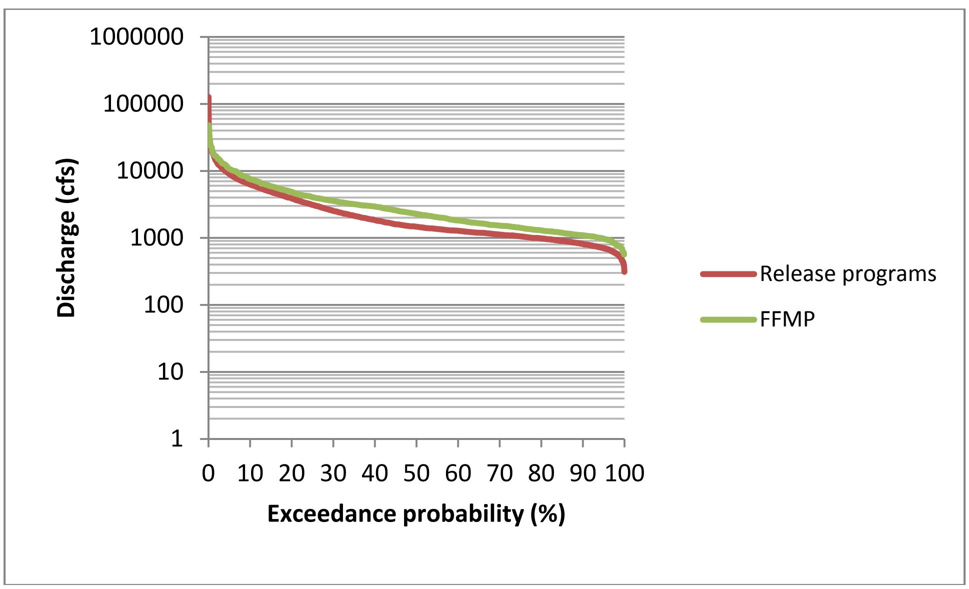


Figure 5.6. Flow duration curve for river discharge at Callicoon, NY (USGS 01427510) in the Delaware River for the period of record from June, 1975 – December, 2010. Release programs: June, 1975 – September, 2007; and FFMP: October, 2007 – December, 2010.

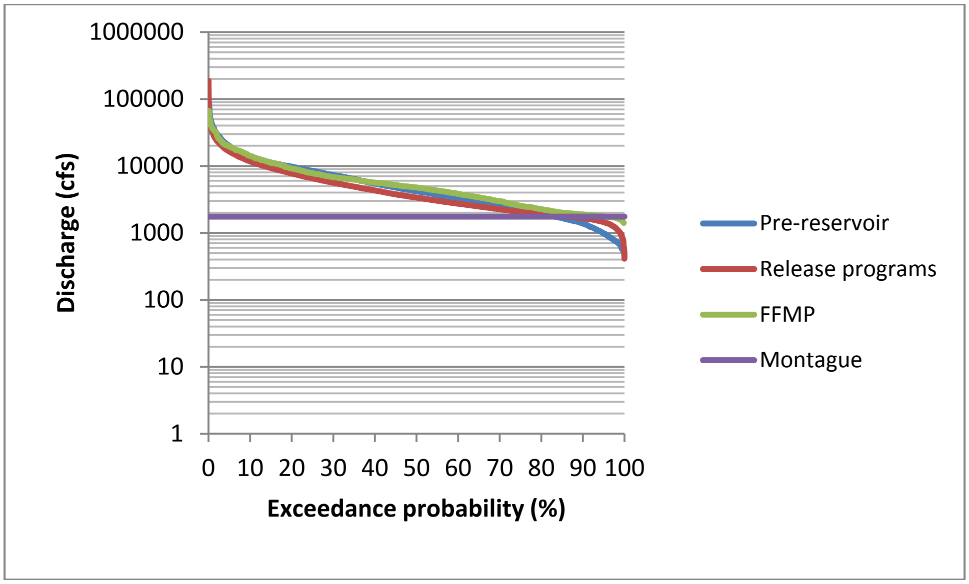


Figure 5.7. Flow duration curve for river discharge at Montague, NJ (USGS 01438500) in the Delaware River for the period of record from October, 1935 – December, 2010. Pre-reservoir: October, 1935 – September, 1953; Release programs: October, 1953 – September, 2007; and FFMP: October, 2007 – December, 2010. The Montague line represents the 1,750 cfs flow target.

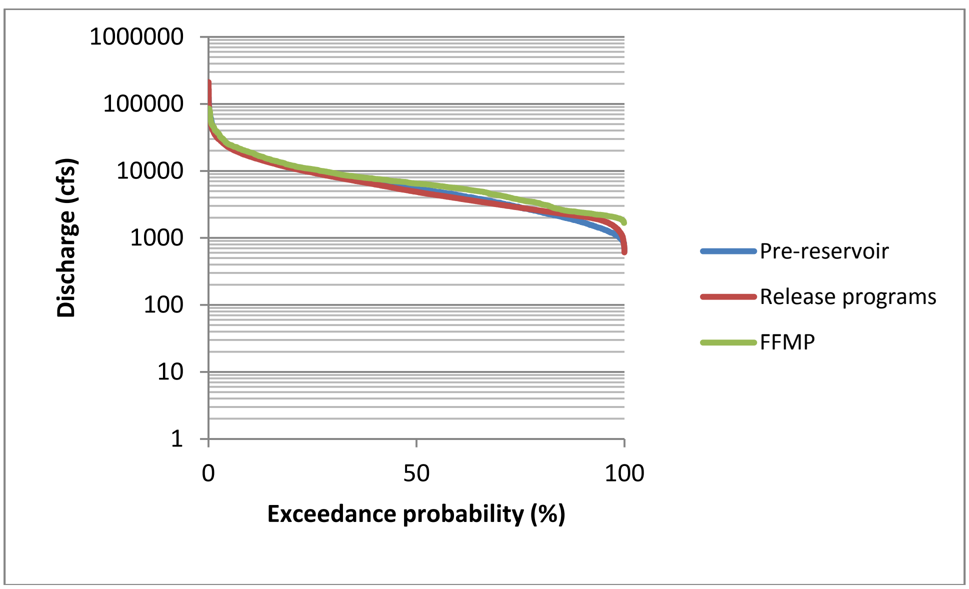


Figure 5.8. Flow duration curve for river discharge at Belvidere, NJ (USGS 01446500) in the Delaware River for the period of record from October, 1922 – December, 2010. Pre-reservoir: October, 1922 – September, 1953; Release programs: October, 1953 – September, 2007; and FFMP: October, 2007 – December, 2010.

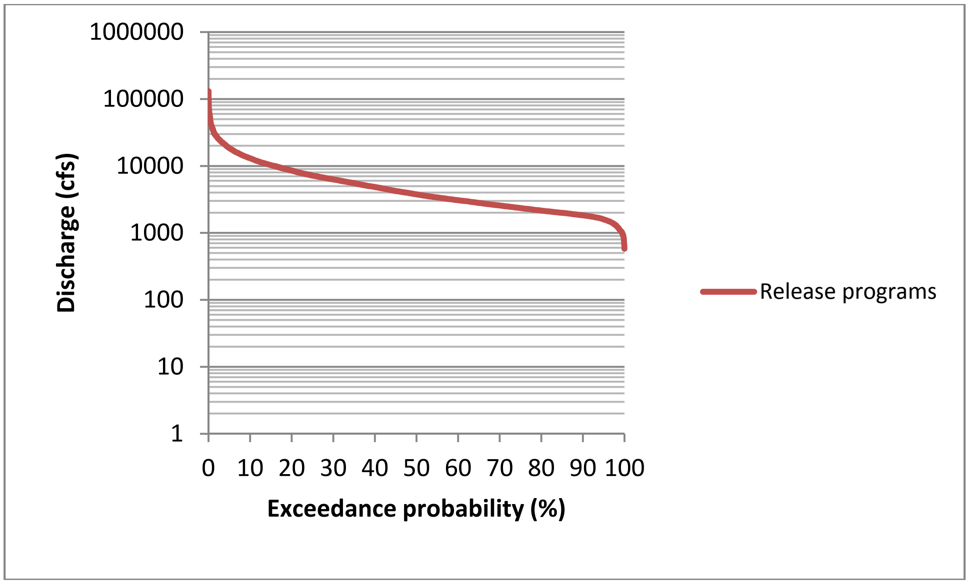


Figure 5.9. Flow duration curve for river discharge at Water Gap, PA. (USGS 01440200) in the Delaware River for the period of record from June, 1964 – January, 1966.

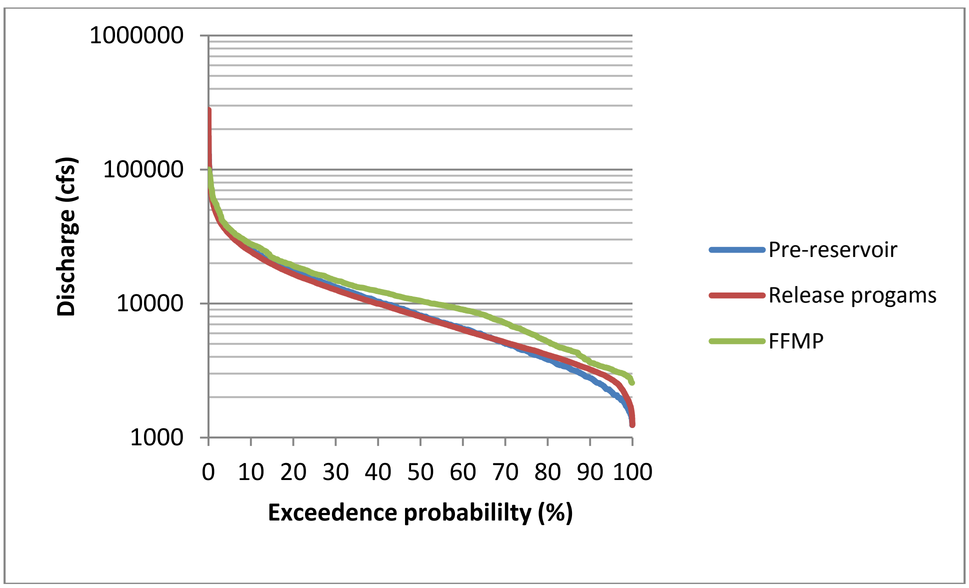


Figure 5.10. Flow duration curve for river discharge at Trenton, NJ (USGS 0146350) in the Delaware River for the period of record from October, 1912 – December, 2010. Pre-reservoir: October, 1912 – September, 1953; Release programs: October, 1953 – September, 2007; and FFMP: October, 2007 – December, 2010.

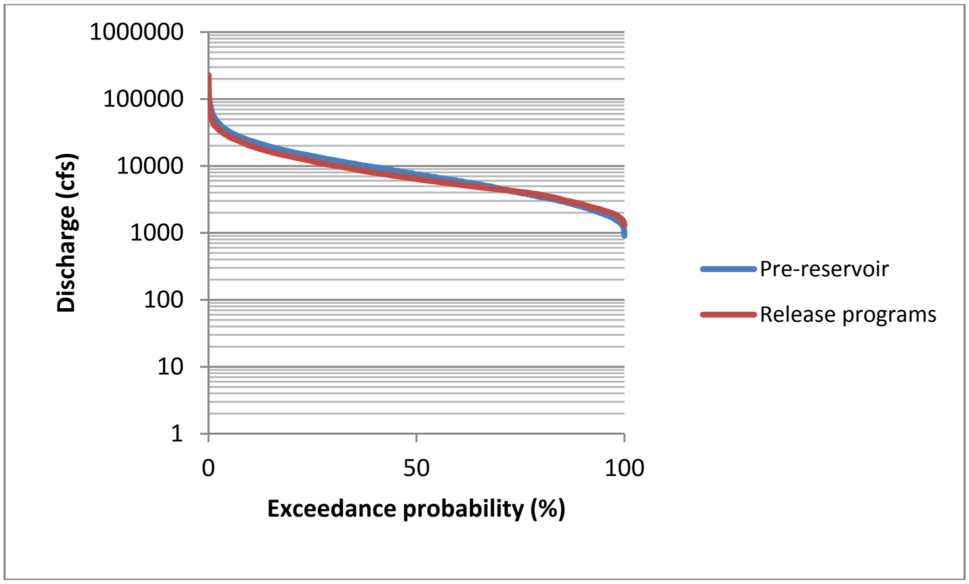


Figure 5.11. Flow duration curve for river discharge at Riegelsville, PA (USGS 01457500) in the Delaware River for the period of record from July, 1906 – September, 1971. Pre-reservoir: July, 1906 – September, 1953; Release programs: October, 1953 – September, 1971.

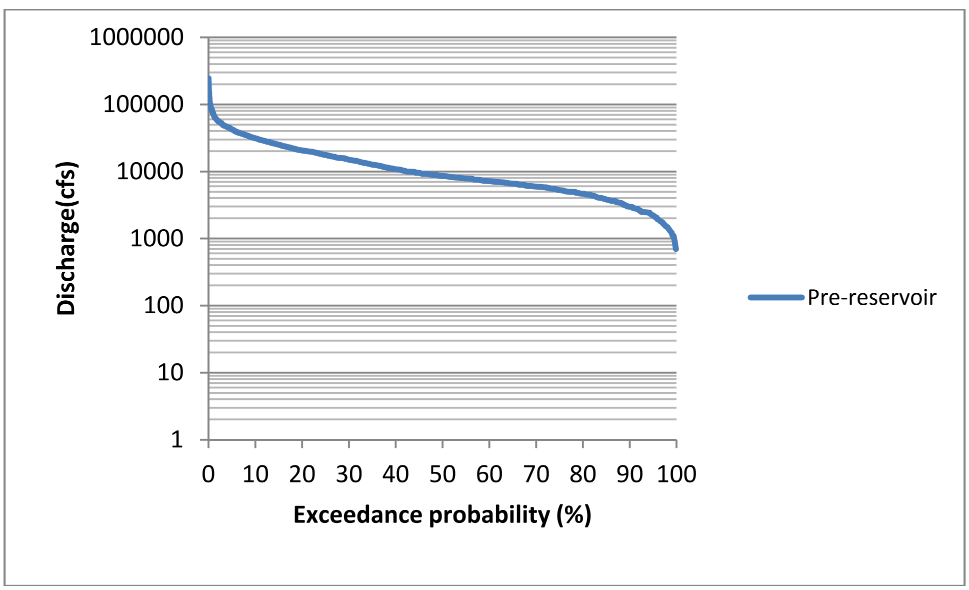


Figure 5.12. Flow duration curve for river discharge at Lambertville, NJ (USGS 01462000) in the Delaware River for the period of record from October, 1897 – September, 1906.

Figure 5.13. Illustration of major dams locate within the Delaware River Basin. (Adapted from the DRBC website).

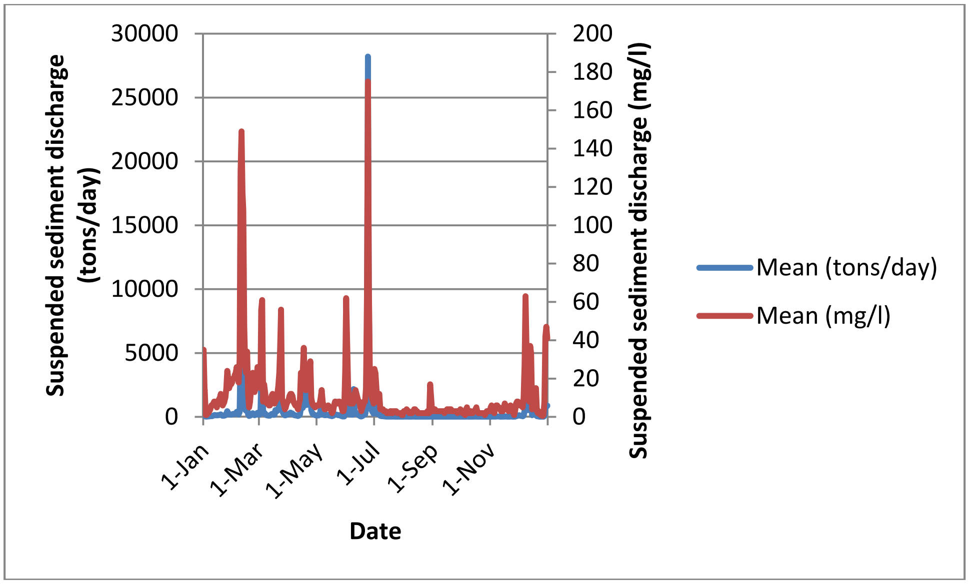


Figure 5.14. Mean suspended sediment discharge (tons/day and mg/l) values for the Delaware River at Water Gap, PA (USGS 01440200) for the period of record from October, 1963 - September, 1972.

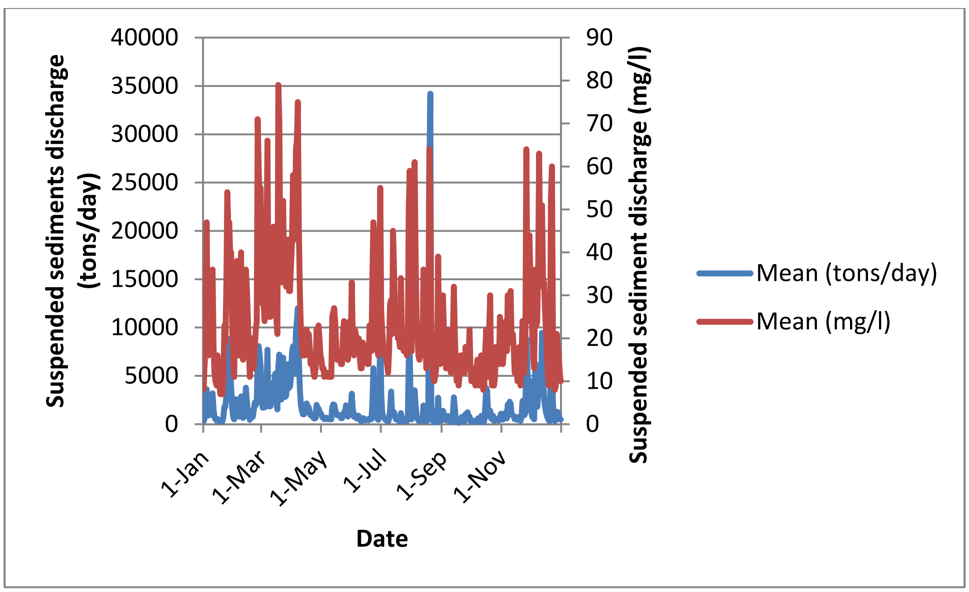


Figure 5.15. Mean suspended sediment discharge (tons/day and mg/l) values for the Delaware River at Trenton, NJ (USGS 01463500) for the period of record from October, 1948 - September, 1982.

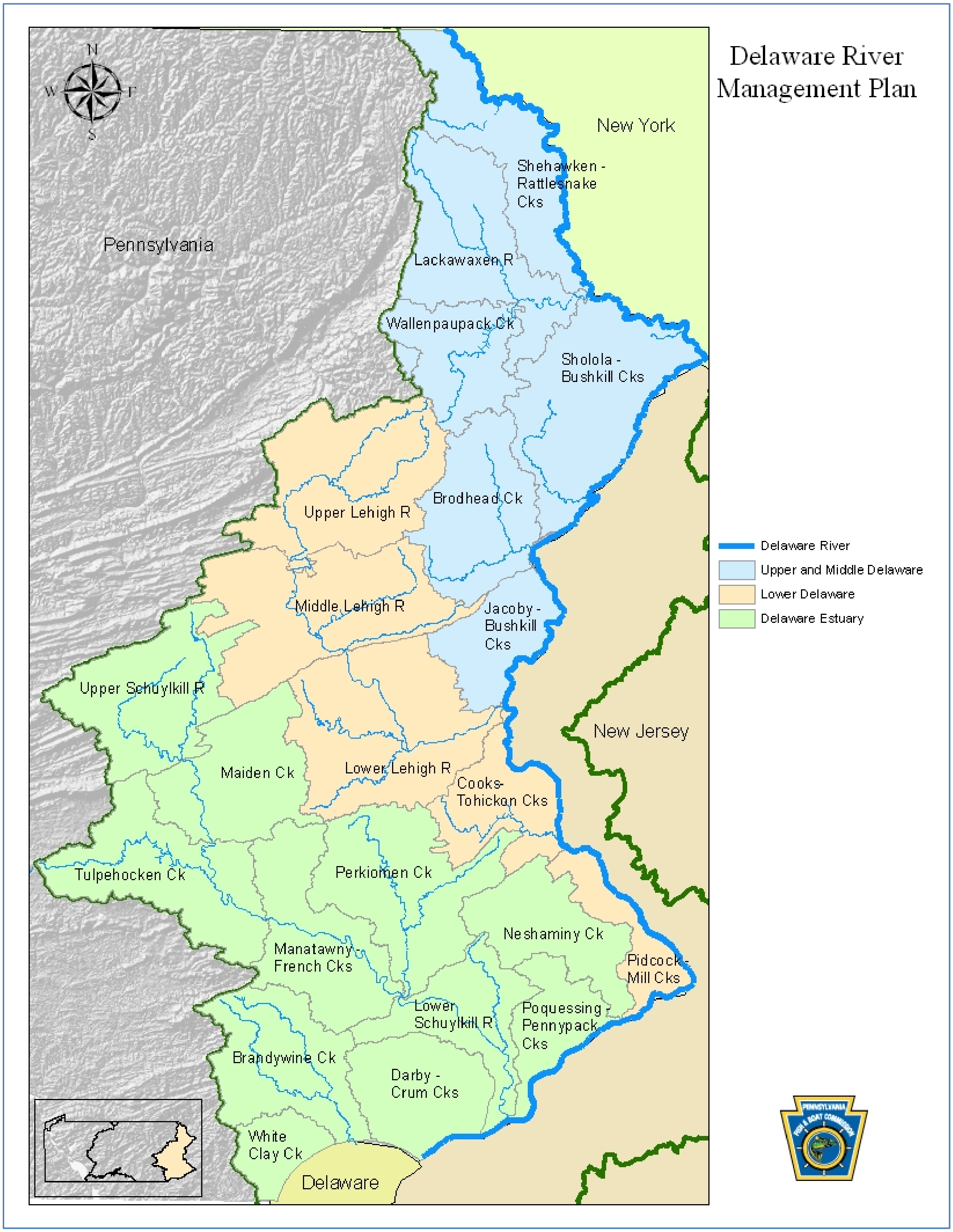


Figure 5.16. Major tributary stream subbasins of the Delaware River Basin within Pennsylvania.

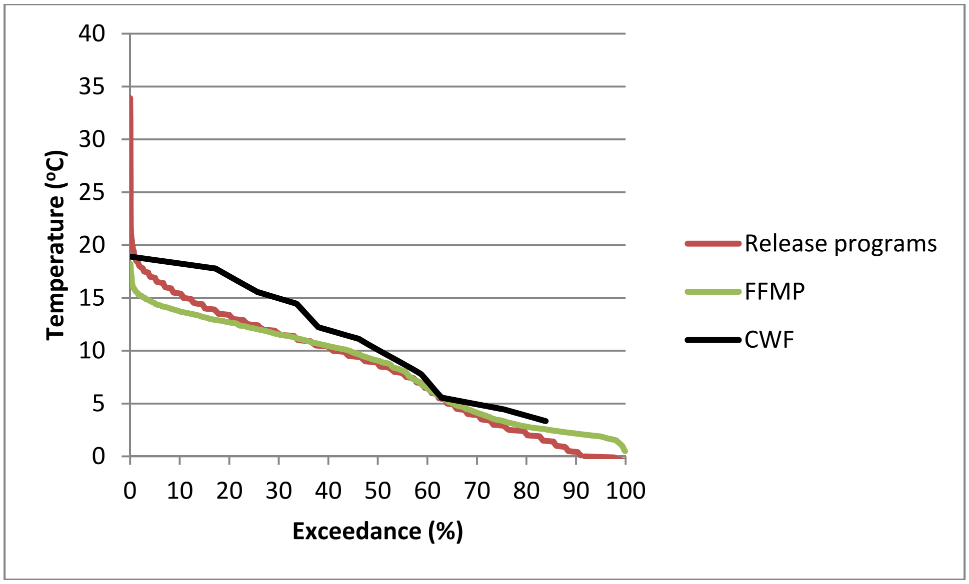


Figure 5.17. Temperature duration curve for river discharge at Hale Eddy, N.Y. (USGS 01426500) in the West Branch Delaware River for the period of record from October, 1963 – December, 2010. Release programs: October, 1963 – September, 2007; FFMP: October, 2007 – December, 2010; CWF: Pennsylvania Chapter 93 Coldwater Fisheries criteria.

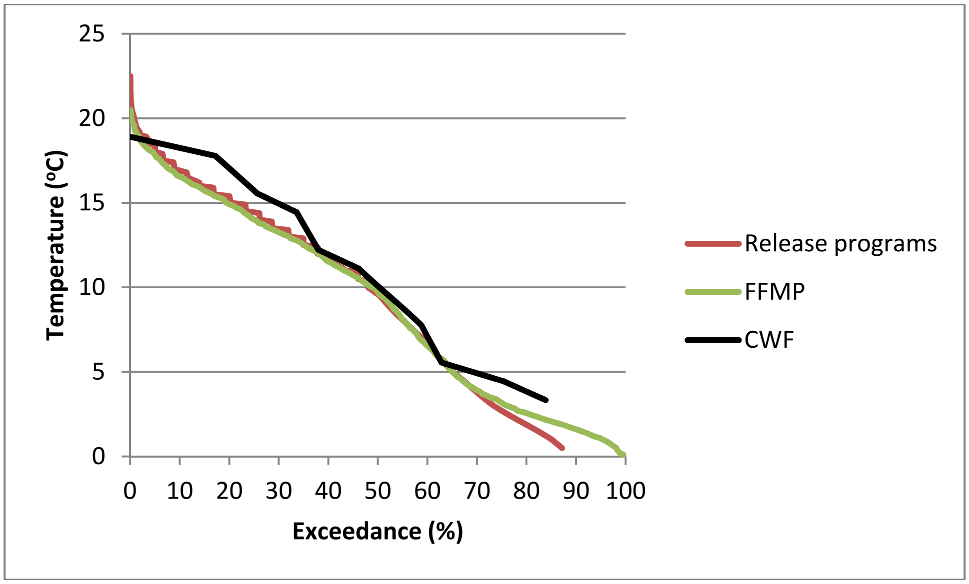


Figure 5.18. Temperature duration curve for river discharge at Hancock, NY (USGS 01427000) in the West Branch Delaware River for the period of record from June, 1966 – December, 2010. Release programs: June 1966 – September, 2007; FFMP: October, 2007 – December, 2010; CWF: Pennsylvania Chapter 93 Coldwater Fisheries criteria.

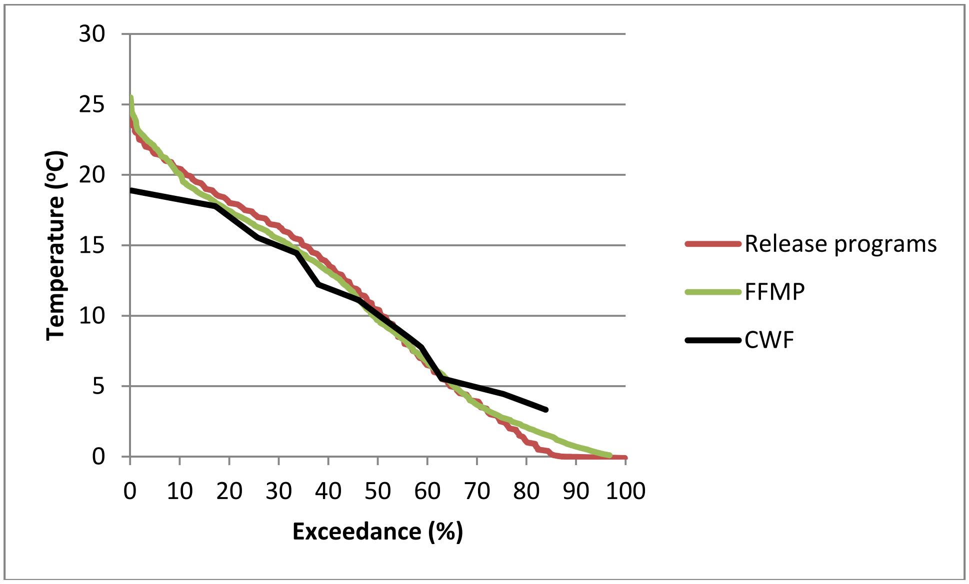


Figure 5.19. Temperature duration curve for river discharge at Lordville, NY (USGS 01427207) in the Delaware River for the period of record from June, 1966 – December, 2010. Release programs: June 1966 – September, 2007; FFMP: October, 2007 – December, 2010; CWF: Pennsylvania Chapter 93 Coldwater Fisheries criteria.

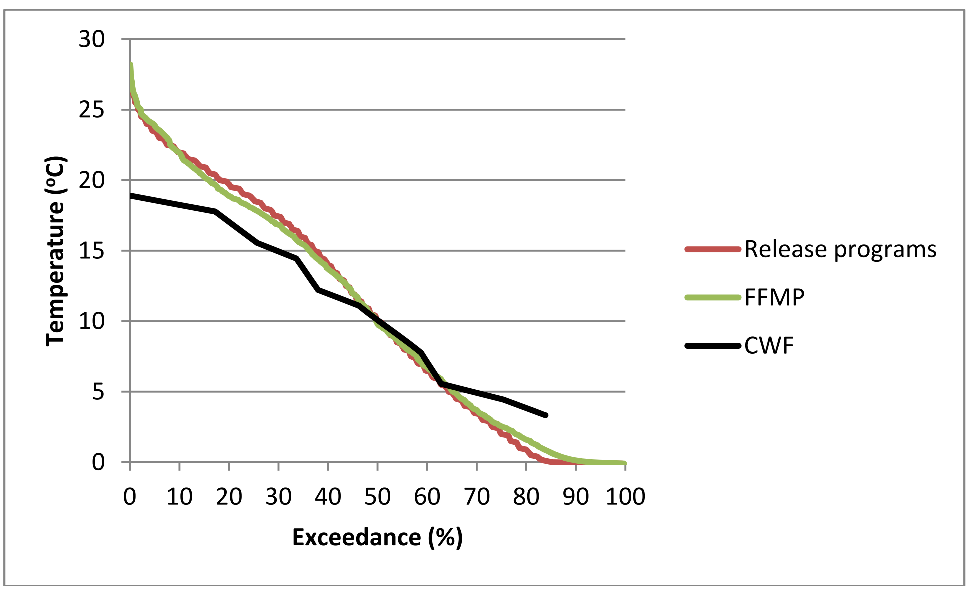


Figure 5.20. Temperature duration curve for river discharge at Callicoon, NY (USGS 01427510) in the Delaware River for the period of record from June, 1975 – December, 2010. Release programs: June 1975 – September, 2007; FFMP: October, 2007 – December, 2010; CWF: Pennsylvania Chapter 93 Coldwater Fisheries criteria.

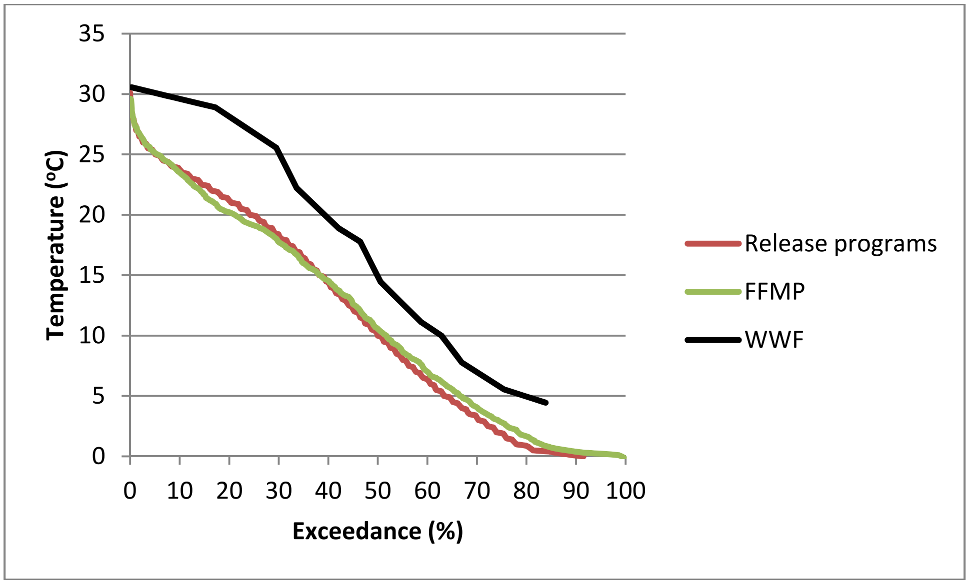


Figure 5.21. Temperature duration curve for river discharge at Lackawaxen, PA (USGS 01428500) in the Delaware River for the period of record from October, 1975 – December, 2010. Release programs: October 1975 – September, 2007; FFMP: October, 2007 – December, 2010; WWF: Pennsylvania Chapter 93 Warmwater Fisheries criteria.

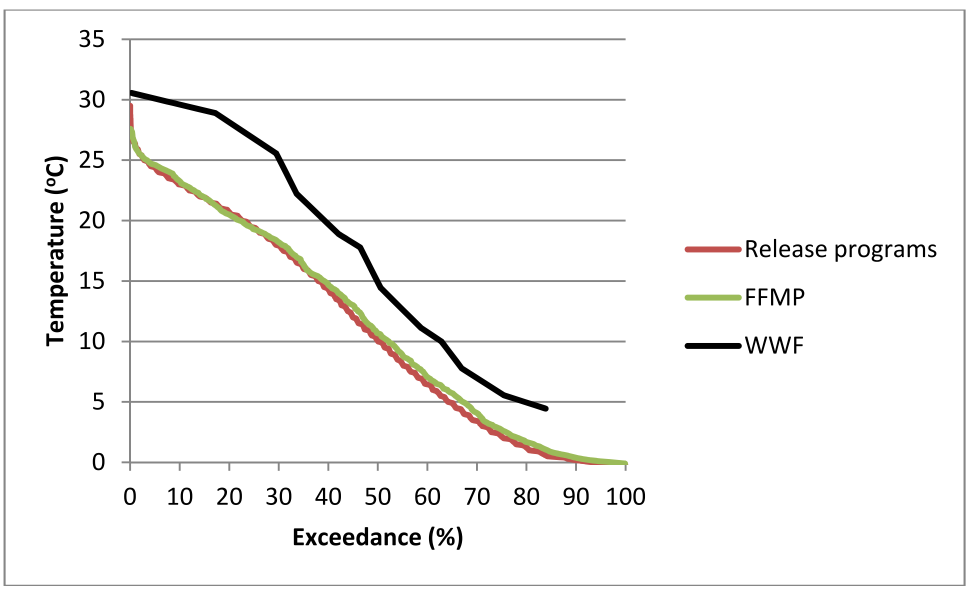


Figure 5.22. Temperature duration curve for river discharge at Barryville, NY (USGS 01432160) in the Delaware River for the period of record from March, 1975 – December, 2010. Release programs: March, 1975 – September, 2007; FFMP: October, 2007 – December, 2010; WWF: Pennsylvania Chapter 93 Warmwater Fisheries criteria.

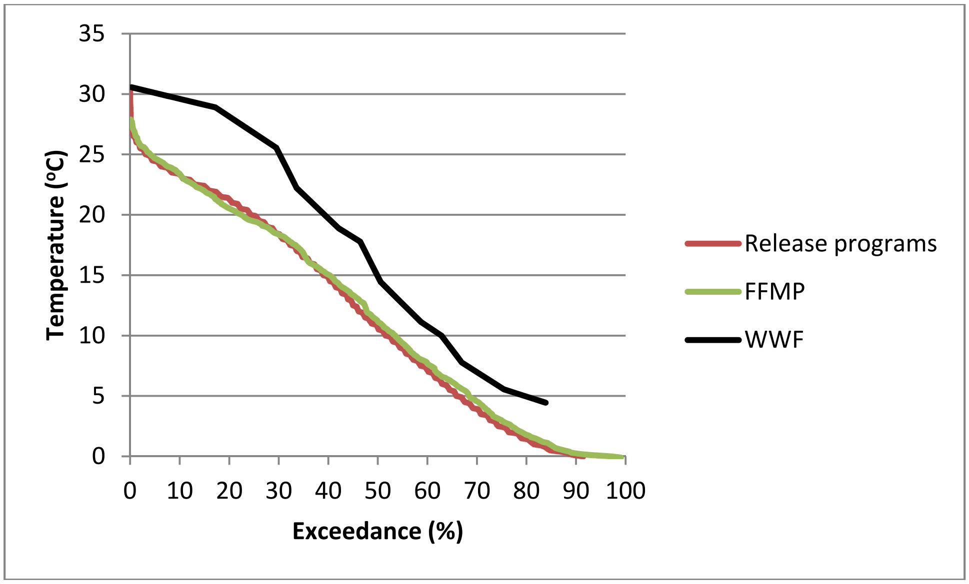


Figure 5.23. Temperature duration curve for river discharge at Pond Eddy, NY (USGS 01432805) in the Delaware River for the period of record from October, 1973 – December, 2010. Release programs: October, 1973 – September, 2007; FFMP: October, 2007 – December, 2010; WWF: Pennsylvania Chapter 93 Warmwater Fisheries criteria.

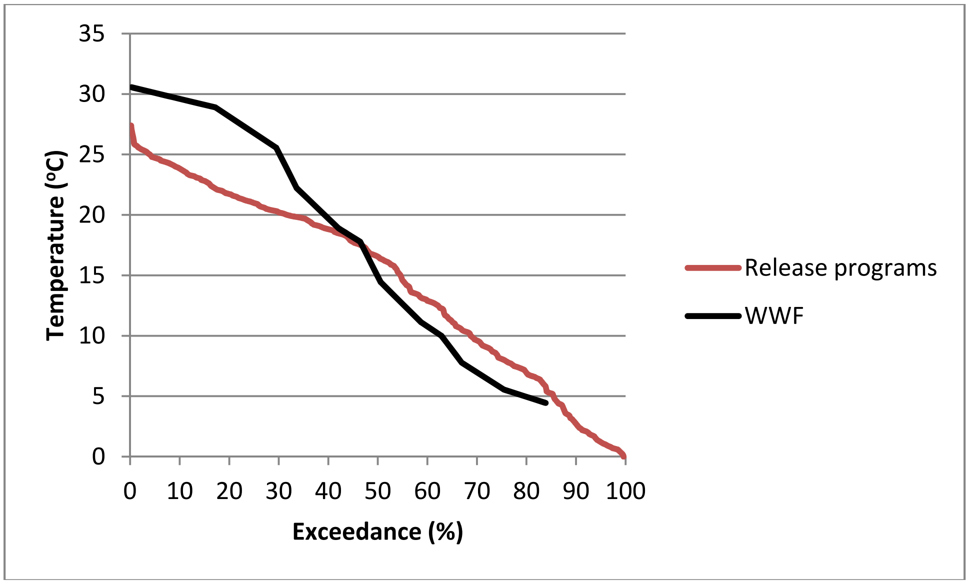


Figure 5.24. Temperature duration curve for river discharge at Water Gap, PA (USGS 01440200) in the Delaware River for the period of record from October, 1975 – December, 2010. Release programs: October 1975 – September, 2007; FFMP: October, 2007 – December, 2010; WWF: Pennsylvania Chapter 93 Warmwater Fisheries criteria.

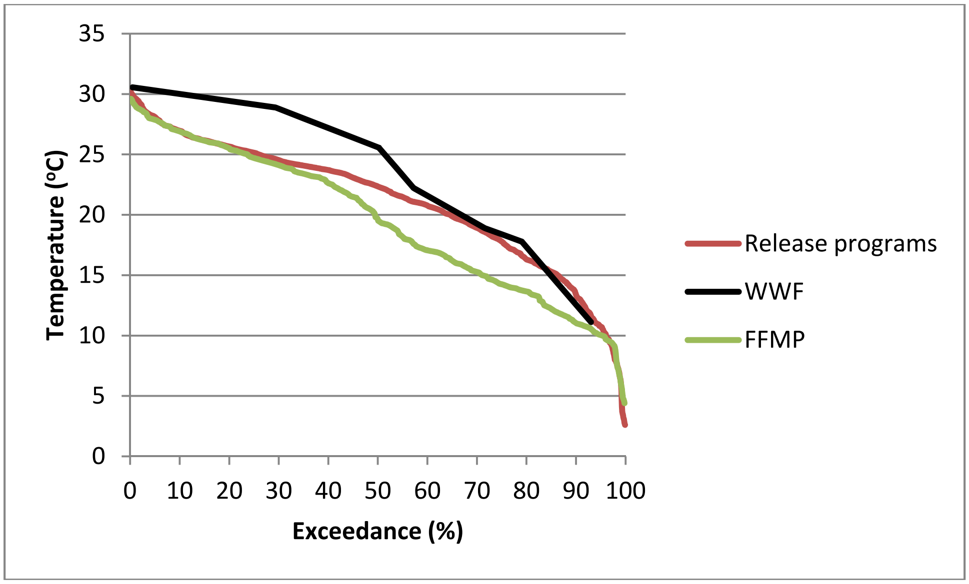


Figure 5.25. Temperature duration curve for river discharge at Point Pleasant, PA (USGS 01460200) in the Delaware River for the period of record from May, 2000 – November, 2010. This gage is seasonally operated (April – November in most years). Release programs: May, 2000 – September, 2007; FFMP: October, 2007 – November, 2010; WWF: Pennsylvania Chapter 93 Warmwater Fisheries criteria.

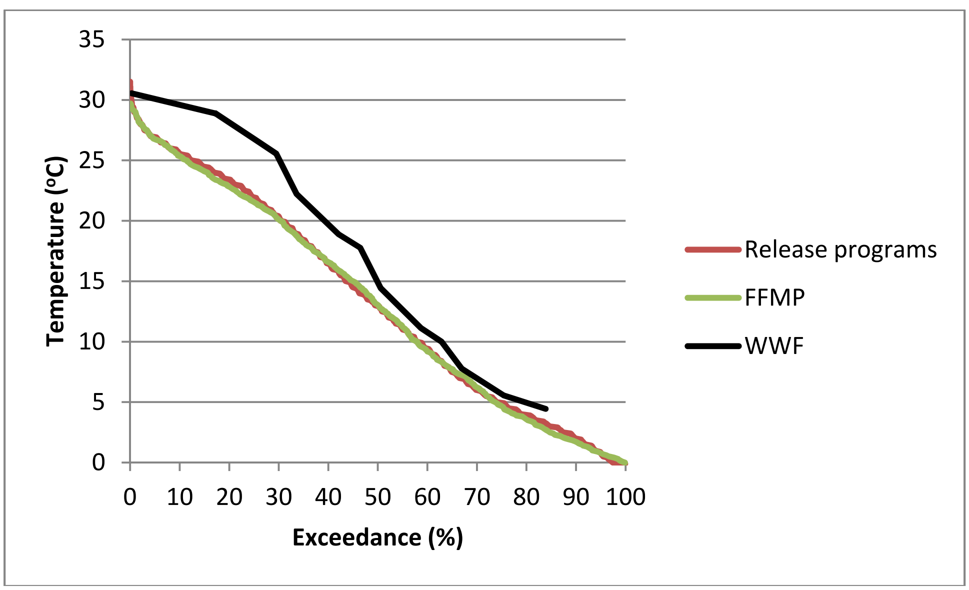


Figure 5.26. Temperature duration curve for river discharge at Trenton, NJ (USGS 01463500) in the Delaware River for the period of record from October, 1965 – December, 2010. Release programs: October, 2000 – September, 2007; FFMP: October, 2007 – December, 2010; WWF: Pennsylvania Chapter 93 Warmwater Fisheries criteria.

6.0 River Habitats

River habitat generally refers to the physical structures in-river and in the immediate vicinity (riparian habitat) of the river that has the potential for providing protection and living space to aquatic organisms. Generally, in-river habitat begins with the shape of a river and the composition of the river bed substrates. Substrate including boulders, cobble and sand can change the shape of a river by affecting water hydrologics. They also provide aquatic organisms diverse habitats that act as protection from water velocities and predation.

6.1 Instream Macrohabitats

Traditional definitions for riffles, rapids, runs, and pools have been established. Briefly, a riffle has comparatively shallow water, usually nominal to thirty-six inches in depth, and a relatively fast current. The water surface is disturbed by the current to the extent of forming small standing waves. A rapid is the more extreme form of a riffle, usually deeper, and distinguished by a steeper elevation change of the river bed. Generally, rapids have larger standing waves, and usually the occurrence of obstructions in the channel. A run is characterized by a moderate current that generally does cause a broken surface. Pools are reaches of channel where flow velocities have slowed, sometimes to almost imperceptible current velocities, acting as depositional areas for suspended materials. Pools within the non-tidal Delaware River however, tend to be more reflective of glides, than a traditional pool. Within glides there is a deceleration of flow velocities relative to run flow velocities allowing for some deposition of materials and a reprieve from turbulent waters, but flows velocities remain relatively fast. The Delaware River supports localized areas that act as more traditional pools. These are found in mostly small inlets and bays off the main channel of the river.

The macrohabitat, including the occurrence of riffle, runs, and pools was well documented for the West Branch Delaware River and upper reach of the Delaware River by Bovee et al. (2007) as part of their model development for relating habitat availability to river flows. For the reaches below the Bovee et al. (2007) study area (downriver from Callicoon, NY), information on river macrohabitats is limited. Some information is available on riffle/rapid occurrence and general water depths via the DRBC mapping efforts (Delaware River Recreation Maps); however, these notations represent approximations rather than a robust survey of geomorphic characteristics. We are unaware of any geomorphic assessments focusing on riffle and run frequency, spacing, size and composition within the reaches below the Bovee et al. (2007) study area.

For the most part, flow in the main channel of the river has a repeating sequence. Typically, this is a riffle/rapid – pool – run or riffle/rapid, run – pool – run pattern. Transitions from one flow type to another is not always abrupt as the transition from a run into a pool can be the gradual deepening or depression in the run; whereas, riffles/rapids are formed typically from declines in the river bed elevation. The length of each habitat type within a sequence is highly variable, with runs dominating the upper reaches and long shallow pools becoming more dominate in the lower reach of the Delaware River. In general, riffles tend to be more common than rapids throughout the Delaware River.

West Branch Delaware River

The shared border reach of the West Branch Delaware River is typical of a large river. Numerous small islands, side channels, and back eddies occur. Back eddies are generally formed from coddle point bars and on inside bends, which form significant turns in river flow. Most of the West Branch Delaware River is dominated by fast runs and riffles. Pools tend to be shallow and relatively fast flowing. At low flows, Bovee et al. (2007) noted that West Branch Delaware River runs and pools were equal in abundance (approximately 2.5 ha/km), with riffles being about half as common. As discharge increased, pool and riffle habitat remained fairly static and run habitat increased. Only in the lower West Branch Delaware River (Oquaga Creek to the mouth) did very fast runs predominate at high flows. Lack of very fast runs at higher flows from Cannonsville Dam to Oquaga Creek was attributed to the formations of very large deltas at tributaries in these locations. These deltas provided strong and stable hydraulic control over a wide range of flows, so the backwater effects needed to create pools were retained, rather than being "drowned out" at higher discharges.

Delineation of the frequency and spacing of riffles and runs in the West Branch Delaware River is ambiguous, due to the strong dependence of river flows relative to the occurrence and persistence of riffle and run habitats (Bovee *et al*. 2007). However, the occurrence of riffles that would occur during lower flow conditions can be identified. The DRBC has generated and provided to the general public a series of maps which gives an approximate overview of the occurrence of riffles and relative water depths extending up to the confluence of Ball's Creek in the West Branch Delaware River.

Delaware River

The entire length of the Delaware River is free flowing. The upper reach of the river, from Hancock, NY downriver to Port Jervis, NY, is characterized as a mix of riffles, runs, and pools. Upriver of Narrowsburg, NY the river has a moderate gradient, with numerous islands, side channels, and backwater areas. Below Narrowsburg, NY the mainstem tends to have a slightly higher gradient with fewer islands and backwaters resulting in more continuous riffles (Figure 4.3). This river reach is similar to the West Branch Delaware River in that runs were second in abundance to pools and both were replaced by fast runs at the higher discharges (Bovee *et al.* 2007). Riffle habitat also was replaced by fast runs at higher discharges. At lower discharges riffle/rapid to run ratio is relatively even with riffles commonly occurring throughout the entire reach of the river.

Within the upper reach, the occurrence of pools is sparse and when pools occur they function more like glides with some slowing of river flow. Further, glides are present in many of the runs, but generally are 10 ft in depth or less and can represent a significant length of the run. Some of the larger glides/pools occur at Lordville, NY (20 ft), Long Eddy. NY (10 ft), Skinners Falls, NY (15 ft), Tusten, NY (10 ft), and at the confluences of Shohola Creek (10ft), Lackawaxen River (12 ft), and Mongaup River (10 ft). There are several deep pools in the upper reach, including the Narrowsburg, NY pool (113 ft) and Pond Eddy, NY pool (60 ft).

The middle reach of the Delaware River from Port Jervis, NY downriver to Easton, PA is inclusive of the Delaware Water Gap National Recreational Area, National Park. This river reach has a lower gradient than the upper Delaware River reach (Figure 4.3). The floodplain within this reach tends to be relatively small and contained on the east and west banks by the Kittatinny, Godfrey, and Blue Mountain ridgelines. The classic riffle, run, pool habitat is evident in the middle reach with runs and pools being more numerous than riffles. The occurrence of islands and side channels and the corresponding backwaters are typical. While the mainstem does take a few sharp turns, such as Wallpack Bend, Water Gap, and just above Belvidere, NJ, channel sinuosity tends to be relatively straight. This river reach is outside the Bovee et al. (2007) study area, and thus remains un-assessed.

Within the middle reach, the occurrences of pools are more common and deeper on average than the pools and glides in the upper reaches. Pools are generally 20 ft or less in depth. The deeper pools are: Dingmans Ferry, PA (22 ft), Wallpack Bend (25 ft), Poxono Island (22 ft), Water Gap (55 ft), Belvidere, NJ (29 ft) and Foul Rift scour hole (42 ft). Generally, pools in the middle reach are separated by the presence of a riffle or rapid. Some of the larger pools, while generally 8 to 20 ft in depth, occupy over a river mile in length, and include Milford Beach (RM 246- 249), Dingmans Ferry (RM 238-240), Bushkill (RM 227 – 230), Wallpack Bend (RM 225 – 225), Smithfield Beach (RM 2180- 220), and Water Gap (RM 211-212).

The lower reach of the Delaware River, from Easton, PA downriver to Trenton, NJ, is inclusive of the Lower Delaware National Wild and Scenic Area, National Park. The gradient of the river becomes slightly steeper than the middle reach, yet the occurrence of riffles continues to decrease (Figure 4.3). The river width tends to widen and becomes dominated by long shallow runs and short pools, with occurrences of a few deep pools and scour holes. Effects of urbanization become apparent starting in the vicinity of Easton, PA, and Phillipsburg, NJ and continue throughout the lower reach. One of the largest impacts is the development of the Delaware Canal in Pennsylvania, and the Delaware and Raritan Canal in New Jersey, which disconnect the floodplain and tributary input from the mainstem. At Riegelsville, PA, downriver to Trenton, NJ, the lower Delaware River is characterized by a narrowing of the floodplain. The geological features provide in-stream ledges, miles-long pools, numerous islands, and riffles with higher gravel content than the cobble-dominated ones upriver.

Within the lower reach, pools are common but are shallower in depth, on average, as compared to pools in the middle reach. Pools in the lower reach are generally 15 ft or less in depth occurring throughout the lower reach. The deeper pools are: Raubs Island, PA (35 ft) and Riegelsville, PA (25 ft). Generally, the pools are relatively short in length and usually form as a depression within the run; however, some pools are formed by the occurrence of riffle, run and island formations. Some of the longer pools, while generally 8 to 15 ft in depth, occupy nearly a river mile in length, and include Easton (RM 183 – 184), Riegelsville (RM 175- 176), Upper Black Eddy (RM 168 –

170), Byram (RM 157-158), Bulls Island (RM 154-156), Lambertville (RM 148-150) and Yardley (RM 135-138).

6.2 Substrates

The physical substrate composing a rivers' bed is influential on the water hydrology, water quality and association of the presence of flora and fauna. Rapid Bioassessment Protocols (RBP; Barbour et al. 1999) are commonly used for the quantification of organic substrates in wadeable streams and rivers systems. For large rivers, procedures outline by Flotemersch et al. (2006) generally prevail. RPB assessments are conducted during DRBC's annual biomonitoring project within the Delaware River, based on protocols developed with the United States Environmental Protection Agency Region 3. These protocols were for the development of biocriteria for the non-tidal Delaware River associated with macroinvertebrates and physical habitat (Anonymous 2006). These assessments however, represent synoptic views of the river substrate that elucidate in-river substrate, but remain site specific.

Organic

Organic substrates refer to structures that were once alive. In other words, they were derived from living material. The presence, frequency of occurrence, and abundance of large woody debris as in-river habitat (e.g., fallen trees) is limited for the West Branch Delaware and Delaware rivers. Assessments (RBP) by DRBC biologists' suggest that the contribution of large woody debris is small relative to dominant habitats such as cobble and boulder. Large woody debris can be locally abundant, however, and functionally important in backwaters, among islands, and along the margins of the main channel. Further, large woody debris has also been important in island and bar formation and maintenance in wider sections of the river, which is not readily apparent, but which can provide a diversity of flow and substrate once established (E. Silldorff, *pers. comm.*). The presence, frequency of occurrence, and abundance of root wads and mats is not available for the West Branch Delaware and Delaware rivers. Given the large width of the river the availability of root wads from terrestrial vegetation is nominal; however, extensive submerged aquatic vegetation can be prevalent in some reaches of the river (Wahl 1959; TNC 1994; Kratzer 1999). We are not aware of available information relating course particulate organic matter (CPOM) and fine particulate organic matter (FPOM) in the West Branch Delaware and Delaware rivers.

Inorganic

Inorganic substrates refer to structures that derived from minerals. Exposed bedrock is a common substrate in the Delaware River Basin, particularly in the upper and middle reaches. However, boulders and cobble are much more prevalent. The occurrence of boulders represents a significant amount of bottom substrate within the West Branch Delaware and Delaware rivers. Boulders can be quite large, offering substantial backwater eddies as havens from mainstem current velocities. We are unaware of any information for the quantification of the extent of inorganic substrates (bedrock and boulders) as an in-river habitat.

Cobble represents the majority of river substrate including pools, runs, riffles and rapids within the West Branch Delaware and Delaware rivers. Generally, this habitat is mostly exposed (i.e., not embedded) and sedimentation is minimal, particularly in the upper and middle reaches of the Delaware River. The quantification of the cobble substrate in the West Branch Delaware and Delaware rivers is limited to riffle habitat. As part of their annual biomonitoring program of macroinvertebrates, DRBC staff, quantify substrate habitat for riffles. While this data is not available in a final report, by far the most common substrate in the riffles throughout the Delaware River is cobble (E. Silldorff, *pers. comm.*). From their surveys, DRBC staff has noted two classes of cobble, which include small, fist sized or less, or a larger cobble, but both occur in near equal frequency.

Smaller particles including gravel, sand, and silts as substrate are infrequent in both the West Branch Delaware and Delaware rivers. Typically, small bars are formed on the downriver side of islands, but they are not persistent and tend to be highly dynamic depending on river flow. There are three distinct, persistent sand bottoms within the non-tidal Delaware River; Lackawaxen, Milford Beach, and Water Gap. These sand bottom substrates are the result of large scour holes immediately upriver. The Kittatinny Beach in the Water Gap represents the largest sand bottom, approximately 0.8 miles in length. Interestingly, Kratzer (1999) in a survey of macrophytes in the upper reach of the Delaware River noted that plant bed substrate was usually a mixture of silt, sand, cobble, and boulder with a single occurrence of bedrock. But, nearly all plant beds had a large percentage of cobble combined with lesser amounts of the other constituents.

Sediment Quality and Contamination

An overview of geology and hydrology in the upper Delaware River was provided by Penzo (unknown date). Soils of the upper Delaware River have two origins: glacial and fluvial. The dominant form of sedimentation is overbank sedimentation in the reaches between Hancock, NY to Callicoon, NY and Narrowsburg, NY to Port Jervis, NY In the reach between Callicoon, NY and Narrowsburg, NY, the floodplain widens and both overbank and point bar depositions predominate.

The DRBC has a long standing history for the monitoring and regulation of sediment contamination in the Delaware River. In the forefront of their efforts are the Delaware Toxics Reduction Program (DelTRiP) and Pollutant Minimizing Plans (PMPs). The DelTRiP is chaired by DRBC and is an effort to track, prioritize, and report the status of contaminated sites that contribute, or potentially contribute, to toxins within the Delaware River basin (DRBC 2007). By Resolution 2005-9 (http://www.state.nj.us/drbc/Res2005-9final.htm) DRBC require a PMP for point and non-point discharges of toxic pollutants following the issuance of a TMDL (Total Maximum Daily Load). The intent of PMP is to develop standards for toxic substances; develop water quality based effluent limitations (WQBEL) and policies and methods for achieving stated standards and WQBEL; however the PMPs are focused principally in the Delaware Estuary.

6.3 Shallow Water Habitats

Shallow water habitat is generally thought of as river water of less than a certain depth limiting the intrusion of large piscivore predators, but remains wetted. In general, for the West Branch Delaware and Delaware rivers, shallow water habitats occur as embayments, backchannels, stream confluences, shoreline margins and riffles. Embayments mostly occur when river stage decreases such that water flow into side channels is interrupted. Generally, shallow water riffles become de-watered on the upriver side of a back or side channel; thus, an embayment of slack water with minimal mixing of fresh river water from the mainstem is generated. In more extreme cases of depressed river stage, these embayments have the potential for becoming completely disconnected from the mainstem, usually for short periods of time. Side channels represent water flows due to a diversion, typically an island, which causes some of the upriver mainstem water to flow in a different direction than the main channel flow. Side channels are usually smaller in volume than the mainstem flow and do not represent the main thalweg of the mainstem. Stream confluences, at times, can represent shallow-water habitat and is dependent on the discharge and flow rates of the tributary stream relative to the mainstem. The shoreline margins are the immediate waters' edge. This zone can be quite large relative to the main channel, particularly on inside bends. Within the West Branch Delaware and Delaware rivers shallow-water habitats primarily occur as riffles and the shoreline margins of the mainstem.

Bovee *et al.* (2007) defined meso-habitat layers, quantifying areas based on selection criterion, for the development of a flow-habitat relational model. Model results of habitat related to flow noted that side channels along with backwaters and disconnected areas were the most dynamic habitat types in the upper Delaware River basin. The variability occurred, at least in part, because habitat types would change from one form to another depending on the amount of discharge. An area might be disconnected at very low flows, become connected as a backwater at an intermediate flow, and connected top to bottom, thereby becoming a side channel, at high flows.

In the flow modeling of Bovee et al. (2007) for the upper Delaware River Basin, the authors identified two species guilds, the shallow-fast and shallow-slow representing species utilization of shallow water habitat. Shallow–fast habitat was intended to represent habitat to riffle dwelling fishes and aquatic macroinvertebrates; whereas, the shallow-slow guild represented habitat necessary of young of the year for virtually all species, and for species found primarily in slack water areas. For their study, Bovee *et al.* (2007) defined shallow water habitat for both guilds as 0.05 to 0.3 m water depth. Shallow-slow habitat types were maximized at the lowest range of flows, with peak areas occurring around 0.1 to 0.3 cubic feet per second per square mile. Shallow-fast habitat types were also maximized at relatively low flows, but not as low as shallow-slow habitat types. At discharges less than 0.3 cubic feet per second per square mile, water velocities tend to be too low to be suitable for this guild, but at discharges greater than 0.6 cubic feet per second per square mile, depths become too large to be considered "shallow."

Embayments

Information pertaining to documenting the presence and frequency of occurrence of embayments within the West Branch Delaware and Delaware rivers is limited. In the upper Delaware River, Bovee et al. (2007) noted that neither embayments nor disconnected habitats accounted for a large portion of the surface area of the model sites; however, the author noted that some were impressive nonetheless. A large embayment is created on the Pennsylvania side across from Callicoon, NY at certain flows, due to the de-watering of the upriver riffle that feeds a side channel. The creation of this embayment is thought to be detrimental to the existing dwarf wedgemussel population Cole (2008); whom recommended flow ranges that maintain flow in the side channel to prevent embayment formation.

Side channels

The occurrence of side channels is relatively common due to the occurrences of natural islands in the West Branch Delaware and Delaware rivers. Side channels generated by the occurrence of islands are, for the most part, unaltered by human activities. Bovee et al. (2007) noted that side channels tended to be the most consistent in the river reaches containing large, highly dissected, and relatively high-elevation islands, and most variable where side channels were around mid-channel, low-elevation bars.

Stream Mouths

The occurrence of tributary discharge is commonly from small drainages throughout the West Branch Delaware and Delaware rivers (Figure 5.16). However, information pertaining to the occurrence of stream mouths acting as shallow water habitat is limited. Bovee et al. (2007) found only two sites in the West Branch Delaware River in their modeling that suggested that regardless of flow, the existing habitat was relative stable, rather than being subsumed into a fast run habitat. The authors suggest that this was due to the formation of very large tributary deltas, which provide strong and stable hydraulic control over a wide range of flows. Thus, the backwater effects needed to create pools were retained, rather than being “drowned out” at higher discharges.

6.4 Islands

Numerous named and unnamed islands occur in the West Branch Delaware and Delaware rivers, many of which are within either federal or state parks (Table 6.1). It is generally believed that islands are an important habitat component, serving as shallow water habitat along shoreline and bar formations on the island toe; as well as serving to provide velocity breaks for aquatic organisms and during flooding events when terrestrial vegetation impedes water flow.

6.5 Man-made Habitats

Some of the most influential manmade structures impacting the West Branch Delaware and Delaware rivers are the NYC reservoirs located within the state of New York. Impacts from these dams are principally flow and temperature related and can be somewhat regulated through the management of released water from the Cannonsville Dam on the West Branch Delaware River; Pepacton Dam on the East Branch Delaware River, and the Neversink Dam on the Neversink River. There are two wing dams located at Lumberville, PA (RM 155.9) and Lambertville, NJ (RM 148.0) that offer significant back eddies, but do not impede fish passage.

Several eel weirs exist within the upper Delaware River Basin. An eel weir is constructed by placing river rock in a "V"-shaped formation with the point of the "V" downriver where the pot is placed. Pennsylvania no longer permits the use of eel weirs in the West Branch Delaware and Delaware rivers; however, New York Department of Environmental Conservation permits and regulates eel weirs in the upper Delaware River (http://www.dec.ny.gov/regs/4018.html). One limitation is that the construction of eel weirs shall not unduly obstruct the natural flow of water or interfere with the free passage of boats. Larger weirs occur at river miles 253, 256, 258, 262, 291, 288, and 270 in the Delaware River.

The remaining principle structures that do provide a semblance of in-stream habitat consist of bridge pier footings (Table 6.2). Pilings for bridges can offer significant habitat for aquatic organisms, particularly fish. Typically, bridge pilings are buffered with boulder rock to reduce erosion of the bridge pilings and can create back eddies offering velocity breaks from mainstem flows.

6.6 Estuarine Habitats

The West Branch Delaware and Delaware rivers while not encompassing estuary habitats are directly influenced by the exchange of aquatic organisms with the Delaware Estuary, below head of tide (RM 133.4) at Trenton, NJ. These influences are principally by diadromous fishes (American eel, American shad, striped bass, river herring, etc.) utilizing the freshwater reaches of the river as part of their life history. Further, reservoir releases within the West Branch Delaware and Delaware rivers are managed achieve a minimum flow target at the USGS gage located in Trenton, NJ for maintaining the salt line in the upper estuary (FFMP 2008; DRBC 2009).

6.7 Riparian Habitats

Riparian corridors bordering rivers naturally exist in a state of dynamic equilibrium, offering a diverse array of form and function. For example, these habitats provide shade and cover, retain and recycle nutrients, modify local microclimates, slow flood waters by allowing for increased flood storage in the floodplain, and sustain broadly based food webs including the terrestrial and aquatic communities. Further, shoreline vegetation, can stabilize river banks, and trap and accumulate overbank sedimentation nutrient input and pollutants from being delivered into the river, and function as a transition between terrestrial and aquatic communities.

Vegetation classification and mapping was conducted in the Upper Delaware Scenic and Recreational River (Perles et al. 2008). Fifty vegetation associations and 14 Anderson Level II land use categories were documented in the park. The most abundant association in the UPDE is Hemlock-Beech-Oak forest covering approximately 4,385.2 ha (10,836 ac) of the park area. There are 14 riparian vegetation associations, five forested, two shrubland, and seven herbaceous, collectively covering approximately 642.05 ha (1,586.5 ac) of the park; however the authors noted that at the time of the survey, shrubland and herbaceous types were most likely under-represented due to high water events. Table 6.3 provides a listing of identified vegetation classifications and estimated percentage of coverage within the UPDE. Riparian vegetation collectively accounted for only 2.9% of the total coverage within the UPDE boundaries.

Perles *et al*. (2007) identified sixty-nine vegetation associations occurring in the Delaware Water Gap National Recreational Area. The vegetation of the region is generally classified as Appalachian Oak Forest, typically dominated by white oak and northern red oak, with sugar maple, sweet birch, bitternut hickory, American beech, and tuliptree. Table 6.4 provides a listing of identified vegetation associations. Dry Oak – Heath Forest (4,416.7 ha.) and Dry Oak – Mixed Hardwood Forest (2,915.9 ha.) were the most dominate associations. Many environmental factors, such as geology, topography, soils, hydrology, and fire, affect the types and distribution of vegetation within DEWA.

Davis *et al.* (2009) further explored the riparian vegetation in the UPDE and DEWA parks, classifying a total of 17 community types: 12 native community types and 5 developed or degraded community types (Table 6.5). Riparian forests were the dominant community type totaling approximately 45% of the total study area. Forested communities occurred on high to low terraces on the mainstem, tributary mouths, and on islands and bars within the channel. The two shrubland communities, accounted for < 5% of the total riparian habitat, typically occur on cobble and sand and gravel bars that are adjacent to or contiguous with the shoreline, including upriver ends of islands. Both are subject to frequent floods, high river velocity and ice-scour. The herbaceous communities (36% of total riparian habitat), was dominated by invasive species (Reed Canary Grass and Japanese Knotweed).

Synder *et al.* (2001) investigated the influence of eastern hemlock on the aquatic community within the Water Gap tributaries in the DEWA. The authors found aquatic invertebrate diversity to be strongly influenced by forest composition. Streams draining hemlock forests supported on average 37% more taxa and higher abundances of brook trout than streams draining mixed hardwoods, however, stream size was a confounding influence. The authors noted within hemlock forests, steam habitat diversity was greater, total nitrite concentrations were lower, and temperature and flow patterns were more stable than streams draining mixed hardwood forests. These factors possibly contributed to aquatic community differences.

6.8 Important Habitats / Habitats of Special Concern

Habitats of special concern are generally related to identifying critical habitat for the promotion and protection of threatened and endangered species and species of concern. As per the federal Endangered Species Act, one component for listing of a species requires the classification of critical habitat that is determined to be essential for the survival of the listed species.

The Pennsylvania State Wildlife Action Plan (SWAP; http://www.fish.state.pa.us/promo/grants/swg/00swg.htm) is a benchmark resource that is designed to proactively manage the state's non-game resources including species of special concern and provide direction for the approval and funding of State Wildlife Grant (SWG) projects. The SWAP identifies habitats and species in need of conservation and provides guidance for research, inventory and monitoring of these resources. Within the PFBC, SWAP responsibilities are primarily tasked to the PFBC's divisions of Fisheries Management, Environmental Services' Natural Diversity Section, and Habitat Management.

Critical spawning habitat for shortnose sturgeon has been identified in the non-tidal reaches of the Delaware River above Trenton, NJ upriver to Scudders Falls (O'Herron 1993). The Delaware Department of Natural Resources and Environmental Control (DNREC) has conducted extensive surveys in the Delaware Estuary to document the habitat and movements of shortnose and Atlantic sturgeon and recently (2009) collected Atlantic sturgeon YOY in the upper estuary (M. Fisher, *pers. comm.*). Within the non-tidal reaches of the Delaware River, shortnose sturgeon have been known to occur as far up river as New Hope, PA Below head of tide critical nursery ground for YOY and juveniles of both shortnose and Atlantic sturgeons has been documented in the Marcus Hook reach. This tidal reach may also be utilized for spawning by Atlantic sturgeon (Fisher, 2009) although the current spawning grounds location is unknown (O'Herron 1993; M. Fisher, *pers. comm.*).

Blueback herring and alewife have recently been federally listed as species of concern. Historically, they were common in the non-tidal Delaware River, particularly in the lower reaches; however, they have become relatively scarce in the non-tidal reaches of the Delaware River. Habitat for these fishes has not been defined in the Delaware River. Typically, these are schooling pelagic fishes that are highly mobile and can move considerable distances within the river. Horwitz et al. (2008) documented five juvenile blueback in the Smithfield Beach pool (RM 218) and speculated upriver occurrence was density-dependent on the abundance of returning adults. Horwitz et al. (2008) also captured one adult alewife in a backwater of Junction Pool just below Hancock, NY.

The bridle shiner is considered an endangered species in Pennsylvania. This species is known to occur in the upper Delaware River mainstem (Horwitz *et al*. 2008). The NYDEC documented bridle shiners in a backwater of the Delaware River in the UPDE in 2005. Horwitz *et al.* 2008, also collected bridal shiners at the same location. Further, Horwitz et al. (2008) found occurrences of bridle shiners at two additional sites in 2006 and 2008. Small changes in the upper Delaware mainstem temperatures are within the bridle shiners life history requirements (Finger 2001). The

DSS model outputs for shallow-slow guild of fish may be overly conservative due to maximum depth constraints of 0.3 m used by Bovee *et al.* (2007) as compared to actual species preference for the deeper portion of a range of 0.18 to 1.11 m deep noted by Finger (2001). Critical habitat for this species has been documented as a vegetative obligates selecting for pools (Leckvarcik 2001, 2006; Finger 2001; Fairchild *et al*. 1998). Observations by PFBC biologists, confirms this association with submerged aquatic vegetation, which should be considered in protecting the habitat of concern for this species.

Ironcolor shiner is a Pennsylvania listed endangered species known to occur in a single tributary within the Delaware River Basin. Horwitz et al. (2008) did not document any occurrences of this species within the UPDE or DEWA of the Delaware River. Critical habitat has been identified as vegetative obligates selecting for pools (Leckvarcik 2001, 2006; Finger 2001; Fairchild *et al.* 1998).

The dwarf wedgemussel, is a federally and Pennsylvania listed endangered species. Lellis (2001, 2002) completed a survey for the occurrence of the mussels within the UPDE and DEWA, finding three significant populations of dwarf wedgemussels from north of Equinunk, PA to Callicoon, NY that were generally associated with shallow water near islands. Cole *et al*. (2008) established recommendations for wetted perimeter for the protection of the dwarf wedgemussels in the UPDE waters. Their study indicated that the downriver most population just above Callicoon, NY is the most vulnerable, and that minimum flows (557 cfs at the Callicoon USGS gage) are necessary for maintaining a minimum wetted perimeter. Cole et al. (2008) also suggested that flows below 734.5 cfs and warm water temperatures (81.5 ^{o}F) may not be sufficient to protect dwarf wedgemussels in high ambient water temperatures; and thus, recommended a flow of 928 cfs for maintaining a fully wetted habitat for moderating temperature. It is expected that better refinement will be offered by a complementary study by the United States Geological Survey, Leestown Science Center, Wellsboro, PA. This study is expected to modify the DSS model with updates from Cole's *et al*. (2008) recommendations and incorporate findings from concurrent laboratory and field studies for refining knowledge on their biological requirements and habitat needs regarding optimal flow for the dwarf wedgemussel populations.

The Nature Conservancy in partnership with the Natural Lands Trust and Partnership for the Delaware Estuary are working to identify priority conservation and restoration areas and develop conservation actions for freshwater, estuarine and marine shellfish habitats in the Delaware River Basin and Estuary. The ultimate goal of the project is to identify a shared set of places and actions that will help guide future conservation actions toward the highest priority areas and advance the conservation of ecosystem function and biodiversity in the Delaware River Basin. As part of this project the Natural Lands Trust is conducting a biological resources assessment to help inform the ecological condition assessment of the Delaware River Basin. The intent is to identify a species or group of species that, through their rarity or functional significance, serve as indicators of ecological integrity in assessing priority protection and restoration areas. Currently, this project is in the developmental phase, but preliminary findings are expected in the summer of 2011.

6.9 Management Options

Priority 1: (on-going activities or recommendations to be implemented in first year of management plan).

- Continue to coordinate through PFBC Division of Environmental Services, Natural Diversity Section, addressing the identification and utilization of habitats for species of concern as prioritized by the State Wildlife Action Plan within the West Branch Delaware and Delaware rivers.

Table 6.1. Listing of named and un-named islands and bars in the West Branch Delaware and Delaware rivers.

	River mile	
Island Name	Lower	Upper
West Branch Delaware River		
Unnamed Island	7.03	7.15
Unnamed Island	6.67	6.77
Unnamed Island	6.08	6.16
Unnamed Island	5.44	5.64
Unnamed Island	5.09	5.25
Unnamed Island	4.27	4.63
Unnamed Island	3.78	3.98
Unnamed Island	2.23	2.32
Delaware River		
Unnamed Island	329.83	330.39
Unnamed Island	329.50	329.86
Frisbie Island	322.70	323.60
Unnamed Island	317.19	317.30
Unnamed Island	314.90	314.99
Unnamed Island	312.95	313.08
Unnamed Island	309.30	309.50
Unnamed Island	305.73	306.28
Unnamed Island	303.92	304.44
Unnamed Island	303.77	303.99
Unnamed Island	303.28	303.54
Big Island	301.10	301.90
Unnamed Island	300.57	301.00
Unnamed Island	300.35	300.48
Unnamed Island	299.02	299.14
Unnamed Island	297.57	297.84
Unnamed Island	291.76	292.01
Unnamed Island	289.42	289.73
Unnamed Island	262.02	262.23
Unnamed Island	260.14	260.40
Cherry Island	258.65	258.90
Unnamed Island	252.70	253.40
Mashipacong Island	249.30	252.00
Quicks Island	248.70	248.80
Minisink Island	243.50	245.10
Namanock Island	241.90	242.90
Shapnack Island	234.55	235.00
Unnamed Island	233.58	233.76
Buck Bar	230.90	231.10
Sambo Island	224.60	224.70
Depew Island	221.50	222.10
Poxono Island	219.90	220.50
Tocks Island	217.20	217.90
Labar Island	216.30	216.70

Depue Island	214.90	215.90
Shawnee Island	213.20	214.70
Schellenbergers Island	212.30	212.95
Unnamed Island	212.11	212.20
Arrow Island	210.30	210.60
Attins Island	202.90	203.30
Thomas Island	202.60	203.00
Macks Bar	201.56	202.10
Dildine Island	201.50	202.40
Macks Island	200.30	200.70
McElhaneys Island	197.84	198.10
Foul Rift Islands	196.40	
Capush Island	194.65	194.75
Masons Island	194.50	194.80
Keifer Island	191.60	192.10
Unnamed Island	185.31	185.56
Getters Island	184.11	184.40
Unnamed Island	180.70	181.00
Unnamed Island	179.71	179.82
Whippoorwill Island	179.30	179.80
Old Sow Island	178.50	178.90
Raubs Island	177.10	177.57
Lynn Island	171.50	171.90
Unnamed Island	170.00	170.20
Unnamed Island	167.89	168.10
Pennington Island	163.00	163.70
Fishing Island	162.40	162.50
Pinkertons Island	161.20	161.60
Walls Island	161.00	161.30
Shyhawks Island	161.00	161.22
Marshall Island	160.80	162.58
Treasure Island	160.20	161.00
Rush Island	160.00	160.25
Resolution Island	160.00	160.25
Walls Island	158.95	159.20
Prahls Island	158.37	159.00
Unnamed Island	158.25	158.45
Lumberville Wing Dams	155.90	
Eagle Island	153.10	153.50
Hendrick Island	152.10	153.40
New Hope-Lambertville Wing Dams	148.00	
Unnamed Island	142.70	143.10
Unnamed Island	140.40	141.00
Unnamed Island	140.00	140.50
Unnamed Island	139.70	140.30
Rotary Island	136.40	137.00
Blauguard Island	135.80	136.10

Table 6.2. Listing of bridges across the shared border waters of the West Branch Delaware and Delaware rivers.

Bridge Name	River Mile
West Branch Delaware River	
Hancock Bridge PA Rt 191	1.3
Delaware River	
Lordville Bridge	321.60
Callicoon Bridge	303.70
Damascus Bridge	298.40
Milanville-Skinners Falls Bridge	295.40
Narrowsburg Bridge, U.S. Route 106	289.90
Tusten Station, Erie R.R. Bridge	285.20
Minisink Ford-Lackawaxen Highway Bridge	277.40
Shohola-Barryville Highway Bridge	273.50
Pond Eddy Highway Bridge	265.50
Mill Rift, Erie RR Bridge	258.40
Matamoras-Port Jervis Highway Bridge, U.S. Routes 6 &	254.75
Port Jevis-Matamoras Highway Bridge, Interstate 84	253.65
Milford-Montague Highway Toll Bridge	246.00
Dingmans Ferry Highway Toll Bridge	238.70
Delaware Water Gap Highway Toll Bridge	212.10
Slateford, D.L.&W. R. R. Bridge	208.60
Portland, L.N.E.R.R. Bridge	207.60
Portland-Columbia Highway Toll Bridge	207.20
D.L.&W. R.R. Bridge	205.40
Riverton-Belvidere Highway Bridge	197.84
Pennsylvania Railroad Bridge, Martins Creek	190.70
Easton, Bushkill St. Toll Bridge	184.03
Easton, Northampton St. Bridge	183.82
Easton, L.&H. R.R. Bridge	183.63
Easton, D.L.W.R.R. Bridge	183.53
Easton, L.V.R.R. Bridge	183.50
Riegelsville Highway Bridge	174.80
Upper Black Eddy-Milford Highway Bridge	167.70
Uhlerstown-Frenchtown Highway Bridge	164.30
Point Pleasant-Byram Highway Bridge	157.20
Lumberville-Raven Rock Bridge (Footbridge)	155.40
Stockton-Center Bridge Highway Bridge	151.90
New Hope-Lambertville Route 202 Toll Bridge	149.70
New Hope-Lambertville Highway Bridge	148.70
Washington Crossing Highway Bridge	141.80
Interstate 95 Bridge, Scudders Falls	139.00
Reading R.R. Bridge (Yardley, PA)	137.30
Morrisville-Trenton, Calhoun St. Bridge	134.34
Morrisville-Trenton, Bridge St. Bridge	133.46

Table 6.3. Listing of identified vegetation classifications in the Upper Delaware Scenic and Recreational River. Adopted from Perles *et al.* (2008).

Vegetation Classification	Pecen	Hexacres	Acres
Forested Vegetation			
Hemlock – Beech – Oak	81.6	16,469	40,469
Northeastern Dry Oak – Hickory Forest	12.5	6,507.7	16,080.8
Lower New England Slope Chestnut Oak Forest	12.2		
Dry ridge Oak – Hickory Forest	4.6		
Central Appalachian Northern Hardwood Forest	5.1	3,200.3	7,908.1
Hemlock - Northern Hardwood forest	5.1		
Semi-rich Northern Hardwood forest	4.2		
High Allegheny Rich Red Oak – Sugar Maple Forest			
Successional Forest	6.0	1,330.4	3,287.5
Northeastern Modified Successional Forest			
Northeastern Oak – Red Maple Successional Forest			
Red Maple – Sweet Birch Hardwood Forest			
Conifer Plantation	0.4	83.4	206.1
Larch Plantation			
Mixed Pine Conifer Plantation			
Terrestrial Forest and Woodland Types	2.9	639.3	1,579.7
Hickory – Eastern Redcedar Rocky Woodland			
Inland Pitch Pine – Oak Forest			
Pitch Pine Rocky Summit			
Red Oak – Heath Woodland/ rocky Summit			
Ridgetop Scrub Oak Barrens			
Sugar Maple – Ash – Basswood Northern Rich Mesic			
White Pine – Oak Forest			
Sparsely Vegetated Cliff			
Successional Non-forested	0.8	168.8	417.1
Northeastern Old Field			
Northeastern successional Shrubland			
Little Bluestem Old Field			
Non-Forest			
Central Appalachian Blueberry Shrubland			
Little Bluestem – Poverty Grass Low – to Mid-			
Non-riparian Wetland (includes 3 forested, 3	0.4	80.5	198.9
Non-riparian Forested Wetland			
Swamp forest – Bog Complex			
Hemlock – Hardwood Swamp			
Southern New England Red Maple Seepage Swamp			
Non-riparian Shrubland Wetland			
Highbush Blueberry bog Thicket		1.02	2.52

Speckled Alder Swamp		2.14	5.29
Steeplebush / Reed Canarygrass Successional		8.86	21.89
Non-riparian Herbaceous Wetland			
Southern New England Bog			
Eastern Cattail Marsh		1.62	4.0
Mixed Forb Marsh	0.1	15.66	38.7
Riparian Vegetation	2.9	642.05	1,586.5
Sugar Maple Flood Plain Forest			
Bitternut Hickory Lowland Forest			
Silver Maple Floodplain Forest			
Sycamore – Mixed Hardwood Floodplain Forest			
River Birch Low Floodplain Forest			
Shrubland Riparian Vegetation			
Birch – Willow Riverbank Shrubland			
Willow River – Bar Shrubland			
Riparian Herbaceous Vegetation			
Water-willow Rocky Bar and Shore			
Northeastern Temperate Cobble Scour Rivershore			
Hairy-fruit Sedge Wetland			
Reed Canarygrass Eastern Marsh		223.41	552.06
Riverside Prairie Grassland			
Northern Riverside Rock Outcrop			
Japanese Knotweed Gravelbar	0.3	61.3	151.5

Table 6.4. Listing of identified vegetation associations and Anderson level II categories in the Delaware Water Gap National Recreational Area. Adopted from Perles *et al.* (2007).

Vegetation association or Anderson level II category	Total Mapped Hectares
Acidic Seep	0.09
Alder Wetland	2.01
Bear Oak - Wavy Hairgrass Shrubland	19.28
Bear Oak - Wavy Hairgrass Shrubland / Dry Oak - Heath Forest	5.82
Big Bluestem - Indiangrass Riverine Grassland	2.78
Big Bluestem - Indiangrass Riverine Grassland / Sycamore - Mixed Hardwood	1.65
Bitternut Hickory Lowland Forest	24.56
Black Walnut Bottomland Forest	34.77
Bottomland Mixed Hardwood Palustrine Forest	68.89
Bottomland Oak Palustrine Forest	56.21
Boulder Vernal Pool Sparse Vegetation	1.50
Built-up Land	369.55
Buttonbush Wetland	7.12
Calcareous Fen	3.53
Calcareous Riverside Outcrop / Calcareous Riverside Seep	3.75
Cattail Marsh	1.20
Conifer Plantation	470.96
Cropland	1,268.52
Dry Eastern Hemlock - Oak Forest	1,075.41
Dry Eastern White Pine - Oak Forest	1,668.61
Dry Hickory Ridgetop Forest	152.82
Dry Hickory Ridgetop Forest / Hickory - Eastern Red-cedar Rocky Woodland	1.76
Dry Oak - Heath Forest	4,416.70
Dry Oak - Heath Forest / Oak - Birch Talus Forest	149.94
Dry Oak - Heath Forest / Pitch Pine - Mixed Hardwood Rocky Summit	12.59
Dry Oak - Mixed Hardwood Forest	2,915.93
Dry Oak - Mixed Hardwood Forest / Oak - Birch Talus Forest	118.96
Eastern Hemlock - Mixed Hardwood Palustrine Forest	29.82
Eastern Hemlock - Northern Hardwood Forest	1,102.80
Eastern Hemlock - Northern Hardwood Forest / Northern Red Oak - Mixed	12.34
Eastern Hemlock Forest	1,013.15
Eastern Red-cedar Forest	46.69
Eastern Red-cedar Forest / Old Field	31.77
Eastern Red-cedar Forest / Successional Shrubland	36.28
Eastern White Pine - Successional Hardwood Forest	683.56
Eastern White Pine Forest	310.33
Eastern Woodland Vernal Pool Sparse Vegetation	7.99
Hairyfruit Sedge Wetland	3.91
Hickory - Eastern Red-cedar Rocky Woodland	64.86
Hickory - Eastern Red-cedar Rocky Woodland / Shale Scree Slope	1.32
Hickory - Eastern Red-cedar Rocky Woodland / Sparsely Vegetated Cliff	55.48
Highbush Blueberry - Leatherleaf Wetland	9.31
Highbush Blueberry - Steeplebush Wetland	19.01
Highbush Blueberry - Steeplebush Wetland / Successional Shrubland	1.98

Japanese Knotweed Herbaceous Vegetation	4.26
Japanese Knotweed Herbaceous Vegetation / Successional Shrubland	1.98
Leatherleaf Peatland	0.82
Little Bluestem Grassland	10.28
Little Bluestem Grassland / Sparsely Vegetated Cliff	0.34
Marl Fen	0.19
Mixed Forb Marsh	23.33
Northeastern Modified Successional Forest	2,139.29
Northeastern Modified Successional Forest / Old Field	1.83
Northeastern Modified Successional Forest / Successional Shrubland	49.39
Northern Red Oak - Mixed Hardwood Forest	1,076.61
Oak - Birch Talus Forest	385.30
Oak - Birch Talus Forest / Sandstone Talus	25.97
Old Field	532.88
Old Field / Built-up Land	0.33
Pitch Pine - Mixed Hardwood Rocky Summit	28.55
Pitch Pine - Mixed Hardwood Rocky Summit / Eastern Red-cedar Forest	0.55
Pond	266.37
Pond / Cattail Marsh	3.07
Red Maple - Black Spruce - Highbush Blueberry Palustrine Woodland	14.35
Red Maple - Black Spruce - Highbush Blueberry Palustrine Woodland / Eastern	3.33
Red Maple - Highbush Blueberry Palustrine Forest	49.70
Red Maple - Sweet Birch Hardwood Forest	1,535.43
Red Maple Palustrine Forest	129.40
Red Maple Palustrine Forest / Tussock Sedge Marsh	0.47
Reed Canarygrass Riverine Grassland	23.00
Reed Canarygrass Riverine Grassland / Japanese Knotweed Herbaceous	0.64
Reed Canarygrass Riverine Grassland / Northeastern Modified Successional	7.16
River	1,178.72
Riverine Scour Vegetation	15.46
Riverine Scour Vegetation / Japanese Knotweed Herbaceous Vegetation	6.03
Riverine Scour Vegetation / Sycamore - Mixed Hardwood Riverine Shrubland	5.96
Sandstone Talus	18.57
Shale Pit	12.19
Shale Scree Slope	20.93
Silky Dogwood Successional Palustrine Shrubland	50.98
Silky Dogwood Successional Palustrine Shrubland / Alder Wetland	6.37
Silky Dogwood Successional Palustrine Shrubland / Tussock Sedge Marsh	0.93
Silky Dogwood Successional Palustrine Shrubland / Wet Meadow	5.07
Silver Maple Floodplain Forest	509.10
Sparsely Vegetated Cliff	18.36
Successional Bear Oak - Heath Shrubland	216.69
Successional Bear Oak - Heath Shrubland / Dry Eastern White Pine - Oak Forest	0.81
Successional Bear Oak - Heath Shrubland / Dry Oak - Heath Forest	1.23
Successional Bear Oak - Heath Shrubland / Highbush Blueberry - Steeplebush	2.15
Successional Bear Oak - Heath Shrubland / Northeastern Modified Successional	2.06
Successional Eastern White Pine Woodland	108.16
Successional Eastern White Pine Woodland / Eastern Red-cedar Forest	4.12
Successional Shrubland	858.84
Successional Shrubland / Cropland	6.69

Sugar Maple - American Basswood Forest	17.10
Sugar Maple - American Beech - Sweet Birch Forest	1,706.72
Sugar Maple - American Beech - Sweet Birch Forest / Northern Red Oak Mixed	42.50
Sugar Maple Floodplain Forest	71.35
Sugar Maple Floodplain Forest / Bitternut Hickory Floodplain Forest	8.90
Sycamore (Willow) - Mixed Hardwood Riverine Dwarf Shrubland	4.43
Sycamore - Mixed Hardwood Floodplain Forest	55.08
Sycamore - Mixed Hardwood Riverine Shrubland	15.16
Sycamore Floodplain Forest	26.43
Transportation Corridor	128.89
Tuliptree - Beech - Maple Forest	66.05
Tussock Sedge Marsh	19.75
Wavy Hairgrass - Common Sheep Sorrell Rock Outcrop	9.62
Wavy Hairgrass - Common Sheep Sorrell Rock Outcrop / Dry Oak - Heath Forest	0.36
Wet Meadow	64.64
Wet Meadow / Old Field	5.37
Wooded Successional Old Field	52.46
Total	**27,944.52**

Table 6.5. Riparian communities within the Upper Delaware Scenic and Recreational River and Delaware Water Gap National Recreational Area, National Parks. Adopted from Davis *et al.* (2009).

Community type	Total combined Area (hectares)
Forest Community	
Silver Maple Floodplain Forest	69.12
Sycamore – Mixed Hardwood Floodplain Forest	54.36
Sugar Maple Floodplain forest	29.81
Bittternut Hickory Lowland Forest	13.18
River Birch Low Floodplain Forest	0.73
Shrubland Community	
Sycamore-Mixed Hardwood Riverine Shrubland	15.69
Sycamore-(Willo)-Mixed Hardwood Riverine Shrubland	1.96
Herbaceous Community	
Reed Canarygrass riverine Grassland	66.08
Japanese Knotweed Herbaceous Vegetation	31.10
Riverine Scour Vegetation	21.92
Big Bluestem-Indiangrass Riverine Grassland	9.09
Hairy-fruit Sedge Wetland	7.51
Water Willow Emergent Bed	1.16
Riverside Rock Outcrop	0.21
Degraded Community	
Agriculture/Old Field	49.16
Northeastern Modified Successional Forest	3.57
Residential	1.06

7.0 Riverine Biota

A plethora of flora and fauna occur in and utilize the West Branch Delaware and Delaware rivers. In the upper basin the consistently high water quality provides habitat for diverse biological communities, including numerous species of mammals, over 130 species of birds, 17 reptile species and 14 amphibian species. There are more than 40 resident and migratory fish species that are also supported by these waters. Nine species of mussels have been documented in the upper and middle reaches of the Delaware River including the federally and state endangered dwarf wedgemussel. The aquatic insect assemblage is very diverse and includes the rare brook snaketail dragonfly and many other pollution-sensitive species. The lower Delaware River basin habitat contains 37 critical habitat areas, and 54 plant species are recognized on a national and state level for many characteristics related to bird breeding and migration. Further, the Delaware River is located along the Atlantic Flyway, one of four major waterfowl migratory routes in the United States

As boundary waters a number of governmental and non-governmental agencies from Pennsylvania, New York, New Jersey, Delaware and the Federal government are involved in the management and stewardship of the West Branch Delaware and Delaware rivers biota. Within Pennsylvania, the PFBC, PGC, and DCNR are jointly tasked with the stewardship of the Commonwealth's ecosystems. Traditionally the PFBC and PGC have relied on revenues from license holders and federal tax rebates associated with sales of hunting and fishing gear. This dependency on license sales provided a tendency for focusing efforts towards those species of license holder interests. The federally supported State Wildlife Grants Program (SWG) was intended to provide financial support for the development of programs that benefit species and their habitats including species not directly aligned with traditional license holders. As required to be eligible to receive SWG funding, the PFBC and PGC have collectively composed a State Wildlife Action Plan (SWAP; http://www.fishandboat.com/promo/grants/swg/00swg.htm). The long-term goal was to implement a comprehensive and ecologically sound program that considers the agencies' traditional and non-traditional constituents while ensuring adequate management attention for all of Pennsylvania's valuable fish and wildlife resources.

7.1 <u>Fish Assemblages</u>

Within the West Branch Delaware and Delaware rivers three major fish communities exist: coldwater, transitional and warmwater. The West Branch Delaware River and a portion of the upper Delaware River reach are characterized as a coldwater aquatic community, maintained by reservoir releases from NYC water supply dams on the West Branch Delaware River (Cannonsville) and East Branch Delaware River (Pepacton). The downriver extent of the coldwater community is dependent on the a variety of factors, primarily the mitigation of the cold water discharge by tributary input and meteorological conditions; but does not occur further downriver than Callicoon, NY (RM 303.7). A transitional aquatic community represents the change from the coldwater to warmwater communities. This community is recognized as a mix of species from both the cold- and warmwater communities. The transitional community is eventually replaced by a warmwater community. The warmwater aquatic community represents the majority of the non-tidal Delaware River, generally recognized from Callicoon, NY to head of tide (RM 133.4) in Trenton, NJ.

The Pennsylvania Natural Heritage Program (PNHP) has provided broad definitions of fish communities occurring within Pennsylvania watersheds as part of the Pennsylvania Aquatic Community Classification (ACC) project (http://www.naturalheritage.state.pa.us/aquaticsIntro.aspx). This project has identified generalized fish communities within major basins including the Delaware River (Walsh et al., 2007; http://www.naturalheritage.state.pa.us /ACC/ACCUser'sManual-Ch.7-FishCommunities.pdf). The ACC project suggested selected fish species as community indicators (Table 7.1). Species occurrences in the West Branch Delaware and Delaware rivers follow community representations similar to those identified by the ACC project. The ACC project identified a lower Delaware River community based on the presence of costal migratory species.

The PFBC is responsible for overseeing management strategies and supporting characterization of trust species under its jurisdictional authority, including gamefish, non-game fish, reptiles, amphibians, and aquatic invertebrates. Fish communities within West Branch Delaware and Delaware rivers are a mix of native and non-native species, some of which have significant recreational value and are typically classified as gamefish. Gamefish species are those that are sought after by anglers and defined by Pennsylvania Code, Title 30. These are generally the larger predators within the system and can be composed of native and non-native fishes (Table 7.2). Brook trout, American shad, and striped bass are a few examples of native gamefish species. Nearly all of the gamefish species in the Delaware River, including brown trout, rainbow trout, smallmouth bass and walleye, are considered naturalized non-native species. The presence of non-native species within the West Branch Delaware and Delaware rivers originate from a variety of sources. Fisheries management agencies have intentionally stocked popular gamefishes within basin waters, while introductions of non-native fishes whether intentional or unintentional commonly arise from aquaria or via angler bait buckets introductions. More information pertaining to a species life history can be obtained from the PFBC web pages Pennsylvania Fishes (http://www.fishandboat.com/pafish/fishhtms/chapindx.htm).

Gamefish targeted in the West Branch Delaware River are composed of typical coldwater community fishes, primarily trout. Within the Delaware River transitional and warmwater communities, the most popular gamefish is smallmouth bass, but others including trout, walleye, panfish and channel catfish are also frequently targeted. In *Section 8.0 – Fisheries*, the recreational fisheries management activities undertaken by the PFBC Division of Fisheries Management (DFM) will be discussed in depth for gamefish of the West Branch Delaware and Delaware rivers.

The West Branch Delaware and Delaware rivers host a variety of anadromous and catadromous indigenous species, collectively these are referred to as migratory species (Table 7.2). Anadromous fish species are those that live in oceanic waters as adults but utilize fresh water for spawning and juvenile nursery habitat. Catadromous fish species live in freshwater as adults, migrating to oceanic waters for spawning. Of the migratory species, the shortnose sturgeon is listed as federally endangered; however, the Atlantic sturgeon, while not listed, may be even more imperiled. Currently, the National Marine Fisheries Service (NMFS) is in the process of determining the appropriateness of listing Atlantic sturgeon under the Endangered Species Act of 1973. Alewife and blueback herring are listed as species of concern due to dramatic declines in returning adult populations into the Delaware River Basin and other coastal basins. The east coast striped bass population is considered fully restored.

Several of these migratory species are considered gamefishes most notably, American shad and striped bass. Both are popular with anglers during their annual spring spawning runs into the Delaware River Basin. River herring are generally sought after by anglers to use as bait for striped bass fishing in the lower Delaware River. American eels are another historically popular gamefish however, as with the American shad, fishing for American eels has declined in popularity.

Spawning American shad are distributed throughout the Delaware River and into the East Branch Delaware and West Branch Delaware rivers. Juvenile shad utilize the river as nursery habitat and out-migrate back to the ocean in October and November. Large spawning striped bass females generally remain below head of tide, but smaller males occur with some frequency in the upper reaches of the Delaware River. American eels are well distributed and abundant throughout the West Branch Delaware and Delaware rivers. Interestingly, Horwitz *et al.* (2008) in a recent survey of the UPDE and DEWA parks recorded the occurrence (N = 5) of blueback herring at Poxono Island (RM 220.0) and a single alewife at Junction Pool (RM 330) just below Hancock, NY.

Within Pennsylvania, most migratory fishes are actively managed under the Atlantic States Marine Fisheries Commission (http://www.asmfc.org/) under their Interstate Fisheries Management Program, and various associated Amendments and Addendums. Refer to *Section 2.0 – Jurisdictions* for an overview of ASMFC and *Section 8.0 - Fisheries* for in-depth discussions on the monitoring, angler use and harvest and restoration of these species in the Delaware River. The ASMFC species-specific management plans also provide a complete review of migratory fishes life histories of those species managed under their purview. Brief life history summaries and species identification can also be obtained from the PFBC web pages Pennsylvania Fishes (http://www.fishandboat.com/pafish/fishhtms/chapindx.htm).

Information on the occurrence, distribution and abundance of non-game fish species in the West Branch Delaware and Delaware rivers comes from a variety of sources. Sampling conducted by the PFBC generally only documents the presence or absence of non-game fishes rather than providing quantification of relative abundance. Further, the majority of fish surveys conducted by the PFBC, Division of Fisheries Management are directed towards maximizing the collection of a specific species, thus, reducing the probability of encountering rarely occurring fish that do not utilize the same habitat as the target species. Fish species occurrence data collected by non-agency personnel are coordinated and documented through the PFBC Division of

Environmental Services, Natural Diversity Section's Scientific Collectors Permit process as part of the permit requirements. The State Wildlife Management Action Plan (http://www.fish.state.pa.us/promo/grants/swg/00swg.htm) provides direction to PFBC for the management and protection of non-game fish within Pennsylvania's waters. Responsibilities within this plan are principally the tasked to the PFBC's divisions of Fisheries Management, Environmental Services' Natural Diversity Section, and Habitat Management. More information pertaining to some non-game species life history can be obtained from the PFBC web pages Pennsylvania Fish (http://www.fishandboat.com/pafish/fishhtms/chapindx.htm).

From 1959-1962 biologists focused on community fish sampling in the upper Delaware River (Springer and Groutage 1967; Table 7.3). This sampling encompassed 13 sites from Hancock, NY to Trenton, NJ. White sucker was predominant in both frequency and abundance. Other well-distributed species collected were: American eel, fallfish, rock bass, redbreast sunfish, smallmouth bass, and walleye. Catch of species such as brown trout, carp, brown bullhead, and largemouth bass were inconsistent but tended to be well represented.

The New York Department of Environmental Conservation fisheries staff, conducted baseline fish surveys in 1977 and 1979 in the West Branch Delaware River from Stilesville, NY to Hancock, NY (Sheppard 1983). Fish samples were obtained from pools, runs, and riffles, via boat electrofishing with relative fish abundances categorized. Fourteen fish species were encountered of which the white sucker was widely distributed and dominate in abundance. Between the 1977 and 1979 surveys, brown trout extended their range downriver and were more abundant in the 1979 survey. Smallmouth bass were common only in the lower reach of the West Branch Delaware River during the 1979 survey; however, Sheppard (1983) thought that erratic river flow and water temperatures contributed to these findings. Fish species captured during both the 1977 and 1979 surveys that did not fluctuate in abundance included: white sucker, black nose dace, shield darter, brown bullhead, and margined madtom. Johnny darter, common shiner, cutlip minnow, longnose dace, fallfish, and American eel decreased in relative abundance from the 1997 to the 1979 survey.

In the early 1980's two general inventories were conducted by PFBC Area Managers. The first conducted in August, 1983 and used seven trap nets set in the Delaware Water Gap National Recreational Area. Ten different fish species were caught, of which rock bass (N = 230, 48.7%), white catfish (N = 118, 25.0%), and redbreast sunfish (N = 84, 17.7%) represented the majority of the total catch (Table 7.4). The second inventory was completed in the lower reach of the Delaware River at eight locations between Yardley, PA (RM 137.3) and the Lambertville wing dam (RM 179.0). This inventory was conducted during the summers of 1982 and 1983 and utilized multi-sized panel gill nets set parallel to shore to collect fish. Eleven different species were caught, of which white perch (N = 115, 64.2%) and channel catfish (N = 30, 16.7%) represented the majority of the total catch (Table 7.5).

The reporting of impingement and entrainment of fishes from power plant cooling water intake structures is required per Section 316(b) of the Clean Water Act. This statute directs the U.S. Environmental Protection Agency to ensure that the location, design, construction, and capacity of cooling water intake structures reflect the best technology available for minimizing adverse environmental impacts. Section 316(b) Phase II Rule generally applies to existing electric generating plants that use more than 50 million gallons per day of cooling water with the intent to reduce mortality according to National Performance Standards. The frequency of reporting is based on the plants need for relicensing through Federal Energy Regulatory Commission (FERC) and or a perceived need by the regulating state agency (PA DEP) and operating plant officials. This reporting also provides PFBC biologists with a measure of fish species occurrence and relative abundance in the reaches of river where these water intakes are located. In general, all impinged and entrained fish should be considered mortalities; particulalry entrained fishes which are normally eggs and larvae typically at many orders of magnitude higher mortalities than impinged fishes which are at a larger life stage. Within the non-tidal Delaware River, the Portland Generating Station located near Mount Bethel, PA (RM 206) is operated by Reliant Energy Incorporated is required to submit a 316(b) report. The Martins Creek Generating Station located near Martins Creek, PA (RM 194) is operated by Pennsylvania Power and Light uses closed loop cooling system and are not required to submit 316(b) reports. Below head of tide, the Fairless Hills Generating Station located near Falls Township, Bucks County, PA (RM 126) is operated by Exelon Energy and also required to submit 316(b) reports.

A variety of fish species are impinged and entrained at the Portland and Fairless Hills generating plants (Tables 7.6 and 7.7; AECOM Environmental, 2008; Kinnel et al. 2008). At the Portland station, margined madtom (N = 906), rock bass (N = 776), bluegill (N = 537), white sucker (N = 463), and channel catfish (N = 203) represented the majority (>81%) of impinged fish; whereas, sea lamprey (N = 1,301,022), channel catfish (N = 554,062), rock bass (N = 423,741), unknown sunfish (N = 396,995), and white suckers (N = 156,592) represent the majority (> 80%) of the total entrained fish, during the 2006 sampling. At the Fairless Hills station, channel catfish (N = 591), bluegill (n = 505), black crappie (N = 425), spottail shiner (N = 370), banded killifish (N = 191), and pumpkinseed (N = 136) represented the majority (>74%) of impinged fishes; whereas unidentified minnows (N = 896,983), American shad (N = 892,422), white perch (N = 515,089), and walleye (N = 332,912) were the majority (> 72%) of the entrained fish. Regarding other species of interest, relatively few smallmouth bass were impacted by either the Portland (impinged: N = 96, entrained: N = 0) or Fairless Hills (impinged: N = 18, entrained: N = 0) stations. Interestingly, a total of 26 larval shortnose sturgeon were entrained at Fairless Hills. Shortnose sturgeon is considered an endangered species in Pennsylvania. The entrainment of larval shortnose sturgeon was likely the result of a combination of environmental conditions, which included a period of abnormally low river flow followed by a relatively rapid increase precisely during the swim-up behavior of 9-14 day old larvae. This was considered a rare coincidence (Kinnel et al. 2008). These generating stations may also represent a significant source of mortality for American shad and river herring species resulting from the entrainment of larvae; however, due to the infrequent reporting requirements, these inferences are difficult to substantiate.

The Academy of Natural Sciences conducted a general inventory of fishes in the Upper Delaware Scenic and Recreational River and Delaware Water Gap National Recreational Area during 2004 to 2008 (Horwitz et al. 2008). The study was designed to determine the distribution and abundance of all fish species. The survey collected 54 and 48 and species in the DEWA and UPDE, respectively. White sucker, pumpkinseed, common shiner, golden shiner and fallfish were the most abundant (Table 7.8). The study identified permanent backwater areas as an important habitat for bridle shiner and other uncommon species in the parks. Other species, including American eel, brown bullhead, sea lamprey, brown trout, northern hog sucker, striped bass, and long nosed dace had higher abundances in high velocity currents, whereas others, including, satinfin shiner, golden shiner, spottailed shiner, and white sucker were more common in low velocity areas.

Essentially, the same species occurring within the West Branch Delaware and Delaware rivers are found in its tributaries. Exchange between the West Branch Delaware River and non-tidal Delaware River mainstem and their tributaries are largely unimpeded. Two exceptions are the Easton Dam (RM 0.0) at the mouth of the Lehigh River and the Delaware Canal, which exists from Easton, PA to Bristol, PA. While the Easton Dam does have a vertical slot fishway, fish must find a relatively small entrance chamber to enter the fishway and move into the Lehigh River. The PFBC annually monitors American shad passage in the spring (April –June) and has documented the passage of numerous resident species suggesting that exchange of fishes between the waters does occur (Table 7.9; Snyder and Arnold 1998, 1999, 2000, 2001, 2002, Arnold 2003, 2004, 2005, 2006, 2007, Arnold and Pierce, 2008). No monitoring of the fishway occurs other than during the spring; however, passage of resident fish is presumed to continue through the remainder of the year. Passage of American shad has not reached target goals designed to support a self-sustaining population in the Lehigh River Basin. The Delaware Canal also poses an impediment in Pennsylvania, particularly to smaller tributaries, which have been altered to drain into the canal. The canal eventually discharges into the Delaware River at various locks and overflow sluice gates. Some tributaries such as the Tohickon Creek, remain directly connected to the Delaware River mainstem and are not impeded by the presence of the Delaware Canal.

7.2 Mussel Assemblages

Protection and management of the mollusk populations of the Commonwealth has been tasked to the Pennsylvania Fish and Boat Commission under Title 30 of the Pennsylvania Code (30 Pa.C.S.A). These include both aquatic gastropod (limpets, slugs, and snails) and bivalve (clams and mussels) populations. The PFBC, Bureau of Fisheries, Division of Environmental Services, Natural Diversity Section in cooperation with the Pennsylvania Natural Heritage Program is tasked with protection of these species. All survey and data management activities are presently funded by the federal State Wildlife Grants (SWG) program in cooperation with PNHP partners.

Qualitative surveys for documenting the occurrence and abundance of freshwater mussels within the UPDE and DEWA were conducted by U. S. Geological Survey (Lellis, 2001, 2002; Table 7.10). In the UPDE a total of eight species of unionids were identified including the federally listed endangered dwarf wedgemussel. The most abundant was the Eastern Elliptio (98.7%) followed by Alewife floater (1.1%) and Eastern floater (0.08%). The Eastern Elliptio and

Alewife floater were commonly found throughout the length of the UPDE. Eastern Floater was mostly found in soft sediments of slower-moving eddies between Damascus, PA to Long Eddy, NY. Dwarf wedgemussel were located between Equinunk, PA downriver to Callicoon, NY in shallow water habitat with gravel and sand substrate. In an effort to protect and enhance populations of the dwarf wedgemussel, Cole et al. (2008) established recommendations for wetted perimeter in the UPDE waters.

In the DEWA, a total of eight species of mollusks were encountered. The most abundant was the Eastern Elliptio (97.7%) followed by Alewife floater (1.9%) and Creeper (0.18%). The Eastern Elliptio was found in all but two sites in variety of habitat types including riffle to pool. The greatest numbers occurred in shallow runs with steady flow. Alewife floater were also uniform in distribution among all habitats but abundance tended to increase below Poxono Island to the Water Gap. Creepers were sporadically distributed but usually occurred in quiet water containing silt or sand substrate. A single dwarf wedge mussel was identified just below Port Jervis, NY and was thought to be displaced from the Neversink River. In the DEWA the greatest diversity of mollusk species occurred around islands between Tocks Island and the Water Gap.

Below the Water Gap, there is little published information on the distribution and diversity of freshwater mussels. However, PPL completed a number of mussel surveys following an accidental release of coal fly-ash into the river in 2005 and determined that the mussel fauna is similar to that found above the Water Gap (Arcadis-BBL 2007). These surveys found Eastern Elliptio to be numerically dominant, with Alewife floater and triangle floater at much lower densities. Although the variability in Eastern Elliptio densities was found to be high among sites, across all sites the densities were around 10 individuals/m^2. Such a high density of mussels in the Delaware River is important to note and preliminary data from other sections of the Delaware River suggest that Eastern Elliptio maintains a similar density for most sections of the river (E.L. Silldorff, *pers. comm.*).

7.3 <u>Insects & Macroinvertebrates Assemblages</u>

The West Branch Delaware and Delaware rivers contain an extraordinarily diverse and healthy assemblage of aquatic macroinvertebrates, including hundreds of species among the insects, snails, clams, and other groups, while across the entire Delaware River Basin more than 800 species of aquatic invertebrates have been collected and identified (Bilger *et al.* 2005).

Annual monitoring by the DRBC in riffle habitats since 2001 provides extensive information on the relative abundances of the different invertebrate groups in these shallow fast-water areas, and a means of assessing the effects of human influences on the river (Silldorff and Limbeck 2009). Supplemental monitoring by the USEPA in 2006 for slower water habitats (glides and pools) complements the DRBC information and leads to a more complete understanding of the importance of different groups throughout the river (Blocksom and Flotemersch, unpublished report). Overall, four groups of invertebrates dominate the assemblage in the Delaware River, with changes in their relative importance among habitats. The mayflies (Ephemeroptera) are diverse and abundant in most river habitats, with their numbers averaging 25% to 35% of the individuals collected in a typical sample across all areas. The Chironomidae midges (fly larvae / Diptera) and a broad group consisting of non-insect invertebrates are likewise abundant and diverse, but their relative abundance is greatest in slow-flowing areas of the river where they each can average 30% of a typical sample. In the faster-flowing riffles, both of these groups are less common and each typically average about 10% of a sample. The caddisflies (Trichoptera) show the opposite pattern across habitats with relatively high abundance (30%) in the faster riffle areas but relatively low abundance in the slow-flowing areas of the river (5%). Additional groups found throughout the river include stoneflies (Plecoptera), dragonflies and damselflies (Odonata), dobsonflies (Megaloptera), beetles (Coleoptera), aquatic catterpillers (Lepidoptera), lacewings (Neuroptera), and other fly larve (Diptera).

Although the ecological assessment of the river based on the macroinvertebrate assemblage is preliminary at this time, important patterns do emerge from the analysis. Overall, the invertebrate assemblage is both diverse and relatively well-balanced, with important contributions from all major groups of invertebrates throughout the West Branch Delaware and Delaware rivers from Hancock, NY to Trenton, NJ In the upper reaches of the river, the coldwater releases from New York City's reservoirs have a measurable effect on the structure and composition of the invertebrates from Hancock, NY through Long Eddy, NY. In the lower reach of the river, the multiple effects from the Lehigh River have negatively affected the invertebrates, reducing their diversity and shifting the assemblage toward more tolerant organisms (Figure 7.1; E.L. Silldorff, *pers. comm.*). The effect of the Lehigh River is particularly troubling as it may represent the largest single impact to the biological community from the various anthropogenic influences in the basin requiring further investigation.

7.4 Amphibians and Reptiles

Detailed occurrence data pertaining to amphibian and reptile occurrence and populations in the West Branch Delaware and Delaware rivers is limited. In Pennsylvania, the PFBC is the agency responsible for the protection and management of amphibians and reptiles. This falls under the Division of Environmental Services, Natural Diversity Section. Table 7.11 is a PFBC checklist of species expected to occur in the West Branch Delaware and Delaware rivers and potentially occurring in the floodplain. The PFBC maintains an information webpage regarding identification of the states amphibians and reptiles at http://www.fish.state. pa.us/amp_rep.htm. Rough distribution maps of amphibians and reptiles occurring in Pennsylvanian can be obtained from the Pennsylvania Herpetological Atlas at http://www.paherpatlas.org/distribution-maps. A more comprehensive treatise on Pennsylvania herpetofaunna natural history and distribution can be found in Hulse *et al.* (2001). Present threats to the native amphibians and reptiles of Pennsylvania include, but are not limited to, habitat loss and degradation due to water pollution, acid precipitation, wetland drainage, and changing land-use patterns.

The Delaware Water Gap National Recreational Area is home to 9 frog and toad species, 13 species of salamanders, 1 species of newt, 14 species of snakes, 10 species of turtles, and two species of lizards (Table 7.12). Many of these amphibians and reptiles suffer population declines from habitat loss or fragmentation, illegal collection, and commercial exploitation. Of the park's 26 species, 8 are of "special concern" in one or both states (Pennsylvania or New Jersey), and one species -- the bog turtle -- is state endangered and also protected under the Endangered Species Act of 1973. In recognition of salamander migrations, the National Park Service temporarily closes River Road within the Park jurisdiction (http://www.nps.gov/dewa/naturescience/upload/cmsstgAMPHI.pdf).

7.5 Non-jurisdictional Vertebrates (birds and mammals)

A diverse array of birds and mammals utilize the aquatic habitats and inhabit the surrounding riparian areas of the West Branch Delaware and Delaware rivers. Stewardship of these animals is within the purview of the Pennsylvania Game Commission (PGC; http://www.pgc.state.pa.us/).

The Delaware River Basin is recognized on a national and state level for many characteristics related to bird breeding and migration. It is located along the Atlantic Flyway, one of four major waterfowl migratory routes in the U.S. The Nockamixon Cliffs historically provide nesting sites for the Peregrine Falcon. Bald Eagles use the river's shoreline and islands for winter habitat. State endangered osprey is making a comeback through a reintroduction program. The Least Bittern, a PA threatened species, breeds in Upper Bucks County.

Various organizations document occurrence and abundance of these animals. Specifically, PGC provides a real-time online checklist program, eBird (http://ebird.org/content/pa), to maximize the utility and accessibility of the vast numbers of bird observations made each year by recreational and professional bird watchers. eBird documents the presence or absence of species, as well as bird abundance through checklist data. Additionally, the Northeast Pennsylvania Audubon Society also has an existing management plan (http://pa.audubon.org/IBA_Consplans/IBA60.pdf) for the UPDE and DEWA Parks.

7.6 Plants and Vegetation

The distribution of various vegetation communities, including terrestrial and vascular aquatic plants, has been documented to some extent in the non-tidal Delaware River.

Primary production

Primary production within the non-tidal Delaware River was quantified at selected locations in the upper, middle and lower reaches (Albert 1981). A total of ten sites were assessed from Hancock, NY to Yardley, PA. Phytoplankton productivity was low in the upper and middle reach sites (Hancock, NY, 34 mgO_2/m3/hr; Lackawaxen, PA, 40 mgO_2/m3/hr; Bushkill, PA, 25 mgO_2/m3/hr; and Smithfield Beach, PA, 31 mgO_2/m3/hr,) with the three most downriver stations having more than an order of magnitude increase in gross phytoplankton productivity in the lower reach (Upper Black Eddy, PA, 258 mgO_2/m3/hr; Bulls Island, NJ, 400 mgO_2/m3/hr; and Yardley, PA 671 mgO_2/m3/hr) at water depth of three feet. The author noted phytoplankton appear to be causing elevated pH (8.5 s.u.) and large diurnal variations in dissolved oxygen in the lower reach of the non-tidal Delaware River. Further, community primary production and community respiration ratios (P/R) ranged from 0.9 to 1.0 in the upper and middle reaches of the Delaware River, suggesting the Delaware River is a mature community. This ratio exceeded one at all of the sites in the lower reach (1.21 to 1.37) suggesting an autotrophic (self-sustaining) community with production increasing at each consecutive sampling site below Easton, PA.

Aquatic vegetation

Wahl (1959) annotated the occurrence and provided an identification key of aquatic plants in the upper and middle reaches and of the Delaware River from two float trips during July, 1959 (Table 7.13). In general, aquatic vegetation, except Elodea, was sparse, occurring chiefly where the current began to increase above a riffle. Riverweed (*Podostemum*) occurred on rock substrate in the relatively deeper riffles. Threadleaf crowfoot (*Rannuculus trichophyllus*) was abundant in the upriver portion of the survey, but infrequent or lacking in the downriver survey. Wahl (1959) also made several speculative conclusions noting that the entrance of the Lackawaxen River most likely produced a change in aquatic flora.

The most comprehensive survey on the river was completed by The Nature Conservancy between Hancock, NY, to a point downstream of Delaware Water Gap, PA (TNC 1994). The authors indicated that the UPDE and DEWA waters had a diverse and healthy aquatic vascular flora, seemingly un-impacted by current river use and recreation. A total of 31 significant aquatic beds were identified in 1991-1992 with the greater proportion (N = 20) of the significant beds located up-river of Port Jervis, NY. This study documented the presence of 28 species of vascular aquatic plants (Table 7.14). Waterweed, Illinois pondweed, clasping-leaved pondweed, and water-crowfoot were common throughout the surveyed waters. In addition, a New York state-threatened hornleaf riverweed was found to be abundant throughout the upper Delaware River. By contrast, a review of this species' status in Pennsylvania found that riverweed disappears at some point in the lower Delaware River (Munch 1993). Qualitative surveys by DRBC staff have tentatively identified this discontinuity at the Lehigh River, with extensive beds of riverweed located in the first riffle upstream (RM 184.1) from the Lehigh River confluence (RM 183.7) but the absence of the species in suitable habitats in any areas downstream from the Lehigh River (E.L. Silldorff, DRBC, *pers. comm.*). The Lehigh River contains elevated concentrations of many anthropogenic stressors as compared to the Delaware River, and similar extirpations from tributary pollution have been documented for this species elsewhere in Pennsylvania (Munch 1993). The role of water quality on riverweed distributions in the Delaware River requires further study.

Kratzer (1999) documented vascular plant occurrence and abundance in waters between Port Jervis, NY to Milford, PA, for use in water quality modeling. Through this research the areal extent and biomass of three common genera (*Elodea, Vallisineria,* and *Potamogeton*) was documented. Kratzer (1999) also noted a large section of the river reach within his study area was populated with periphyton assemblages on rocky substrates. Periphyton are microorganisms, diatoms and algae, which live attached to aquatic substrates and grow into expansive community beds.

In the Delaware River a substantial periphyton community exists. Traditionally, periphytons are assessed in conjunction with macroinvertebrates as an indicator of environmental stressors, such as excess nutrients; however, these communities also serve ecological functions including aquatic habitat. Limbeck and Smith (2007; http://www.state.nj.us/drbc/Periphyton_pilotstudy0307.pdf) completed a pilot study in 2005 for a periphyton monitoring network and found that eutrophication due to high nutrient concentrations may be problematic in the lower non-tidal portion of the Delaware River. The Delaware River generally possesses a diatom community characteristic of high water quality and high biological integrity. The northern Delaware River diatoms are more indicative of oligotrophic conditions, and below the Lehigh River, the diatoms were more representative of eutrophic conditions.

Terrestrial vegetation

Perles *et al.* (2007, 2008), and Davis *et al.* (2009) classified and mapped terrestrial vegetation for the riparian habitat and immediate surrounding drainage basin vegetation for the UPDE and DEWA reaches of the Delaware River. Refer to *Chapter 6.7 – Riparian Habitats* for further discussion.

7.7 Species of Special Conservation Concern (Federal and State)

In 1973 the federal Endangered Species Act (ESA; http://www.fws.gov/Endangered/pdfs/ESAall.pdf) was passed to protect and recover imperiled species and the ecosystems upon which they depend. Within Pennsylvania the PFBC and PGC collectively manage those species identified in the State Wildlife Action Plan. These include species identified for the federal ESA and state-level protection (Table 7.15). A comprehensive list and species status for the Delaware River basin by USGS HUC watersheds can be viewed on-line http://www.naturalheritage.state.pa.us/ AllSpecies.aspx. Through the designation in the State Wildlife Action Plan, funds are available for research and management measures via the State Wildlife Grants Program.

7.8 Non-native and Invasive Species

An invasive species is an alien species that causes economic or environmental harm, or harm to human health. Alien species are, with respect to the a particular ecosystem, any species including its seeds, eggs, spores, or other biological material capable of propagating that species, that is not native to that ecosystem. Aquatic invasive species are a sub-set of invasive species that impact aquatic ecosystems. Currently, Pennsylvania manages invasive species under the Aquatic Invasive Species Management Plan (PA Invasive Species Council 2006; http://www.anstaskforce.gov/State%20Plans/PA_AISMP. pdf). The goal for the Pennsylvania Aquatic Invasive Species Management Plan is to minimize the harmful ecological, economic and human health impacts of aquatic invasive species through the prevention and management of their introduction, expansion and dispersal into, within and from Pennsylvania. Within the PFBC, management of aquatic invasive species is jointly managed through the Bureau of Fisheries, divisions of fish Production Services, Environmental Services, and Fisheries Management. The PFBC maintains a web page information sheet (http://www.fish.state.pa.us/ais.htm) and public outreach programs (http://www.fish.state.pa.us/cleanyourgear.htm).

Within the Delaware River Basin there are very few locations remaining that are undisturbed or sufficiently resilient to resist the establishment of invasive species. The USGS maintains a listing of non-indigenous aquatic species (http://nas.er.usgs.gov/) which can be searched using Hydrologic Unit Codes. For the upper (HUC 02040101), middle (HUC 02040104) and lower (HUC 02040105) non-tidal Delaware River reaches, a total of 1 invertebrate, 1 crustacean, 2 mollusks, 24 fishes, 25 plants and 3 reptiles are currently listed (Table 7.16). Non-native or exotic fish species present in the non-tidal Delaware River and its basin waters are common carp, native to Asia and Europe; goldfish, native to Asia; and brown trout, native to Europe. Other fishes such as bluegill, smallmouth bass, rainbow trout, rock bass, and walleye are native to other areas of the U. S. which have been transplanted and naturalized into the Delaware River and its basin waters. A few of the listed fish such as alewife are native to the Delaware River mainstem, but are listed as non-native by USGS due their presence in lakes and ponds within the basin where they are not native. In their *2008 State of the Basin* report (DRBC 2008) the DRBC identifies invasive species that occur in the Delaware River Basin.

A few invasive species including the flathead catfish, northern snakehead, the diatom alga Didymo (*Didymosphenia geminata*), the red-eared slider and the closely related yellow-bellied slider are of some concern. Flathead catfish have only recently begun invading the lower reaches of the non-tidal Delaware River, but angler reports have suggested that it now occurs as far up river as Narrowsburg, NY (RM 290). Further, during 2010 fall sampling PFBC biologists' collected numerous YOY and adult flathead catfish at both the Sandts Eddy, PA (RM 189.2) and Point Pleasant, PA (RM 155.9) stations. The northern snakehead, while not currently recognized in the non-tidal reaches of the Delaware River does exist in the upper tidal waters. Both of these species are recognized to have voracious feeding behaviors, and their impacts to other fish are unknown.

In the upper reaches of the Delaware River and within the West Branch Delaware River, Didymo, commonly referred to as rock snot, is beginning to over-grow benthic habitats. Didymo is a microscopic diatom that rapidly colonizes to form thick grey, brown, and/or white cottony mats on river bottoms. Didymo is thought to be native to northern Europe and North America coolwater habitats; however, in recent years it has expanded in range. Specifically, in the upper reaches of the Delaware River, Didymo is quickly becoming a nuisance species that can interfere with the relationship between benthic macroinvertebrates and fish communities that forage on insects. Whereas, it was originally thought that the Didymo outbreak was composed of one species, there are now indications that the infestation in the upper Delaware may be comprised of multiple diatom species.

Red-eared sliders and yellow-bellied sliders are popular animals in the pet trade. The two species now have reproductive colonies and are spreading in the Delaware basin primarily as a result of intentional releases by well-meaning owners who, unable to care for the large, adult animals, release them into local waters. There they are believed to compete with native turtle species, including the Pennsylvania state threatened redbelly turtle, for habitat, food, and nesting sites.

7.9 Animal and Plant Health

The heath of Pennsylvania's fish falls within the purview of the PFBC through the Fish Health Pathology Unit in the Division of Fish Production Services. As part of routine sample processing the PFBC externally examines fish for the occurrence of diseases and pathogens, during field activities. Depending on frequency of occurrence and severity, specimens suspected of infection are sent to PFBC laboratories for diagnosing and tracking. The PFBC also investigates reports by anglers and interested citizens concerning the possibility of fish displaying compromised health conditions in waters open to public recreation. While many pathogens naturally occur in the waters of the West Branch Delaware and Delaware rivers, they typically do not cause widespread disruptions to fish populations. Currently, the USFWS and USGS with assistance from the PFBC are surveying smallmouth bass populations in the Delaware River within the Cherry Valley National Wildlife Refuge. This is being completed as part of an ongoing survey of disease occurrence within the National Wildlife Refuge System (http://www.fws.gov /Refuges/).

The disease VHS (Viral Hemorrhagic Septicemia) has emerged in Pennsylvania waters in recent years (Shiels undated, http://www.fishandboat.com/pafish/all/vhs/fact_sheet_ vhs.pdf; http://www.fish.state.pa.us/pafish/all/vhs/vhs.htm). VHS is a coldwater disease, which affects susceptible fish at water temperatures primarily between 37 and 54 °F. Hence, it is most often seen in the mid-to-late spring. The PFBC has adapted regulations (58 PA Code §§63.51, 71.8 and 73.3) relating to the sale, introduction, transportation and importation of VHS-susceptible species of fish (http://www.fish.state.pa.us/rulemakings/notices/2008_12_02vhs.pdf). The occurrence of VHS within the Delaware Basin has not been found to be widespread.

Most agency and public activities that are water related carry some level of risk of transporting unwanted fishes, aquatic species or pathogens. The PFBC staff has developed biosecurity protocols to reduce the risks associated with PFBC activities (http://www.fish.state.pa.us/cleanyourgear.htm). Approaches which address the pathways for the spread of unwanted aquatic organisms and manage those risks are needed to be better prepared for controlling the spread of diseases. Commission staff will continue to work internally and engage other resource agencies on regional and national levels to minimize the impacts of VHS and other unwanted aquatic invasive species.

7.10 Management Options

Priority 1: (on-going activities or recommendations to be implemented in first year of management plan).

- Develop a monitoring approach for providing characterization of the occurrence and quantification of fish communities within the West Branch Delaware and Delaware rivers. The intent is to provide a long-term baseline to identify species spatial and temporal trends inclusive of game and non-game fishes. Additionally, an anticipated study objective would also lend to the characterization of species of special concern and invasive species distributions and habitat utilization of fishes within the rivers.

Table 7.1. Indicator species for Atlantic basin fish communities as identified by the Pennsylvania Natural Heritage Program, Pennsylvania Aquatic Community Classification project.

Common name	Species
Atlantic Basin Fish: Coolwater Community 1	
Slimy sculpin	*Cottus cognatus*
Brown trout	*Salmo trutta*, stocked
Fathead minnow	*Pimephales promelas*
Pearl dace	*Margariscus margarita*
Atlantic Basin Fish: Coolwater Community 2	
Blacknose dace	*Rhinichthys atratulus*
White sucker	*Catostomus commersonii*
Golden shiner	*Notemigonus crysoleucas*
Atlantic Basin Fish: Warmwater Community 1	
Central stoneroller	*Campostoma anomalum*
Northern hogsucker	*Hypentelium nigricans*
River chub	*Nocomis micropogon*
Longnose dace	*Rhinichthys cataractae*
Cutlips minnow	*Exoglossum maxilingua*
Mottled sculpin	*Cottus bairdii*
Margined Madtom	*Noturus insignis*
Creek chub	*Semotilus atromaculatus*
Tosyface shiner	*Notropis rubellus*
Fantail darter	*Etheostoma fabellare*
Greenside darter	*Etheostoma blenniodes*
Atlantic Basin Fish: Warmwater Community 2	
Redbreast sunfish	*Lepomis auritus*
Rock bass	*Ambloplites rupestris*
Spotfin shiner	*Cyprinella spiloptera*
Fallfish	*Semotilus corporalis*
Smallmouth bass	*Micropterus dolomieu*
Spottail shiner	*Notropis hudsonius*
Common shiner	*Luxilus cornutus*
Tessellated darter	*Etheostoma olmstedi*
Pumpkinseed	*Lepomis gibbosus*
Bluntnose minnow	*Pimephales notatus*
Bluegill	*Lepomis macrochirus*
Green sunfish	*Lepomis cyanellus*
Satinfin shiner	*Cyprinella analostana*
Swallowtail shiner	*Notropis procne*
Yellow bullhead	*Ameiurus natalis*
Shield darter	*Percina peltata*
American eel	*Anguilla rostrata*
Largemouth bass	*Micropterus salmoides*
Common carp	*Cyprinus carpio*

Atlantic Basin Fish: Lower Delaware River Community	
White perch	*Morone americana*
Channel catfish	*Ictalurus punctatus*
Blueback herring	*Alosa aestivalis*
Eastern silvery minnow	*Hybognathus regius*
White catfish	*Ameiurus catus*
Striped bass	*Morone saxatilis*
Gizzard shad	*Dorosoma cepedianum*
American shad	*Alosa sapidissima*
Banded killifish	*Fundulus diaphanus*

Table 7.2. Listing of gamefish species within the West Branch Delaware River and Delaware River.

Common name	Species	Community	Nativity	Stocking
Alewife	*Alosa pseudoharengus*	Migratory	Native	
American eel	*Anguilla rostrata*	Migratory	Native	
American shad	*Alosa sapidissima*	Migratory	Native	
Atlantic sturgeon	*Acipenser oxyrhynchus*	Migratory	Native	
Black Crappie	*Pomoxis*	Warm		
Blueback herring	*Alosa aestivalis*	Migratory	Native	
Bluegill	*Lepomis macrochirus*	Warm		
Bowfin	*Amia calva*			
Brown Bullhead	*Ameiurus nebulosus*			
Brown Trout	*Salmo trutta*	Cold		
Chain Pickerel	*Esox niger*			
Channel Catfish	*Ictalurus punctatus*			
Fallfish	*Semotilus corporalis*			
Gizzard shad	*Dorosoma cepedianum*	Migratory	Native	
Hickory shad	*Alosa mediocris*	Migratory	Native	
Largemouth Bass	*Micropterus salmoides*	Warm		
Muskellunge (and hybrids)	*Esox masquinongy*			Yes
Northern Hog Sucker	*Hypentelium nigricans*		Native	
Northern Pike	*Esox lucius*			
Pumpkinseed	*Lepomis gibbosus*			
Rainbow Trout	*Oncorhynchus mykiss*	Cold		
Redbreast Sunfish	*Lepomis auritus*		Native	
Rock Bass	*Ambloplites rupestris*		Native	
Sea lamprey	*Petromyzon marinus*	Migratory	Native	
Shortnose sturgeon	*Acipenser brevirostrum*	Migratory	Native	
Smallmouth Bass	*Micropterus dolomieu*			
Striped bass	*Morone saxatilis*	Migratory	Native	
Walleye	*Sander vitreus*	Transitional		
White Catfish	*Ameiurus catus*			
White Crappie	*Pomoxis annularis*			
White Perch	*Morone americana*			
White Sucker	*Catostomus*	Transitional		
Yellow Bullhead	*Ameiurus natalis*			
Yellow Perch	*Perca flavescens*			

Table 7.3. Checklist and abundance of species collected during the Tri-state rotenone survey in the Delaware River, 1959-1962. Adopted from Springer and Groutage (1967**).**

	EB	WB	Long Eddy	Milanville	Mongaup	Matamoras	Black Is.	Tocks Is.	Belvidere	Raubs Is.	Marshall Is.	Scudders Falls	Trenton
Number of samples	3	3	3	4	3	1	4	3	2	2	3	1	1
Alewife				1					2		1	523	75
American eel		27		1	5		6	1	4	31		6	30
American shad	5		25	719	306	14	1186	1517	674	49	390	77	
Banded killifish	1	6	62	12			24	7	20	71	18	6	35
Black crappie				1			1			20	3	23	
Blacknose dace	361	13	69	21			14	6	1	3	9		
Blueback herring												291	50
Bluegill		2	1	1	7	1		5		89	7	5	
Bluntnose minnow										2	2		
Brown bullhead	1	5	17	39	2		29	15	17	132	73	152	5
Brown trout	65	3	139	1			1	2		3			
Carp						24	103	15	57	1	19	20	
Chain pickerel	47	10	14	6	4	7	10	1	1		2	1	
Channel catfish											49	29	
Comely shinner	324	13	51	966	13	3	125	48	24	25	34	1	
Common shiner	568	706	1419	1036	10		1794	189	44	41	14		
Creek chub	6	6	6	1							17		
Creek chubsucker										2	1		
Cutlip minnow	924	393	1360	791	169		382	185	18		2		
Fallfish	1570	765	1952	894	189	341	4674	1709	595	59	90	3	
Golden shiner	22	33	37	1			25	3	66	286	117	8	8
Goldfish								1	1	46		12	
Green sunfish									1	7			1
Johnny darter	367	54	285	154	2	19	37	29	86	45	32	12	20
Largemouth bass				4	2	1	5	6	16	14	4	14	
Longnose dace	1357	253	167	2	39	17	380	49	31	32	78	6	
Marginated madtom	506	300	396	670	245	1	670	12	3	6	2	45	
Mummichog													300
Pumpkinseed	2	6	31	57	2		31	1	2	121	39	2	8
Quillback								2			7	30	
Rainbow trout	3		79	3									

Redbreast sunfish	14	160	234	484	387	47	261	161	138	57	265	4	10
Redfin pickerel								1	1	1		1	
Rock bass	2	154	59	241	75	10	157	62	106	8	18		
Watinfin shiner	397		628	512	135	45	843	1100	201	288	132	13	
Sea lamprey	1												
Shield darter	495	473	271	629	15		654	241	45	8	17	1	
Silvery minnow											126	1696	36
Smallmouth bass	10	206	158	1061	294	94	1028	648	308	46	21		
Spottail shiner	214	35	608	399	18	103	1390	1557	195	829	5083	2475	9
Stoneroller	92	217	36	21									
Striped bass										5	19	1	
Swallowtail shiner	93	2	41	379	1		30	133	22	135	65		
Walleye	40	9	14	115	7	16	52	12	43	5		1	
White catfish				1			1	2	19	1	44	69	5
White crappie									1			7	
White perch										7	73	221	296
White sucker	545	375	1137	242	128	350	2307	1544	1020	392	449	88	100
Yellow perch	8	3	6	10	6		30	1		5		32	

Table 7.4. Total catch by species from the PFBC trap net survey in the Delaware Water Gap National Recreation Area in August 1983.

	River Mile							
Species	**210.6**	**217.9**	**225.9**	**228.**	**234.3**	**238.6**	**246.0**	**Total**
Effort (hours soaked)	147.6	150.0	138.0	48.0	47.0	37.2	46.0	
Black Crappie	5							5
Bluegill	2			1			3	6
Brown Bullhead				1	1			2
Channel Catfish	1	2	8	1	3			15
Muskellunge		1						1
Pumpkinseed	7		1					8
Redbreast Sunfish	19	1	42		1	1	20	84
Rock Bass	33	36	103	12	15	4	27	230
Smallmouth Bass		1	2					3
White Catfish	23	8	50	8	25		4	118
Total	90	49	206	23	45	5	54	472

Table 7.5. Total catch by species from the PFBC experimental gill net survey in the Delaware River from Yardley, PA upriver to Lambertville wing dam (Lambertville, NJ).

	River Mile								
Species	**137.30**	**143.97**	**152.28**	**155.99**	**159.39**	**168.08**	**174.85**	**179.00**	**Total**
	1982								
Effort (hours soaked)	94.4	112.5	100.6	116.6	89.1	93.7			
Brown Bullhead		2							2
Channel Catfish	9	14		1	1				25
Pumpkinseed	1								1
Redbreast Sunfish					1				1
Rock Bass			2						2
Smallmouth Bass	1		2	1					4
Walleye				1					1
White Catfish	1	1		1	1				4
White Perch	46	19	8	3	4				80
Total	58	36	12	7	7				120
	1983								
Effort (hours soaked)					120.6	118.0	127.5	140.3	
Black Crappie							1		1
Brown Bullhead						1			1
Channel Catfish					1	3		1	5
Redbreast Sunfish					1	1	2	1	5
Rock Bass					1	1			2
Smallmouth Bass					2				2
Walleye						1	1		2
White Catfish					2	2	1	1	6
White Perch					18	6	11		35
Total					25	15	16	3	59

Table 7.6. Impingement and entrainment of fishes at the Portland Generating Station. Adapted from AECOM Environment (2008). E = egg; YSL = yolksac larvae; L= larvae; YOY = young-of-the-year.

	Fish length statistics			Impingement		Entrainment	
Species	**Mean (cm)**	**Min (cm)**	**Max (cm)**	**Total collected**	**Annualized estimate**	**Life stage**	**Annualized estimate**
Alewife	11.2	8.9	16	5	61	L	37172
American shad				20			
Black crappie	9.2	8.2	10.3	3	34		
Bluegill	14	3.9	33.8	20	537		
Brown trout				1			
Brown bullhead	6.4	6.4	6.4	4	13		
Channel catfish	15.5	5.1	20.6	8	203	J	55406
Common carp						YSL	67141
Fallfish	9.6	9.6	9.6	1	15		
Fathead minnow	5.1	5.1	5.1	1	13		
Johnny darter						L	13864
Gizzard shad	36.5	36.5	36.5	4	14		
Golden shinner				1			
Largemouth bass				7		YSL	19320
Logperch						L	11087
Margined madtom	8.8	6.1	12.6	14	906		
Pumpkinseed	11.9	5.4	79	4	56		
Quillback				1			
Redbreast sunfish	20.3	19.4	21.3	3	34		
Rock bass	14.1	5.3	21.4	42	776	L	42374
Sea lamprey				2		YSL	13010
Smallmouth bass	16.5	8	30.1	13	96		
Spotfin shiner						L	38706
Spotted sunfish				1			
Swallowtail shiner	10.2	10.2	10.2	1	10		
Tessellated darter	8.2	7.9	9	7	143		
Trout-perch						YSL	11087
Uknown centrarchid						E	39699
Unknown clupeidae	6.3	6.3	6.3	1	47		
Unknown perch						L	36676
Unknown shiner	7.2	7.1	7.2	4	26	L	54329
Unknown sucker						E	15659
Unknown sunfish	20.6	20.6	20.6	2	7	L	14743
Unknown sunfish						J	19320
Walleye	46.8	46.8	46.8	1	13	YSL	11087
White catfish	5.5	5.5	5.5	1	47		
White sucker	35.7	6.7	48	10	463	L	37836
White sucker						YSL	10254
Yellow perch	13.4	13.4	13.4	1	13		
Total				**183**	**3529**		**3,813,**

Table 7.7. Impingement and entrainment of fishes at the Fairless Hills Generating Station. Adapted from Waterfield *et al.* (2008). E = egg; YSL = yolksac larvae; L= larvae; YOY = young-of-the-year.

	Length statistics (cm)			Impingement		Entrainment		
	mean	**min**	**max**	**Total collected**	**Annualized estimate**	**Life stage**	**Total collected**	**Annualized estimate**
Alewife	66	52	73	3	18			
American eel	171.8	34	325	5	31	YOY	16	70,087
American shad						E	5	892,422
Atlantic croaker	34	34	34	1	6			
Atlantic menhaden						L	1	4,380
Banded killifish	7.15	53	97	31	191			
Bay anchovy						L	8	35,043
Black crappie	96.5	62	127	69	425			
Blue crab	32	25	43	11	68			
Blueback herring	55	53	57	2	12			
Bluegill	67	34	178	82	505			
Brown bullhead	60	60	60	1	6			
Carp						E	6	35,795
Channel catfish	93.9	44	181	96	591	YOY	17	74,467
Clupeidae						E	5	30,558
Cyprinidae						E	680	896,983
Fallfish	77	48	91	4	25			
Flathead catfish	92	70	127	3	18			
Fourspine						L	1	4,380
Gizzard shad	121.5	79	164	2	12			
Green sunfish	63.2	52	93	15	92			
Hogchoker	41.6	34	47	7	43	L	6	26,282
Lamprey						L	24	105,130
Largemouth bass	78	69	87	2	12			
Lepomis sp.	83.5	69	98	2	12	E	7	49,791
Margined madtom						L	6	26,282
Mummichog	75.7	56	86	3	18	L	3	13,141
Muskellunge	216	216	216	1	6			
Pumpkinseed	64.4	50	124	22	136			
Redbreast sunfish	97.8	81	127	4	25			
Rock bass	87	56	100	4	25			
Shortnose sturgeon						L	26	12,750
Smallmouth bass	157	117	204	3	18			
Spottail shiner	74.2	57	94	60	370	L	1	4,380
Striped bass						E	4	3,421
Tessellated darter	60.4	39	82	11	68	L	44	192,738
Unidentified						E	4	178,638
Walleye						L	76	332,912
White catfish	83	80	86	3	18			
White crappie	95.3	75	107	9	55			
White perch	64.6	40	144	20	123	E	592	515,089
White sucker	77	77	77	1	6	L	21	91,989
Yellow perch	149	89	204	6	37	L	8	35,043
Total				**483**	**2,976**		**1,863**	**36,317,014**
95% confidence interval				2,784-3,260			2,287,763 - 5,199,158	

Table 7.8. Total number of each fish species documented between 2004 and 2007 in the Delaware Water Gap National Recreational Park (DEWA) and Upper Delaware Scenic and Recreational River (UPDE). Adopted from Horwitz *et al.* (2008).

Common name	Rank	Total	DEWA	UPDE
Alewife	55	1		1
American brook lamprey	55	1	1	
American eel	8	1466	642	707
American shad	26	361	98	163
Banded killifish	25	191	7	19
Black crappie	45	16	13	2
Blacknose dace	7	1705	1091	134
Blueback herring	51	5	5	
Bluegill	11	1042	978	42
Bluespotted sunfish	23	284	82	166
Bluntnose minnow	20	311	0	46
Bridle shiner	27	173	87	70
Brook trout	39	56	55	1
Brown bullhead	12	1005	891	111
Brown trout	32	120	72	36
Central stoneroller	55	1		1
cf mottled sculpin	55	1		
Chain pickerel	28	161	108	51
Channel catfish	49	11	11	
Comely shiner	37	75	30	45
Common carp	43	27	9	14
Common shiner	5	2225	1223	816
Creek chub	30	132	91	1
Creek chubsucker	47	14	3	1
Cutlip minnow	13	950	175	402
Eastern mudminnow	34	92	9	83
Fallfish	3	2286	1030	938
fathead minnow	36	76	63	13
Gizzard Shad	40	55	2	53
Golden Shiner	4	2261	778	1474
Goldfish	51	5	5	
Green Sunfish	31	119	96	17
Largemouth Bass	18	442	392	34
Longnose dace	14	821	278	341
Margined madtom	19	329	76	249
Muskellunge	50	8	7	1
Northern hog sucker	42	39	17	18
Pumpkinseed	2	2628	2497	86
Quillback	51	5	5	
Rainbow trout	44	20	8	10
Redbreast sunfish	17	533	214	300
redfin pickerel	35	79	39	
Rock bass	16	585	256	294
Satinfin shiner	33	105	45	56
Sea lamprey	10	1343	262	1055

Shield darter	24	225	133	66
Slimy sculpin	22	287	225	
Smallmouth bass	15	7696	185	579
Spotfin shiner	38	63	40	
Spottail shiner	9	1200	768	423
Striped bass	48	13	3	10
Swallowtail shiner	29	141	93	29
Tessellated darter	6	2098	779	766
Walleye	41	53	24	29
Western mosquitofish	54	3		
White sucker	1	6444	3015	1709
Yellow bullhead	45	16	14	2
Yellow perch	20	303	192	109

Table 7.9. Total passage of fishes through the Easton Dam vertical slot fishway on the Lehigh River at the confluence of the Delaware. Monitoring was initiated in 1995 for the documentation of American shad spawning run during a three month window (April – June) and did not occur in the other months of the year. Adopted from Synder and Arnold (2000) and Arnold and Pierce (2009).

Year	1995	1996	1997	1998	1999	2000	2001	2002	2003	2004	2005	2006	2007	2008	2009
Gamefish															
Bass spp.	303	348	218	483	358	1149	377	584	221	147	161	1026	398	592	719
Catfish spp.	284	503	330	268	237	790	367	381	122	262	340	830	378	525	573
Chain pickerel	0	0	0	0	2	0	0	0	0	0	0	0	0	0	0
Crappie spp.	0	2	2	0	0	0	0	0	0	0	0	0	0	0	0
Muskellunge	9	6	1	0	3	10	8	7	2	11	3	2	6	9	8
Sucker spp.	1718	1607	435	209	2019	573	2292	1156	1867	3797	688	2549	9408	6960	3045
Sunfish spp.	368	289	130	210	140	1214	504	346	77	83	225	893	167	491	513
Trout spp.	109	43	79	193	111	231	267	309	75	199	313	282	160	129	170
Walleye	3	2	0	1	1	0	1	2	0	1	37	0	7	20	10
Yellow perch	2	31	2	0	2	0	3	1	0	0	1	6	0	0	0
Nongame fish															
Carp	338	1386	274	497	353	732	651	726	558	437	679	1322	600	640	567
Golden shiner	0	2	0	0	0	0	0	0	0	0	0	0	0	0	0
Minnows/Fallfish	0	4	11	63	221	67	279	109	66	351	258	257	14	15	55
Quillback	0	0	0	11	9	17	21	22	8	24	26	34	28	31	29
Migratory															
American eel	1	4	0	2	4	1	0	12	0	1	35	20	6	24	1
American shad	873	1141	1428	3293	2346	2094	4740	3314	422	754	675	2023	1397	408	425
Gizzard shad	51	23	15	45	1263	337	392	121	6	16	21	720	472	192	206
Herring spp.							0	0	0	1	11	0	0	0	0
Sea lamprey	6	27	38	22	181	253	894	490	233	6936	1882	1366	5657	4674	1738
Striped bass	19	5	1	0	0	0	0	1	0	1	3	1	3	2	0

Table 7.10. Freshwater mussel total count, catch-per-unit-effort, and percentage of total mussel population for the mainstem Delaware River in the Upper Delaware Scenic (UPDE) and Recreational River and Delaware National Water Gap Recreation Area (DEWA). Adopted from Lellis (2001, 2002).

Common name	Species	Total No.	CPUE	Percent
		UPDE		
Eastern elliptio	*Elliptio complanata*	181,747		98.71
Alewife floater	*Anodonta implicata*	2,075		1.13
Eastern floater	*Pyganodon cataracta*	143		0.08
Squawfoot/Creeper	*Strophitus undulatus*	109		0.06
Triangle floater	*Alasmidonta undulata*	15		0.008
Brook floater	*Alasmidonta varicosa*	14		0.008
Dwarf	*Alasmidonta heterodon*	13		0.007
Eastern pearlshell	*Margaritifera*	3		0.002
		DEWA		
Eastern elliptio	*Elliptio complanata*	120,382	123.5	97.67
Alewife floater	*Anodonta implicata*	2,448	2.51	1.99
Squawfoot/Creeper	*Strophitus undulatus*	223	0.23	0.18
Triangle floater	*Alasmidonta undulata*	91	0.09	0.07
Eastern floater	*Pyganodon cataracta*	77	0.08	0.06
Yellow lampmussel	*Lampsilis cariosa*	23	0.02	0.02
Brook floater	*Alasmidonta varicosa*	10	0.01	0.01
Dwarf	*Alasmidonta heterodon*	1	0.001	0.001

Table 7.11. List of amphibian and reptile species recognized by PFBC expected in the West Branch and non-tidal Delaware River and potentially occurring in the floodplain. P = potential/likely occurrence if the habitat is suitable; X = Confirmed specimen data with PFBC.

Common name	Species	Riverine	Floodplain
American Toad	Bufo americanus		P
Black Racer	Coluber constrictor		P
Brown Snake	Storeria dekayi		P
Bullfrog	Rana catesbeiana	P	P
Coastal Plain Leopard Frog	Rana sphenocephala		X
Common Garter Snake	Thamnophis sirtalis		X
Copperhead	Agkistrodon contortrix		P
Eastern Box Turtle	Terrapene carolina		P
Eastern Fence Lizard	Sceloporus undulatus		P
Eastern Hognose Snake	Heterodon platirhinos		P
Eastern Newt	Notophthalmus viridescens		X
Eastern Painted Turtle	Chrysemys picta picta	X	X
Eastern Ribbon Snake	Thamnophis sauritus		P
Eastern Spadefoot	Scaphiopus holbrookii		X
Five-lined Skink	Eumeces fasciatus		P
Fowler's Toad	Bufo fowleri		P
Gray Treefrog	Hyla versicolor		P
Green Frog	Rana clamitans	X	X
Jefferson Salamander	Ambystoma jeffersonianum		P
Map Turtle	Graptemys geographica	X	
Marbled Salamander	Ambystoma opacum		P
Milk Snake	Lampropeltis triangulum		X
Northern Cricket Frog	Acris crepitans		X
Northern Water Snake	Nerodia sipedon	X	
Pickerel Frog	Rana palustris	P	P
Rat Snake	Elaphe obsoleta		P
Redback Salamander	Plethodon cinereus		P
Redbelly Snake	Storeria occipitomaculata		P
Redbelly Turtle	Pseudemys rubriventris	X	
Ringneck Snake	Diadophis punctatus		P
Slimy Salamander	Plethodon glutinosus		P
Smooth Green Snake	Liochlorophis vernalis		P
Snapping Turtle	Chelydra serpentina	X	X
Spiny Softshell	Apalone spinifera	X	
Spotted Salamander	Ambystoma maculatum		P
Spotted Turtle	Clemmys guttata		P
Spring Peeper	Hyla crucifer		X
Stinkpot	Sternotherus odoratus	X	X
Timber Rattlesnake	Crotalus horridus		X
Wood Frog	Rana sylvatica		P
Wood Turtle	Glyptemys insculpta	X	X
Worm Snake	Carphophis amoenus		P

Table 7.12. Occurrence of amphibians and reptiles documented within the Delaware Water Gap National Recreational Area by Park ecologists.

Common name	Species	Abundance
	Amphibians	
Eastern American toad	*Bufo americanus americanus*	Abundant
Fowler's toad	*Bufo woodhousii fowleri*	Common
Northern cricket frog	*Acris crepitans crepitans*	Rare
Gray treefrog	*Hyla versicolor*	Common
Northern spring peeper	*Pseudacris crucifer crucifer*	Abundant
American bullfrog	*Rana catesbeiana*	Abundant
Green frog	*Rana clamitans melanota*	Abundant
Pickerel frog	*Rana palustris*	Common
Wood frog	*Rana sylvatica*	Common
Jefferson salamander	*Ambystoma jeffersonianum*	Rare
Spotted salamander	*Ambystoma maculatum*	Common
Marbled salamander	*Ambystoma opacum*	Common
Silvery salamander	*Ambystoma platineum*	Rare
Northern dusky salamander	*Desmognathus fuscus fuscus*	Common
Mountain dusky salamander	*Desmognathus ochrophaeus*	Rare
Northern two-lined salamander	*Eurycea bislineata*	Common
Long-tailed salamander	*Eurycea longicauda longicauda*	Rare
Northern spring salamander	*Gyrinophilus porphyriticus porphyriticus*	Uncommon
Four-toed salamander	*Hemidactylium scutatum*	Uncommon
Redback salamander	*Plethodon cinereus*	Abundant
Northern slimy salamander	*Plethodon glutinosus*	Uncommon
Northern red salamander	*Pseudotriton ruber ruber*	Uncommon
Red-spotted newt	*Notophthalmus viridescens viridescens*	Abundant
	Reptiles	
Eastern worm snake	*Carphophis amoenus amoenus*	Rare
Northern black racer	*Coluber constrictor constrictor*	Common
Northern ringneck snake	*Diadophis punctatus edwardsii*	Uncommon
Black rat snake	*Elaphe obsoleta obsoleta*	Common
Eastern hognose snake	*Heterodon platirhinos*	Uncommon
Eastern milk snake	*Lampropeltis triangulum triangulum*	Uncommon
Northern water snake	*Nerodia sipedon sipedon*	Common
Smooth green snake	*Opheodrys vernalis*	Rare
Northern brown snake	*Storeria dekayi dekayi*	Common
Northern redbelly snake	*Storeria occipitomaculata occipitomaculata*	Common
Eastern ribbon snake	*Thamnophis sauritus sauritus*	Uncommon
Eastern garter snake	*Thamnophis sirtalis sirtalis*	Common
Northern fence lizard	*Sceloporus undulatus hyacinthinus*	Uncommon
Five-lined skink	*Eumeces fasciatus*	Uncommon
Northern copperhead	*Agkistrodon contortrix mokasen*	Uncommon
Timber rattlesnake	*Crotalus horridus*	Uncommon
Common snapping turtle	*Chelydra serpentina serpentina*	Abundant
Painted turtle	*Chrysemys picta*	Abundant
Spotted turtle	*Clemmys guttata*	Uncommon
Wood turtle	*Glyptemys insculpta*	Uncommon
Bog turtle	*Glyptemys muhlenbergii*	Rare
Common map turtle	*Graptemys geographica*	Uncommon
Redbelly turtle	*Pseudemys rubriventris*	Rare
Eastern box turtle	*Terrapene carolina carolina*	Uncommon
Red-eared slider	*Trachemys scripta elegans*	Rare
Common musk turtle	*Sternotherus odoratus*	Uncommon

Table 7.13. Listing of aquatic vascular plant occurrence from Wahl (1959) survey of the upper and middle Delaware River reaches.

Species	Characterization	Stockport	Stalker	Damascus	Narrowsburg	Masthope	Lackawaxen	Shohola	Pond Eddy	Port Jervis	Milford	Dingmans	Egypt Mills
Potamogeton illinoensis	freq. throughout	x	x		x				x			x	x
Potamogeton hybrid	freq - Shohola to Bushkill							x	x	x	x	x	x
Potamogeton perfoliatus var.	freq. throughout	x	x	x	x				x	x		x	x
Potamogeton crispus	freq - Pond Eddy to Bushkill								x	x	x	x	x
Potamogeton berchtoldi fieber	infreq. – Port Jervis to Bushkill									x		x	x
Elodea nuttallii	common throughout	x	x	x	x			x	x	x	x	x	x
Elodea canadensis	rare – Stockport only	x											
Ranunculus trichophyllus	freq – Stockport to Stalker.	x						x		x			
Podostemum		x	x	x	x	x	x	x	x	x	x	x	
Podostemum ceratophyllum	common – rocks in riffles throughout												
Vallisneria americana	occasional Pond Eddy to Bushkill								x		x	x	x
Heteranthera dubia	occasional Pond Eddy to Bushkill								x	x	x	x	x
Isoetes engelmanni	Stockport and Damascus	x	x	x									

Table 7.14. Abundance of identified vascular aquatic plants within the Upper Delaware Scenic and Recreational River and Delaware Water Gap Recreational Area, 1991-1992. Adopted from TNC (1994).

Name	**Scientific name**	**Abundance**
Water-starwort	*Callitriche heterophylla*	Rare
Spring water-starwort	*Callitriche verna*	Rare
Coontail	*Ceratophyllum demersum*	Rare
waterweed	*Elodea spp.*	Abundant throughout
Water star-grass	*Heteranthera dubia*	Rare (Hancock – Lackaxwen;
Engelmann's quilwort	*Isoetes engelmannii*	Rare
Riverbank quillwort	*Isetes riparia*	Rare
duckweed	*Lemna minor*	Rare
Water milfoil	*Myriophyllum spicatum*	Rare
Yellow pond-lily	*Nuphar luteum*	Rare
Small yellow pond-lily	*Nuphar microphyllum*	Rare
Water-lily	*Nymphaea odorata*	Rare
Golden Club	*Orontium aquaticum*	Rare
Riverweed	*Podostemum*	Abundant throughout
Water smartweed	*Polygonum amphibium*	Rare
Curly pondweed	*Potamogeton crispus*	Common Callicoon – Slateford Ck
Ribbonleaf pondweed	*Potamogeton epihydrus*	Rare
Illinois pondweed	*Potamogeton illinoensis*	Common throughout
Knotty pondweed	*Potamogeton nodosus*	Uncommon Hancock – Callicoon; Rare
Clasping-leaved	*Potamogeton perfoliatus*	Common throughout
Slender pondweed	*Potamogeton pusillus*	Rare
Snailseed pondweed	*Potamogeton spirillus*	Rare
Flat-stemmed pondweed	*Potamogeton*	Rare
Hybrid pondweed	*Potamogeton hybrid*	Uncommon throughout
Water-crowfoot	*Ranunculus trichophyllus*	Common throughout
Bladderwort	*Utricularia vulgaris*	Rare
Eel-grass	*Vallisneria americana*	Rare Hancock – Lackawaxen;Common

Table 7.15. Threatened and endangered species as listed in the Federal Endangered Species Act and Pennsylvania by Title 58, Chapter 75 of the Pennsylvania Code. Status: E = Endangered; T = Threatened; C = Candidate; SOC = species of concern.

Common Name	Species	Listing Agency	Status
Alewife	*Alosa pseudoharengus*	NMFS	SOC
American brook lamprey	*Lampetra appendix.*	PA	C
Atlantic sturgeon	*Acipenser oxyrinchus*	NMFS/PA	C/E
Banded sunfish	*Enneacanthus obesus.*	PA	E
Black bullhead	*Amerius melas.*	PA	E
Blueback herring	*Alosa aestivalis*	NMFS	SOC
Bog Turtle	*Clemmys muhlenbergii*	USFWS	T
Bog Turtle	*Glyptemys muhlenbergii.*	PA	T
Bowfin	*Amia calva*	PA	C
Bridle shiner	*Notropis bifrenatus.*	PA	E
Broad-headed Skink	*Eumeces laticeps.*	PA	C
Clubshell	*Pleurobema clava*	USFWS	E
Coastal Plain Leopard	*Rana sphenocephala.*	PA	T
Dwarf Wedgemussel	*Alasmidonta heterodon*	USFWS/PA	E/T
Easter Puma	*Felis concolor couguar*	USFWS	E
Eastern mudminnow	*Umbra pygmaea.*	PA	C
Eastern pearlshell mussel	*Margaritifera margaritifera.*	PA	T
Eastern Spadefoot Toad	*Scaphiopus holbrookii.*	PA	T
Hickory shad	*Alosa mediocris*	PA	E
Indiana Bat	*Myotis sodalis*	USFWS	E
Ironcolor shiner	*Notropis chalybaeus.*	PA	E
Longear sunfish	*Lepomis megalotis.*	PA	E
New Jersey Chorus Frog	*Pseudacris triseriata kalmi.*	PA	T
Northeastern Bulrush	*Scirpus ancistrochaetus*	USFWS	E
Northern riffleshell	*Epioblasma torulosa*	USFWS	E
Orangefoot Pimpleback	*Plethobasus cooperianus*	USFWS	E
Pink Mucket	*Lampsilis abrupta*	USFWS	E
Piping Plover	*Charadrius melodus*	USFWS	T
Red-bellied Turtle	*Pseudemys rubriventris.*	PA	T
Rough Pigtoe	*Pleurobema plenum*	USFWS	E
Shortnose sturgeon	*Acipenser brevirostrum*	NMFS/PA	E/E
Small Whorled Pogonia	*Isotria medeoloides*	USFWS	T
Timber Rattlesnake	*Crotalus horridus.*	PA	C
Virginia Spiraea	*Spiraea virginiana*	USFWS	T

Table 7.16. Species identified by the USGS on their non-indigenous aquatic species listing for the non-tidal Delaware River, by Hydrologic Unit Code. The upper Delaware River (HUC 02040101), middle Delaware River (HUC 02040104; 02040105). NT = native transplant from other river basins within the North American contenient (i.e., not endigienous to the Delaware River Basin).

Group	Common name	Species	Origin	Upper Del. R.	Middle Del. R	Lower Del. R.
Coelenterates-Hydrozoans	freshwater jellyfish	*Craspedacusta sowerbyi*	Exotic	x	x	x
Crustaceans-Crayfish	rusty crayfish	Orconectes rusticus	NT			x
Fishes	pirapatinga, red-bellied pacu	Piaractus brachypomus	Exotic			x
Fishes	bowfin	*Amia calva*	NT	x	x	
Fishes	mimic shiner	*Notropis volucellus*	NT	x		
Fishes	rudd	*Scardinius*	Exotic	x		
Fishes	tench	*Tinca tinca*	Exotic			x
Fishes	goldfish	*Carassius auratus*	Exotic		x	x
Fishes	common carp	*Cyprinus carpio*	Exotic		x	x
Fishes	rock bass	*Ambloplites rupestris*	NT		x	x
Fishes	green sunfish	*Lepomis cyanellus*	NT		x	
Fishes	bluegill	*Lepomis macrochirus*	NT			x
Fishes	smallmouth bass	*Micropterus dolomieu*	NT		x	
Fishes	largemouth bass	*Micropterus salmoides*	NT		x	
Fishes	black crappie	*Pomoxis nigromaculatus*	NT		x	x
Fishes	white crappie	*Pomoxis annularis*	NT			x
Fishes	channel catfish	*Ictalurus punctatus*	NT			x
Fishes	flathead catfish	*Pylodictis olivaris*	NT			x
Fishes	wiper	*Morone chrysops x M.*	NT			x
Fishes	muskellunge	*Esox masquinongy*	NT		x	
Fishes	rainbow smelt	*Osmerus mordax*	NT		x	
Fishes	walleye	*Sander vitreus*	NT	x	x	x
Fishes	rainbow trout	*Oncorhynchus mykiss*	NT	x	x	
Fishes	Atlantic salmon	*Salmo salar*	NT	x		
Fishes	brown trout	*Salmo trutta*	Exotic	x	x	
Mollusks-Bivalves	Asian clam	*Corbicula fluminea*	Exotic		x	x
Mollusks-Gastropods	mud bithynia, faucet snail	*Bithynia tentaculata*	Exotic		x	

Plants	smooth field sow thistle	*Sonchus arvensis*	Exotic		x	
Plants	Creeping whorled mint, gingermint	*Mentha gracilis*	Exotic		x	
Plants	oriental lady's thumb, bristly lady's	*Polygonum caespitosum*	Exotic		x	
Plants	Field sow thistle	*Sonchus arvensis*	Exotic		x	
Plants	True forget-me-not	*Myosotis scorpioides*	Exotic		x	
Plants	water-cress	*Nasturtium officinale*	Exotic		x	x
Plants	Creeping yellow cress	*Rorippa sylvestris*	Exotic		x	
Plants	giant chickweed	*Myosoton aquaticum*	Exotic			x
Plants	Eurasian water-milfoil	*Myriophyllum spicatum*	Exotic		x	x
Plants	Spearmint	*Mentha spicata*	Exotic		x	
Plants	hydrilla	*Hydrilla verticillata*	Exotic			
Plants	yellow iris	*Iris pseudacorus*	Exotic			
Plants	purple loosestrife	*Lythrum salicaria*	Exotic		x	x
Plants	European water-clover	*Marsilea quadrifolia*	Exotic		x	x
Plants	Redtop, black bent, water bentgrass	*Agrostis gigantea*	Exotic		x	
Plants	Barnyard grass	*Echinochloa crusgalli*	Exotic		x	
Plants	rough-stalked meadow grass	*Poa trivalis*	Exotic		x	
Plants	Lady's thumb, smartweed, spotted	*Polygonum persicaria*	Exotic		x	
Plants	Bitter dock	*Rumex obtusifolius*	Exotic		x	
Plants	curly pondweed	*Potamogeton crispus*	Exotic	x	x	x
Plants	Moneywort	*Lysimachia nummularia*	Exotic		x	
Plants	Bittersweet nightshade	*Solanum dulcamara*	Exotic		x	x
Plants	mudmat	*Glossostigma*	Exotic			
Plants	European brooklime	*Veronica beccabunga*	Exotic			
Plants	water-chestnut	*Trapa natans*	Exotic		x	x
Reptile - Turtle	Red-eared slider	*Trachemys scripta*	Exotic			
Reptile - Turtle	Diamond-backed Terrapin	*Malaclemys terrapin*	NT			x
Reptiles-Crocodilians	American Alligator	*Alligator mississippiensis*	NT		x	

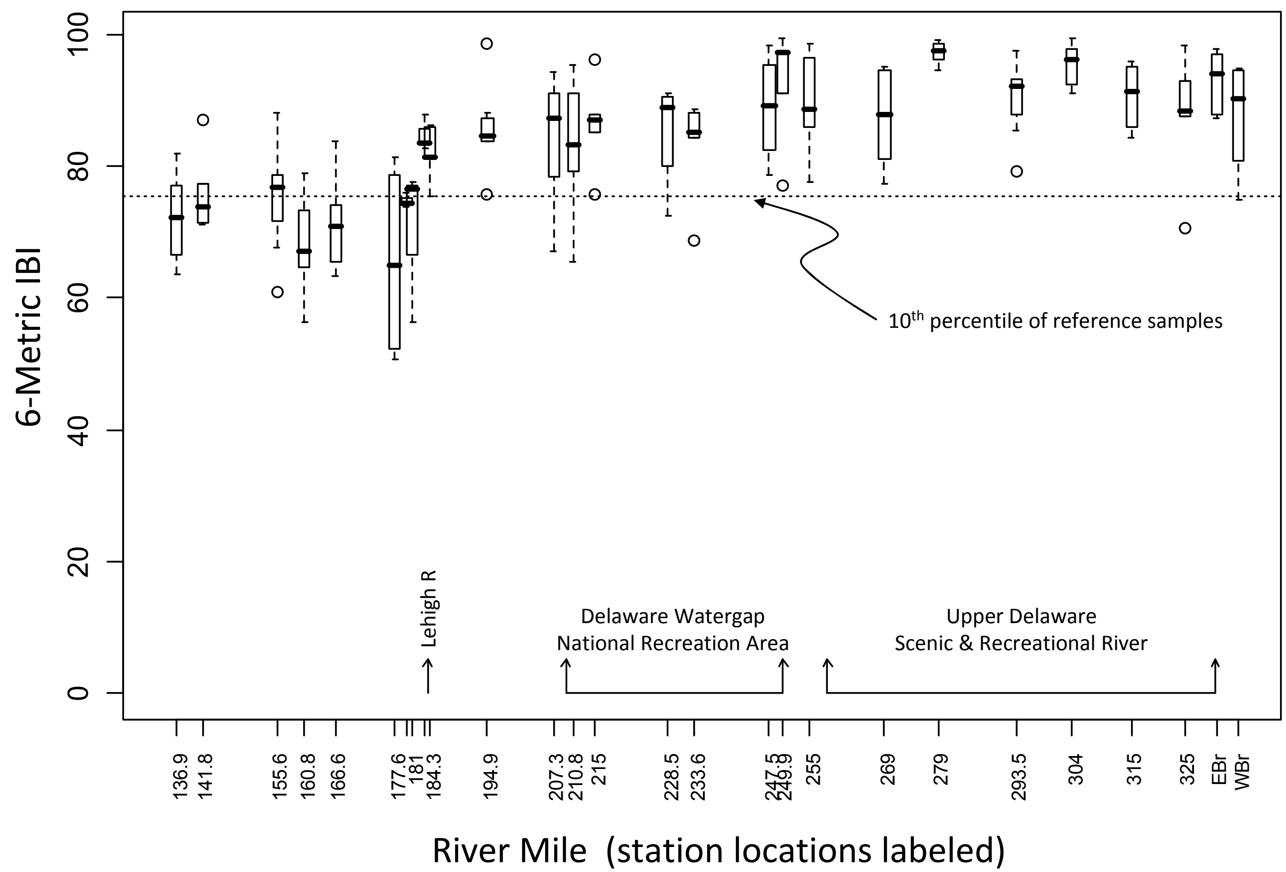


Figure 7.1. Box-and-Whisker Plot of DRBC Index of Biological Integrity (IBI) for Riffle-Based Macroinvertebrate Samples, 2001-2008 (adopted from Silldorff & Limbeck 2009).

8.0 Fisheries

The West Branch Delaware and Delaware rivers support a diversity of fisheries. Today, these fisheries are principally recreational. With the exception of a few commercial netting/weir operators licenses, which are permitted by both New York and New Jersey, major commercial netting/weir operations no longer exist in the non-tidal reaches of the Delaware River Basin. Pennsylvania does not permit traditional commercial netting/weir operations within the Commonwealth's waters.

The PFBC strives to offer anglers a variety of fishing experiences through the protection, conservation, and enhancement of aquatic resources. A goal of the PFBC Division of Fisheries Management (DFM) is to manage species-specific fisheries for optimizing angler experiences. The DFM proactively manages individual gamefish to achieve species-specific target management benchmarks. Attainment of target benchmarks requires fisheries managers to employ a variety of management techniques, which may include fishery resource assessments, angler use and harvest surveys, implementation of regulations, and the stocking of forage and gamefish species. Fisheries assessments are conducted through the periodic monitoring of established survey sites sampled at the same time of year with similar types of equipment. These surveys provide PFBC biologists' with data needed to evaluate management strategies. Most surveys are conducted to monitor the status of key gamefish species or fish species that are being restored. Key gamefish species in the West Branch Delaware and Delaware rivers include brown trout, rainbow trout, smallmouth bass, and American shad, a species that has been the focus of restoration efforts. Walleye, muskellunge, channel catfish American eel, panfish species (bluegill, redbreast sunfish, and rock bass), and flathead catfish are species generally supporting relatively smaller fisheries.

8.1 Management Sections

The PFBC, Division of Fisheries Management often manages large flowing water resources based on management sections. These sections target specific river reaches based on similar water conditions or physical habitat in those reaches. Management strategies including regulations and stockings can then be directly related to specific reaches. The West Branch Delaware is managed as one section while the Delaware River is divided into eight management sections. Combined, these waters encompass 204.5 river miles (West Branch Delaware River: 7.5 RM; non-tidal Delaware River: 197 RM) extending from the New York – Pennsylvania state border near Balls Eddy, PA to the head of tide near Trenton, NJ (Table 8.1).

8.2 Fishing Regulations

Fisheries management strategies can include the use of regulations. Regulations are crafted to control the angler impact on a fish population and typically act to restrict on angler use and harvest of fish by limiting the length a fishing season is open, limiting the total number of fish an angler can legally harvest per day, or limiting the minimum length that a fish must reach to be harvested. Fishing for all species in the West Branch Delaware and Delaware rivers are currently regulated under §61.1 of the Fish and Boat Code Commonwealth Inland Regulations. An abridged summary of regulations is annually updated and made available free of charge to all anglers (Table 8.2; http://www.fish.state.pa.us/bookfish.htm).

Given the roles of the West Branch Delaware and Delaware rivers as political borders with New York and New Jersey to Pennsylvania, these waters are managed under standardized regulations among basin states. However some variation occurs due to individual state objectives. Electronic listing of fishing summary regulations for the shared boundary waters is at http://www.fish.state.pa.us/fishpub/summary/delaware.html for Pennsylvania, http://www.dec.ny.gov/outdoor/7917.html for New York and at http://www.state.nj.us/dep/fgw/digfsh09.htm for New Jersey. Reciprocal recognition of fishing licenses is recognized. A Pennsylvania or New York license is valid on the Delaware River (including the West Branch Delaware River) between New York and Pennsylvania when fishing from a boat or from either shore (http://www.fishandboat.com/fishpub/summary/boundary.html). A Pennsylvania or New Jersey license is valid on the Delaware River between New Jersey and Pennsylvania when fishing from a boat or from either shore. Anglers must abide by all rules and regulations of the state in which fishing is occurring and where a vessel was retrieved.

The National Saltwater Registry (https://www.countmyfish.noaa.gov/) is a relatively new program requiring all anglers to register either with the federal program or individual states that issue acceptable alternatives to the federal registry. The PFBC has entered into an agreement with the National Oceanic and Atmospheric Administration (NOAA) exempting Pennsylvania anglers from the National Saltwater Registry. The exemption will remain in effect while the PFBC works to establish its own free registration for applicable anglers. The states of New York, New Jersey, and Delaware all maintain their own registrations as alternatives to the National Saltwater Registry. Anglers fishing the West Branch Delaware and Delaware rivers in New York waters need to have a valid New York Marine License if targeting migratory fishes.

8.3 Stocking Programs

Historically, the PFBC has stocked a variety of fish species into the West Branch Delaware River and Delaware River mainstems (Table 8.3). However, stocking has been substantially reduced in recent years in favor of managing for self sustaining populations of fish. Only muskellunge fingerlings are consistently stocked annually into the Delaware River by the PFBC. Fingerling muskellunge, ranging in length from 5-6 inches, are stocked in late summer to early fall months in fishery management sections 04, 05 and 06. Tiger muskellunge were also stocked during the same period and season in sections 07 and 08. This program was recently adjusted with the intent of enhancing the existing fisheries by concentrating stockings in selected reaches. Sections 05 and 06 were targeted for increased stocking rates while stocking was discontinued in section 04 beginning in 2006. To date, no evaluation of the changes in the muskellunge stocking program as it relates to the Delaware River has been conducted. The discontinuance of stocking walleye in 2008 was in accordance with the state-wide program to determine if natural reproduction of walleye was capable of supporting recreational angling in Pennsylvania's rivers. This evaluation is under development pending recommendations in the

PFBC Walleye Management Plan. The NYDEC presently does not stock any fish in the West Branch Delaware and Delaware rivers. Further, NYDEC has not stocked trout into the West Branch Delaware River since 1994. Some fish, particulalry muskellunge and walleye are stocked into the Delaware River by New Jersey.

Restoration Programs

Since 1985, the PFBC has been actively involved in a hatchery-based effort to restore American shad to the Lehigh and Schuylkill rivers, major tributaries of the Delaware River. The goal of this program is to achieve a returning run of 165,000 – 465,00 adult American shad to the Lehigh and Schuylkill rivers, providing 20,000 to 100,000 angler trips with an estimated economic value of $508,000 to $2,540,000 annually (PFBC 1988). American shad have strong homing instincts to return to natal waters for spawning. The PFBC restoration program anticipates hatchery-raised fry will return to the waters in which they were stocked three to four years following stocking (Hendricks et al. 2002).

As part of the PFBC restoration program, live, spawning-condition, adult American shad are captured from the Delaware River at Smithfield Beach (RM 218.0). These shad are strip-spawned to provide eggs for hatchery rearing at the PFBC Van Dyke Shad Research facility. Prior to release into the Lehigh and Schuylkill rivers, all shad fry reared at the research facility are marked by immersion in oxy-tetracycline in order to distinguish them between wild shad during subsequent evaluations (PFBC 2004; Arnold and Pierce, 2006). Since 2003, all fry reared from Delaware River eggs have been stocked within the Delaware River Basin. Hatchery fry are stocked in equal numbers in the Lehigh and Schuylkill rivers. Any excess American shad are stocked back into the Delaware River at Smithfield Beach. The intention is to mitigate the spawning potential loss to the Delaware River shad population from the strip-spawning operation. Unfortunately shad passage appears insufficient to reach restoration goals in these rivers. The PFBC is currently working to find alternative solutions for improving fish passage at existing fishways within the Lehigh River.

8.4 <u>Fish Consumption Advisories</u>

Fish consumption advisories are developed and updated each year through an interagency workgroup directed by the PA DEP that includes the PFBC, Pennsylvania Department of Agriculture, and the Pennsylvania Department of Health. Advisories originate from PA DEP testing results of fish tissues. Generally, when a consumption advisory is necessary it stems from elevated levels of mercury or polychlorinated biphenyls (PCB), which are known to bioaccumulate in piscivorous fishes. The extent of these compounds and other contaminants within the Delaware River Basin has been documented by USGS through their National Water-Quality Assessment Program (Fisher et al. 2004, Brightbill et al. 2004, Riva-Murray et al. 2003). Both mercury and PCB concentrations are variable in basin waters; however, trends in PCB concentrations in fish tissue at sites from Upper Knights Eddy, NY, Port Jervis, N,Y., Milford, PA, Delaware Water Gap, PA, Yardley, PA, and Trenton, NJ in the Delaware River showed improvement compared to historic levels (Riva-Murray et al. 2003).

Current consumption advisories are available on-line via the PFBC website (http://www.fishandboat.com/fishpub/summary/sumconsumption.pdf). Statewide, all recreationally caught sport fishes Pennsylvania are subject to a one-meal-a-week consumption advisory. One meal is considered to be one-half pound of fish for a 150-pound person. This advisory does not apply to fish raised for commercial purposes or bought in stores or restaurants. Table 8.4 lists specific consumption advisories for the West Branch Delaware and Delaware rivers. For further information or the most current advice contact: Dept. of Environmental Protection: 717-787-9637 (www.depweb. state.pa.us); Dept. of Health: 717-787-1708 (www.health.state.pa.us); or Fish & Boat Commission: 814-359-5147 (www.fish.state.pa.us).

8.5 Stock Assessments and Population Monitoring

Fixed Site Surveys - Methodology

The PFBC has established a series of sampling locations in the Delaware River focused on monitoring gamefish species. The intent of this sampling is to provide a means to track annual trends in species-specific populations. Inferences are drawn to describe general shifts of relative abundance, size and age-distributions. Locations of sampling sites were established based on the best known available habitat for a targeted species and typically termed “fixed stations”.

Within the Delaware River, the PFBC continuously surveys multiple fixed stations (Table 8.5). Fixed stations are sampled annually and principally target smallmouth bass populations. These sampling efforts include a midsummer survey targeting YOY smallmouth bass and early fall survey targeting all smallmouth bass. Other gamefish (e.g., walleye, trout) are considered secondary targeted species at these fixed stations and are most likely under-represented given that the sampling focus is on smallmouth bass. For example, the farthest up-river fixed station is near Damascus, PA, well below the upper Delaware River and West Branch Delaware River reaches where trout typically occur. The YOY smallmouth bass survey is conducted from mid to late-July using a single-pass backpack electrofishing technique. The fall survey (late September – October) is conducted as a single-pass nighttime flatbottom boat electrofishing technique focusing on shoreline habitat.

Smallmouth Bass Fishery

The smallmouth bass population of the West Branch Delaware and Delaware rivers is maintained entirely by natural reproduction. This fishery is generally located below Callicoon, NY. Annual PFBC monitoring of smallmouth bass YOY within the Delaware River highlights the variability in recruitment with catches ranging from 0.0 – 26.5 bass per 50 m of shoreline sampled (Figure 8.1). Peaks in YOY abundance were observed in 1991, 1995, 1997, 2001, 2005, and 2007. Comparison among sites suggests that the catch of YOY smallmouth bass tends to be greatest in the lower reach below Easton, PA; however, the catch of YOY smallmouth bass at the Matamoras, PA site in the upper reach can, at times, be high. The catch of YOY smallmouth bass was low in 2006. This was the result of strong flooding in late June, which effectively washed-out smallmouth bass fry. Similarly, high flows observed during nesting in 2009 also resulted in a low abundance of YOY smallmouth bass. This was more likely due to the lack of suitable shallow water habitat for nesting. Long-term data monitoring of smallmouth bass recruitment has determined that river flow is a plays a significant role in smallmouth bass recruitment success. Generally, YOY smallmouth bass abundance is above average during low flow years; whereas, YOY smallmouth bass abundance is below average in years of high or fluctuating flows during early summer.

The relative abundance of the entire (all ages) smallmouth bass population within the Delaware River is determined from fall surveys. The smallmouth bass population has been quite variable among years with electrofishing catches ranging from 10.8 – 170.0 bass/hr (Figure 8.2a). The total smallmouth bass catch in 2006 represent the greatest peak of relative abundance in the upper (Matamoras, PA to Damascus, PA) and middle (Easton, PA to Milford, PA) reaches of the Delaware River. Generally, the smallmouth bass population is well-represented by multiple size classes, however the occurrence of large bass (≥ 15 inch) is relatively rare. Since the adoption of the 12 inch minimum length regulation in 1991, there has been a slight increase in the catch of smallmouth bass greater than or equal to nine inches. There is no identifiable pattern in the catch of smallmouth bass ≥ 12 inches (Figure 8.2b) and ≥ 15 inches (Figure 8.2c). This is most likely due to their relatively low occurrence in the PFBC surveys. The catch of large bass (≥ 12 inches and ≥ 15 inches) in the middle and upper reaches of the river was exceptional in 2006. The catch of bass ≥ 12 inches was 15.7 bass/hr in the middle reach and 22.2 bass/hr in the upper reach, while the catch of bass ≥ 15 inches was 4.1 bass/hr in the middle reach and 1.8 bass/hr in the upper reach. These catches were well above the long-term average of 4.4 bass/hr and 0.8 bass/hr for bass ≥ 12 inches and ≥ 15 inches, respectively.

Examination of smallmouth bass catch by age suggests that the smallmouth bass population in the mainstem Delaware River is dominated by the younger age classes (Figure 8.3). Although varied, apparent peaks of relative abundance of age 1 and 2 year smallmouth bass occurred in 1992 and 2006 in all survey stations. With the exception of a peak in 2006, the relative abundance for ages 3 and 4 remained relatively stable in all years for all stations. There were no detectable trends of relative abundance for ages 5 – 7. This was primarily a funtion of their infrequent collection. Smallmouth bass older than 8 years of age at the time of capture were rare at any station in the mainstem waters. An objective of the smallmouth bass monitoring was to evaluate the potential of relating current adult age-class relative abundances to the past year-class. Results suggest that in Pennsylvania's large rivers, generally any age class (4+ or younger) recruitment index explained the most variation in the catch rate of smallmouth bass of the next older age of the same year-class (Lorantas et al. 2010). Further Lorantas et al. (2010) indicated age 1+ recruitment index explained more variability of older age classes than the age 0+ (YOY) recruitment index of the same year class.

In cooperation with the PFBC, the NYDEC also monitored the smallmouth bass population within their respective border waters to evaluate more restrictive harvest regulations for smallmouth bass (Angyal and Arnold 2008). Sampling for smallmouth bass was conducted from

1990 – 1995 at Sparrowbush, NY (RM 258), Pond Eddy, NY (RM 265), Narrowsburg, NY (RM 290), and Long Eddy, NY (RM 315). Catch-per-unit-effort (CPUE) for YOY smallmouth bass was highly variable (0.0 to 3.5 bass/50 m of shoreline surveyed) with peaks in relative abundance observed in 1991, 1993, and 1995 (Figure 8.4a). Catch-per-unit-effort for adults was also highly variable (4.0 to 63.2 bass/hour of electrofishing) with no consistent peaks of abundance among sites (Figure 8.4b). The YOY CPUE tended to decline at further upriver sites relative to downriver sites. It was unclear whether the variability detected between-sites was in part due to variations of adult spawning stock, spawning habitat, juvenile habitat, or juvenile mortality factors (Angyal and Arnold 2008). Similarity, there was no detectible trend in adult bass CPUE. Examination of the length-at-age data did not suggest any consistent trends attributable to the imposition of the minimum size regulation.

Trout Fishery

Since the building and subsequent operation of the Cannonsville Dam in the early 1960's on the upper West Branch Delaware River, the downriver tailwaters have supported a robust coldwater fish community dominated by populations of brown trout and rainbow trout. Brook trout also occur, but to a lesser extent and are mostly emigrants from local tributaries. Most wild trout inhabiting the tailwaters are spawned in tributary streams where they reside before immigrating to the large rivers, but reproduction does occur in the river reaches immediately downstream of the Cannonsville and Pepacton (East Branch Delaware River) dams. Wild trout populations are dominated by brown trout throughout the West Branch Delaware River; whereas rainbow trout comprise one-half to two-thirds of the wild trout population in the Delaware River between Hancock, NY and Lordville, NY. The most downriver extent of the trout fishery in the Delaware River is generally recognized to be Callicoon, NY (RM 303.7).

Most of the existing trout fisheries data has been gathered by the NYDEC, Division of Fish, Wildlife & Marine Resources. Sanford (1992) presented the status of the trout fishery in the upper Delaware River Basin, based on survey data collected in the 1980's. In the West Branch Delaware River, more consistent cold water temperatures resulted in a less diverse fish population and a more abundant trout population than in the East Branch Delaware River or upper Delaware River. Data collected in 1987 documented the trout biomass during an early summer survey near Stilesville, NY and Hale Eddy, NY to be between 11-17 lbs/ac. Angler catch rates of trout averaged 0.6-0.9 trout/hour from 1980-1990, while harvest rates average 0.13-0.14 trout /hour.

McBride (2002) documented trout movement in the upper Delaware Basin using radio-telemetry. A total of 111 adult brown and rainbow trout were implanted with radio transmitters throughout the West Branch Delaware, East Branch Delaware, upper Delaware, and lower Beaver Kill rivers (a tributary to the East Branch Delaware River) and tracked for three years (1995-1997). With the exception of trout tagged in the Beaver Kill River, which tended to remain within that system, radio tagged trout moved throughout the various river systems, mostly during summer months. Total distances traveled varied among species with wild rainbow trout ranging the greatest distance (127.1 mi) followed by wild brown trout (77.3 mi) and hatchery brown trout

(60.0 mi). The average distances traveled were 31.7, 18.8, and 13.1 mi for wild rainbow trout, wild brown trout and hatchery brown trout, respectively. Trout movement during the summer was due to high summer water temperatures, which required trout to seek thermal refugia somewhere within the system. Interestingly, McBride (2002) suggested that there did not appear to be a single temperature threshold that triggered trout movement during periods of elevated summer temperatures and documented the persistent presence of trout in the upper Delaware River mainstem during the summer of 1997 even during prolong period of high (>75.2 ^{o}F) water temperatures. Movement was also related to trout seeking suitable habitat within the river or river tributaries for spawning. Other movements occurred during times of the year that did not appear to be related to increases in water temperatures or associated with the spawning period. McBride's (2002) findings provide evidence that the trout in the upper Delaware Basin should be managed as a single population.

As part of a multi-year monitoring project Elliot (2001, 2004), and McBride (2008) documented the trout biomass within the West Branch Delaware and Delaware rivers. Trout population studies have been conducted most years since 1993 at four standardized study sites. These efforts were principally undertaken to evaluate the response of trout populations to various flow regimes created by the management of reservoir releases from the Cannonsville and Pepacton dams. Trends in trout biomass ranged from 4.7 lbs/ac to 166.1 lbs/ac with trout biomass generally being greater at the Stilesville, NY site as compared to the other sites at Deposit, NY, Hale Eddy, NY, and Balls Eddy, PA (Figure 8.5). The dramatic increase of trout density and biomass observed in 2006 and 2007 was due to the influx of hatchery stocked brown trout in Cannonsville Reservoir during the record flood of 2006. Hatchery trout of any kind were absent prior to 2006. In general terms, there was no apparent trend observed for trout abundance as flow regimes were further modified for supporting the tailwater fishery. Trout abundances recorded during 2004-2007 were generally within range of estimates reported during earlier sampling efforts. Elliot (2001) and McBride (2008) concluded that the inherent variability within the upper basin for trout populations precluded a clear statement on cause-and-effect benefits of flow releases from the NYC reservoirs to increased trout biomass.

In a further effort to examine benefits to trout populations in the West Branch Delaware River based on perceived improved reservoir releases, McBride (2008) examined wild trout abundance of young fish. It was anticipated that the habitat created and maintained by following the release schedule for NYC reservoirs outlined in Revision 7 over the three year period (2005-2007) would result in increased numbers of fingerling, yearling and two year old trout. Inferences were limited to age 1-3 wild brown trout. Results at Stilesville, NY documented a clear increase of age 1 brown trout densities; however, densities of age 1-3 wild brown trout at the remaining three downriver sites were highly variable among years (Table 8.6). Environmental conditions, including three major flood events (September 2004, April 2005, and June 2006), most likely impacted trout populations and masked any benefits of the Revision 7 releases (McBride 2008).

The PFBC has conducted only four surveys in the shared border wasters of the West Branch Delaware River since 1980 (Billingsley 1980, 1986, Arnold 2003). Few adult trout were collected from the SR 0191 pool (RM 1.2; brown trout: N = 9; rainbow trout: N = 1) or the Home pool (RM 2.3; brown trout: N = 17; rainbow trout: N = 1) off Winterdale Road (Billingsley 1980, 1986). Arnold (2003) surveyed the Balls Eddy pool (RM 4.6) and the SR 0191 pool to assess the biomass of brown trout and rainbow trout in the West Branch Delaware River. Young-of-the-year trout assessments were conducted via day backpack electrofishing along the Pennsylvania shoreline. Abundance of yearling and older trout were assessed via nightboat electrofishing. In the Balls Eddy pool, a total of 122 YOY and 323 adult brown trout and 6 YOY and 26 adult rainbow trout were collected. Brown trout and rainbow trout biomass estimates were 254 kg/ha and 49.26 kg/ha, respectively. Brown trout and rainbow trout abundance in the SR 0191 pool were estimated to be 11.87 kg/ha and 4.56 kg/ha, respectively. Arnold (2003) also documented the presence of migratory fish including American eel, sea lamprey, and American shad, but did not quantify their abundance.

The West Branch Delaware and Delaware rivers are managed for naturally reproducing brown trout and rainbow trout. Target benchmarks for these species have not yet been established by the PFBC; however the PFBC classifies trout biomass within the West Branch Delaware River as supportive of Class C mixed (brown trout and rainbow trout) wild trout population (Arnold 2003). The upper Delaware River reaches; encompassing fishery management sections 01 and 02 downriver to Peggy Run (RM 289.0) just below Narrowsburg, NY, supports a low density (Class D) wild trout population. The mainstem waters downriver from Interstate 84, trout are generally considered to be emigrants from stocked tributaries.

In their 1992 *Fishery Management Plan for the Upper Delaware Tailwaters*, the NYDEC established a series of benchmarks for both the West Branch Delaware River and upper Delaware River reach for trout populations (Sanford 1992). The original intent was to provide both short and long-term targets, with the achievement of the long-term targets dependent on changes in trout fishing regulations and management of releases from the NYC reservoirs. The NYDEC determined a long-term target benchmark for trout catch rate in the West Branch Delaware and Delaware rivers of 1.0 trout per hour with a harvest rate not to exceed 0.1 trout per hour (Sanford 1992). These long-term objectives sought to create opportunities for anglers to consistently observe and catch wild, trophy size, trout in designated reaches of the river where the anticipated average length of harvested trout was approximately 14 inches with a corresponding weight of 1.0 pound. McBride (2002) clearly demonstrated that trout freely move throughout the upper Delaware River Basin, inclusive of the East Branch Delaware, West Branch Delaware and upper Delaware rivers, and suggested trout management in these reaches be considered as one system. With respect to this consideration, the PFBC and the NYDEC have a long history of standardizing fishing regulations for the West Branch Delaware and Delaware rivers. More restrictive trout fishing regulations were enacted in 1992 including a minimum length of 12" and a creel limit of 3 trout per day while maintaining the traditional Opening Day of trout (second Saturday in April to September 30th). These regulations were in place in both the West Branch Delaware River and upper Delaware River, above Interstate 84. In 1995, the creel limit was further reduced two trout per day while retaining the same season and minimum length limit in the West Branch Delaware River; whereas, the minimum length limit was changed to 14 inches and the creel limit was changed to 1 trout/day in the upper

Delaware River. In 1996, a catch and release artificial lures only season from September 30 – Opening Day was initiated. The season was amended to October 15th - Opening Day in 2006. Additionally, a no-kill season in the West Branch Delaware River limits fishing to artificial lures only from October 16th until 8:00 a.m. on the Opening Day of trout season. Above the Pennsylvania-New York border, a 2.0 mile Catch and Release, Artificial Lures Only section is available in the reach below Deposit, NY.

In addition to the trout fishery, Sanford (1992) also noted the presence of other gamefish species. Management strategies for these gamefish in the West Branch Delaware River are secondary to the existing trout fishery. Less than 1% of the angling effort was directed at warmwater and migratory species as determined by creel surveys (Sanford, 1993; McBride, 2003).

The trout fishery within the West Branch Delaware River provides exemplary angling opportunities. This fishery extends into the upper Delaware River, as supported in part by improved reservoir releases from the NYC reservoirs for supporting a coldwater tailrace. Given the importance of trout in providing recreational angling opportunities in the upper Delaware River, additional directed sampling of the trout population is necessary to properly characterize the existing population. Monitoring efforts need to be broadened to encompass waters inclusive of the reaches above Callicoon, NY. This need is exemplified by the publication of the NYDEC-PFBC white paper advocating reservoir releases for supporting a coldwater ecosystem in the upper Delaware River.

Channel Catfish Fishery

The channel catfish fishery within the Delaware River is maintained entirely by natural reproduction. It is perceived that channel catfish are well distributed throughout the Delaware River; however no monitoring surveys have been accomplished for characterizing channel catfish population within the Delaware River. Assessment protocols for channel catfish will be forthcoming in the anticipated PFBC Catfish Management Plan.

Ancillary information pertaining to channel catfish in the lower reaches of the Delaware River may be obtained from the catch records of the Lewis haul seine fishery. In 2008 the Delaware River Basin Fish and Wildlife Management Cooperative contracted the Lewis haul seine fishery to provide catch records for all species landed during their annual spring fishery for American shad. Catfish species represent one of the most commonly caught species in the Lewis haul seine, representing 18.0 to 49.1% of the total catch in a given year.

Walleye Fishery

Walleye are a popular sport fish in the Delaware River. Traditionally, the PFBC has stocked fingerling walleye to maintain this fishery, but was discontinued in 2008 to determine if natural reproduction was sufficient to sustain the fishery (Table 8.3). Traditionally, YOY and adult walleye have not been the focus of PFBC's sampling efforts in the Delaware River. These fish were collected as a secondary target species during the smallmouth bass fall fixed station surveys. Collections of walleye have been infrequent in these surveys, but occurrences indicate that walleye are well distributed throughout the Delaware River. Catch rates were highly variable (0.2 to 5.9 fish/hour) with YOY composing 0.0 to 34.7% of the total catch (Figure 8.6). The underrepresentation of walleye catches in the PFBC surveys precludes dawning inferences of trends in walleye populations. Additional directed sampling of the walleye population is necessary to properly characterize the existing population. Anticipated sampling protocols are being developed by PFBC in their state-wide Walleye Management Plan.

Monitoring of the walleye populations in the upper reaches of the Delaware River were accomplished by the NYDEC to evaluate more restrictive harvest regulations for walleye in cooperation with the PFBC (Angyal and Arnold 2008). All survey work for adults was accomplished during late-September from 1990 – 1995 at Sparrowbush, NY(RM 258), Pond Eddy, NY (RM 265), Narrowsburg, NY (RM 290), and Long Eddy, NY (RM 315). Catch-per-unit-effort for adult walleye was variable (0.6 to 13.6 fish/hour) with no consistent peaks in abundance among sites (Figure 8.7). The relatively low catch of walleye precluded conclusions about between site or between year differences in walleye size and age structures; however, the authors suggested that the 1987 and 1991 year classes were very strong.

Muskellunge (Purebred/Tiger) Fishery

There is a well known muskellunge fishery within the Delaware River. Smithfield Beach (RM 218.0) in the Delaware Water Gap National Recreational Area is frequently sought by anglers for its excellent muskellunge opportunities. Maintenance stocking of purebred muskellunge (Fishery Management Sections 05 and 06) and tiger muskellunge (Fishery Management Sections 07 and 08) occur annually in the Delaware River (Table 8.3). The muskellunge population is not actively monitored within the Delaware River. It is believed that muskellunge reproduce in the Delaware River to some extent, but it is unknown if the population can support the fishery through natural reproduction. The incidental catches of muskellunge and tiger muskellunge during the PFBC fall fixed station monitoring for smallmouth bass adults are not reflective of muskellunge and tiger muskellunge relative abundance in the Delaware River. Catches were primarily of YOY and most likely hatchery fingerlings given the timing of the fixed station survey, which occurred approximately 3 weeks after fingerling muskellunge stockings. Extensive investigation is required to address the success of stocking and characterization of the population.

Panfish Fishery

Panfishes (e.g, rock bass, red breast sunfish, bluegill) are commonly targeted sport fish within the Delaware River. All of these fish are maintained entirely by natural reproduction. These fish are well distributed throughout the Delaware River, but abundances are reduced in the coldwater tailrace of the NYC reservoirs. Within the Delaware River, no targeted monitoring of these fish occurs on an annual basis.

Migratory Species

Unique to the Delaware River Basin is its ability to sustain fisheries for migratory species (American shad, striped bass, river herring and American eel). Management strategies for migratory fishes are under the direction of the Atlantic States Marine Fisheries Commission (ASMFC) in which Pennsylvania is a participant. Further, within the Delaware River Basin including Pennsylvania, interstate fisheries issues are also vetted through the Delaware River Basin Fish & Wildlife Management Cooperative (DRBFWMC). A plethora of information is available pertaining to life history requirements, stock assessments, and commercial and recreational use of migratory species in the various species-specific ASMFC fisheries management Amendments, Addendums, and technical stock assessments. Please refer to their website at http://www.asmfc.org/ for a review of species-specific information.

American shad

Coast wide stock assessments along the Atlantic have been prepared for the ASMFC. The first stock assessment was conducted in 1988 (ASMFC 1988) using the Shepherd stock-recruitment model to estimate maximum stainable yield (MSY) and maximum sustainable fishing rate (F_{msy}). The Delaware River was characterized as having an MSY of 651,500 pounds, and F_{msy} of 0.795 but the Delaware River stock was currently depleted due to considerable pollution, which severely reduced the Delaware River shad populations. In 1998, a Thompson-Bell yield-per-recruit (YPR) model was used to derive overfishing definition (F_{30}) in river systems where information was available (ASMFC 1998). Findings indicated no evidence of recent stock declines for the Delaware River adult stock. Further, the 1998 assessment indicated no evidence of recruitment failure of YOY for the Delaware River. The latest Atlantic coast-wide American shad stock assessment was completed in 2007 (ASMFC 2007). This assessment indicated American shad stocks were at all-time lows and did not appear to be recovering; but the stock abundance and YOY production in the Delaware River was considered stable. Mortality rates were not estimated for the Delaware River stock given the perceived ambiguity of ageing from scale and otolith structures. The assessment identified the primary causes for the continued stock declines as a combination of excessive total mortality, habitat loss and degradation, and migration and habitat access impediments.

Over the past several decades, a significant amount of effort has been dedicated to the monitoring of returning adult spawning American shad and the subsequent outmigration of YOY in the Delaware River. Early efforts are summarized by Massmann (1971) and Miller et al. (1982) both of whom provide a comprehensive review of American shad in the Delaware River. In a review of the existing fisheries in the Delaware River during the 1960’s, Massmann (1971) noted that the returning American shad spawning run and subsequent outmigration were severely impacted by the pollution related dissolved oxygen block in the vicinity of Philadelphia, PA.

Early estimates of returning population abundance were assessed by mark and recapture studies (1975-1983, 1986, 1989, and 1992) and hydroacoustic assessments (1991-2007; Figure 8.8; Miller et al. 1975, Anonymous 2007). Mark and recapture population abundance estimates were conducted annually at the Lewis haul seine fishery, with tag recovery information obtained through a voluntary logbook diary of the sport fishery. Schafer estimates were calculated to overcome the high potential of downriver migration (potentially out of the recreational fishery). Peterson estimates ranged from 106,202 shad to 882,648 shad; suggesting an increasing abundance in the early 1990's. Schafer estimates tended to follow a similar pattern prior to 1980, after which, Schafer estimates tended to be considerasbly lower than Peterson estimates. Hydroacoustic technologies were initiated in 1992 as a means for providing a shad population index at a reduced level of effort than the mark/recapture surveys conducted in previous years. While the total American shad passage ranged from 22,800 to 524,300 suggesting that the stock rebounded from previous lows observed in the 1980's, the hydroacoustic monitoring program was terminated after 2007 due to unresolved issues of target identification, potential of over-estimation from duplicate counting and a loss of hydroacoustic gear due to flood events.

Since 1996, the PFBC has annually collected adult American shad during their spring spawning migration at a single station located in the Delaware Water Gap National Recreational Area at Smithfield Beach (RM 218.0). Efforts from this survey were principally to collect ripe American shad for strip spawning in support of the PFBC American shad restoration program for the Lehigh and Schuylkill rivers, tributaries of the Delaware River, and secondarily to provide biological data as required by ASMFC. The American shad population within the Delaware River is maintained entirely by natural reproduction. Specific methodology and detailed findings were described by Snyder and Arnold (1998, 1999, 2000, 2001, 2002), Arnold (2003, 2004, 2005, 2006, 2007), and Arnold and Pierce (2008). Prior to 1999, CPUE was defined as total shad catch per net and in later years (1999-present) expressed as total catch per time soaked weighted by total number of nets deployed each night of sampling (shad/foot-net-hour*10,000; Figure 8.9). Estimates of CPUE (shad/net) prior to 1999 suggest a decrease in the relative abundance of returning adult American shad from a peak in 1990 (15.9 shad/net), after which the CPUE (shad/net) remained relatively stable (mean = 3.4 shad/net). No apparent trend in estimated CPUE (shad/foot-net-hour*10,000) after 1999, was evident. Both indices however, did illustrate a peak relative abundance of returning shad in 2005 and 2010.

Estimated ages of American shad collected from the PFBC efforts at Smithfield Beach from 1996 to 2010 suggests relatively stable distributions among years (Figure 8.10). In general, females ranged in age from 3 through 8, with the majority being ages 4 and 5. Female shad over the age of 7 are rarely caught. Male American shad typically return to the Delaware River at a younger age than females, ranging from age 2 through age 6. The catch of male American shad is typically age 4 fish. Male shad over the age of 5 are rarely caught. Beginning in 2008, age determination through scale interpretation was discontinued in 2008, although scales continue to be collected and catalogued. American shad age determination is currently completed through otolith analysis. The discontinuation of the use of scales by the PFBC was based on the recommendations of the Delaware River Basin Fish and Wildlife Management Cooperative Technical Committee. This recommendation originated from the Atlantic States

Marine Fisheries Commission, American Shad and River Herring Technical Committee Stock Assessment Sub-committee. These recommendations were based on ambiguity of ages incurred by scale re-absorption by shad and sever erosion of the scale margin obscuring annual marks due to their lengthy migration up the Delaware River.

American shad are recognized as iteroparous spawners (ability to spawn for multiple years) in most northern rivers including the Delaware River. The frequency of repeat spawners is relatively low, conservatively estimated to represent less than 18% percent of the catch at Smithfield Beach (RM 218.0) in any given year. The majority of repeat spawners are second year spawners, principally from the previous year. The frequency of shad returning for more than two years is very low, representing less than 3.5% in any given year. No shad returning to Smithfield Beach have been documented beyond five repeated spawning seasons, and only a single female shad was identified as returning for four seasons.

The PFBC conducted a four year survey (1997 – 2001) of returning adult American shad at a fixed electrofishing station located in the proximity of Raubsville, PA (RM 178.5). The principle intent was to assess the restoration success of returning stocked American shad fry to the Lehigh River as spawning adults (Hendricks et al. 2002). A total of 653 American shad were caught during the ourse of this survey. The number of shad collected per hour of electrofishing was variable (1997: 29.2 shad/hr; 1999: 13.7 shad/hr; 2000: 30.8 shad/hr; and 2001: 49.2 shad/hr) among survey years. With the exception of 2001 when the median age for males was 4, the estimated ages of American shad from scales ranged from 3 to 8 with a median age of 5 for both females and males. Virgin spawners comprised the majority of shad collected; however, repeat spawning shad made up 9.0 – 26.4% of those collected. The percent contribution of hatchery-reared fry was estimated at 5 – 15% with significantly more marked shad originating from the Lehigh River being caught on the western shore which is influenced by the outflow of the Lehigh River (Hendricks et al. 2002).

Recently, additional characterization of the adult spawning American shad population was accomplished in the UPDE National Park during the spring of 2009 by the U.S. Fish and Wildlife Service, National Park Service, and NYDEC (Mohler 2010). Three pools, Sparrowbush (RM 258.1), Narrowsburg (RM 290.0), and Buckingham (RM 325.0) were electrofished for adult American shad in May 19-21, 2009. Eighty-four of the ninety-two shad that were caught were removed for biological assessment. Eight shad were implanted with a numbered plastic dart tag and released alive in anticipation of a future recapture to allow for a comparison of scales between capture years in an effort to verify aging structures. Catch-per-Unit-of-Effort (shad/hour electrofished) was less than 17.0 shad/hour at any of the three sites surveyed. American shad were not as frequently encountered at the Buckingham site relative to the two downriver sites. Ages estimated from otoliths ranged from 4 to 9 for females and 3 to 7 for males with median ages of 5 and 4 for females and males, respectively. Monitoring of these three pools was continued in 2010 and is funded by the National Park Service through 2013. Further, the PFBC re-initiated their American shad Raubsville, PA electrofishing survey in 2010 (CPUE: 22.9 shad/hour) for comparison of spatial trends of CPUE estimates of relative shad abundance in the upper Delaware River.

The outmigration of YOY American shad from the non-tidal Delaware River has been annually monitored by the New Jersey Department of Environmental Protection, Division of Fish and Wildlife from 1979 to 2007 (NJDEP 2007). Juvenile relative abundance was determined from seine hauls during August, September, and October at various locations in the Delaware River with the longest time-series at four locations including: Milford, PA (RM 246.0), Water Gap, PA (RM 211.0), Phillipsburg, NJ (RM 184.0), and Trenton, NJ (RM 133.0). Other sites (i.e., Yardley, PA, Lambertville, NJ, Fullers Hole, NJ, Delanco, NJ, Hawk Island, NJ, Raritan River, NJ, Byrum, NJ and Matamoras, PA) were sampled for various durations and eventually discontinued. Estimated geometric means ranged from 1.15 to 265.9 shad/haul, with the greatest peaks of relative abundance observed in 1996 (265.9 shad/haul) and 2007 (175.9 shad/haul; Figure 8.11). The non-tidal YOY index was discontinued in 2008 in favor of relying on the estuarine juvenile striped bass beach seine survey (1980-present) by NJDEP in which YOY American shad are routinely collected. Survey sites included for estimating YOY American shad outmigration occur from head of tide (RM 133.0) downriver to the Delaware Memorial Bridge (RM 68.7). The tidal CPUE estimated ranged from 0.13 to 18.2 shad/haul, which significantly correlated ($r^2 = 0.6194$) with the non-tidal index (Figure 8.11). This correlation relies on the detection of peak CPUE values. Thus, it is reasonable to use the tidal index to detect peak production years; however, mounting evidence suggests that the tidal beach seine survey is indexing a separate population of YOY American shad, and may not be representative of the non-tidal outmigration (Russ Allen, NJDEP pers comm.). Given the potential disparity between the tidal and non-tidal indices of American shad YOY production, it would be prudent to seek re-initiation of the non-tidal index for monitoring YOY production.

The Lewis haul seine fishery, located in Lambertville, NJ (RM 147.0), has been in existence prior to the beginning of the last century and represents the single remaining in-river commercial fishery for American shad in the non-tidal Delaware River. Information from this fishery is can provide a reasonable indication of spawning run strength. The CPUE (catch/haul) from this fishery increased significantly concurrent with the marked water quality improvements associated with implementation of the Clean Water Act. In the past 17 years however, the CPUE has declined (Figure 8.12) providing evidence that the American shad run in the Delaware River is significantly depressed from its highs in the late 1980’s and early 1990’s. In recent years the Delaware River Basin Fish and Wildlife Management Cooperative has contracted the Lewis haul seine fishery to provide catch data for all species landed since 2008 to ensure the continued time series and for use as an index of returning shad relative abundance.

The American shad fishery in the Delaware River relies on the annual spawning run of adult shad returning to their natal river for spawning. In 2010, the ASMFC approved Amendment 3 to the Interstate Fishery Management Plan for Shad and River Herring, declaring significant restrictive management regulations for shad populations by the year 2013. These restrictions are dependent on a states’ ability to demonstrate that angling activities will not diminish the potential future stock reproduction and recruitment. The PFBC is currently working with the basin states through the DRBFWMC to develop a Delaware River Basin American shad

Management Plan. Anticipated elements of the American shad plan are to determine the sustainability of Delaware River American shad population, identify target benchmarks and methods for assessment of those benchmarks, and provide a strategy for the recovery of American shad within the basin. Monitoring efforts by the PFBC for American shad will be adjusted based on the suggested management actions of this anticipated Delaware River American shad Management Plan. A draft document will need to be submitted to ASMFC Shad and Herring Technical Committee by August 1, 2011, if the Delaware River Basin states pursue sustainability of the Delaware River American shad population.

Striped bass

No specific routine directed sampling has occurred for striped bass (*Morone saxatilis*) in the non-tidal mainstem waters of the Delaware River; however, PFBC annually surveys the returning adult spawning population in the upper tidal reaches of the Delaware Estuary in conjunction with the State of Delaware as part of Pennsylvania's compliance to ASMFC. Recent years' monitoring by the PFBC is suggests that there has been a slight decline in relative abundances of returning striped bass in the Delaware Estuary from 1995 through 2009 (Kaufmann et al. 2008, 2009). A recent coast-wide stock assessment determined that the Atlantic coast striped bass population, including the Delaware River stock, was fully restored (46th Northeast Regional Stock Assessment Workshop, 2008).

Within the non-tidal reaches of the Delaware River limited ancillary information of the occurrence of striped bass can be garnered from PFBC fall fixed station monitoring targeting smallmouth bass. The occurrence of striped bass in this survey tended to be greater at stations in the lower (below Easton, PA) and middle (Easton, PA up-river to Matamoras, PA) reaches of the Delaware River. Striped bass were not caught in the upper Delaware River above Matamoras, PA. Captured striped bass were small, generally ranging from 3 to 17 inches long, which typically corresponded to fish between zero and four years of age. Only two striped bass that were collected exceeded the legal minimum length limit of 28 inches in the non-tidal portion of the Delaware River. Due to the infrequent collection of striped bass, no inferences of population trends can be drawn.

In September 2000, PFBC biologists conducted a synoptic survey targeting striped bass in the upper and middle reaches of the Delaware River (Arnold, 2000). Day boat electrofishing was conducted in the Buckingham (RM 325), Long Eddy (RM 315), Hankins (RM 311), Damascus (RM 298), Narrowsburg (RM 288), and Lackawaxen (RM 277) pools. A total of five striped bass were caught, with only two exceeding the 28 inch minimum length limit. Arnold (2000) also reported that NYDEC state biologists caught sub-legal (< 28 inches) striped bass in the Pond Eddy (RM 265), and Sparrowbush (RM 257) pools along with a single legal length striped bass from the Sparrowbush pool during previous years surveys. Based on the PFBC September 2000 survey, Arnold (2000) suggested future sampling concentrate at the confluences of large tributaries and in the fast moving water entering the pool head.

Arnold (2000) further reviewed reported angler catches of striped bass received by state officials. Reports have been received of striped bass occurring in the Hancock, NY area, including the East Branch Delaware and West Branch Delaware rivers; and throughout the upper and middle reaches of the Delaware River above Delaware Water Gap, PA (RM 211.0). General consensus concluded that the catch of striped bass was sporadic in most pools of the Delaware River. Angler reports suggested that sub-legal and legal-sized striped bass can be consistently caught in the Mongaup (RM 261), Cherry Island (RM 258), Minisink Island (RM 245) and Water Gap (RM 211) pools after mid-summer.

The most recent Atlantic Coast wide stock assessment for striped bass was updated in 2009 (ASMFC 2009). The peer-reviewed assessment indicated that striped bass are not overfished and overfishing is not occurring. Since 1982, the striped bass population has increased from about 7 million fish to an average of 58 million fish during the last five years. Given the return of striped bass populations to historical levels, it would be prudent to resurvey the non-tidal reaches of the Delaware River to establish baseline population characteristics (CPUE, size and age distributions) and to determine if the current regulations are providing the maximum recreational benefit while sufficiently protecting the population from overharvest. In response to the improved striped bass population within the Delaware Estuary, the PFBC relaxed fishing regulations within its tidal waters. A slot limit was created to allow for the harvest of 2 striped bass between 20-26 inches from April through May in waters from the Pennsylvania-Delaware state border upriver to the Calhoun Street Bridge (RM 134.3). A 28 inch minimum length, 2 striped bass per day creel limit applies for the remainder of the year.

River herring (Alewife and Blueback Herring)

Blueback herring and alewife, collectively referred to as river herring, occur along the Atlantic coastline and are managed by ASMFC. A stock assessment by Crecco and Gibson (1990) evaluated the status of six blueback herring stocks and nine alewife stocks between New Brunswick, Canada and North Carolina, excluding the Delaware River, using long-term commercial catch and effort, age composition, and relative abundance data for juveniles and adults. Five stocks were determined to be overfished: St. John River alewife and blueback herring, Damariscotta River alewife, Potomac River (VA) alewife, and Chowan River alewife. Four stocks were determined to be experiencing recent stock declines but not considered overfished: Potomac River blueback herring, Chowan River blueback herring, Nanticoke River (MD) alewife, and Rappahannock River (VA) alewife. The assessment estimated ocean landings as constituting 20-30% of total river herring landings. An updated stock assessment on blueback herring and alewife was conducted in 2005 as part of Amendment 1 to North Carolina's River Herring Fishery Management Plan. This assessment determined that river herring were overfished and overfishing was occurring.

No directed monitoring is currently conducted for river herring in the non-tidal reaches of the Delaware River. Based on data contained in the 316(b) compliance reports from power generation stations in the non-tidal Delaware River, river herring do move as far upriver as the Portland Generating Station (RM 206) where a total of 61 adult alewife and 37,172 alewife larvae were reported impinged and entrained, respectively (AECOM Environmental 2008; Table 7.6). Farther down river just below head of tide at the Fairless Hills generating station 18 adult alewife and 12 blueback herring were impinged (Kinnel et al. 2008; Table 7.7). In addition, Horwitz et al. (2008) also recorded five blueback herring at Poxono Island (RM 220.0) and a single alewife at Junction Pool (RM 330) just below Hancock, NY, suggesting that these species migrate well up into the Delaware River, but not in significant numbers. Additionally, in the mid-1980's large numbers of river herring were commonly landed as by-catch in the Lewis haul seine fishery, but were never quantified. Relatively few river herring have been caught in this fishery since in the late 1990's.

In 2009, the ASMFC approved Amendment 2 to the Interstate Fishery Management Plan for Shad and River Herring, declaring significant restrictive management regulations for river herring populations by the year 2012. These restrictions were dependent on a states' ability to demonstrate that fishing activities will not diminish the potential future stock reproduction and recruitment. It was determined by the basin states, through the DRBFWMC, that insufficient data existed for characterizing sustainability of river herring populations in the Delaware River. In response, all Delaware River Basin states are initiating proposed rulemaking to close the river herring fishery. At the January, 2011 PFBC Commission meeting, this proposed rule was accepted for publication in the Pennsylvania Bulletin. It is anticipated this proposed rule will go into effect January 1, 2012, as mandated per ASMFC Amendment 2. Additionally, as required by Amendment 2, the Delaware River Basin states will develop a river herring management recovery plan through the DRBFWMC. Monitoring efforts by the PFBC for river herring will be adjusted based on the suggested management actions of this anticipated Delaware River River Herring Management Plan.

Hickory shad

Generally, hickory shad do not utilize the non-tidal reaches of the Delaware River, typically remaining below head of tide at Trenton, NJ (RM 133.0). No directed monitoring was or currently is conducted for hickory shad in the non-tidal reaches of the Delaware River.

American eel

Within the non-tidal Delaware River no directed sampling of American eel has been conducted. However, ancillary information has been collected on the abundance of eels during the PFBC summer fixed station monitoring of YOY smallmouth bass and supplied to the National Academy of Sciences as part of their ongoing research (Figure 8.13). The estimated CPUE was variable among years ranging from a mean of 1.4 to 51.3 eels per 50 m of electrofishing. Since 2005, sites in the lower Delaware River, particularly at Yardley, PA, Point Pleasant, PA, and Upper Black Eddy, PA exhibited higher eel counts than at stations farther up-river.

American eels are managed by the ASMFC (ASMFC 2008). Current stock status for American eel is poorly understood due to limited and non-uniform stock assessment efforts and protocols across the range of the species. Reliable indices of abundance of this species are scarce.

Limited data from indirect measurements (harvest by various gear types and locations) and localized direct stock assessment information are currently collected. The management unit for American eel is its distribution across territorial and inland waters along the Atlantic Coast from Maine to Florida. There are no defined biological reference points in terms of either spawning stock biomass or fishing rates for this management unit. Also, there are presently no measures of absolute abundance or fisheries exploitation rates with which to assess stock status. However, commercial landings have been declining (ASMFC 2006).

Sturgeon

Currently, no commercial or recreational fisheries exist in the Delaware River for either Atlantic or shortnose sturgeon. The PFBC does not have any monitoring programs specifically directed at sturgeons in the Delaware River. It is known that shortnose sturgeon do occur in the lower reaches of the non-tidal Delaware River (O'Herron 1993). Shortnose sturgeon is known to spawn in the reach from Trenton, NJ to New Hope, PA. Atlantic sturgeon is actively managed by the Atlantic States Marine Fisheries Council (ASMFC 2006).

8.6 <u>Angler Use and Harvest</u>

The West Branch Delaware and Delaware rivers provide the public a plethora of angling opportunities throughout their entire reach. Therefore to estimate impacts on riverine fish populations from angler utilization, fishery managers routinely conduct creel surveys, commonly referred to as angler use and harvest surveys. Depending on the extent and objectives of the specific creel survey, recreational fisheries are often described in terms of angler expenditures, total number of trips, total hours fished, targeted gamefishes, catch and harvest rates, and estimates of potential yields.

The NYDEC has documented an extensive time-series (1968-1999) of angler effort that provides excellent insight into angler utilization of the existing trout population. The West Branch Delaware River and upper Delaware River are principally recognized as a trout fishery (Sanford 1993 and McBride 2003). Historical records (1962-1987) estimated number of angler trips within the West Branch Delaware River increased from 1,805 to 14,925 trips per year; whereas in the upper Delaware River from Hancock, NY downriver to Callicoon, NY, estimated number of angler trips for trout varied from 10,241 and 24,315 trips per year (Figure 8.14; Keller 1988; Sanford 1992).

Additional survey data was collected from 1989 through 1991 (Sanford 1993) and 1992 through 1996 and 1999 to evaluate impacts of management changes on catch rates, creel rates and size distribution of trout (McBride, 2003). Survey sties were primarily focused in the West Branch Delaware River; however, one site was located in the Delaware River at Lordville, NY. Specifically in the shared border waters between New York and Pennsylvania, anglers took between 3,975 and 9,209 trips and expended between 17,727 and 43,925 hours fishing. Angler catch rates ranged from 0.48 to 0.88 trout/hour and generally did not reach the long-term management target of 1.0 trout per hour (Figure 8.15; Sanford 1992). Wild brown trout dominated the harvest (50-86%) followed by hatchery brown trout (7-41%), wild rainbow trout (4-20%), and wild brook trout (1%; McBride 2003). Examination of wild trout harvest rates illustrated that wild rainbow trout harvest was lowest in waters in proximity of Deposit, NY and highest in waters below the Pennsylvania-New York border, while harvest of wild brook trout was highest in proximity of Deposit, NY and lowest in waters below the Pennsylvania-New York border. At the Lordville, NY site in the Delaware River, fewer angler trips (952 – 1,332) and hours fished (3,665 – 5,773) were documented as compared to angler expenditures in the West Branch Delaware River. Angler catch rates varied from 0.14 to 0.34 trout/hour (Figure 8.15). From 1989 to 1994 wild rainbow trout accounted for the majority (78%) of the harvest followed by wild brown trout (14%) and hatchery brown trout (7%; McBride 2003).

Sanford (1993) noted that warmwater fish and migratory fish were an important component of the fishery in the Lordville, NY reach of the upper Delaware River. Fourteen to forty-six percent of the anglers interviewed in the Lordville reach targeted non-trout species and 19-60% of the harvest was non-trout species. Smallmouth bass, walleye and American shad were the most frequently targeted non-trout species in the Lordville reach. McBride (2003) reported that during the survey period from 1989 through 1999, 71% of the encountered anglers targeted trout, 14% targeted shad, 4% targeted bass, 4% targeted walleye and 1% targeted other species.

An economic survey of the upper Delaware River trout fishery was completed in 1996. This survey estimated that angler expenditures resulted in approximately $17.7 million in local business revenue during 1996 (Maharaj et al., 1998).

Downriver of Callicoon, NY the Delaware River supports a warmwater fishery dominated by smallmouth bass. Other fish species including channel catfish, rock bass, bluegill, redbreast sunfish, muskellunge, walleye, and American eels comprise significant but relatively smaller recreational fisheries. American shad and striped bass also provide a seasonal fishery in the Delaware River during the late spring months.

In their creel survey of the upper Delaware River, Hoopes et al. (1983) indicated that the upper Delaware River mainstem supported seasonal fisheries with anglers targeting American shad during the spring before transitioning to smallmouth bass and trout. The authors estimated a total of 74,055 angler hours were expended from 13,134 trips. A total of 30,746 smallmouth bass were caught with the majority being landed during summer (N = 21,816; 70.9%) and fall (N = 6,072; Table 8.7). Of the smallmouth bass caught, 27.8 % (N = 8,569) were harvested. During the springtime fishery for migrating American shad, anglers caught an estimated total of 34,889 shad between April 12th - May 30th, of which 88% (N = 30,783) were harvested (Table 8.7). Smallmouth bass, American eel (N = 7,907), American shad (N = 2,434), and rock bass (N = 2,381) were the principal fish caught during the summer months; however, the total catch of rainbow trout (N = 1,196) increased in the early fall. Other species, including walleye, chain pickerel, and panfish were caught with less frequency (Table 8.7). Interestingly, the survey completed by Hoopes et al. (1983), indicated that brown trout and rainbow trout were a relatively minor component of the total catch in the upper Delaware River. Additionally, when anglers were queried on which fish they were targeting during the summer, 41.2% indicated smallmouth bass, 9.5% indicated rainbow trout and 3.7% indicated brown trout.

The most recent and comprehensive characterization of the recreational fisheries in the Delaware River was accomplished in 2002 (Volstad et al. 2003). This study encompassed portions of the upper estuary waters (RM 76), the entire non-tidal Delaware River mainstem and the tail waters of the East Branch Delaware River up to Downsville, NY. This study was a cooperative effort among basin states (New York, Pennsylvania, New Jersey and Delaware) through the Delaware River Basin Fish and Wildlife Management Cooperative. A total of 260,849 angler hours from 79,854 trips were estimated to have occurred by anglers fishing in the non-tidal reach of the Delaware River. By river reach, 192,207 hours (N = 59,819 trips), 49,887 hours, (N = 14,071 trips), and 48,403 hours (N = 13,889 trips) were estimated for the lower (head of tide up-river to Water Gap, PA), middle (Water Gap, PA up-river to Narrowsburg, NY) and upper (Narrowsburg, NY upriver into the East Branch Delaware River to Downsville, NY), respectively. Sixty-nine percent of the interviewed anglers targeted American shad from March to June, whereas smallmouth bass were targeted by 63% of the anglers from July to October.

Total angler catch, harvest and fishing rates, were estimated from the 2002 survey (Volstad *et al.* 2003). Percent species composition of catches reported by anglers interviewed indicated that smallmouth bass was the most frequently caught species (Figure 8.16). The study estimated a total smallmouth bass catch of 93,936 fish, that was almost exclusively a catch-and-release fishery 1.5% (N = 1,428; Table 8.8). Most (79.7%) of the smallmouth bass were caught from head of tide up-river to the Water Gap, PA with the fewest (N = 1,884) being caught above Narrowsburg, NY (Table 8.8). Average angler catch rates varied among river reach (0.12 – 0.39 bass/hour) with average angler catch rates specifically targeting smallmouth bass ranging from 0.77 – 1.10 bass/hour). Channel catfish also provided a significant fishery although the majority (N = 48,552, 79%) of channel catfish were caught in tidal waters (Volstad et al. 2003). Above head of tide, a total of 10,151 channel catfish were caught in the river reaches principally below the Water Gap, PA with average angler catch rates ranged from 0.01 – 0.04 fish/hour in the non-tidal reaches (Table 8.8). Below Water Gap, PA rock bass (N = 7,976; catch rate 0.03 bass/hour) was commonly caught; whereas above Narrowsburg, NY rainbow trout (N = 2,230), brown trout (N= 481) and walleye (N = 1,813) were more commonly caught. A large portion of the walleyes (74%) were harvested.

American shad generates a springtime fishery in the Delaware River; however in recent years the American shad fishery has been declining. In a review of existing fisheries in the Delaware River during the 1960’s, Massmann (1971), indicated that American shad were an important fishery in the non-tidal Delaware River, such that catches in the upper reaches were nearly equal to those from the lower reaches.

A 1964 creel survey suggested that between Hancock, NY and Port Jervis, NY, over 21,000 anglers fished some 117,000 hours and caught approximately 21,000 American shad (Marshall 1971). Based on available creel survey data, aerial flights, and several reasonable assumptions, Marshall (1971) estimated that anglers caught approximately 25,000 shad during the 1971 Delaware River shad run. Three days of aerial counts between Trenton, NJ to Hancock, NY documented an average of 191 shoreline anglers and 188 boats containing an estimated 447 anglers fishing for shad. Based on these estimates boat anglers caught 726 shad/day on weekends while shore anglers caught 208 shad/day (Marshall 1971). This equates to a seasonal catch of 13,068 shad by boat anglers 5,496 shad by shore anglers. Weekday angling pressure was estimated to be 60% of the weekend pressure.

Miller and Lupine (1987 1996), conducted creel surveys on the Delaware River specifically to document the American shad fishery in the Delaware River above head of tide. During the 1986 survey, the authors documented 65,690 anglers expending 299,597 hours fishing for American shad. A total of 56,320 shad were caught for an average catch rate of 0.19 shad/hour, of which 48.7% (n = 27,471) were harvested. The majority of the shad were caught in two reaches: Milford, NJ to Kittatiny Beach (n = 26,385) and Kittatiny Beach to Port Jervis, NY (N = 22,243). Nearly ten years later, Miller and Lupine (1996) estimated angler expenditure of 337,571 angler hours for a total catch of 83,141 shad resulting in an average catch of 0.25 shad/hour. Twenty percent of the total shad catch was harvested. Angler catch declined 94% in the Delaware above Port Jervis, NY from 37,323 shad to 2,268 in only six years (Hoopes et al., 1983, Miller and Lupine, 1987). Miller and Lupine (1987) estimated that anglers spent approximately $1.6 million during the nine week survey period, which equates to an annual recreational value of $3.2 million dollars generated by the Delaware River shad fishery.

As part of the 2002 creel survey, special consideration went into the survey design to adequately capture the springtime American shad and striped bass fisheries (Volstad et al 2003). Both American shad and striped bass composed a large percent (12% and 11%, respectively) of angler catch in the Delaware River below Narrowsburg, NY (Figure 8.16). An estimated total of 35,281 (N =1,190 in tidal waters, N = 34,091 in non-tidal waters) American shad were caught by anglers, of which an estimated 6,627 (19%; N = 315 in tidal waters, N = 6,312 in non-tidal waters) were harvested (Table 8.8). No American shad were reported caught by anglers in the upper non-tidal reach from above Narrowsburg, NY. Estimates of angler catch during the 2002 survey were substantially lower than those recorded by Miller and Lupine in 1986 and 1995. The 2002 catch was 63% lower than the 1986 catch and 42% lower than the 1995 catch (Miller and Lupine 1987, 1996). Generally, the striped bass fishery is centered in the Delaware Estuary, but a growing fishery is being utilized by anglers in the lower reach of the non-tidal Delaware River. An estimated 36,328 striped bass (N = 20,146 in tidal waters; N = 16,182 in non-tidal waters) were caught (Volstad et al. 2003). Of the 36,328 striped bass caught, 538 were harvested (Table 8.8).

The 2002 creel survey also provides some insight into river herring and American eel fisheries (Vlostad et al. 2003). An estimated 7,553 (N = 2,411 in tidal waters, N = 5,142 in non-tidal waters) river herring were caught. A large percent (65%; N = 4,916) of caught river herring were harvested, principally for use as bait by striped bass anglers (Table 8.8). American eel continues to support a minor fishery throughout the Delaware River. During the early 1980's anglers caught 7,989 eels in the upper Delaware River of which 4,076 were harvested (Hoopes et al. 1983; Table 8.7). Hoopes et al. (1983) described the eel fishery as primarily a summer fishery. The 2002 creel survey (Volstad et al. 2003) indicated that the American eel fishery was principally a night fishery (9 PM to midnight) when anglers caught a total of 2,522 eels in the non-tidal reach of the Delaware River and harvested 1,376 eels.

Comprehensive angler use and harvest surveys are often monetarily prohibitive, thus, fisheries managers may choose to employ an angler diary program to provide interim information between large scope creel surveys. Two angler diary programs have been conducted on the Delaware River. The first was conducted by the NYDEC from 2002-2007 and was limited to the upper Delaware River Basin above Callicoon, NY and included the East Branch Delaware and West Branch Delaware rivers. The diary program was intended to characterize the trout fishery (McBride 2002, 2003, 2005, 2007). The National Park Service and the PFBC jointly conducted an ongoing angler diary program for the entire Delaware River Basin, since 2001, (Lorantas and Myers 2003, Lorantas et al. 2004, Lorantas and Myers 2005, Lorantas and Myers 2007, Pierce and Myers 2007). Licensed guides operating in the Upper Delaware Scenic and Recreational River are required to participate and private citizens are highly encouraged to participate in the program. While this logbook program was intended to be inclusive of the entire Delaware River mainstem and tidal waters, volunteer participation has been low and the reported catches are generally reflective of the licensed guides operating in the upper Delaware River.

Anglers participating in the NYDEC diary program (2002 – 2007) for the upper Delaware River (McBride 2003, 2004, 2005, 2007, 2008) maintained detailed records of their fishing trips throughout the years (Figure 8.17). Anglers participating in the program logged between 116.7 to 384.1 wade angling hours (47 to 108 trips) throughout the survey period. Boat anglers logged between 32.6 and 161.3 hours (7 to 40 trips) throughout the survey period. Total angler catch rates for all trout varied from 0.16 to 0.43 trout/hour and 0.21 to 0.83 trout/hour, for wade and boat anglers respectively. River-wide catch rates have been fairly consistent since 2002 for wade anglers; whereas boat angling catch rates have declined since 2005. Overall, the voluntary logbook program has documented increased angler catch rates as compared to the period 1989 -1999.

Anglers participating in the NPS-PFBC joint diary program (Lorantas and Myers 2003, 2005, 2007; Lorantas et al. 2004; Pierce and Myers 2007) logged 9,610 – 13,186 hours during 1,431 – 1,983 trips (Table 8.9). Overall, brown trout, rainbow trout and smallmouth bass comprised the majority of the catch. The total catch of smallmouth bass was the highest of all species reported followed by brown trout and rainbow trout. Smallmouth bass average catch rates ranged from 0.07 to 0.35 bass/hour. Depending on the river reach and survey year, smallmouth bass catch rates occasionally exceeding 2.0 bass per hour. Catch rates for trout were variable with brown trout (0.76 – 0.207 trout/hour) being caught at higher rates than rainbow trout (0.064 – 0.111 trout/hour) for most years with the exception of 2001, when catch rates for rainbow trout were higher than for brown trout. Harvest of any species was generally less than 1% of the total catch.

It is anticipated the PFBC will initiate an on-line angler diary with no monetary cost to anglers. The intent of this program is to provide anglers opportunity to voluntarily submit catch records to allow PFBC biologists insight to total angler use and harvest from the Commonwealth's waters. In return the program will provide services to the angler to view and print their own results and keep track of their catches. It is unknown when this service will become available to the general public.

There is a need to continue documenting angler use and harvest of various fisheries within the West Branch Delaware and Delaware rivers. Changes in angler behavior can have dramatic impacts on management actions for ensuring the sustainability of a fishery. Unfortunately, large-scale intensive creel surveys are monetarily prohibitive in both resources and capital. In contrast, voluntary angler log books require extensive public involvement and outreach. As a compromise, there is interest by the PFBC, DFM in evaluating the feasibility of conducting focused angler use and harvest creel surveys on a smaller reach-specific scale using traditional creel survey protocols; but rotate through the river on a periodic basis. The intent would be to keep our understanding of contemporary trends in angler behavior while reducing demand on staffing and capital.

Tournament angling can represent a substantial component of the recreational component within the Commonwealth's waters. Presently, organized events of 10 participants or larger are required to receive a special activities permit through the PFBC, Bureau of Law Enforcement in cooperation with the PFBC, Bureau of Fisheries, DFM. The permitted tournaments are required to report catch and harvest data for the tournaments which is tracked by the DFM Warm-Water Unit. Principally this effort has been to evaluate the impact of black bass tournaments within the Commonwealth's waters. Tournaments are not permitted to be held during closed seasons or during "no harvest" periods for targeted species. Informal tournaments with smaller numbers of participants (<10 individuals) remain undocumented.

Tournaments conducted on the West Branch Delaware and Delaware rivers are principally for black bass and American shad. Within recent years (2007-2010), a total of 102 tournaments have been permitted by PFBC with the majority (77%) being in the Delaware Estuary. Within the Delaware River, only 23 tournaments have been permitted principally for bass. Angler participation varied from 17 to 41 participants, with most tournaments lasting for less than 4 days with total catch ranging from a total of 11 to 37 bass. A spring American shad fishing tournament, *Forks of the Delaware Shad Fishing Tournament and Festival*, is held annually in Easton, PA (http://www.shadtournament.com/). This tournament is entering its 29th year in 2011 and has traditionally been and continues to be harvest oriented for the largest fish; however, the tournament now requires a 22 inch minimum length for weigh-in in an effort to reduce harvest. Further, the tournament in 2011 was cut to four from eight days. Data records of tournament participation and catch are not available for this shad tournament from the PFBC tournament database. In years past, the PFBC did not require the event coordinator to report tournament catch. The completeness of the PFBC tournament database for the West Branch Delaware and Delaware rivers is subject to the nature and location of the sponsor of the tournament. For example, a tournament targeting the largest fish may not fully represent total angler catch.

Additionally, given the Delaware River as border water, the location of the sponsor/event may not be required to submit for a special activities permit with Pennsylvania.

8.7 Commercial Fisheries

Pennsylvania no longer permits traditional net/weir commercial fisheries within the Commonwealth's waters; however, a few commercial fisheries do exist within the West Branch Delaware and Delaware rivers. These fisheries are principally for the operation of eel weirs in the upper Delaware River licensed by the state of New York. Currently, a summary document is being prepared to describe the eel weir fishery in the Delaware River reaches within the State of New York's jurisdiction.

The only remaining commercial netting in the non-tidal reaches of the Delaware River is the Lewis haul seine located in Lambertville, NJ (RM 148.7). This fishery represents a family tradition rather than utility for substantial economic gain. The fishery targets the spring American shad spawning run using various sized (100-350 ft) shore-based nylon haul seines. Catch records from this fishery span over 100 years (Figure 8.12). In general, the total catch of American shad has declined; however, catches increased in the mid 1990's following large scale water quality improvements and the subsequent elimination of a dissolved oxygen block in the tidal waters around the city of Philadelphia. In an effort to continue the time series and evaluate its utility as an indicator of adult relative abundance, the Delaware River Basin Fish and Wildlife Management Cooperative have contracted to continue the Lewis haul seine fishery. This fishery provides an excellent long-term index of the American shad migration. Funding for this fishery should continue in the future to provide managers a continued, uninterrupted index of relative shad abundance in the Delaware River.

Fishing guides and charter boats operating in the Pennsylvania waters are required to obtain a permit from the PFBC with the passing of Act 159 legislation (House Bill 2155) in 2004. By definition a "fishing guide" is any person who operates a commercial enterprise whereby he or she guides or leads other persons for the purpose of fishing on the waters of the Commonwealth. Further, "commercial enterprise" has been defined as an operation where a person provides fishing guide or charter boat services in exchange for any consideration, including money, goods or services (http://www.fishandboat.com/chboat_faq.htm). The PFBC is tasked with regulating and issuing these permits. Presently, the PFBC continues to list all registered charter boats and fishing guides on its website (http://www.fishandboat.com/images/admin/guides/Report1.htm).

The National Park Service Upper Delaware Scenic and Recreation River requires mandatory reporting of individual angler effort and catch statistics for all permitted fishing guides operating within parks boundaries. Licensed guides have been providing catch information to the NPS through the Delaware River and Estuary Angler Logbook diary program, which is jointly operated by NPS-UPDE and PFBC, since its inception in 2001 (Lorantas and Myers, 2003, 2005, 2007; Lorantas et al., 2004; Pierce and Myers, 2007). The log book program is also voluntary to individual anglers wishing to participate.

8.10 Management Options

Priority 1: (on-going activities or recommendations to be implemented in first year of management plan).

- Continue directed sampling annually for the monitoring of YOY and adult smallmouth bass for identifying spatial and temporal population trends within the Delaware River. The study design will be adjusted as appropriate to provide representative sampling in the upper Delaware River basin. The intent for this survey is to forecast future angling opportunities based on current population status and determine the feasibility of developing target benchmarks for triggering proactive management actions for optimization and protection of the smallmouth bass population.

- Continue with annual monitoring of American shad populations through current sampling programs to describe the annual springtime adult spawning migration into the Delaware River. This monitoring effort will be adjusted as appropriate based on the direction of the Delaware River Shad Management Plan mandated by the Atlantic States Marine Fisheries Commission Amendment 3 Shad and River Herring Management Plan.

Priority 2: (recommendations with implementation date in years 2-3 of management plan)

- Coordinate with the PFBC Coldwater Unit and NYDEC fisheries staff to evaluate the feasibility of annual quantification of YOY and adult trout populations in the West Branch Delaware and Delaware rivers. The intent of this program is to allow managers to track population trends and aid in supporting the NYDEC-PFBC white paper.

- Develop sampling protocols for supporting small-scale reach-specific angler use and harvest surveys to provide basic description of trends in angler behavior and to aid in determination of regulatory and management practices.

Priority 3: (recommendations with implementation date in years 4-5 of management plan)

- Develop monitoring programs for channel catfish and walleye within the Delaware River for assessing their baseline population status as per state-wide species-specific management plans.

Table 8.1. Fishery Management Section descriptions for the mainstems of West Branch Delaware and Delaware rivers.

Section	RM	Length km	Length mi	Description
West Branch Delaware River				
1	8 - 0	12.8	7.9	Extends from the state border with New York, Wayne County extending downriver to the confluence with the East Branch Delaware River just below the town of Hancock, NY
Delaware River				
1	330.7 – 312.6	30.6	18.1	Extends from the confluence with the East Branch Delaware River just below the town of Hancock, New York downriver to Kellam Bridge near the confluence of Little Equinunk Creek at Stalker, PA
2	312.6 – 289.0	39.4	23.6	Extends from Kellam Bridge near the confluence of Little Equinunk Creek at Stalker, PA downriver to the confluence of Peggy Run, near Narrowsburg, NY
3	289.0 – 277.7	19.3	11.3	Extends from the confluence of Peggy Run, near Narrowsburg, NY downriver to the confluence of Lackawaxen River, Lackawaxen, PA
4	277.7 – 250.0	46.0	27.7	Extends from the confluence of Lackawaxen River, Lackawaxen, PA downriver to the confluence of Cummins Creek, Millrift, PA
5	250.0 – 209.5	65.2	40.4	Extends from the confluence of Cummins Creek, Millrift, PA downriver to the confluence of Slateford Creek, Slateford, PA
6	209.5 – 183.6	41.6	25.8	Extends from the confluence of Slateford Creek, Slateford, PA downriver to the confluence of Lehigh River, Easton PA
7	183.6 – 157.0	42.7	26.5	Extends from the confluence of Lehigh River, Easton PA downriver to the confluence of Tohickon Creek, Point Pleasant, PA
8	157.0 – 133.7	37.2	23.1	Extends from the confluence of Tohickon Creek, Point Pleasant, PA downriver to Trenton Falls, NJ

Table 8.2. Commonwealth Inland regulations – by location for the Delaware River mainstem waters inclusive of the West Branch Delaware River and the Delaware Estuary for the 2011 season.

Species	Seasons	Minimum size	Daily Limit
Trout	April 16 at 8:00 a.m. through October 15	North of I-84: 14 inches	1 (combined species)
		South I-84: no minimum	5 (combined species)
		West Branch Delaware River: 12 inches*	2 (combined species)
Bass (Smallmouth & Largemouth)	Jan. 1 through April 15 and June 18 through Dec 31	12 inches	5 (combined species)
	April 16 through June 17	No harvest -Catch and immediate release	
Muskellunge and Tiger Muskellunge	Open year-round	40 inches	1
Northern Pike	Open year-round	24 inches	2
Pickerel	Open year-round	12 inches	5
Walleye	The portion of the Delaware River between New Jersey and Pennsylvania – open year-round The portion of the Delaware River between New York and Pennsylvania – Jan. 1 through March 14 and May 7 through Dec. 31	18 inches	3
American shad	Open-year round	No minimum	6 – From the PA state line upstream to the Commodore Barry Bridge 3 – From the Commodore Barry Bridge upstream
River Herring (Alewife and Blueback Herring)	Open-year round	No minimum	35 – From the PA state line upstream to the Commodore Barry Bridge 10 – From the Commodore Barry Bridge upstream
American Eel	Open-year round	8 inches	50
American Eel (as Baitfish)	Open-year round	6 to 8 inches	50

Table 8.2 (continued). Commonwealth Inland regulations – by location for the Delaware River mainstem waters inclusive of the West Branch Delaware River and the Delaware Estuary for the 2011 season.

Species	Seasons	Minimum size	Daily Limit
Striped Bass and Hybrid Striped Bass	From the Pennsylvania state line upstream to Calhoun Street Bridge; Jan. 1 through March 31 and June 1 through Dec. 31	28 inches	2
	April 1 through May 31	20 to 26 inches	
	From Calhoun Street Bridge upstream – open year-round	28 inches	
Hickory Shad	Closed year-round		
Sturgeon	Closed year-round		
Mussels/Clams	Closed year-round		

* A special no-kill season with the use of artificial lures only has been established on the West Branch Delaware River

Table 8.3. Historical stocking records by PFBC into the Delaware River mainstem reaches, separated by Fishery Management Sections. Stage = lifestage; Fing = fingerling lifestage. Bold numbers indicate tiger muskellunge.

	American shad		Channel catfish		Hickory Shad		Muskellunge		Walleye	
	Stage	No.	Stage	No.	Stage	No.	Stage	No.	Stage	No.
					Delaware River Section 02					
1983									Fry	3,550,000
					Delaware River Section 04					
1980										
1981										
1982										
1983			Fing.	10,370						
1984									Fry	2,100,000
1985										
1986									Fing.	20,000
1987									Fing.	20,000
1988									Fing.	5,300
1989									Fing.	17,500
1990							Fing.	6,217	Fing.	52,650
1991							Fing.	1,750	Fing.	17,550
1992							Fing.	8,750	Fing.	35,100
1993									Fing.	17,550
1994									Fing.	17,550
1995									Fing.	17,550
1996							Fing.	2905	Fing.	17,550
1997							Fing.	1,750	Fing.	17,550
1998							Fing.	1,750	Fing.	17,550
1999							Fing.	7,000	Fing.	17,550
2000							Fing.	7,000	Fing.	17,550
2001							Fing.	3484	Fing.	17550
2002							Fing.	3400	Fing.	17538
2003							Fing.	1747	Fing.	17550
2004							Fing.	3498	Fing.	17550
2005							Fing.	1498	Fing.	14834

	American shad		Channel catfish		Hickory Shad		Muskellunge		Walleye	
	Stage	No.	Stage	No.	Stage	No.	Stage	No.	Stage	No.
2006									Fing.	15000
2007									Fing.	14993
2008									Fing.	15000
Delaware River Section 05										
1980										
1981										
1982										
1983										
1984							Fing.	4000	Fry	4,000,000
1985							Fing.	3600		
1986							Fing.	4000	Fing.	30000
1987									Fing.	60000
1988							Fing.	8350	Fing.	64800
1989							Fing.	18000	Fing.	21600
1990							Fing.	6217	Fing.	64950
1991							Fing.	1750	Fing.	64950
1992							Fing.	8750	Fing.	86600
1993									Fing.	21650
1994									Fing.	69900
1995									Fing.	69900
1996							Fing.	2905	Fing.	43200
1997							Fing.	2300	Fing.	21600
1998							Fing.	2300	Fing.	21600
1999							Fing.	9200		
2000							Fing.	9200	Fing.	43200
2001							Fing.	4596	Fing.	21600
2002							Fing.	9189	Fing.	21565
2003							Fing.	2295	Fing.	21600
2004					Fry	1,815,701	Fing.	6898	Fing.	43200
2005	Fry	169802			Fry	3,200,000	Fing.	2299	Fing.	22997
2006	Fry	52782			Fry	750,000	Fing.	4600	Fing.	46000
2007	Fry	47587					Fing.	2300	Fing.	45839

	American shad		Channel catfish		Hickory Shad		Muskellunge		Walleye	
	Stage	No.	Stage	No.	Stage	No.	Stage	No.	Stage	No.
2008	Fry	158151					Fing.	7800	Fing.	23000
Delaware River Section 06										
1980										
1981										
1982										
1983										
1984							Fing.	2500	Fry	4,000,000
1985							Fing.	2500		
1986							Fing.	2500	Fing.	30000
1987							Fing.	2300		
1988							Fing.	7250	Fing.	45900
1989							Fing.	14000	Fing.	15350
1990							Fing.	5850	Fing.	46050
1991							Fing.	1500	Fing.	46050
1992							Fing.	7123	Fing.	61400
1993									Fing.	15350
1994										
1995									Fing.	13670
1996							Fing.	1500	Fing.	13700
1997							Fing.	1500	Fing.	13700
1998							Fing.	1500	Fing.	13700
1999							Fing.	6000		
2000							Fing.	6000	Fing.	13700
2001							Fing.	3000	Fing.	13700
2002							Fing.	5997	Fing.	13693
2003							Fing.	1499	Fing.	13700
2004							Fing.	4497	Fing.	13700
2005							Fing.	2197	Fing.	21998
2006							Fing.	4400	Fing.	22000
2007							Fing.	2200	Fing.	21800

	American shad		Channel catfish		Hickory Shad		Muskellunge		Walleye	
	Stage	No.	Stage	No.	Stage	No.	Stage	No.	Stage	No.
2008							Fing.	4400	Fing.	22000
Delaware River Section 07										
1980										
1981										
1982										
1983			Fing.	10,370			Fing.	4350	Fry	2,700,000
1984									Fing.	21400
1985							Fing.	4350		
1986							Fing.	275	Fing.	21400
1987							Fing.	3050	Fing.	5900
1988									Fing.	21700
1989							Fing.	305		
1990									Fing.	43400
1991							Fing.	3050		
1992										
1993									Fing.	5600
1994										
1995										
1996										
1997										
1998										
1999							Fing	1200		
2000										
2001							Fing	1200		
2002							Fing	1200		
2003										
2004							Fing	1200		
2005										
2006							Fing	1200		
2007										
2008							Fing	1200		

	American shad		Channel catfish		Hickory Shad		Muskellunge		Walleye	
	Stage	No.	Stage	No.	Stage	No.	Stage	No.	Stage	No.
Delaware River Section 08										
1980										
1981										
1982							Fing	950	.	
1983									Fry	2,400,000
1984							Fing	3800	Fing.	18950
1985										
1986							Fing	3800	Fing.	18950
1987										
1988							Fing	3550	Fing.	17800
1989										
1990										
1991										
1992										
1993										
1994										
1995										
1996										
1997										
1998										
1999										
2000										
2001										
2002										
2003										
2004					Fry	1,815,700				
2005					Fry	3,200,000				
2006					Fry	750,000				
2007										
2008										

Table 8.4. Fish consumption advisory for recreationally harvested fishes from the entire Delaware River Basin.

Water Body	Area under advisory	Species	Meal frequency	Contaminant
Beltzville Lake *(Beltzville State Park) (Carbon Co.)*	Entire lake	Walleye	2 meals/month	Mercury
Bush Kill *(Monroe and Pike Co.)*	Confluence of Saw Creek to mouth	American eel	2 meals/month	Mercury
Delaware River	Source to Trenton, NJ-Morrisville, PA bridge	American eel	2 meals/month	Mercury
Delaware Estuary, including the tidal portion of all PA tributaries and the Schuylkill River to the Fair- mount Dam *(Bucks, Philadelphia, & Delaware Co.)*	Trenton, NJ-Morrisville, PA Bridge to PA/DE border	White perch, Channel catfish Flathead American eel, Carp	1 meal/month Do Not Eat	PCB
Lake Wallenpaupack *(Pike & Wayne Co.)*	Entire lake	Walleye	1 meal/month	Mercury
Lehigh River *(Northampton Co.)*	Confluence of Saucon Creek to mouth	Carp, American eel	1 meal/month	PCB
Levittown Lake *(Bucks Co.)*	Entire lake	White perch	1 meal/month	PCB
Little Neshaminy Creek *(Bucks Co.)*	Entire basin	Carp	1 meal/month	PCB
Promised Land Lake *(Promised Land State Park) (Pike Co.)*	Entire lake	Largemouth bass	1 meal/month	Mercury
Prompton Reservoir *(W. Br. Lackawaxen River) (Wayne Co.)*	Entire lake	Largemouth bass Walleye	1 meal/month 2 meals/month	Mercury
Red Clay Creek *(Chester Co.)* (includes all tributaries)	Entire basin	American eel	1 meal/month	PCB
Schuylkill River *(Schuylkill Co.)*	Confluence of Mill Cr. at Port Carbon to Auburn Dam	Brook trout Brown trout, Rainbow trout	Do Not Eat 6 meals/year	PCB
Schuylkill River *(Schuylkill & Berks Co.)*	Confluence of Mahannon Cr. at	Bluegill, Brown bullhead	1 meal/month	PCB

Schuylkill River *(Berks, Chester, & Montgomery Co.)*	Felix Dam above Reading to Black Rock	Carp, Channel catfish	6 meals/year	PCB
Schuylkill River *(Chester, Montgomery, & Phila. Co.)*	Black Rock Dam to Fairmount Dam in Philadelphia	Carp Channel catfish, Flathead catfish	Do Not Eat 1 meal/month	PCB
Schuylkill River *(Berks, Chester, Montgomery & Philadelphia Co.)*	Felix Dam above Reading to Fairmount Dam	American eel White sucker	Do Not Eat 1 meal/mouth	PCB
Stairway Pond *(Pike Co.)*	Entire pond	Largemouth Bass	2 meals/month	Mercury
Tobyhanna Creek *(Carbon and Monroe Co.)*	Pocono Lake dam to mouth	Smallmouth bass	2 meals/month	Mercury
Tulpehocken Creek *(Berks Co.)*	Blue Marsh Dam to mouth	Brown trout, Rainbow trout	1 meal/month	PCB
West Branch Brandywine Creek *(Chester Co.)*	From business Rt. 30 (Lincoln Highway) in	American eel	6 meals/year	PCB
West Branch Schuylkill River *(Schuylkill Co.)*	Entire basin	Brook trout	1 meal/month	PCB

Table 8.5. The PFBC fixed station locations and dates sampled for young-of-the-year and adult smallmouth bass within the Delaware River.

Management Section	Years sampled YOY	Years sampled adult	River Mile	Nearest Municipality
		Upper		
2	1987-2002; 2005-present	1986-87; 1989-96;1998; 2005-present	298.4	Damascus
2	1987-2002; 2006-present	1986-87; 1989-1995	289.0	Tusten
3	1987-2002; 2005-present	1986-87; 1989-1996; 1998; 2006-present	277.5	Lackawaxen
4	1987-2003; 2005-present	1986-87; 1989-1995	255.3	Matamoras
		Middle		
5	1987-2003; 2006 -present	1987; 1989-1995	246.0	Milford
5	1987-2003; 2005-present	1986-87; 1989-1996; 1998; 2005-present	238.6	Dingmans' Ferry
5	1989-2003; 2006 -present	1986; 1989-1995	225.9	Bushkill
5	1987-present	1986-87; 1989-1996; 1998; 205 -present	211.6	Water Gap
6	1990-2003; 2005-present	1989 – 1996; 1998; 2006-present	189.2	Sandts Eddy
		Lower		
7		1989-2000	179.8	Whippoorwill Island
7	1989-present		178.0	Raubsville
7	1989-present		171.0	Kintnersville
7		1989-2000; 2005-present	168.2	Upper Black Eddy
8	1989-present	1989-2000; 2005-present	155.9	Point Pleasant
8	1989-present	1989-2000; 2006-present	138.0	Yardley

Table 8.6. Trout density (fish/acre) of age 1, 2, and 3 wild brown trout at NYDEC four standard sites in the West Branch of the Delaware River. Reproduced from McBride (2008).

Site	Age class	2004	2005	2006	2007
Stilesville					
	1	33	28	47	109
	2	14	14	23	14
	3	13	8	31	56
Deposit					
	1	5	3	21	5
	2	6	2	9	2
	3	7	4	10	3
Hale Eddy					
	1	18	11	12	22
	2	9	6	7	14
	3	5	5	11	11
Balls Eddy					
	1	19	3	9	10
	2	9	3	8	5
	3	7	3	11	6

Table 8.7. Total catch and harvest estimates on the upper Delaware River between April 12th – October 17th, 1982, adapted from Hoopes *et al.* (1983). Period 1: April 12th – May 30th, 1982; Period 2: May 31st – September 6th, 1982; Period 3: September 7th – October 17th, 1982.

	Period 1		Period 2		Period 3	
Species	Catch	Harvest	Catch	Harvest	Catch	Harvest
American eel	73	54	7907	4004	9	9
American shad	34889	30783	2434	942		
Bluegill			257	99		
Brown bullhead	170	170				
Brown trout	257	189	207	26		
Carp	73	0	233	233		
Chain pickerel	28	28	675	634	84	84
Rainbow trout	57	28	90	60	1196	1196
Redbreast sunfish			506	141	265	24
Rock bass			2381	391	197	167
Smallmouth bass	2858	1056	21816	5713	6072	1800
Walleye	9559	9435	149	97	68	68
White sucker	550	418				

Table 8.8. Angler catch and harvest statistics from the 2002 creel survey in the East Branch Delaware and Delaware rivers. Adapted from Volstad et al. (2003). Tidal RM 76.0 up-river to Trenton, NJ; Non-tidal Lower reach: Trenton, NJ upriver to Water Gap, PA; Non-tidal Combined Upper and Middle reach: Water Gap, PA up-river to Downsville, NY.

	Catch	Harvest	Catch	Harvest
American shad				
Non-tidal Combined Upper and	0.1493	0.0144	10249	986
Non-tidal Lower reach	0.1240	0.0277	23842	5325
Total non-tidal	0.1307	0.0242	34091	6312
Tidal	0.0085	0.023	1190	315
Total	0.0881	0.0165	35281	6627
Striped bass				
Non-tidal Combined Upper and	0.0044	0.0013	300	88
Non-tidal Lower reach	0.0826	0.0011	15882	206
Total non-tidal	0.0620	0.0011	16182	291
Tidal	0.1443	0.0017	20146	244
Total	0.0907	0.0013	36328	538
River herring				
Non-tidal Combined Upper and	0.0005	0.0000	37	0
Non-tidal Lower reach	0.0266	0.0180	5105	3452
Total non-tidal	0.0197	0.0132	5142	3452
Tidal	0.0173	0.0105	2411	1465
Total	0.0189	0.0123	7553	4916
Smallmouth bass				
Non-tidal Combined Upper and	0.2768	0.0104	18997	716
Non-tidal Lower reach	03899	0.0037	74938	711
Total non-tidal	0.3601	0.0055	93936	1428
Tidal	0.0319	0.0000	4457	0
Total	0.2457	0.0036	98393	1428
Channel catfish				
Non-tidal Combined Upper and	0.0182	0.0098	1250	672
Non-tidal Lower reach	0.0463	0.0056	8901	1067
Total non-tidal	0.0389	0.0067	10151	1739
Tidal	0.3477	0.0533	48552	7444
Total	0.1466	0.0229	58703	9183
Rock Bass				
Non-tidal Combined Upper and	0.0368	0.0067	2526	461
Non-tidal Lower reach	0.0284	0.0003	5449	61
Total non-tidal	0.0306	0.0020	7976	522
Tidal	0.0000	0.0000	0	0
Total	0.0199	0.0013	7976	522

Table 8.9. Angler total catch and total catch rates of selected species from the National Park Service and PFBC Delaware River and Estuary Angler Logbook program.

	2001		2002		2003		2004		2005		2006	
	No.	Rate	No.	Rate	No.	Rate	No.	Rate	No.	Rate	No.	Rate
American eel	8	0.000	24	0.024	12	0.002	8	0.000	4	0.000	0	0.000
American shad	1375	0.119	708	0.063	345	0.035	330	0.031	330	0.031	35	0.007
Brook trout	25	0.001	13		22	0.002	18	0.000	23	0.002	24	0.002
Brown Trout	1582	0.076	1686	0.122	2245	0.185	2795	0.171	1961	0.145	2155	0.207
Bluegill			61	0.010	44	0.008	13	0.001	60	0.011	28	0.012
Chain Pickerel	1	0.000	3	0.000	8	0.001	4	0.001	1	0.000	11	0.001
Channel catfish	42	0.004	197	0.197	117	0.021	163	0.023	172	0.030	74	0.018
Common carp	150	0.000	198	0.067	141	0.024	100	0.013	38	0.006	96	0.022
Largemouth	2	0.000	111	0.033	18	0.004	65	0.008	42	0.008	19	0.004
Pumpkinseed	2	0.000	31	0.005	3	0.001	18	0.002	12	0.002	12	0.003
Rainbow Trout	1775	0.111	1154	0.095	1011	0.079	1209	0.064	1236	0.103	807	0.084
Redbreast	100	0.017	651	0.088	487	0.075	586	0.057	528	0.059	290	0.057
River herring	440	0.039	418	0.037	380	0.040	37	0.003	25	0.002	11	0.020
Rock bass	18	0.000	161	0.013	115	0.010	105	0.004	194	0.014	53	0.006
Smallmouth	2430	0.070	2604	0.202	2529	0.156	3385	0.196	5147	0.338	3551	0.346
Striped bass	157	0.024	525		257	0.040	135	0.020	593	0.127	6	0.001
Walleye	59	0.001	105	0.011	176	0.020	145	0.007	143	0.017	235	0.029
White catfish	1	0.000	8	0.001	8	0.001			2	0.000	1	0.000
White perch	23	0.005	78	0.010	116	0.023	11	0.001	359	0.071	10	0.002
White sucker	8	0.001	1	0.000	12	0.002	3	0.000	9	0.001	3	0.000
Participants	62		52		50		45		42		35	
Trips	1,962		1,826		1,815		1,983		1,810		1,431	
Hours	11,444		11,979		10,886		13,186		12,035		9,610	

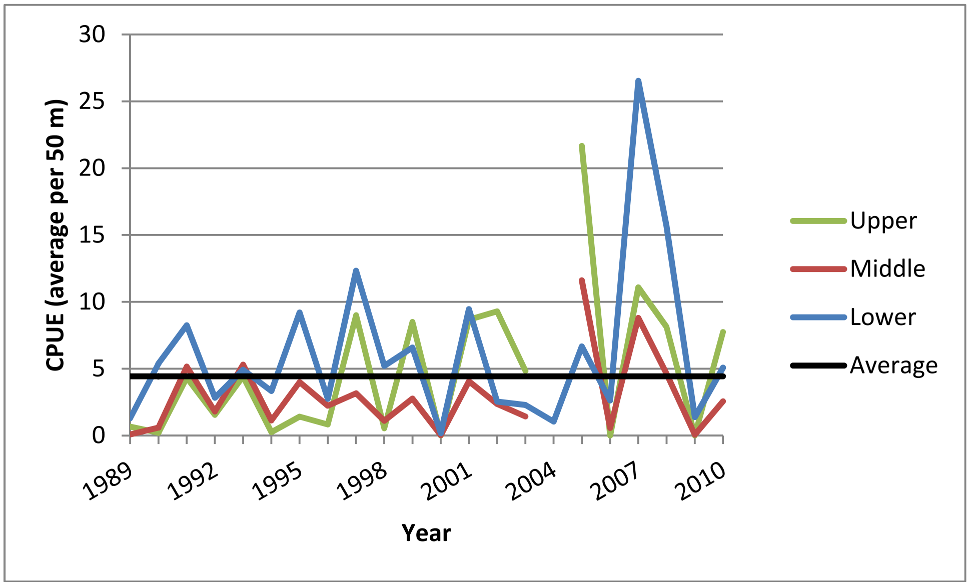


Figure 8.1. Estimated catch-per-unit-effort of YOY smallmouth bass by river reach from the PFBC midsummer fixed station survey.

A.

B.

C.

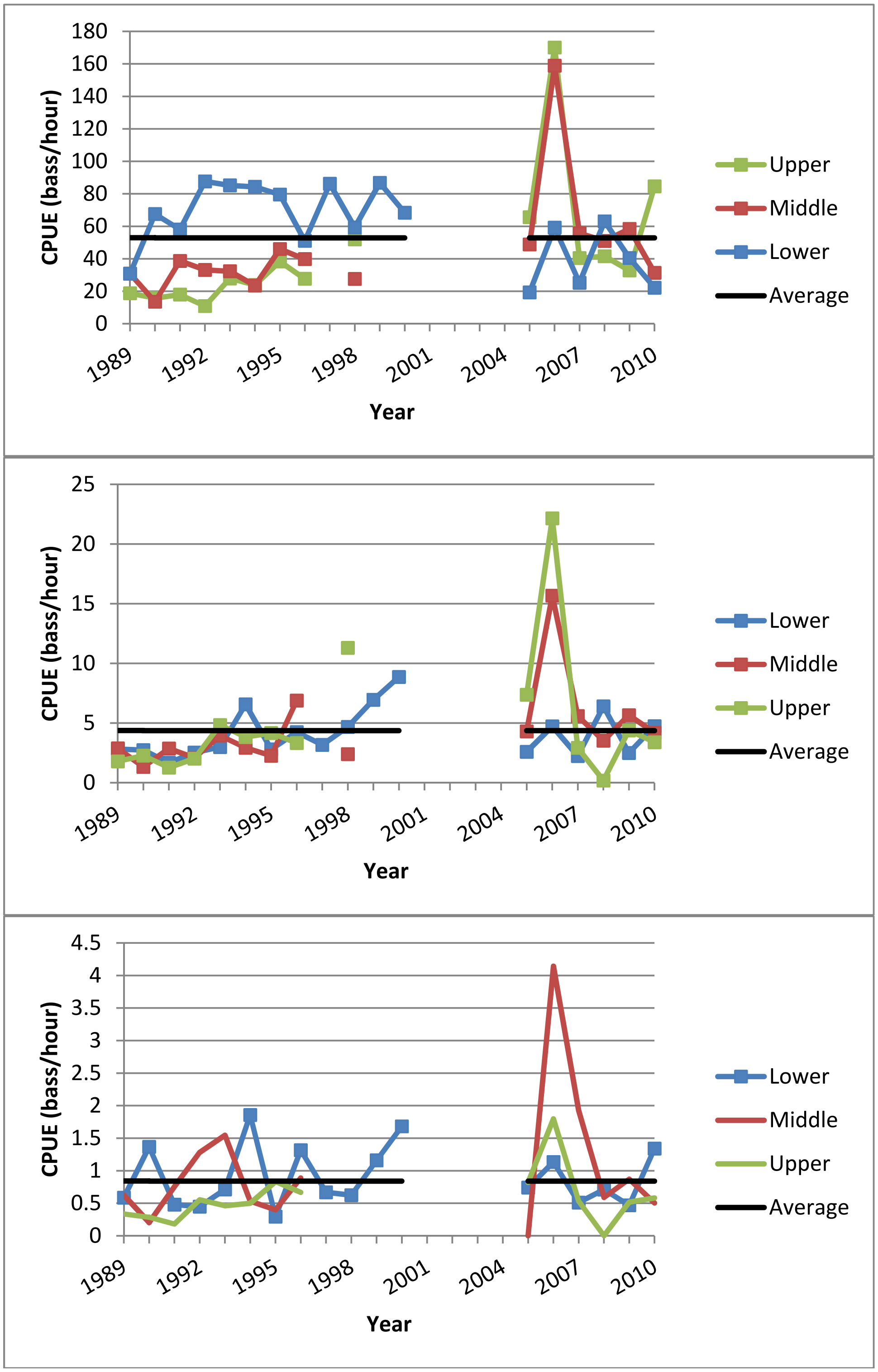


Figure 8.2. Estimated catch-per-unit-effort (bass/hour) of smallmouth bass by river reach from the PFBC fall fixed station survey. A. all collected smallmouth bass; B. Smallmouth bass ≥ 12 inches; C. Smallmouth bass ≥15 inches.

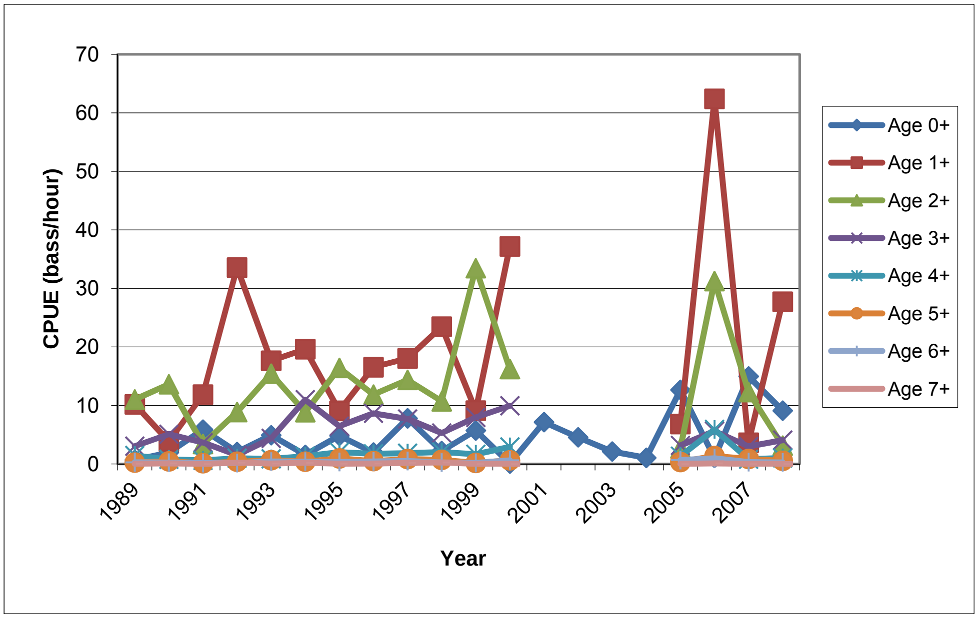
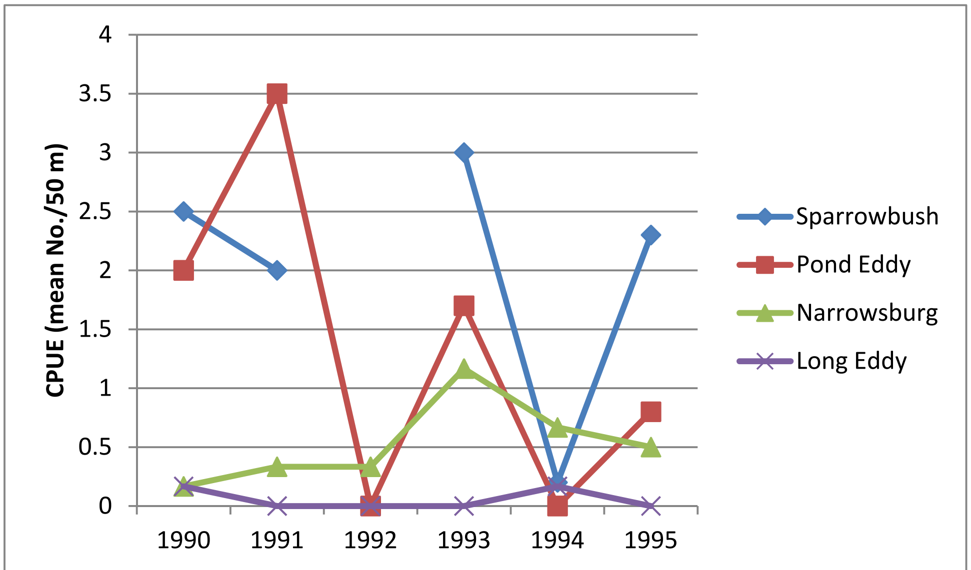


Figure 8.3. Catch-per-unit-effort (bass/hour) of smallmouth bass by age from the PFBC fall fixed site surveys. Ages 8+ and older were omitted from the illustration due to rarity in station samples.

A.



B.

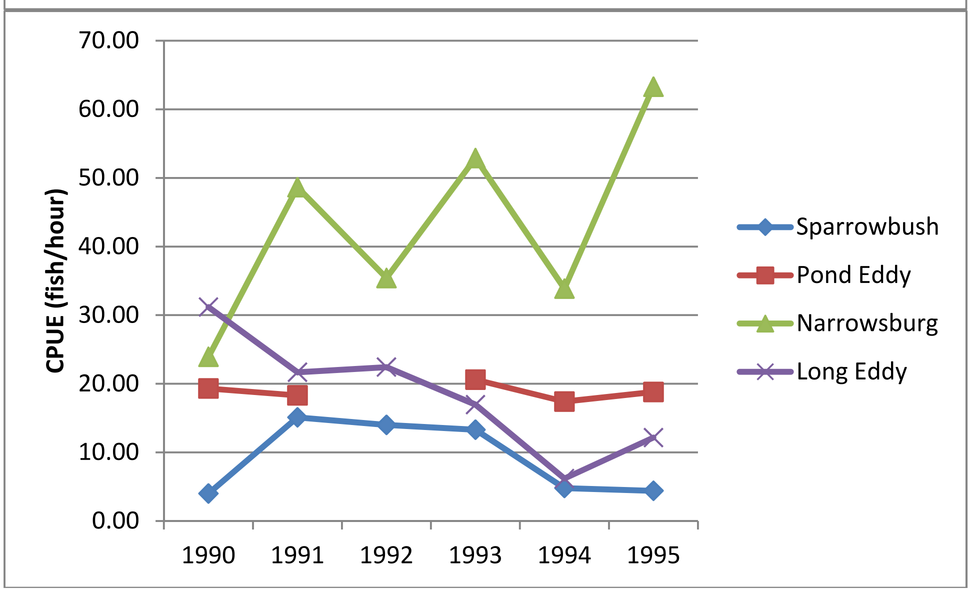


Figure 8.4. Catch-per-unit- of-effort (fish/hour) for YOY (A) and (B) adult smallmouth bass from the fixed station electrofishing sampling in the Delaware River mainstem reaches by NYDEC via electrofishing gear. Adopted from Angyal and Arnold (2008).

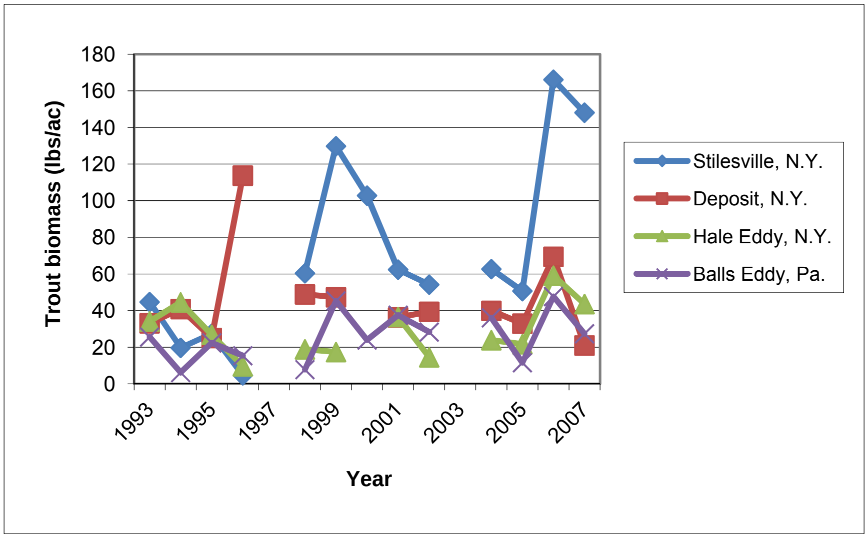


Figure 8.5. Trout biomass (lbs/acre) estimated by NYDEC at four standardized sampling sites in the West Branch Delaware River. Reproduced from McBride (2008).

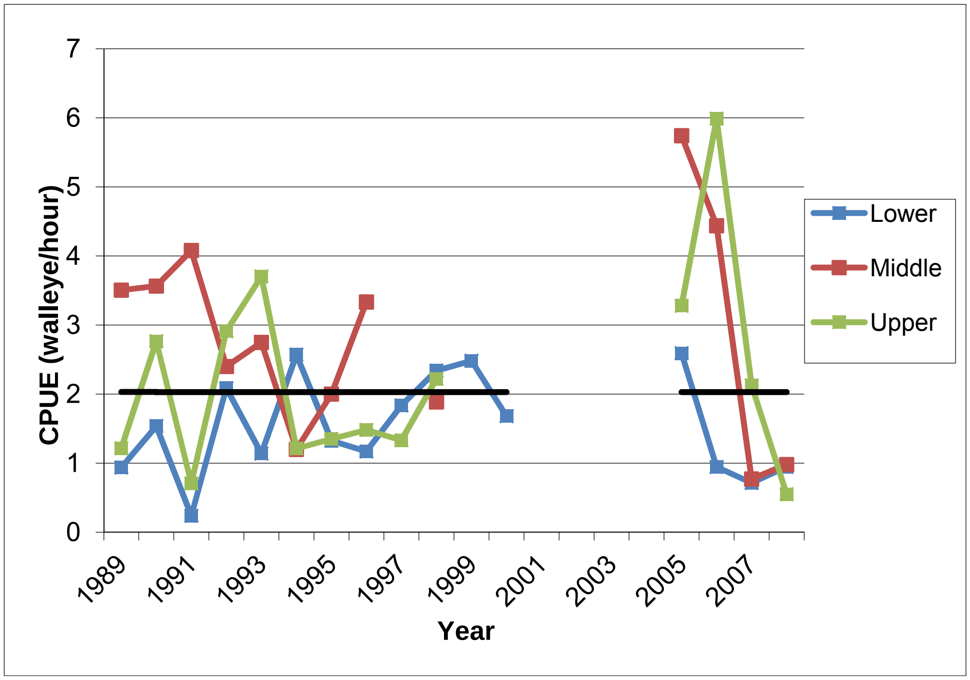


Figure 8.6. Estimated catch-per-unit-effort (fish/hour) of walleye by river reach from the PFBC fall fixed station survey.

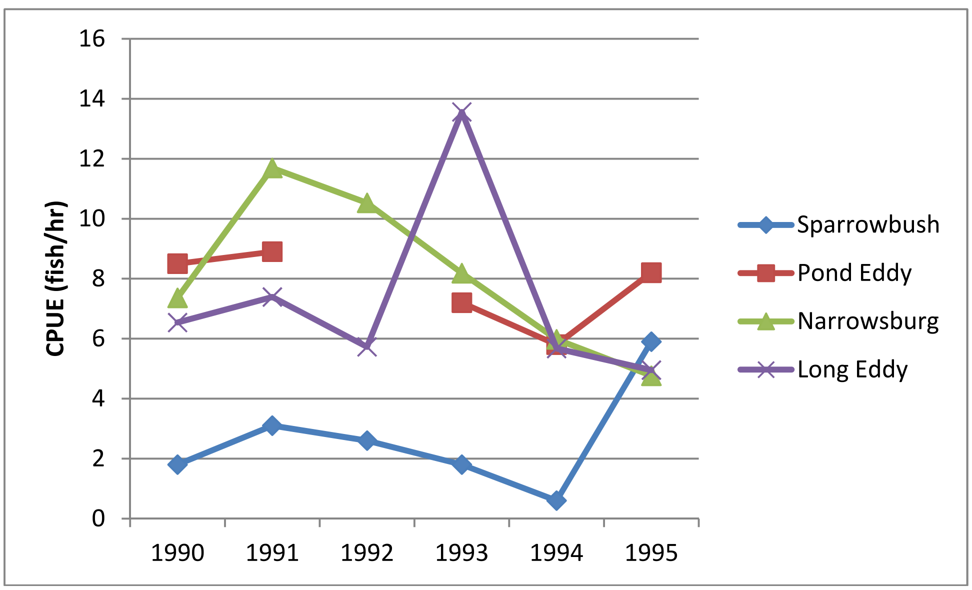


Figure 8.7. Catch-per-unit-of-effort (fish/hour) for walleye from the fixed station electrofishing sampling in the Delaware River mainstem reaches by NYDEC via electrofishing gear in early-mid-fall months. Adopted from Angyal and Arnold (2008).

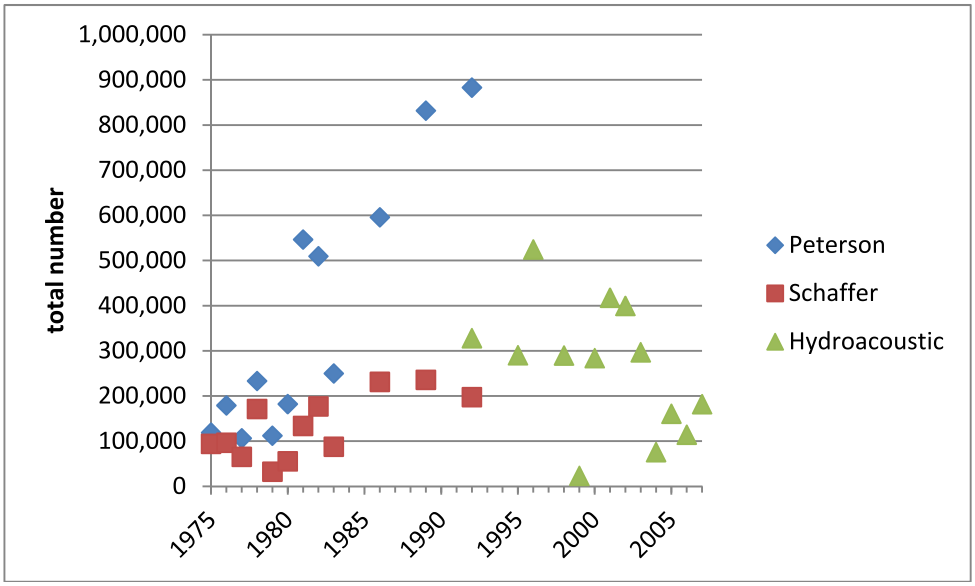


Figure 8.8. Population estimates of returning American shad to the Delaware River. Peterson and Schaffer estimates were based on tagging of shad from the Lewis haul seine at Lambertville, NJ The hydroacoustic estimates were based on estimating passage at the U.S Route 222 bridge.

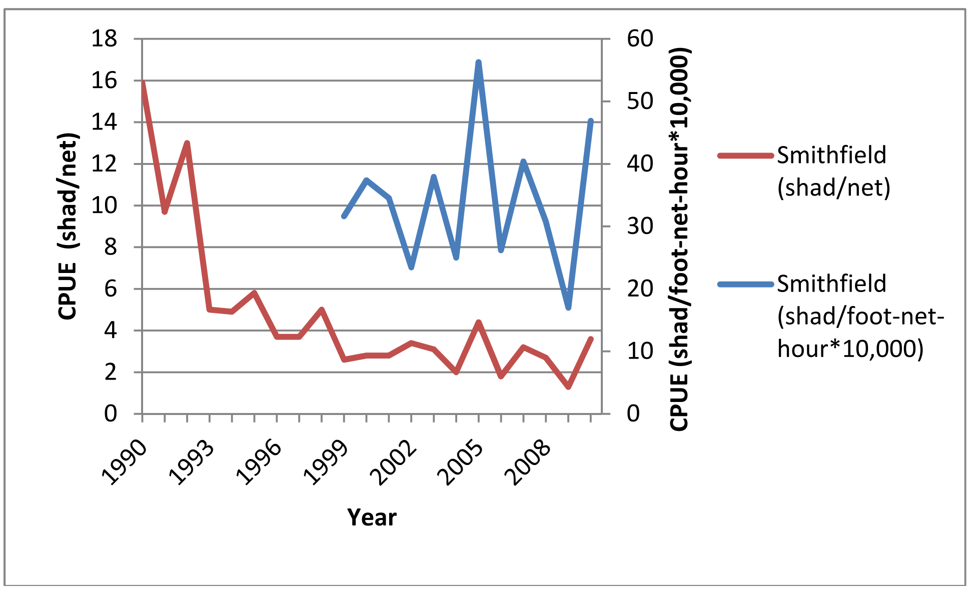
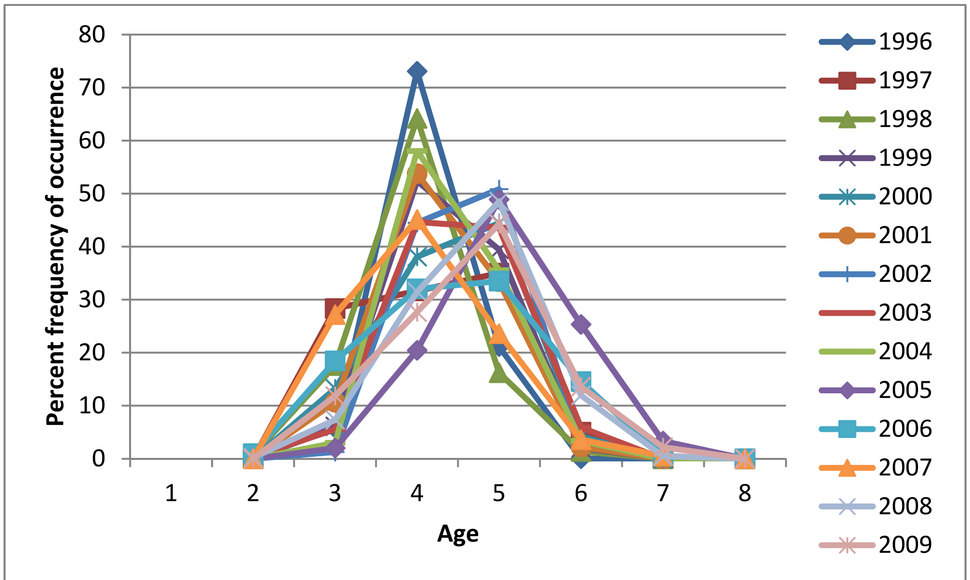


Figure 8.9. Catch-per-unit-of-effort of returning adult American shad collected in floating gill nets set in the Smithfield Beach pool (RM 218.0).

A.



B.

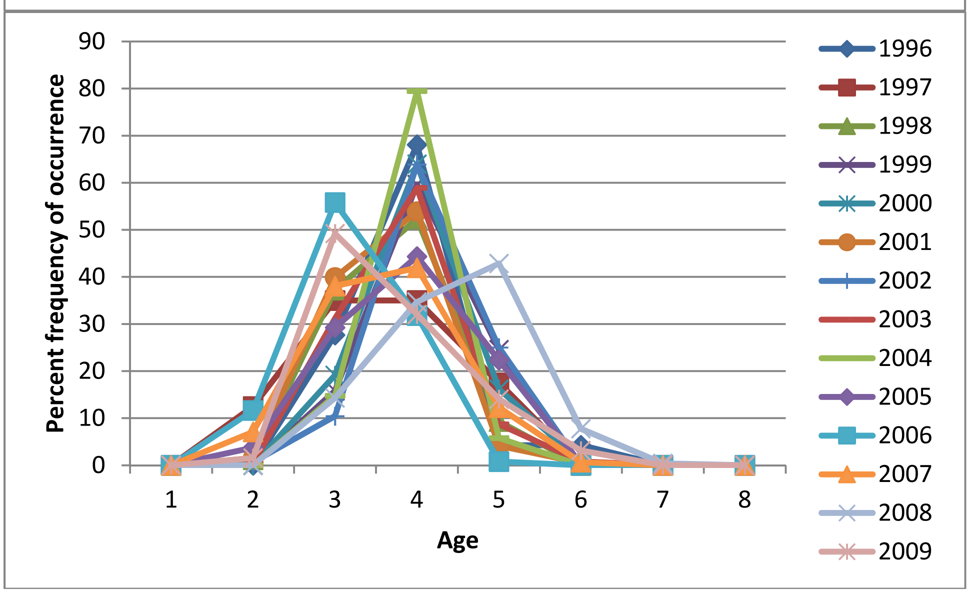


Figure 8.10. Age distribution of returning female (A) and male (B) American shad collected in floating gill nets set in the Smithfield Beach pool (RM 218.0). Presented data is from age estimates derived from scale microstructure in all years excepting 2008 when age was estimated from otoliths.

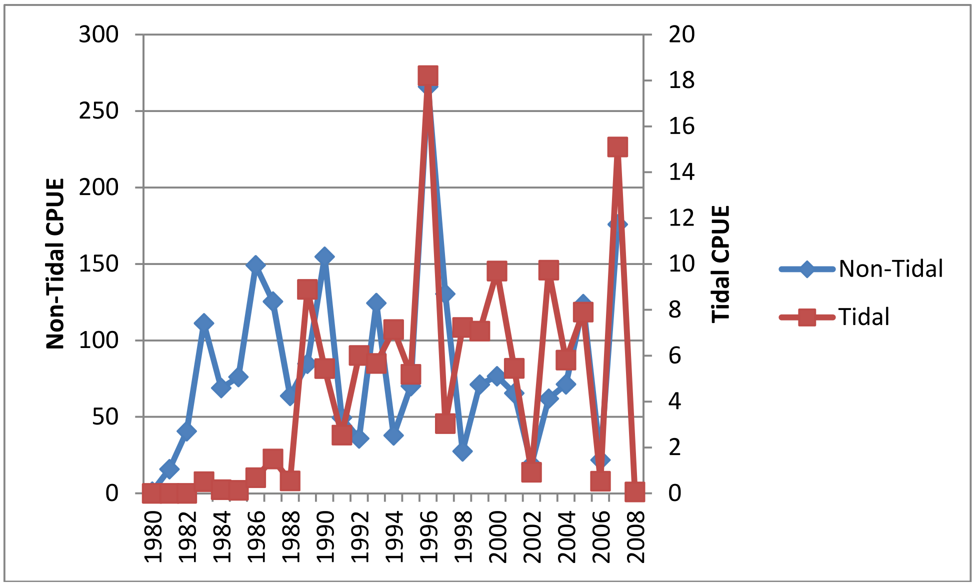


Figure 8.11. Catch-per-unit-effort (geometric mean) of young-of-the-year American shad collected by NJ Department of Environmental Protection Division of Fisheries, from the non-tidal stations in the Delaware River (Trenton, NJ up-river to Milford, PA) and tidal (Delaware Memorial Bridge up-river to Trenton, NJ) stations in the Delaware estuary.

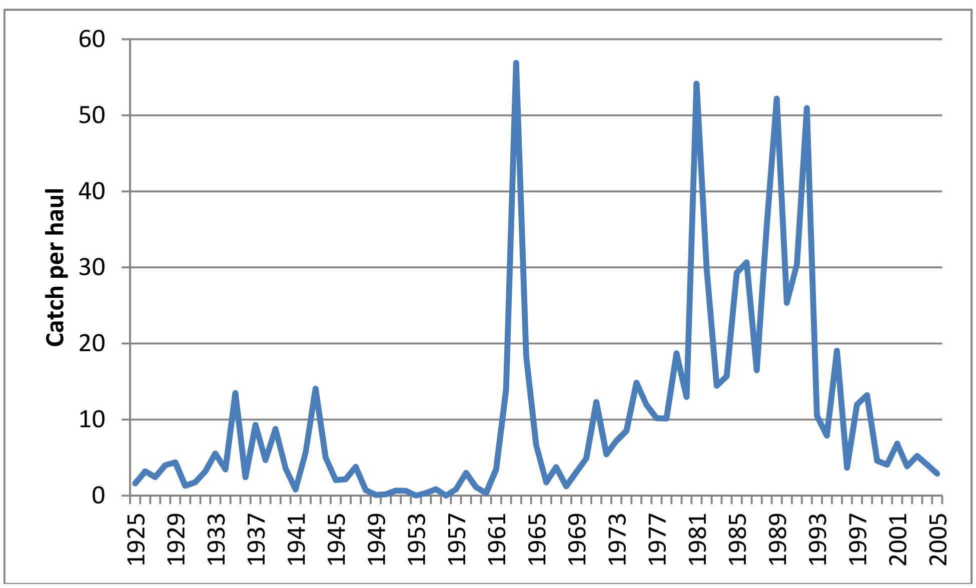


Figure 8.12. Catch-per-haul of American shad in the Lewis haul seine fishery, located in Lambertville, NJ.

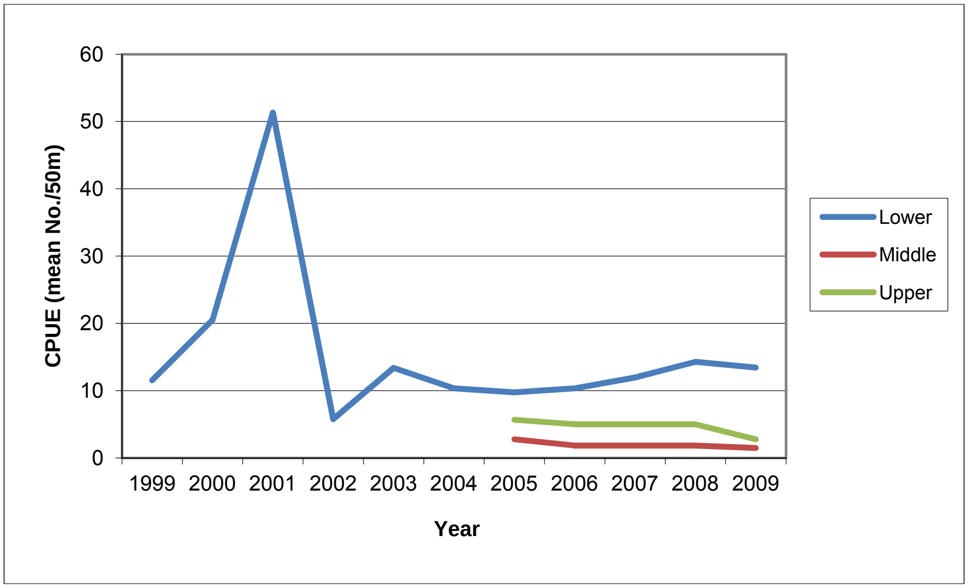


Figure 8.13. Estimated catch-per-unit-effort of American eel (all sizes) by river reach from the PFBC midsummer fixed station survey.

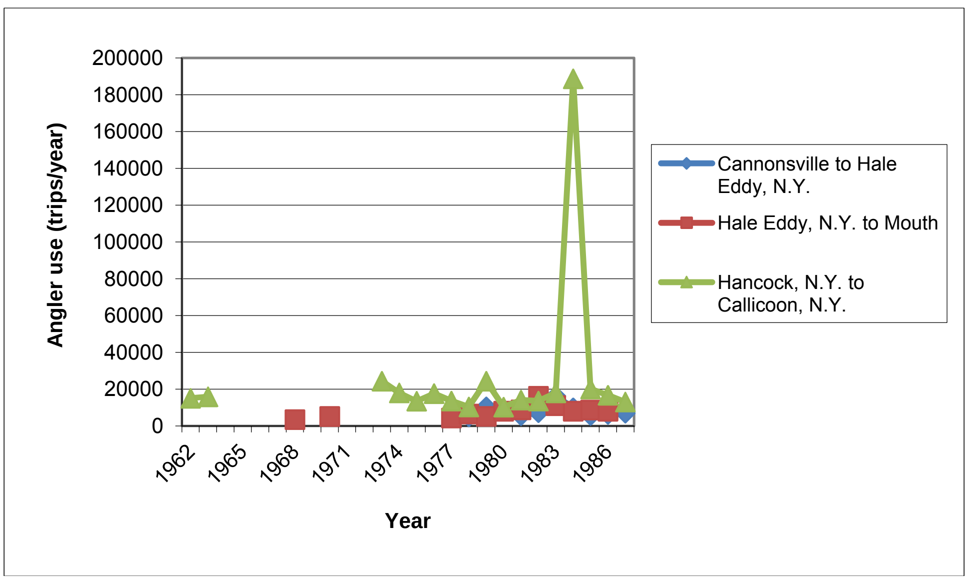
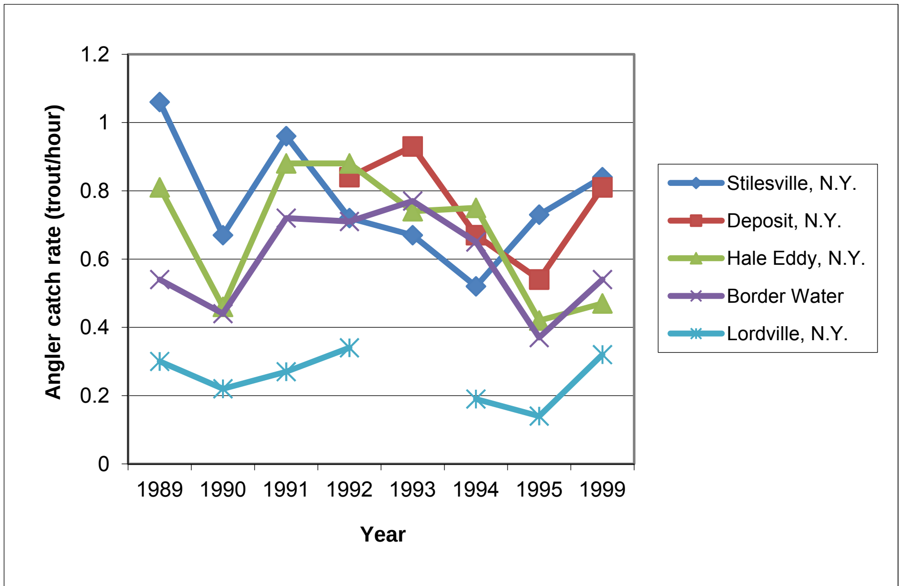


Figure 8.14. Estimated angler use (angler trips/year) on the West Branch Delaware River and upper Delaware River mainstem based on aerial angler counts (adapted from Keller 1988, Sanford 1992).

A.



B.

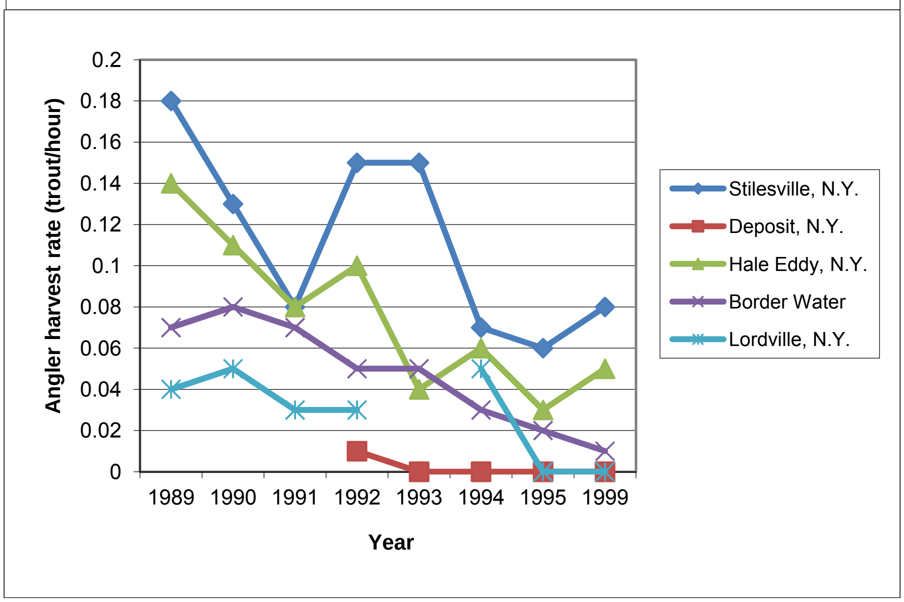
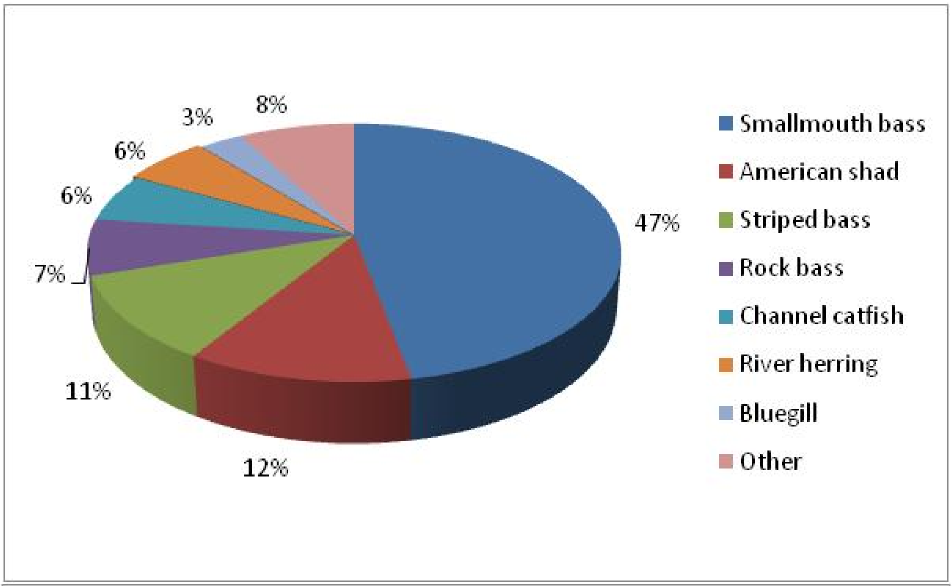


Figure 8.15. Summary of estimated catch rate (A) and harvest (B) for the West Branch Delaware and Delaware rivers down to Lordville, NY. Reproduced from Sanford (1993) and McBride (2003).

A.



B.

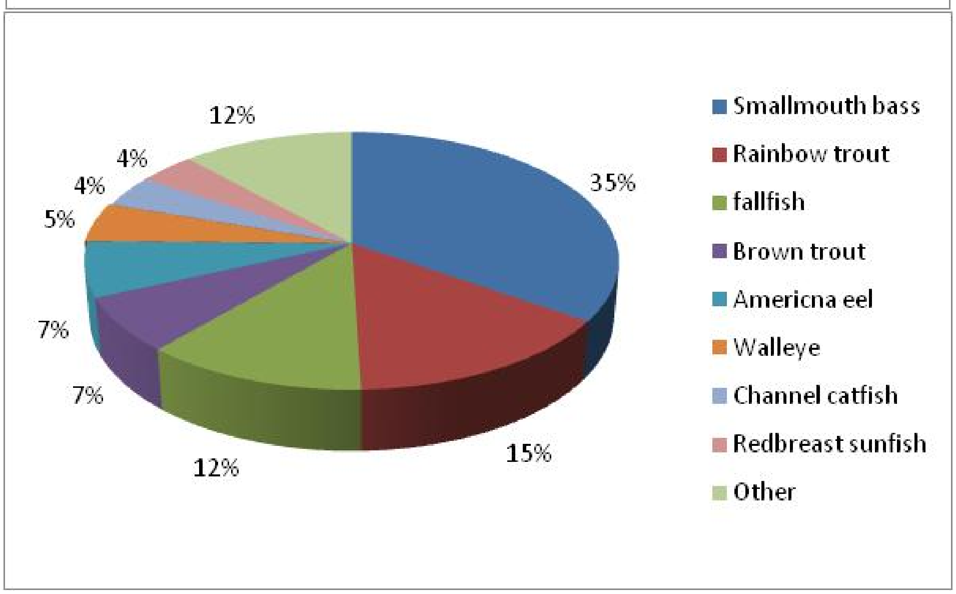
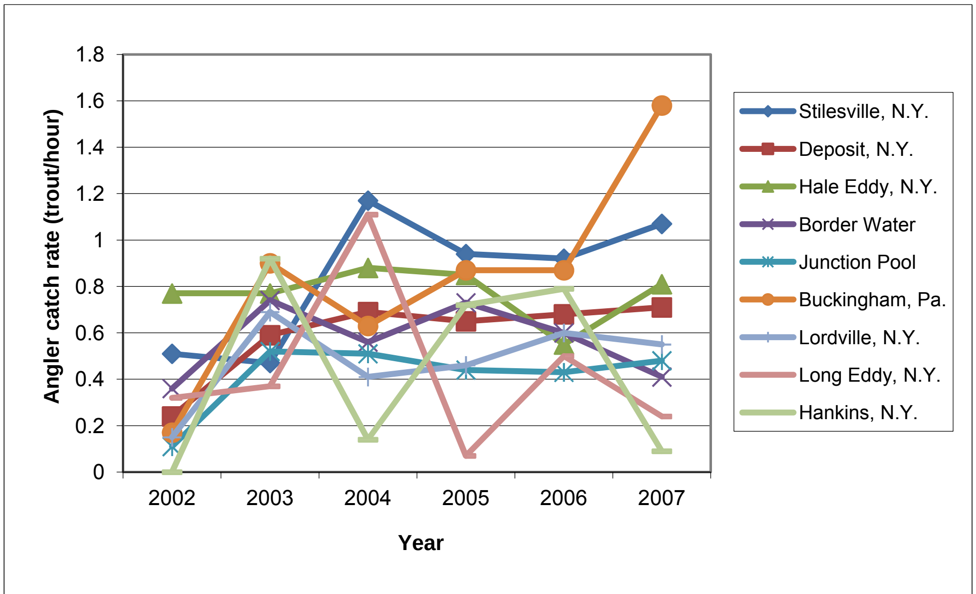


Figure 8.16. Percent angler catch composition of interviewed anglers encountered during the 2002 creel survey of the East Branch Delaware and Delaware rivers (Volstad et al. 2003). A). Trenton, NJ at head-of-tide up-river to Narrowsburg, NY; B) Narrowsburg, NY up-river to Downsville, NY.

A.



B.

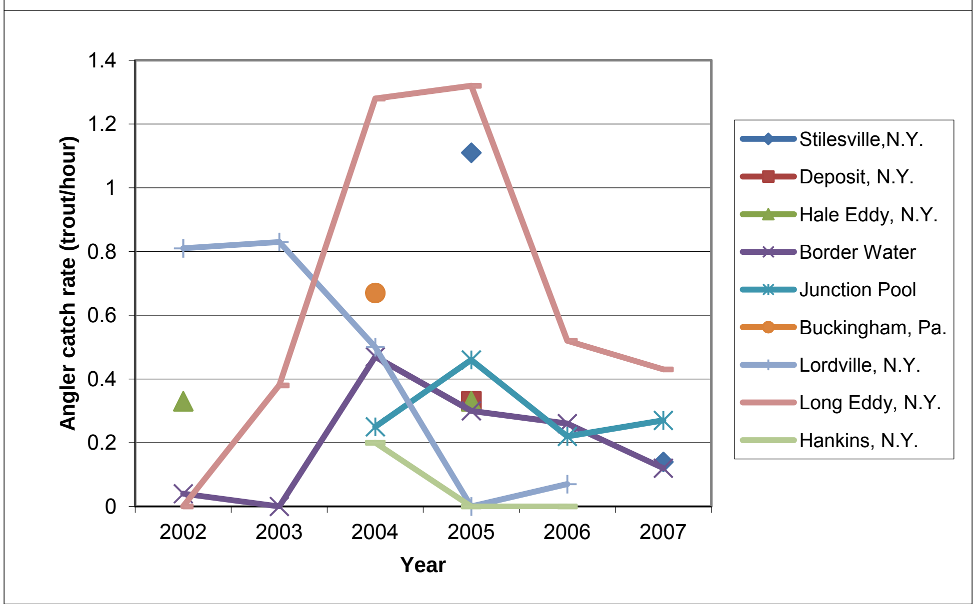


Figure 8.17. Summary of NYDEC volunteer angler log book program for shore anglers (A) and boat anglers (B) catch rate of all trout (trout/hour) from 2004 to 2007, from the West Branch Delaware River and upper Delaware River. Adapted from (McBride 2007).

9.0 Human Dimensions

9.1 Boating Activities

Commercial Vessels

Within the West Branch Delaware River and non-tidal reach of the Delaware River there are no commercial merchant vessels transporting bulk commodities. Canal systems were historically used for commercial transport of freight, principally coal, but have since been abandoned. To date, commercial boat traffic is limited to supporting tourist activities. The Bucks County Riverboat Company (http://www.buckscountyriverboats.com/index.html) operates a pontoon boat in the lower reach of the non-tidal Delaware River for tourists to enjoy the scenic Delaware River vistas. Additionally, it is anticipated that upon completion of canal repairs within the Delaware Canal State Park a concessionaire will resume boat tours of the canal using old time mule-drawn barge rides below New Hope, PA. Canoeing, kayaking and rafting are extremely popular on the West Branch and Delaware rivers supporting numerous liveries. The National Park Service maintains a listing of boat liveries operating within park boundaries of the UPDE (http://www.nps.gov/upde/planyourvisit/boatrentals.htm) and DEWA. The PFBC also maintains an informal listing of liveries within the state that is periodically updated (http://www.fishandboat.com/livery.htm).

Recreational Vessels

The West Branch Delaware and Delaware rivers are open to various recreational water craft. The distance that a recreational boat can travel on the river is generally limited only to individual boats ability to negotiate shallow water. Generally, these are small power boats, rafts, canoes, kayaks, and tubes. All powered boats and any unpowered boat using a PFBC access area or property, a DCNR state park, or property where the owner requires such documentation are required to be registered semi-annually with the PFBC Bureau of Administration, Division of Licensing and Registration. All unpowered vessels not falling into the above category are not required to be registered but are required to display a launch permit to use PFBC accesses and properties and DCNR state parks. Further information regarding registration of recreational vessels can be found at http://www.fish.state.pa.us/registration.htm. All recreational vessels operated in the waters of the Commonwealth, including the West Branch Delaware and Delaware rivers, are subject to the regulations published in Title 58 of the Pennsylvania Code or the Pennsylvania Boating Handbook (http://www.fish.state.pa.us/book boat.htm).

Military Vessels (e.g., Coast Guard)

Military vessels are not normally operated in the West Branch Delaware River and non-tidal reaches of the Delaware River. The closest Coast Guard Station is the Sector Delaware Bay located in Philadelphia, PA.

Access Facilities

Numerous private and public access points for fishing exist along the length of the West Branch Delaware and Delaware rivers. Table 9.1 provides a listing of access points identified during the 2002 survey of angler use and harvest in the Delaware River (Volstad et al. 2003). Public access to the West Branch Delaware and Delaware rivers may also be available through state and federal lands (Table 2.1). Access points are also available online from a variety of sources including but not limited to the PFBC (http://www.fish.state.pa.us/mpag1.htm), NPS (UPDE: http://www.nps.gov/upde/index.htm; DEWA: http://www.nps. gov/dewa/index.htm), DRBC (http://www.state.nj.us/drbc/drbc.htm), and New Jersey DFW (http://www.state.nj.us/dep/fgw/pdf/delacces.pdf). While all of the accesses points will accommodate walk-in anglers, some are designed to launch a boat and have limited parking. The PFBC has developed a management plan for directing internal actions for pursuing and managing public access within the state. The West Branch Delaware and Delaware rivers do not support marinas. However, individual property owners with shoreline rights can apply for permitting to install and maintain private docks for personal use in the Delaware River.

9.2 Tourism and Recreational Use

The West Branch Delaware and Delaware rivers provide a wide array of recreational opportunities. Some of the most popular activities include boating, fishing, swimming, and wildlife watching. Other activities include camping, hiking, biking and hunting. Three National Parks including the Upper Delaware Scenic and Recreational River (http://www.nps.gov/upde/index.htm), Delaware Water Gap National Recreation Area (http://www.nps.gov/dewa/index.htm), and the Lower Delaware National Wild and Scenic River (http://www.nps.gov/lode/index.htm) support a variety of these activities throughout the Delaware River.

Angling is a popular direct use of the West Branch Delaware and Delaware rivers. Total angling effort on the non-tidal reach of the Delaware River during 2002 was estimated to be 260,849 angler hours (79,854 trips; Volstad et al. 2003). Due to the underlying survey design this estimate included both shore and boat anglers, and a portion of the East Branch Delaware River. Boat anglers accounted for 80% of the total effort. A thriving guide industry has developed to provide services for interested anglers. Generally, the guide industry has been focused in the upper Delaware River, specifically the tailwaters of the NYC targeting the trout fishery. At present, the economic values of the recreational use of the West Branch Delaware and Delaware rivers are largely un-documented. An economic survey of the NYC reservoir tailwater fishery in the upper Delaware River estimated that angler expenditures resulted in approximately $17.7 million in local business revenue during 1996 (Maharaj et al., 1998). However, the economic value of other recreational pastimes, including, but not limited to paddling, nature viewing, and facility use (picnicking and swimming, etc) remain un-characterized.

Stretching from the headwaters of the Delaware from Hancock, NY to the head of tide in Trenton, NJ, the Delaware Water Trail (http://www.delrivgreenway.org/content/What%20We%20Do/Trails/

Trails%20Index.html#), , offers opportunities for water-based recreation. This trail encompasses all of the non-tidal reaches of the Delaware River, including reaches within the Upper Delaware Scenic and Recreational River, Delaware Water Gap National Recreation Area, and the Lower Delaware National Wild and Scenic River. This trail is maintained by the National Park Service, and its partners in the National Wild and Scenic system. As part of this water trail, primitive camp sites on the river are available only to boaters and canoeists travelling from one access point to another when the distance is too great to be covered in one day (http://www.nps.gov/dewa/planyourvisit/canoe-camping.htm).
Campsites are limited to a one-night stay and are on a first-come, first-served basis.
Canoe campsites are open all year unless the river is closed due to an emergency. At present there are no fees and no reservation system.

Currently under construction, the Joseph M. McDade Recreation Trail in the Delaware Water Gap National Recreational Area (http://www.nps.gov/dewa/planyourvisit/hikes-mcdade.htm) will provide 37 miles of hiking, biking, and cross-country skiing on the Pennsylvania side of the River. Two sections are presently completed from the Hialeah Picnic Area to Turn Farmstead Trailhead (5 miles), and from Milford Beach to Pittman Orchard at route 209 (2.7 miles).

The Appalachian National Scenic Trail is a footpath stretching more than 2,175-miles through 14 eastern states from Maine to Georgia. The trail is maintained by the National Park Service (http://www.nps.gov/appa/index.htm). In Pennsylvania, the trail follows the Blue Ridge Mountain Range, drops into the town of Delaware River Water Gap, PA before crossing the Delaware River on Interstate 80 in the DEWG Park. From there, the Trail continues into New Jersey along the Kittatinny Mountain Ridge line up to New Jersey's High Point State Park (http://www.state.nj.us/dep/parksandforests/parks/highpoint.html).

Opportunities for a variety of other outdoor activities are available in conjunction with the West Branch Delaware and Delaware rivers and include nature viewing, fall color viewing, bird watching, fishing, cross-country skiing and visits to historical sites. The National Park Service maintains a variety of activities that can be accessed via their websites for "Plan Your Visit" to the Park at http://www.nps. gov/upde/planyourvisit/index.htm for the Upper Delaware Scenic and Recreational River, and http://www.nps.gov/dewa/planyourvisit/index.htm for the Delaware Water Gap National Recreational Area, and http://www.nps.gov/lode/planyourvisit/index.htm for the Lower Delaware National Wild and Scenic River.

9.3 Funding Opportunities

The State Wildlife Grants Program (http://www.fish.state.pa.us/promo/grants/swg/00swg.htm) provides federal funds to the Pennsylvania Fish and Boat Commission and Game Commission and is administered by the U.S. Fish and Wildlife Service. These monies are available for high-priority conservation projects for endangered, threatened and at-risk species across Pennsylvania identified by the State Wildlife Action Plan (SWAP; http://www.fishandboat.com/promo/grants/swg/00swg.htm). Applications for grants are reviewed annually and funded through a competitive selection process. The National Park Service offers grants to non-profit and governmental agencies for the preservation and understanding of park resources (http://www.nps.gov/pub_aff/grants.htm). Specifically, the UPDE and DEWA have funded various levels of research within their boundaries through partnerships with outside non-profit and governmental agencies.

9.4 Education and Research

The PFBC, Bureau of Policy, Planning, and Communication (PPC), Division of Communications, Education and Outreach Section currently provides hands – on training and educational materials on various topics related to the enjoyment and understanding of the aquatic environment. These programs target all levels from kindergarten through high school. The Bureau of Policy Planning and Communication also partners with colleges conducting research and providing educational opportunities within the Delaware River Basin. The PFBC sponsored workshops and the materials provided are designed for use by classroom educators and can easily be adapted for use with any group. The workshops are designed to provide educators with introduction to the background content as well as exposure to learning activities associated with that content. Some of the sponsored programs include: ProjectWILD, WILD Aquatic, Pennsylvania Amphibians and Reptiles Workshop, Trout in the Classroom, Shad in the Classroom, Pennsylvania League of Angling Youth, State-Fish Art Contest, PA Basic Boating, Boating and Water Safety Awareness, and Fishing Skills Instructor Training. Interactions with K-12 and the general public are handled primarily by the PFBC's northeast and southeast regional education and outreach coordinator and staff, with offices in Sweet Valley and Elm, Pennsylvania.

Similarly, the DCNR, Bureau of State Parks and the National Park Service, offers educational programs and activities at State Park facilities as well as material for use in schools (http://www.dcnr.state.pa.us/stateparks/ education/index.aspx), (http://www.nps.gov/upde/forteachers/index.htm, http://www.nps.gov/dewa/forteachers/index.htm, http://www.nps.gov/lode/forteachers/index.htm). The Pocono Environmental Education Center (PEEC; http://www.peec.org/) is one of the most respected and recognized environmental education centers in the northeastern United States. This unique public/private partnership has served the education community for over thirty years offering education services to schools, families, Scouts, and outdoor enthusiasts.

Several local Colleges and Universities offer higher education opportunities within the non-tidal Delaware River Basin. These institutions can offer research and learning experiences directly within the Delaware River Basin through their curriculum and research activities. East Stroudsburg University (http://www.esu.edu/), Lafayette College (http://www.lafayette.edu/), Cedar Crest College (http://www.cedarcrest.edu/ca/index.shtm), and Lehigh University (http://www.lehigh.edu/default.asp) represent some of the larger institutions in close proximity to mainstem waters.

A number of governmental and non-governmental organizations have conducted or maintain on-going research programs. Federal agencies include DRBC, NPS, US EPA, USGS PA Water Science Center, USGS Leetown Science Center, USGS PA Cooperative Fisheries and Wildlife

Research Unit, USFWS, and the U.S. NWS. State agencies include PA DEP, DCNR, PGC, PFBC, NY Department of Environmental Conservation, and New Jersey Department of Environmental Protection. Other organizations include Academy of Natural Science of Philadelphia, The Nature Conservancy, Trout Unlimited, and Western Pennsylvania Conservancy.

9.5 River Stewardship

The evolving sense of environmental responsibility has been growing in the United States over the past few decades. Today, this stewardship presence is strong within governmental, non-profit and private organizations. The best stewards of the rivers are likely the people who use them the most including angler, boating, and environmental organizations. Numerous angler organizations are currently involved in issues pertaining directly with the Delaware River. National organizations including Trout Unlimited, Muskies Inc, and Pennsylvania Federation Sportsmen's Club (http://www.pfsc.org/) maintain local chapters throughout the drainage basin. Friends of the Upper Delaware River (http://www.fudr.org/), the Delaware River Shad Fisherman's Association (http://mgfx.com/ fishing/assocs/drsfa/), and the Pennsylvania BASS Federation (http://www.pabass.com/) are organizations with interest in specific fisheries.

The Delaware River Basin Commission maintains a listing of organizations interested in protecting and monitoring the watershed resources in the Delaware River Basin (http://www.state.nj.us/drbc/watershedgroups.htm). Entities listed are primarily non-profit organizations and private clubs. Other listings of private organizations acting as stewards of the Delaware River can usually be found within individual state park web listings.

The Nature Conservancy (TNC: http://www.nature.org/) is a international organization whose mission is to preserve the plants, animals, and natural communities that represent the diversity of life on Earth by protecting lands and waters they need to survive. The TNC, has been active in many projects within the Delaware River, specifically in the upper Delaware River (http://www.nature.org/ wherewework/northamerica/states/pennsylvania/preserves/art19487.html); and chaired the Sub-Committee for Ecological Flows for evaluating releases from the NYC reservoirs.

Two active non-profit organizations are the Delaware Riverkeeper Network and the Delaware River Greenway Partnership. The Delaware Riverkeeper Network (DRN: http://www.delawareriverkeeper.org/), established in 1988 upon the appointment of the Delaware Riverkeeper, is a nonprofit membership organization. The DRN's staff and volunteers work throughout the entire Delaware River Basin including portions of Pennsylvania, New Jersey, Delaware and New York. Its programs include: Advocacy to protect water quality and habitat; Awareness to Action, which works to organize local communities into activists to protect local streams; Litigation and other legal action to enforce environmental laws; Monitoring by volunteers along the entire length of the River; and Restoration to provide communities the expertise, community training and organizing needed to restore damaged streams and waterway ecosystems.

The Delaware River Greenway Partnership (http://www.delrivgreenway.org/content/Welcome%21/Welcome%21%20Index.html) is a non-profit organization founded in 1998 that works to bring individuals, communities, businesses, recreational users and all levels of government together to promote and protect a continuous corridor of natural and cultural resources along the Delaware River and its tributaries. The Delaware River Greenway Partnership seeks to engage with public and private partners to promote stewardship of the Lower Delaware National Wild and Scenic River and its tributaries and to foster a shared sense of place among communities that adjoin the river by preserving and enhancing its ecological, scenic, historic, cultural and recreational resources. The DRGP's activities are concentrated in the region from the Delaware Water Gap through the upper Estuary, but some projects necessarily extend beyond these boundaries.

9.6 Management Options

Priority 1: (on-going activities or recommendations to be implemented in first year of management plan).

- Continue to provide and develop partnerships for supporting educational programs for schools and general public consumption to promote the stewardship of the West Branch Delaware and Delaware rivers.

- Continue to provide web-based summary articles on the status of the PFBC activities related to the West Branch Delaware and Delaware rivers.

Table 9.1. Listing of boat access to the West Branch Delaware and Delaware rivers. Adopted form Volstad *et al.* 2003).

State	Access	RM	Descriptive location
			West Branch Delaware River
PA	Balls Eddy	3.5	3.5 miles north of Hancock bridge Rt. 191
PA	Shehawken	1	Rt. 191 and Rt. 317 jtn.
			Delaware River
NY	Hancock, 191 Bridge	330	
PA	Shingle Hollow Access Area	328.6	Approx 1 mile north of Stockport Creek off Rt 191
PA	Buckingham	325	Approx. 2.2 miles north of Equinink, PA off Rt. 191
PA	Equinunk	322.5	
NY	Lordsville	321.6	
NY	Long Eddy	315.2	
NY	Basket Creek,	314	Under the Rt 97 viaduct
NY	Kellams Bridge	312.6	
NY	Hankins River Rest Stop	310	Hankins, NY
NY	Red Barn Camp Ground	311	Hankins, NY
NY	Callicoon	303	In Hamlet of Callicoon, NY, off Rt. 97
PA	Callicoon	303	Approx. 0.5 miles south of Callicoon bridge off PA Legislative Rt. 63110; north from Rt. 371
NY	Cocheton	298	Rt. 97 upstream of highway bridge.
PA	Damascus	298	Just downstream from the PA Rt. 371 bridge off Legislative Rt. 63027
NY	Skinners Falls	295	Across from Milanville, PA
NY	Narrowsburg	290	Off Main Street
PA	Narrowsburg	290	Off Rt. 652 below Narrowsburg bridge
NY	Tusten/Ten Mile R NY	284	
NY	Zane Grey	278	Rt. 590, at confl. Lackawaxen R.
NY	Highland	274	
NY	Mongaup	261.2	
NY	Sparrowbush	258.1	Off Rt. 97 north of Rt. 42 junction
PA	Matamoras	256	Approx. 1.5 miles north of Matamoras/Port Jervis bridge off Rt. 209
NY	West End Beach Access	255.5	
PA	Milford Beach	246	Rt. 209
PA	Dingman's Ferry	239	Rt. 209
PA	Eshback	232	Rt. 209
PA	Bushkill	228	Rt. 209
NJ	Depew	220	Old Mine Road, 9.3 miles north of Del. Water Gap

NJ	Poxono	219	Old Mine Road, 8.0 miles north of Del. Water Gap
PA	Smithfield Beach	218	River Road)
NJ	Worthington STP	217	Old Mine Road, 3.0 miles north of Del. Water Gap
NJ	Kittatinny Beach	211	Del. Water gap Interstate 80 bridge
PA	Up river end Arrow Island	210.8	Del. Water Gap, downriver Kittatiny Beach
PA	Portland Footbridge	207.2	
PA	Portland Generating Station	206	River Rd., 0.8 miles below Portland-Columbia bridge
PA	Mount Jack County Park	200	
PA	Doe Hollow	198	River Road upriver from Belvidere bridge
NJ	Belvidere	197	Downriver of bridge
PA	Martins Creek Generating	194	Rt. 611, 1 mile north of Martin's Ck
PA	Sandts Eddy	189	611, 5.2 miles above Easton
PA	Frost Hollow Overlook	186	Rt. 611, 2.3 miles north of Easton
NJ	Phillipsburg Boat Ramp	184	Riverside Way, "free bridge"
PA	Scott Park Boat Ramp	184	Rt. 611, at confl. of Lehigh river
PA	Hugh Moore Park	184	south bank of confl, Lehigh River
PA	Wi-Hit-Tuk County Park	181	Rt. 611, 3 miles south of Easton
PA	Theodore Roosevelt Rec.	178	Rt. 611, 1 mile south Raubsville, PA
PA	Fry's Run Park	177	Rt. 611, 6 miles south of Easton
PA	Riegelsville	174	Rt. 611, just north of jct. Rt. 212
PA	Durham Furnace Access	174	Canal Access
NJ	Holland Church Access	174	Off River Rd.,1 mile south of Riegelsville bridge
PA	Lock #20 Access	172	Canal Access
PA	Upper Black Eddy	168	Rt. 32 just below Milford bridge
PA	Giving Pond Access	166	Rt 32
NJ	Frenchtown Access Area	165	
NJ	Kingwood	163	Rt. 29, 2 miles below Frenchtown
PA	Tinicum Park	163	Rt. 32, Erwinna
NJ	Byram Access Area	156.5	Rt. 29, 3.4 miles north of Stockton
PA	Lumberville Wing Dam -	156	
NJ	D&R Canal St. Pk - Bull's	155	Rt. 29,m 3.3 miles north of Stockton
PA	Virginia Forrest Rec. Area	154	Rt. 32, approx. 2 miles south of Lumberville
NJ	D&R Canal St. Pk. -	149	Bridge St. behind Lambertville Station
NJ	D&R Canal St. Pk. -	147	Rt. 29, 1.8 miles south of Lambertville/New
NJ/PA	Washington Crossing	142	
NJ	Scudders Falls Access	139	
PA	Yardley	139	Rt. 32 north end of Yardley Borough
PA	Ferry Road Access	134	
NJ	Stacy Park River Rest	134	
PA	Morrisville Access	133	
NJ	Old Warf	133	Rt. 29 south of Lalor St. in City of Trenton, NJ

10.0 Management Options

This is a compendium of all management options recommended for action throughout the management plan. The following management actions are copies *verbatim* from previous sections of this plan. The data and information regarding each of the actions listed below can be found in the respective sections.

Priority 1: (on-going activities or recommendations to be implemented in first year of management plan).

- Continue directed sampling annually for the monitoring of YOY and adult smallmouth bass for identifying spatial and temporal population trends within the Delaware River. The study design will be adjusted as appropriate to provide representative sampling in the upper Delaware River basin. The intent for this survey is to forecast future angling opportunities based on current population status and determine the feasibility of developing target benchmarks for triggering proactive management actions for optimization and protection of the smallmouth bass population.

- Continue with annual monitoring of American shad populations through current sampling programs to describe the annual springtime adult spawning migration into the Delaware River. This monitoring effort will be adjusted as appropriate based on the direction of the Delaware River Shad Management Plan mandated by the Atlantic States Marine Fisheries Commission Amendment 3 Shad and River Herring Management Plan.

- Develop a monitoring approach for providing characterization of the occurrence and quantification of fish communities within the West Branch Delaware and Delaware rivers. The intent is to provide a long-term baseline to identify species spatial and temporal trends inclusive of game and non-game fishes. Additionally, an anticipated study objective would also lend to the characterization of species of special concern and invasive species distributions and habitat utilization of fishes within the rivers.

- Continue to coordinate with PA DEP, DRBC, Decree Party, and other associated agencies for managing reservoir releases from the NYC water supply dams that best protect/promote aquatic communities in the Delaware River Basin.

- Pursue further refinement of the NYDEC-PFBC white paper recommendations for flow recommendations to support the existing coldwater fishery in the West Branch Delaware River and upper Delaware River by using the existing hydrologic modeling tools to further explore alternative reservoir releases to improve the protection of the aquatic coldwater and downriver communities.

- Continue to coordinate through PFBC Division of Environmental Services, Natural Diversity Section, addressing the identification and utilization of habitats for species of concern as prioritized by the State Wildlife Action Plan within the West Branch Delaware and Delaware rivers.

- Continue to maintain open communication with other federal and state resource management agencies and remain active in the Delaware River Basin Fish and Wildlife Management Cooperative for the vetting of interstate fisheries issues.

- Continue to provide and develop partnerships for supporting educational programs for schools and general public consumption to promote the stewardship of the West Branch Delaware and Delaware rivers.

- Continue to provide web-based summary articles on the status of the PFBC activities related to the West Branch Delaware and Delaware rivers.

<u>Priority 2:</u> (recommendations with implementation date in years 2-3 of management plan)

- Coordinate with PA DEP through the PFBC, Bureau of Fisheries, Division of Environmental Services to develop fishery measures for high quality, warmwater fishery criteria for inclusion in PA Code, Chapter 93 as identified under Goal 2, Item H of the PFBC Strategic Plan.

- Coordinate with the PFBC Coldwater Unit and NYDEC fisheries staff to evaluate the feasibility of annual quantification of YOY and adult trout populations in the West Branch Delaware and Delaware rivers. The intent of this program is to allow managers to track population trends and aid in supporting the NYDEC-PFBC white paper.

- Develop sampling protocols for supporting small-scale reach-specific angler use and harvest surveys to provide basic description of trends in angler behavior and to aid in determination of regulatory and management practices.

<u>Priority 3:</u> (recommendations with implementation date in years 4-5 of management plan)

- Develop monitoring programs for channel catfish and walleye within the Delaware River for assessing their baseline population status as per state-wide species-specific management plans.

- Identify opportunities for combining resources with other governmental agencies to maximize the ability for field activities, while reducing the associated cost.

- Coordinate with partner agencies to determine the feasibility of installation of water quality monitoring stations in the upper Delaware River Basin above Callicoon, NY to assess the extent of spatial and temporal patterns of the coldwater tailrace in the upper Delaware River.

11. Literature Cited

46th Northeast Regional Stock Assessment Workshop (46th SAW). 2008. 46th SAW assessment summary report. US Dept Commer, Northeast Fish Sci Cent Ref Doc. 08-01; 24 p. Available from: National Marine Fisheries Service, 166 Water Street, Woods Hole, MA 02543-1026.

AECOM Environmental. 2008. 316(b) Best professional judgment for Best Technology available report – Portland Generating station Mt. bethel Township, Pennsylvania. Prepared form Reliant Energy. NPDES Permit No. PA0012475.

Albert, R. C. 1981. Primary production of the non-tidal Delaware River July and august, 1980: Report No. 2 Upper Delaware River Summer Limnological Program. Delaware River Basin Commission 25 State Police Drive, West Trenton, NJ 08628.

Anderson, R. M. D. A. Kreeger. 2010. Potential for impairment of freshwater mussel populations in DRBC Special Protection Waters as a consequence of natural gas exploratory well development. Joint U.S. Fish and Wildlife Service and Parnership for the Delaware Estuary white paper. http://www.state.nj.us/drbc/Anderson-Kreeger.pdf

Angyal, R. K. and D. A. Arnold. 2008. Evaluation of Delaware River smallmouth bass and walleye regulations changes, 1989-1996. Draft report NYDEC New Paltz, NY 12561.

Anonymous, 2006. Assessment techniques and biological criteria for free flowing large rivers: Special emphasis on non-tidal section of the Delaware River Basin. Prepared for Delaware River Basin Commission 2006 Project Research Plan Version 4.3 06 September 2006. Delaware River Basin Commission 25 State Police Drive, West Trenton, NJ 08628

Anonymous, 2007. Management of trout fisheries in Pennsylvania waters. Bureau of Fisheries, Division of Fisheries Management. 3rd edition. Pennsylvania Fish and Boat Commission 450 Bellefonte, PA 16823.

Arnold, D. A. 2000. Upper Delaware River Striped Bass. Memorandum to Division of Fisheries Management Chief, D. Snyder. Pennsylvania Fish and Boat Commission 450 Bellefonte, PA 16823.

Arnold, D. A. 2003. 2003 Survey Delaware River, West Branch, Section 01, 1A, PFBC files, 450 Robinson Lane, Bellefonte, PA 16823

Arnold, D. A. 2003 Documentation and Quantification of Alosids Utilizing Fish Passage Facilities and Collection of Biological Data on Adult American Shad. Grant No. NA16F12358 C

Arnold, D. A. 2004 Documentation and Quantification of Alosids Utilizing Fish Passage Facilities and Collection of Biological Data on Adult American Shad. Pennsylvania Fish and Boat Commission 450 Bellefonte, PA 16823.

Arnold, D. A. 2005 Documentation and Quantification of Alosids Utilizing Fish Passage Facilities and Collection of Biological Data on Adult American Shad. Grant No. NA04NMF4070242 Pennsylvania Fish and Boat Commission 450 Bellefonte, PA 16823.

Arnold, D. A. 2006 Documentation and Quantification of Alosids Utilizing Fish Passage Facilities and Collection of Biological Data on Adult American Shad. Grant No. NA04NMF4070242 Pennsylvania Fish and Boat Commission 450 Bellefonte, PA 16823.

Arnold, D. A. and D. J. Pierce. 2007. Lehigh River Fisheries Management Plan. Bureau of Fisheries, Division of Fisheries Management. Pennsylvania Fish and Boat Commission. 450 Bellefonte, PA 16823.

Arnold, D. A. 2007 Documentation and Quantification of Alosids Utilizing Fish Passage Facilities and Collection of Biological Data on Adult American Shad. Grant No. NA05NMF4071206, Pennsylvania Fish and Boat Commission 450 Bellefonte, PA 16823.

Arnold, D. A. and D. J. Pierce. 2008. Documentation and Quantification of Alosids Utilizing Fish Passage Facilities and Collection of Biological Data on Adult American Shad. 5th Semi Annual Report for P.L. 99-659, Project 2-IJ-240,Grant No. NA05NMF4071206 (multi-year; 2006-2010) Pennsylvania Fish and Boat Commission 450 Bellefonte, PA 16823.

Arnold, D. A. and D. J. Pierce. 2008 Documentation and Quantification of Alosids Utilizing Fish Passage Facilities and Collection of Biological Data on Adult American Shad. 6th Semi Annual Report for P.L. 99-659, Project 2-IJ-240, Grant No. NA05NMF4071206 (multi-year; 2006-2010) 5 Year Plan (2006-2010). Pennsylvania Fish and Boat Commission 450 Bellefonte, PA 16823.

Arcadis-BBL. 2007. "Phase IV Completion Report." Report submitted to PADEP on behalf of PPL Martins Creek, LLC, following completion of Phase IV in the remediation and monitoring efforts for the fly-ash spill of 2005. 426 pp.

ASMFC. 1998. American shad stock assessment peer review report. Atlantic States Marine Fisheries Commission, Washington, D.C. www.asmfc.org

ASMFC. 1998. Amendment 1 to the Interstate fishery Management Plan for shad and river herring. Fishery Manag. Rep. No. 35. Atlantic States Marine Fisheries Commission, Washington, D.C. www.asmfc.org

ASMFC. 2003. Interstate fisheries Management Program Charter. Atlantic States Marine Fisheries Commission, Washington, D.C. www.asmfc.org

ASMFC. 2003. Amendment 6 to the Interstate Fishery Management Plan for Atlantic striped bass. Fishery Manag. Rep. No. 41. Atlantic States Marine Fisheries Commission, Washington, D.C. www.asmfc.org

ASMFC. 2006. Terms of Reference & Advisory Report to the American Eel Stock Assessment Peer Review. Stock Assessment Report No. 06-01. Atlantic States Marine Fisheries Commission, Washington, D.C. www.asmfc.org

ASMFC. 2006. Addendum III to Amendment 1 of the interstate fishery management plan for Atlantic sturgeon. Atlantic States Marine Fisheries Commission, Washington, D.C. www.asmfc.org

ASMFC. 2007. American shad stock assessment report. Stock Assessement Report No. 07-01 (Supplement) Volume 1. Atlantic States Marine Fisheries Commission, Washington, D.C. www.asmfc.org

ASMFC. 2007. Addendum I to Amendment 6 to the Atlantic Striped Bass Fishery Managements Plan. Atlantic States Marine Fisheries Commission, Washington, D.C. www.asmfc.org

ASMFC. 2008. Review of the Atlantic States Marine Fisheries Commission Fishery Management Plan for American eel (*Anguilla rostrata*). www.asmfc.org

ASMFC. 2008. Addendum II to the Fishery Management Plan for American Eel. Atlantic States Marine Fisheries Commission, Washington, D.C.www.asmfc.org

ASMFC. 2009. 2009 Stock assessment Report for Atlantic striped bass. Atlantic States Marine Fisheries Commission, Washington, D.C. www.asmfc.org

ASMFC. 2009. Amendment 2 to the Interstate fishery Management Plan for shad and river herring (river herring management). Atlantic States Marine Fisheries Commission, Washington, D.C.www.asmfc.org

ASMFC. 2010. ASMFC Approves American Shad Amendment States Water Fisheries to be Closed by January 1, 2013 unless Sustainability is Demonstrated; Promotes Catch and Release Recreational Fisheries. Press Release. Atlantic States Marine Fisheries Commission, Washington, D.C.www.asmfc.org

Barbour, M.T., J. Gerritsen, B. D. Snyder, and J. B. Stribling. 1999. Rapid Bioassessment protocols for use in streams and wadable rivers: Periphyton, benthic macroinvertebrates and fish, Second Edition. EPA 841-B-99-002. U. S. Environmental Protection Agency; Office of Water, Washington D. C.

Bilger, M.D., Riva-Murray, Karen, and Wall, G.L., 2005, A checklist of the aquatic invertebrates of the Delaware River Basin, 1990-2000: U.S. Geological Survey Data Series 116, 29 p.

Billingsley, C. 1980. West Branch Delaware River Section 01 Survey Data forms. Pennsylvania Fish & Boat Commission files. 450 Robinson Lane, Bellefonte, PA 16823.

Billingsley, C. 1986. West Branch Delaware River Section 01 Survey Data forms. Pennsylvania Fish & Boat Commission files. 450 Robinson Lane, Bellefonte, PA 16823.

Blocksom, K.A. and J.E. Flotemersch. unpublished. "Development of RIVPACS-type predictive model for the non-tidal portion of the Delaware River." Interim report submitted by USEPA-NERL to USEPA-R3 and DRBC, April 2008. 27 pp.

Bovee, K.D., Waddle, T.J., Bartholow, J., and Burris, L., 2007. A decision support framework for water management in the upper Delaware River: U.S. Geological Survey Open-File Report 2007-1172, 122 p.

Brightbill, R. A., K. Riva-Murray, Michael D. Bilger, and J. D. Byrnes. 2004. Total mercury and methylmercury in fish fillets, water, and bed sediments from selected streams in the Delaware River basin, New Jersey, New York, and Pennsylvania, 1998-2001. United States Geological survey. Water-resources Investigations Report 03-4183. http://pubs.usgs.gov/wri/wri03-4183/wrir03-4183.pdf

Cole, J. C., P. A. Townsend, and K. N. Eshleman. 2008. Predicting Flow and Temperature Regimes at Three *Alasmidonta heterodon* Locations in the Delaware River. Technical Report NPS/NER/NRTR—2008/109. National Park Service. Philadelphia, PA.

Craig Snyder, C. J. Young, D. Smith, D. Lemarie, R. Ross, R. Bennett 2001. Influence of Eastern Hemlock on Aquatic Biodiversity in Delaware Water Gap National Recreation Area. USGS 2048-03. http://www.lsc.usgs.gov/aeb/2048-03/dewarept.pdf.

Crecco, V. A., and M. Gibson. 1990. Stock assessment of river herring from selected Atlantic coast rivers. Spec Rep. No.19. Atlantic States Marine Fisheries Commission, Washington, D.C.

Davis, A.F., B. A. Eichelberger, S. Fanok, G. S. Podniesinski. 2009. Riparian plant communities on the Delaware River. The Nature Conservancy. BRC-RCI-11-15.

DCNR. Shaping a sustainable Pennsylvania – DCNR's Blueprint for Action. Pennsylvania Department of Conservation Natural Resources. http://www.dcnr.state.pa.us/info/shapefuture/actionplanfinal.pdf

DRBC. Tri-state Watershed Management Plan. 25 State Police Drive, West Trenton, NJ 08628. http://www.state.nj.us/drbc/tristate.htm.

DRBC 1977. Docket D-77-20. Experimental modification to the current release schedules from Cannonsville, Pepacton and Neversink Reservoirs, Delaware and Sullivan Counties, New York. Delaware River Basin Commission 25 State Police Drive, West Trenton, NJ 08628. http://www.state.nj.us/drbc/Reservoir_NYC/D-77-20.pdf

DRBC 1981. The final report and environmental impact statement on the Level B study. Delaware River Basin Commission 25 State Police Drive, West Trenton, NJ 08628.

DRBC 1982. Interstate Water Management Recommendations of the Parties to the U.S. Supreme Court Decree of 1954 to the Delaware River Basin Commission Pursuant to Commission Resolution 78-20. Commission 25 State Police Drive, West Trenton, NJ 08628. http://www.state.nj.us/drbc/regs/GoodFaithRec.pdf

DRBC 1983. Docket No., D-77-20 CP (Revised). Modification to the release schedules from Cannonsville, Pepacton, and Neversink Reservoirs Delaware and Sullivan counties, New York. Delaware River Basin Commission 25 State Police Drive, West Trenton, NJ 08628. http://www.state.nj.us/drbc/Reservoir_NYC/D-77-20CPRev.pdf

DRBC 1993. Docket No., D-77-20 CP (Revision No. 2) Modification to the release schedules from Pepacton and Neversink Reservoirs Delaware and Sullivan counties, New York. Delaware River Basin Commission 25 State Police Drive, West Trenton, NJ 08628. http://www.state.nj.us/drbc/Reservoir_NYC/D-77-20CPRev2.pdf

DRBC 1999. Docket No., D-77-20 CP (Revision No. 3) Modification to the release schedules from Cannonsville, Pepacton and Neversink Reservoirs Delaware and Sullivan counties, New York. Delaware River Basin Commission 25 State Police Drive, West Trenton, NJ 08628. http://www.state.nj.us/drbc/Reservoir_NYC/D-77-20CPRev3.pdf

DRBC 1999. Docket No., D-77-20 CP (Revision No. 4) Modification to the release schedules from Cannonsville, Pepacton and Neversink Reservoirs Delaware and Sullivan counties, New York. Delaware River Basin Commission 25 State Police Drive, West Trenton, NJ 08628. http://www.state.nj.us/drbc/Reservoir_NYC/D-77-20CPRev4.pdf

DRBC 1999. Ground water protected area regulations southeastern Pennsylvania. Delaware River Basin Commission 25 State Police Drive, West Trenton, NJ 08628. http://www.state.nj.us/drbc/regs/gwpa.pdf

DRBC. 2000. Resolution 2000-8. Establish a Flood Advisory Committee. Delaware River Basin Commission 25 State Police Drive, West Trenton, NJ 08628. http://www.state.nj.us/drbc/Res2000-8.htm

DRBC 2002. Docket No., D-77-20 CP (Revision No. 5). Delaware River Basin Commission 25 State Police Drive, West Trenton, NJ 08628. http://www.state.nj.us/drbc/Reservoir_NYC/Res2002-06Rev5.pdf

DRBC 2003. Docket No., D-77-20 CP (Revision No. 6). Delaware River Basin Commission 25 State Police Drive, West Trenton, NJ 08628. http://www.state.nj.us/drbc/Reservoir_NYC/Res2003-04Rev6.pdf

DRBC 2004. Docket No., D-77-20 CP (Revision No. 7). Delaware River Basin Commission 25 State Police Drive, West Trenton, NJ 08628. http://www.state.nj.us/drbc/Res2004-3.pdf

DRBC 2004. Docket No., D-77-20 CP (Revision No. 8). Delaware River Basin Commission 25 State Police Drive, West Trenton, NJ 08628. http://www.state.nj.us/drbc/Reservoir_NYC/Res2004-09Rev8.pdf

DRBC 2004. Water Resources Plan for the Delaware River Basin. Delaware River Basin Commission 25 State Police Drive, West Trenton, NJ 08628. http://www.state.nj.us/drbc/basinplan.htm.

DRBC 2004a. Lower Delaware River Eligibility Determination for DRBC Declaration of Special Protection Waters. Delaware River Basin Commission, West Trenton, NJ. 22 pp. + 4 Appendices. http://www.state.nj.us/drbc/LD/eligibilitySPWfinal-rpt.pdf.

DRBC 2004b. Lower Delaware Monitoring Program: 2000-2003 Results and Water Quality Management Recommendations. Delaware River Basin Commission, West Trenton, NJ. 46 pp. + 5 Appendices. http://www.state.nj.us/drbc/LD/finalreport1-13.pdf.

DRBC 2005. Resolution 2005-2. Delaware River Basin Commission, West Trenton, NJ. 46 pp. + 5 Appendices. http://www.state.nj.us/drbc/Res2005-2-LDspw.pdf

DRBC 2006. Regulated Flow Advisory Committee (RFAC) bylaws. Delaware River Basin Commission 25 State Police Drive, West Trenton, NJ 08628. http://www.state.nj.us/drbc/RFAC_Bylaws_022306.pdf.

DRBC 2006. Docket No., D-77-20 CP (Revision No. 9). Delaware River Basin Commission 25 State Police Drive, West Trenton, NJ 08628. http://www.state.nj.us/drbc/Reservoir_NYC/Res2006-18Rev9.pdf

DRBC 2006. Resolution 2006-3. Modifying membership of Delaware River Basin Flood Advisory Committee. Delaware River Basin Commission 25 State Police Drive, West Trenton, NJ 08628. http://www.state.nj.us/drbc/Res2006-3.pdf

DRBC 2006. Resolution 2006 – 20. Authorization of acceptance of funds for evaluating the potential for reservoirs throughout the Basin to be used to mitigate flooding on the Delaware River and its tributaries. Delaware River Basin Commission 25 State Police Drive, West Trenton, NJ 08628. http://www.state.nj.us/drbc/Flood_Website/Res2006-20.pdf

DRBC 2007. Delaware River Basin Compact. Reprinted 2007. Delaware River Basin Commission 25 State Police Drive, West Trenton, NJ 08628. http://www.state.nj.us/drbc/regs/compa.pdf.

DRBC 2007. Delaware Toxics Reduction Program Annual Report 2007. Delaware River Basin Commission 25 State Police Drive, West Trenton, NJ 08628. http://www.state.nj.us/drbc /deltrip/2007/deltrip_full_27feb.pdf

DRBC 2008. Delaware River: State of the basin report. Delaware River Basin Commission 25 State Police Drive, West Trenton, NJ 08628. http://www.state.nj.us/drbc/SOTB/ index.htm.

DRBC 2008. 2008 Delaware River and Bay integrated list water quality assessment. Delaware River Basin Commission 25 State Police Drive, West Trenton, NJ 08628 http://www.state.nj.us/drbc/08IntegratedList/EntireReport.pdf.

DRBC 2008. Resolution No. 2008-09. Delaware River Basin Commission 25 State Police Drive, West Trenton, NJ 08628. http://www.state.nj.us/drbc/Res2008-9-LDspw.pdf

DRBC 2009. Hydrologic conditions in the Delaware River Basin: Annual report 2008. Delaware River Basin Commission 25 State Police Drive, West Trenton, NJ 08628 http://www.state.nj.us/drbc/08hydro/report.pdf.

DRBC 2009. Delaware River Basin Water Code with Amendments through March 11, 2009. Delaware River Basin Commission 25 State Police Drive, West Trenton, NJ 08628 http://www.state.nj.us/drbc/regs/ watercode031109.pdf.

DRBC 2009. Determination of the Executive Director concerning natural gas extraction activities in shale formations within the drainage area of special protection waters. Delaware River Basin Commission 25 State Police Drive, West Trenton, NJ 08628 http://www.state.nj.us/drbc/EDD5-19-09.pdf.

DRBC 2009. DRBC releases results of flood analysis model: News Release. Delaware River Basin Commission 25 State Police Drive, West Trenton, NJ 08628. http://www.state.nj.us/drbc/newsrel_model121509.htm

DRBC 2009. Delaware River basin flood analysis model and associated studies analysis of potential flood mitigation with existing reservoirs: Overview and next steps. Delaware River Basin Commission 25 State Police Drive, West Trenton, NJ 08628. http:/ /www.state.nj.us/drbc/Flood_Website/FloodAnalysisModel/Summary.pdf

DRBC 2009. Delaware River Recreational Maps. Delaware River Basin Commission 25 State Police Drive, West Trenton, NJ 08628

DRBC 2010a. Supplemental determination of the Executive Director concerning natural gas extraction activities in shale formations within the drainage area of Special Protection Waters. Delaware River Basin Commission 25 State Police Drive, West Trenton, NJ 08628. http://www.state.nj.us/drbc/SupplementalEDD6-14-10.pdf

DRBC 2010b. Amendment to supplemental determination of the Executive Director concerning natural gas extraction activities in shale formations within the drainage area of Special Protection Waters. Delaware River Basin Commission 25 State Police Drive, West Trenton, NJ 08628. http://www.state.nj.us/drbc/AmendedSuppEDD072310.pdf

DRBC 2010c. Docket No. D-2009-13-1. Special Protection Waters. Stone Energy Corporation surface water withdrawal for natural gas exploration and development projects West Branch Lackawaxen River withdrawal site Mount Pleasant Township, Wayne County, Pennsylvania. Delaware River Basin Commission 25 State Police Drive, West Trenton, NJ 08628. http://www.state.nj.us/drbc/dockets/2009-013-1.pdf

DRBC 2010d. Water Resource Program FY 2010 – 2015. Delaware River Basin Commission 25 State Police Drive, West Trenton, NJ 08628. http://www.state.nj.us/drbc/WRP2010-2015.pdf

DRBC 2010e. Natural Gas Development Regulations. Article 7 of Part III – Basin Regulations. Delaware River Basin Commission 25 State Police Drive, West Trenton, NJ 08628. http://www.state.nj.us/drbc/naturalgas-draftregs.pdf

DRBC 2010f. 2010 Delaware River and Bay integrated list water quality assessment. Delaware River Basin Commission 25 State Police Drive, West Trenton, NJ 08628. http://www.state.nj.us/drbc/10IntegratedList/FinalReport.pdf

DRBC 2010g. Docket No. D-2010-022-1. Special Protection Waters. XTO Energy Surface Water Withdrawal for Natural Gas Exploration and Development Projects. Oquaga Creek Withdrawal Site. Town of Sanford, Broome County, New York. Delaware River Basin Commission 25 State Police Drive, West Trenton, NJ 08628. http://www.state.nj.us/drbc/dockets/D-2010-022-1.pdf

DRBFWMC. 1980. A management plan for the American shad (*Alosa sapidissima*) in the Delaware River basin. Pennsylvania Fish and Boat Commission, 450 Robinson Lane, Bellefonte, PA 18623.

DRBFWMC. 1982. A fishery management plan for the American shad (*Alosa sapidissima*) in the Delaware River basin. Pennsylvania Fish and Boat Commission, 450 Robinson Lane, Bellefonte, PA 18623.

DRBFWMC. 1992. Dredging, Blasting and Overboard Disposal In The Delaware River Basin. Pennsylvania Fish and Boat Commission, 450 Robinson Lane, Bellefonte, PA 18623.

DRBFWMC. 2010. Revisions to the 1992 policy for dredging, blasting and overboard disposal. Pennsylvania Fish and Boat Commission, 450 Robinson Lane, Bellefonte, PA 18623.

Elliot, W. P., 2001. Delaware River tailwaters experimental releases monitoring 1997-1999. NYDEC Region 3 Fisheries. New Paltz, NY

Elliot, W., B. Angyal, and N. McBride. 2004. Delaware Tailwaters Monitoring Report, 2004. New York Department of Environmental Conservation, Bureau of Fisheries, Albany, NY.

Engtsrom-Heg, R. 1990. Guidelines for stocking trout streams in New York State. New York Department of Environmental Conservation, Bureau of Fisheries, Albany, NY.

Fairchild, G. W., R. J. Horwitz, D. A. Nieman, M.R. Boyer, and D. F. Knorr. 1998. Spatial variation and historical change in fish communities of the Schuylkill river drainage, Southeast Pennsylvania. Am. Midl. Nat. 139: 282-295.

FFMP 2007. Flexible Flow Management Plan. Office of the Delaware River Master. 10 Buist Road, Suite 304 Milford, PA 18337. http://water.usgs.gov/osw/odrm/document_archive/FFMP_original.pdf.

FFMP. 2008. Flexible Flow Management Plan. Office of the Delaware River Master. 10 Buist Road, Suite 304 Milford, PA 18337. http://water.usgs.gov/osw/odrm/documents/FFMP_FINAL.pdf.

FFMP. 2011. Flexible Flow Management Plan. Office of the Delaware River Master. 10 Buist Road, Suite 304 Milford, PA 18337. http://water.usgs.gov/osw/odrm/documents/ffmp_ost_052511_final.pdf

Finger, B. L. 2001. Life history and range of Pennsylvania's endangered bridle shiner, *Notropis bifrenatus* (Cope). M.S. Thesis, Pennsylvania State University College of Agricultural Sciences. University Park, PA. 79 p.

Fischer, J. M., K. Riva-Murray, R. E. Hickman, D. C. Chichester, R. A. Brightbill, K. M. Romanok, and M. D. Bilger. 2004. Water quality in the Delaware River Basin, Pennsylvania, New Jersey, New York, and Delaware, 1998-2001. United States Geological Survey Circular 1227. http://pubs.usgs.gov/circ/2004/1227/pdf/circular1227.pdf

Fisher, M. 2009. Atlantic sturgeon progress report. State Wildlife Grant Project T-4-1. Delaware Division of Fish and Wildlife, Department of Natural Resources and Environmental Control, 4876 Hay Point Landing Rd Smyrna, DE 19977.

Flotemersch, J. E., J. B. Stribling, and M. J. Paul. 2006. Concepts and Approaches for the Bioassessment of Non-wadeable Streams and Rivers. EPA 600-R-06-127. US Environmental Protection Agency, Cincinnati, Ohio.

Foote, P.S. 1977. Blood lactic acid levels and mortality of American shad (*Alosa sapidissima*) utilizing the Holyoke Dam Fish Lift, Massachusetts, 1974 and 1975. Pages 261-284 *In:* Proceedings of a workshop on American shad, Dec. 14-16, 1976, Amherst, MA.

Gamble, 2002. Addendum I to Amendment I and Technical Addendum 1 to the Interstate Fishery Management Plan for shad and river herring. Atlantic States Marine Fisheries Commission Fishery Management Report No. 35b., Atlantic States Marine Fisheries Commission Washington, D.C. www.asmfc.org

Gibson, M.R., V.A. Crecco, and D.L. Stang. 1988. Stock assessment of American shad from selected Atlantic coast rivers. Atlantic States Marine Fisheries Commission. Special Report No. 15.

Hendricks, M. L., R. L. Hoopes, D.A. Arnold, and M. L. Kaufmann. 2002. Homing of hatchery-reared American shad to the Lehigh River, a tributary to the Delaware River. N. Am. J. Fish. Manag. 22: 243-248.

Hoopes, R. L. 1981. Upper Delaware River angler use and harvest. Pennsylvania Fish & Boat Commission. 450 Robinson Lane, Bellefonte, PA 18623.

Hoopes, R. L., R. A. Lahr, C. W. Billingsley. 1983. Angler use and fish harvest from the upper Delaware River during 1982. Pennsylvania Fish & Boat Commission. 450 Robinson Lane, Bellefonte, PA 18623.

Horwitz, R., P. Overbeck, D. Keller, S. Moser. 2008. Fish inventories of Delaware Water Gap National Recreational Area and Upper Delaware Scenic and Recreational River. National Park Service, Northeast Region. Philadelphia, PA. Natural Resources report NPS/NERCHAL/NRR-XX/XXX.

Hulse, A.C., C.J. McCoy, and E. Censky. 2001. Amphibians and reptiles of Pennsylvania and the Northeast. Cornell University Press, Ithaca, NY.

Jackson, J.K. and B. W. Sweeney. 2010. Expert report on the relationship between land use and stream condition (as measured by water chemistry and aquatic macroinvertebrates) in the Delaware River Basin. Stroud Water Research Center. Avondale, PA 19311. http://www.state.nj.us/drbc/Sweeney-Jackson.pdf

Kaufmann, M., B. Chikotas, and M. Hosack. 2008. Delaware River Estuary – Sections 02, 03, & 04. Pennsylvania Fish & Boat Commission files. 450 Robinson Lane, Bellefonte, PA 18623.

Kaufmann, M., B. Chikotas, and M. Hosack. 2009. Delaware River Estuary – Sections 02, 03, & 04. Pennsylvania Fish & Boat Commission files. 450 Robinson Lane, Bellefonte, PA 18623.

Keller, W. 1988. Estimate angler trips for some east central New York waters based on aerial angler counts from 1960-1986. New York Department of Environmental Conservation 96p.

Kinnel, J.C., M. F. Bingham, C. M. Spagnardi, J.S. Whaley, R.W. Blye, Jr., G.B. Waterfield, B.W. Lees, J.S. Raulli. 2008. Development of annual current and baseline impingement mortality and entrainment estimates, Fairless Hills generating station. Prepared for Exelon Generation Company, LLC.

Kratzer, T. W. 1999. Delaware River rooted aquatic-plant biomass study from Port Jervis, NY (Route 84 Bridge) to Milford, PA (Route 206 Bridge). Delaware River Basin Commission. 25 State Police Drive, West Trenton, NJ 08628

Kocher, Christopher M., Abigail M. Pattishall, Robert Miller. 2000. Lehigh River mine drainage assessment and abatement plan to mitigate the mine drainage impacts to the Lehigh River watershed. Wildlands Conservancy. 3701 Orchid Place, Emmaus, PA 18049. http://wildlandspa.org/Rivers/pdf/Lehigh%20River%20Mine%20Drainage%20Assessment%20and%20Abatement%20Plan.pdf

Lanka, R.P., W.A. Hubert, and T.A. Wesche. 1987. Relations of geomorphology to stream habitat and trout standing stock in small Rocky Mountain streams. Transactions of the American Fisheries Society 116:21-28.

Lellis, W. A. 2001. Freshwater mussel survey of the Upper Delaware Scenic and Recreational River qualitative survey 2000. Prepared for the National Park Service. U.S. Geological Survey. Northern Appalachian Research Laboratory. Wellsboro, PA 16901

Lellis, W. A. 2002. Freshwater mussel survey of the Delaware Water Gap National Recreation Area qualitative survey 2001. Prepared for the National Park Service. U.S. Geological Survey. Northern Appalachian Research Laboratory. Wellsboro, PA 16901

Limbeck, R. and G. Smith, 2007. Pilot Study: Implementation of a periphyton monitoring network for the non-tidal Delaware River. Delaware River Biomonitoring Program, Delaware River basin Commission 25 State Police Drive, West Trenton, NJ 08628 http://www.state. nj.us/drbc/Periphyton_pilotstudy0307.pdf.

Leckvarcik, L. G. 2006. Restoration of the Pennsylvania-endangered Bridle Shiner, Notropis bifrenatus (COPE) and Ironcolor shiner, Notropis chalybaeus (COPE) in Brodhead

Creek watershed, Monroe County. Thesis. Pennsylvania State University, College of Agricultural Sciences.

Lorantas, R. M. and J. L. Myers. 2003. Delaware River and Estuary Angler Log 2001 Summary. Pennsylvania Fish & Boat Commission, 450 Robinson Lane, Bellefonte, PA 18623.

Lorantas, R. M., D. P. Kristine, J. L. Myers. 2004. Delaware River and Estuary Angler Log 2004. Pennsylvania Fish & Boat Commission, 450 Robinson Lane, Bellefonte, PA 18623.

Lorantas, R. M. and J. L. Myers. 2005. Delaware River and Estuary Angler Log 2003. Pennsylvania Fish & Boat Commission, 450 Robinson Lane, Bellefonte, PA 18623.

Lorantas, R. M. and J. L. Myers. 2007. Delaware River and Estuary Angler Log 2004. Pennsylvania Fish & Boat Commission, 450 Robinson Lane, Bellefonte, PA 18623.

Lorantas, R. M., T. Wagner, D. Arnold, J. Detar, M. Kaufmann, K. Kuhn, R. Lorson, R., Wnuk, and A. Woomer. 2010. Smallmouth bass electrofishing catch rate in large Pennsylvania rivers and examination of smallmouth bass recruitment indices. Pennsylvania Fish & Boat Commission, 450 Robinson Lane, Bellefonte, PA 18623. *In draft.*

Maharaj, V., J. Mcgurrin, and J. Carpenter. 1998. The economic impact of trout fishing on the Delaware River tailwaters in New York. Report prepared for American Sportfishing Association and Trout Unlimited. 28 pp.

Massmann, W. H. analysis of the river fisheries. U. S. Fish and Wildlife Service, Bureau of Sport Fisheries and Wildlife, Washington, D. C.

Marshall, R. W., 1971. Shad creel census. Unpublished Data. Pennsylvania Fish & Boat Commission, 450 Robinson Lane, Bellefonte, PA 18623.

May, E.B. and R. Christianson. 1992. Job V, Task 4, American shad study: Report on 1991 serochemical studies on response to transport. Pages 5-69 to 5-87 *In* Restoration of American shad to the Susquehanna River, Annual Progress Report, 1991. Susquehanna River Anadromous Fish Restoration Committee.

May, E.B. and T. Koch. 1991. Job V, Task 4, American shad study: Evaluation of serochemical markers to demonstrate response to transport. Pages 5-53 to 5-88 *In* Restoration of American shad to the Susquehanna River, Annual Progress Report, 1990. Susquehanna River Anadromous Fish Restoration Committee.

McBride, R.S., M. L. Hendricks, and J. E. Olney. 2005. Testing the validity of Cating's (1953) method for age determination of American shad using scales. Fisheries 30 (10): 10-18.

McBride, N. 2002. Radiotelemetry study of trout movement in the Delaware tailwaters and the Beaver Kill: 1995-1997. New York Department of Environmental Conservation Region 4 Fisheries Office Stamford, NY 12167.

McBride, N. 2003. Delaware tailwaters 2002 angler diary program. New York Department of Environmental Conservation Region 4 Fisheries Office Stamford, NY 12167.

McBride, N. 2003. Delaware tailwaters creel census. Federal aid Project NY FA-5-R (Final report for job 201). New York Department of Environmental Conservation Region 4 Fisheries Office Stamford, NY 12167.

McBride, N. 2004. Delaware tailwaters 2003 angler diary program. New York Department of Environmental Conservation Region 4 Fisheries Office Stamford, NY 12167.

McBride, N., 2005. Delaware tailwaters 2004 angler diary program. New York Department of Environmental Conservation Region 4 Fisheries Office Stamford, NY 12167.

McBride, N. 2007. Delaware tailwaters 2007 angler diary program. New York Department of Environmental Conservation Region 4 Fisheries Office Stamford, NY 12167.

McBride, N., R. Angyal, D. Zielinski, R. Klosowski, R. Bode, and W. Elliot. 2008. Final Report: Delaware River tailwaters monitoring, May 1, 2004 – September 30, 2007. New York Department of Environmental Conservation, Division of Fish, Wildlife and Marine Resources, Albany, NY, 12233 files.

Millard, M.J., W.J. Fletcher, J. Mohler, S.D. McCormick, M.O'Dea, D.Lerner, and A. Moeckel. 2001. Evaluating sedation as a means to suppress the stress response associated with handling and transport of American shad. *In* Restoration of American shad to the Susquehanna River, Annual Progress Report, 2000. Susquehanna River Anadromous Fish Restoration Committee.

Miller , J. P., F. R. Griffiths, and P. A. Thurston-Rogers. 1982. The American shad (*Alosa sapidissima*) in the Delaware River basin. Report prepared for the Delaware River Basin Fish and Wildlife Management Cooperative. 132 pp.

Miller, J.P., J.W. Friedersdorf, F.R. Griffiths, R.C. Reichard, L. Loften. 1976. Annual progress report Delaware River basin anadromous fish project. AFS-2-8; Feb. 1974-Jan. 1975. U.S. Fish and Wildlife Service.

Miller, J. and A. Lupine 1987. Angler utilization and economic survey of the American shad fishery in the Delaware River. Delaware River Shad Fisherman's Association Hellertown, PA.

Miller, J. and A. Lupine 1996. Creel survey of the Delaware River American shad recreational fishery. Delaware River Shad Fisherman's Association Hellertown, PA.

Moberg, T., C. Apse, and M. DePhilip. 2010. Flow Alteration in the Upper Delaware River Basin: A historical analysis of Water Supply reservoir management impacts (1954 to 2009). The Nature Conservancy. Eastern U. S. Region Freshwater Program 14 Maine Street, Suite 401 Brunswick, Maine 04011.

Mohler, J. W. 2010. Age structure of American shad in the upper Delaware River. Phase I report for work performed in May 2009. U. S. Fish and Wildlife Service. Northeast fishery Center, Lamar, PA Inter-agency Agreement No. F4531-09-0708.

Munch, S. 1993. Distribution and condition of populations of *Podostemum ceratophyllum* (riverweed) in Pennsylvania. J. Penn. Acad. Sci. 67(2): 65-72.

Murphy, B.R. and D.W. Wallace, editors. 1996. Fisheries Techniques, second edition. American Fisheries Society. Bethesda, MD.

NJDEP, 2007. Investigations and Management of New Jersey's Freshwater fisheries Resources. Job Performance Report Grant F-48R-21.

NPS. 1986. Final River Management Plan: Upper Delaware Scenic and Recreational River New York and Pennsylvania. Prepared by the Conference of Upper Delaware Townships in cooperation with the National Park Service. National Park Service. (http://www.nps.gov/upde/parkmgmt/upload/river_management_plan.pdf)

NPS 1987. General Management Plan Summary. Delaware Water Gap National Recreational Area Middle Delaware national Scenic and Recreational River / Pennsylvania – New Jersey. National Park Service. (http://www.nps.gov/dewa/parkmgmt/upload/DEWAGMPSummary1987.pdf)

NPS 2008. Lower Delaware River Management Plan. National Park Service. (http://www.nps.gov/chal/sp/p07new3.htm)

NYC 2010. New York City's Operations Support Tool (OST) white paper. Prepared to the Delaware River basin Supreme Court Decree Parties. New York City Department of Environmental Protection. October 8, 2010.

O'Herron, J. C., K. W. Able, R. W. Hastings. 1993. Movements of shortnose sturgeon (Acipenser brevirostrum) in the Delaware River. Estuaries 16(2): 235-240.

Palmerton Natural Resources Trustee Council. 2007. Data Report for the Scoping Study on Metal Contaminant Levels in Sediment and Concurrent Aquatic Habitat Evaluation for the Palmerton Zinc Natural Resource Damage Assessment, Palmerton, Pennsylvania.

PA Invasive Species Council, 2006. Pennsylvania Invasive Species Council: Aquatic Invasive Species Management Plan. Commonwealth of Pennsylvania. http://www.anstaskforce.gov/StatePlans/PA_AISMP.pdf)

Pennsylvania State Commissioners of Fisheries. 1901. Report of the State Commissioners of Fisheries for the year 1900. Harrisburg, PA, 194 pp.

Penzo, M. Geology and hydrology of the upper Delaware valley: Literature Review.

Perles, S. J., G. S. Podniesinski, E. Eastman, L. A. Sneddon, and S. C. Gawler. 2007. Classification and Mapping of Vegetation and Fire Fuel Models at Delaware Water Gap National Recreation Area: Volume 1 of 2 Technical Report NPS/NER/NRTR—2007/076

Perles, S. J., G. S. Podniesinski, M. A. Furedi, B. A. Eichelberger, A. Feldmann, G. Edinger, E. Eastman, and L. A. Sneddon. 2008. Vegetation classification and mapping at Upper Delaware Scenic and Recreational River. National Park Service. Tech. Rep. NPS/NER/NRTA-2008/133.

PFBC. 1988. Revised strategic fishery management plan for American shad restoration in the Schuylkill and Lehigh River Basins. Pennsylvania Fish & Boat Commission, 450 Robinson Lane, Bellefonte, PA 18623.

PFBC. 2004. Delaware River American shad egg take stock replenishment plan. Pennsylvania Fish & Boat Commission, Bureau of fisheries, Division of Research, 450 Robinson Lane, Bellefonte, PA 18623.

PFBC. 2007. Lehigh River fisheries management plan. Pennsylvania Fish & Boat Commission. 450 Robinson Lane, Bellefonte, PA. http://www.fishandboat.com/newsreleases/2007/lehigh_fm_plan.htm.

PFBC. 2010. Recommended improvements to the Flexible Flow Management Program for coldwater ecosystem protection in the Delaware River tailwaters. Pennsylvania Fish & Boat Commission. 450 Robinson Lane, Bellefonte, PA. http://www.fish.state.pa.us/water/rivers/delaware/dela_flex_flow.pdf

PGC, 2009. 2009-2014 Strategic Plan Pennsylvania Game Commission. Pennsylvania Game Commission. 2001 Elmerton Avenue, Harrisburg, PA 17110. http://www.portal.state.pa.us/portal/server.pt/document/737229/2009-2014_strategic_plan_pdf

PPL 2002. Application for license for major project – existing dam: Volume I license application. FERC Project 487. http://www.pplweb.com/NR/rdonlyres/4CA38158-CC9A-4F76-AA84-D7DF48293854/0/relicensing_%20application.pdf

Pierce, D. J. and J. L. Myers. 2007. Delaware River and Estuary Angler Log 2005 & 2006. Pennsylvania Fish & Boat Commission, 450 Robinson Lane, Bellefonte, PA 18623.

Riva-Murray, K., R.A. Brightbill, and M. D. Bilger. 2003. Trends in concentrations of Polychlorinated Biphenyls in fish tissue from selected sites in the Delaware River basin in New Jersey, New York, and Pennsylvania, 1969-98. United State Geological Survey. Water Resources Investigations Report 01-4066. http://ny.water.usgs.gov/pubs/wri/wri014066/wrir01-4066.pdf

Sanford, D. K. 1989. A fish survey of the lower East and West Branches of the Delaware River during 1987. New York Department of Environmental Conservation, Division of Fish, Wildlife and Marine Resources, Bureau of Fisheries – Region 4. 53 p.

Sanford, D. K. 1992. A fishery management plan for the upper Delaware tailwaters. New York Department of Environmental Conservation, Division of Fish, Wildlife and Marine Resources, Bureau of Fisheries – Region 4. 53 p.

Sanford, D. K. 1993. Report summarizing creel census on the Delaware River near Lordville and on the West Branch of the Delaware River downstream of the Cannonsville Reservoir in 1989, 1990, and 1991. New York Department of Environmental Conservation, Division of Fish, Wildlife and Marine Resources, Bureau of Fisheries

Santoro, E.D. and R.L. Limbeck. 2008. Nutrient Criteria Strategy for the Tidal And Non-Tidal Delaware River , April 25, 2008 Version. Delaware River Basin Commission. 25 State Police Drive, West Trenton, NJ 08628 (http://www. state.nj.us/drbc/DRBC-NutrientStrategy042508.pdf)

Schultz, C. H. editor. 1999. The geology of Pennsylvania. Pennsylvania Geological Survey. Harrisburg, PA. 888p.

Sheppard, J. D. 1980. New York reservoir releases monitoring and evaluation program: Performance report tot eh period 1 July 1978 – 31 December 1979. Technical report 80-1. New York State Department of Environmental Conservation. Albany, NY.

Sheppard, J.D. 1983. New York reservoir releases monitoring and evaluation program on the Delaware River summary report: Technical report 83-5. New York State Department of Environmental Conservation. Albany, NY.

Shiels, A. L. Undated. Viral Hemorrhagic Septicemia (VHS) in Pennsylvania: Summary. Pennsylvania Fish & Boat Commission. PFBC files. 450 Robinson Lane, Bellefonte, PA 18623.

Sillforff, E. 2010. Testimony in the matter of Delawaare River Basin Commission Adjudicatory Administrative hearing on natural gas exploratory wells. http://www.state.nj.us/drbc/Silldorff.pdf

Silldorff, E.L. and R.L. Limbeck. 2009. Interim Methodology for Bioassessment of the Delaware River for the DRBC 2010 Integrated Assessment. Delaware River Basin Commission draft report to the Biological Advisory Subcommittee; revision date 24-July-2009. 26 pp. (http://www.state.nj.us/drbc/Bioassessment-draft-July2009rev.pdf)

Sloto, R. A. and D. E. Buxton. 2007. Estimated ground-water availability in the Delaware River basin, 1997-2000. USG Scientific Investigations Report 2006-5125-Versin 1.1 (http://pubs.usgs.gov/sir/2006/5125/pdf/sir2006-5125_ver1.1.pdf)

Springer, J. E. and T. M. Groutage. 1967. Tri-state fishery study: A cooperative investigation of the Delaware River fishery 1959-1962. National Park Service Natbib # 23063.

Snyder, C. J. Young, D. Smith, D. Lemarie, R. Ross, R. Bennett. 2001. Influence of Eastern Hemlock on aquatic biodiviersity in Delaware Water Gap National Recreational Area. U. S. Geological Survey. (http://www.lsc.usgs.gov/aeb/2048-03/dewarept.pdf)

Snyder, R. A. and D. A. Arnold. 1998. Documentation and Quantification of Alosids Utilizing Fish Passage Facilities and Collection of Biological Data on Adult American Shad. Grant No. NA76FI0083 Pennsylvania Fish and Boat commission 450 Bellefonte, PA 16823.

Snyder, R. A. and D. A. Arnold. 1999. Documentation and Quantification of Alosids Utilizing Fish Passage Facilities and Collection of Biological Data on Adult American Shad. Grant No. NA86FI0214 Pennsylvania Fish and Boat commission 450 Bellefonte, PA 16823.

Snyder, R. A. and D. A. Arnold. 2000. Documentation and Quantification of Alosids Utilizing Fish Passage Facilities and Collection of Biological Data on Adult American Shad. Grant No. NA96FI0220 Pennsylvania Fish and Boat commission 450 Bellefonte, PA 16823.

Snyder, R. A. and D. A. Arnold. 2001. Documentation and Quantification of Alosids Utilizing Fish Passage Facilities and Collection of Biological Data on Adult American Shad. Grant No. NA06FI0191 Pennsylvania Fish and Boat commission 450 Bellefonte, PA 16823.

Snyder, R. A. and D. A. Arnold. 2002. Documentation and Quantification of Alosids Utilizing Fish Passage Facilities and Collection of Biological Data on Adult American Shad. Grant No. NA16FI1107 Pennsylvania Fish and Boat commission 450 Bellefonte, PA 16823.

Stirratt, H. 2000. Technical Addendum I to Amendment 1 of the Interstate Fishery Management Plan for shad and river herring. Atlantic States Marine Fisheries Commission, Washington, D.C. www.asmfc.org

Taylor, G. G. 1971. Descriptions of the Tocks Island Reservoir project, the Kittatinny Mountain Project, and the Delaware Water Gap National Recreational Area. USFWS, Bureau of Sport Fisheries and Wildlife, Boston, MA 02109.

The Nature Conservancy. 1994. A survey of the aquatic vascular plants of the Upper Delaware River. Prepared for the U. S. Department of interior, MidAtlantic Region of the National Park Service. Cooperative agreement No. 4000-9-8009.

USFWS 2008. Cherry Valley National Wildlife Refuge: Draft feasibility study and environmental assessment. National wildlife refuge system Northeast region 300 Westgate Center Drive Hadley, MA 01035.

USGS 2010. Summary of hydrologic conditions in the Upper Delaware River basin. Prepared by the Office of the Delaware River Master, Milford, Pennsylvania. http://water.usgs.gov/osw/odrm/monthly/November10.pdf

Volstad, J.H., W. Richkus, J. Miller, A. Lupine, and J. Dew. 2003. The Delaware River Creel Survey 2002. Pennsylvania Fish and Boat Commission, Versar Inc. Columbia, Maryland.

Volz, C. D. 2011. Testimony in the Matter of Delaware Riverr Basin Commission consolidated Administrative Adjudicatory hearing on natural gas exploratory wells. Univ. Pittsburg. http://www.state.nj.us/drbc/Volz.pdf

Wahl, H. A., 1959. Survey of aquatic plants of the upper Delaware River from the junction of the east and west branches to Bushkill: July 20 – 25, 1959.

Walsh, M. C., Jeremy Deeds, and B. Nightingale. 2007. User's manual and data guide to the Pennsylvania Aquatic Community Classification. Pennsylvania Natural Heritage Program, Western Pennsylvania Conservancy, Middletown, PA, and Pittsburgh, PA. (http://www.naturalheritage.state.pa.us/aquaticsUserMan.aspx)

Waterfield, G. B. R. W. Blye, Jr., B.W. Lees, and J. W. Dieterich. 2008. Entrainment and impingement monitoring studies at Fairless Hills Generating Station during 2005-2006. Prepared for Exelon generation Company, LLC by Normandeau Associates, Inc.

Appendix A.

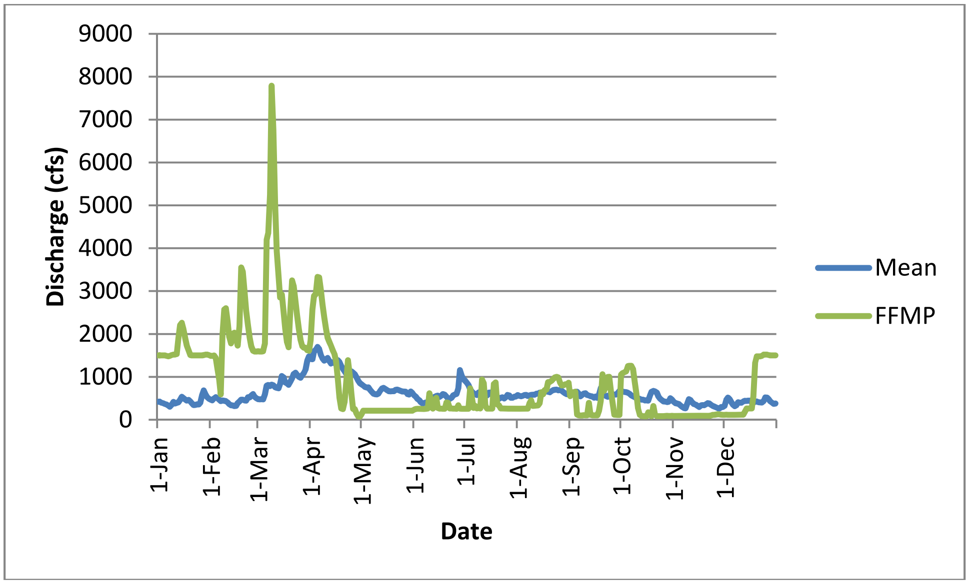


Figure A.1. Mean daily discharge values for the West Branch Delaware River at Stilesville, NY (USGS 01425000) for the period of record from October, 1963 to September, 2008. Also included is the discharge during the FFMP water management from Oct 1, 2007 to September 30, 2008.

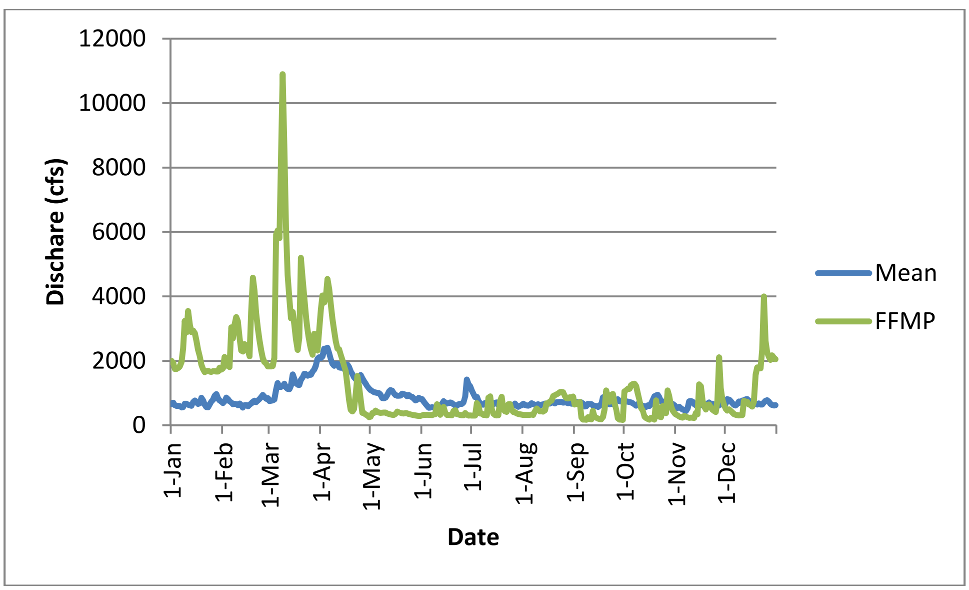


Figure A.2. Mean daily discharge values for the West Branch Delaware River at Hale Eddy, NY (USGS 01426500) for the period of record from October, 1963 to September, 2008. Also included is the discharge during the FFMP water management from Oct 1, 2007 to September 30, 2008.

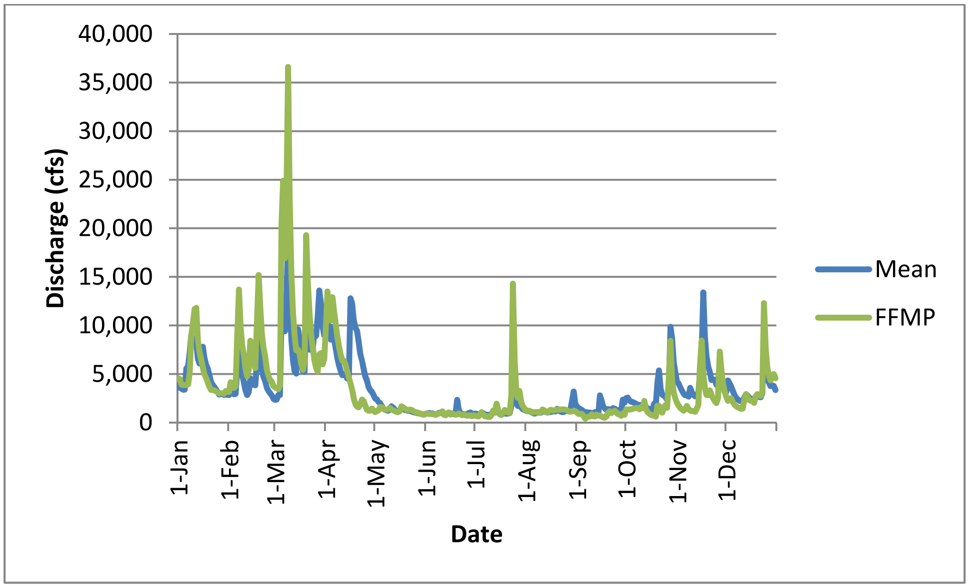


Figure A.3. Mean daily discharge values for the Delaware River at Lordsville, NY (USGS 01427207) for the period of record from October, 2005 to September, 2008. Also included is the discharge during the FFMP water management from Oct 1, 2007 to September 30, 2008.

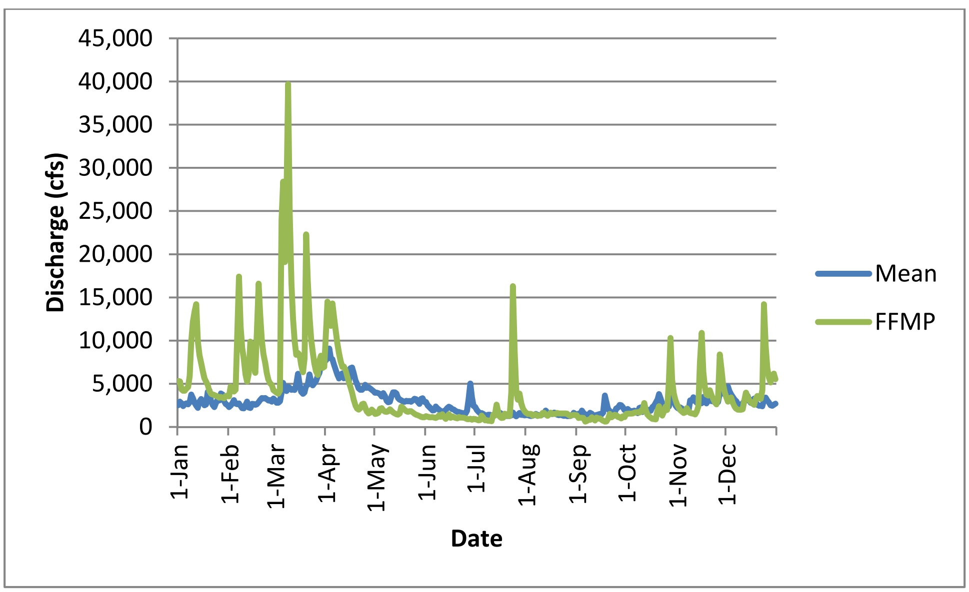


Figure A.4. Mean daily discharge values for the Delaware River at Callicoon, NY (USGS 01427510) for the period of record from October, 1975 to September, 2008. Also included is the discharge during the FFMP water management from Oct 1, 2007 to September 30, 2008.

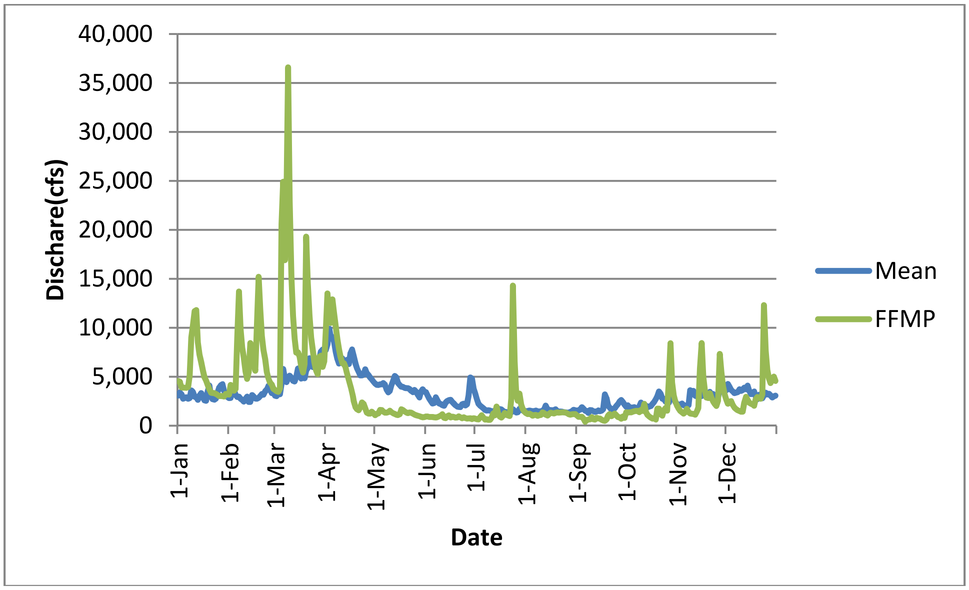


Figure A.5. Mean daily discharge values for the Delaware River at Lackawaxen, PA (USGS 01428500) for the period of record from October, 1963 to September, 2008. Also included is the discharge during the FFMP water management from Oct 1, 2007 to September 30, 2008.

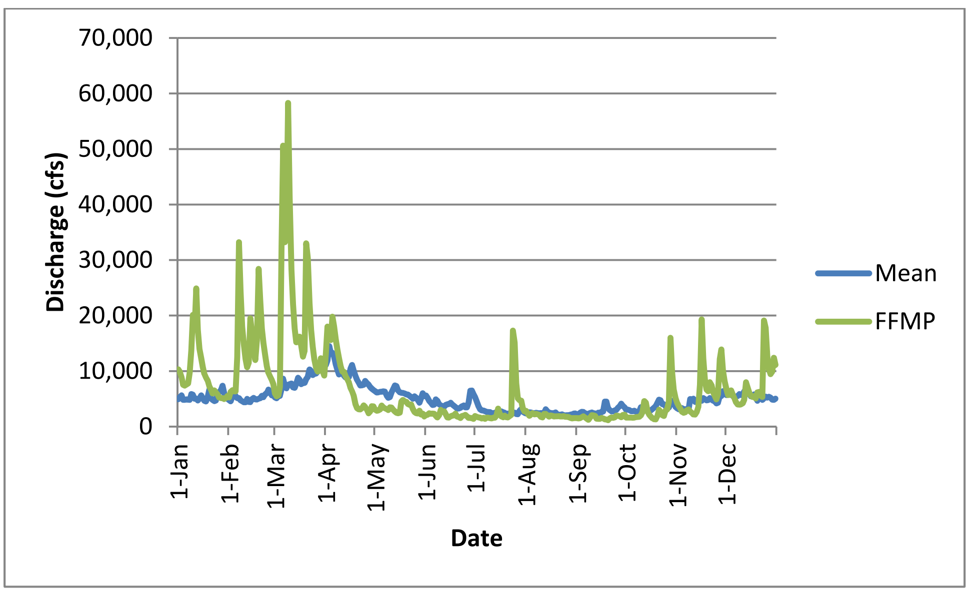


Figure A.6. Mean daily discharge values for the Delaware River at Montague, NY (USGS 01438500) for the period of record from October, 1939 to September, 2008. Also included is the discharge during the FFMP water management from Oct 1, 2007 to September 30, 2008.

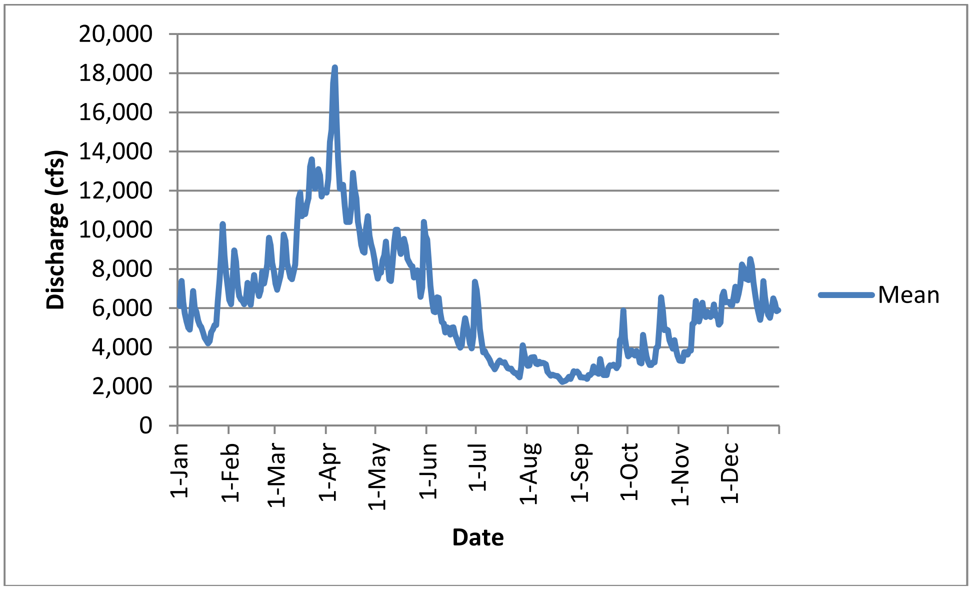


Figure A.7. Mean daily discharge values for the Delaware River at Water Gap, PA (USGS 01440200) for the period of record from October, 1963 to September, 1992.

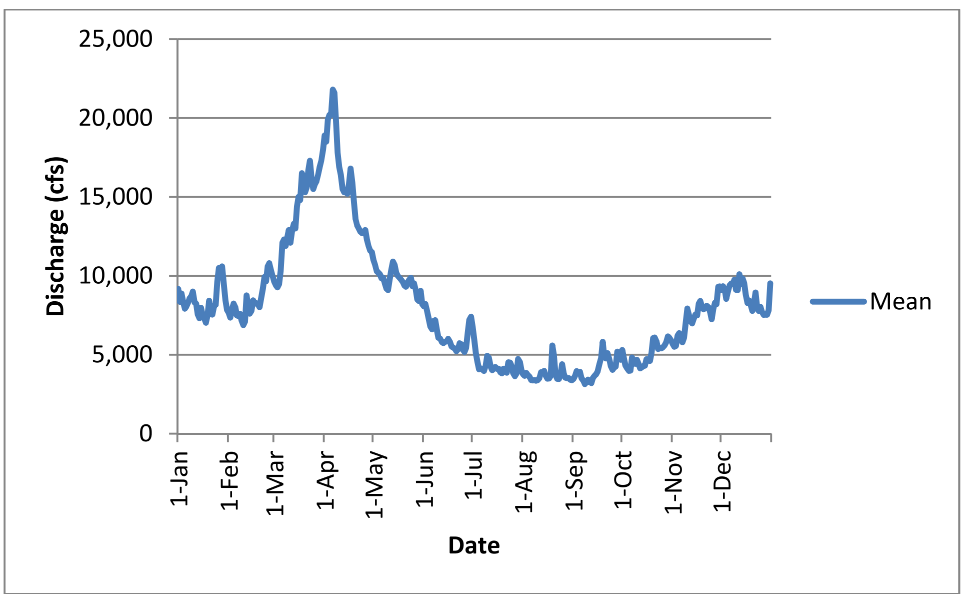


Figure A.8. Mean daily discharge values for the Delaware River at Belvidere, NJ (USGS 01446500) for the period of record from October, 1939 to September, 2008.

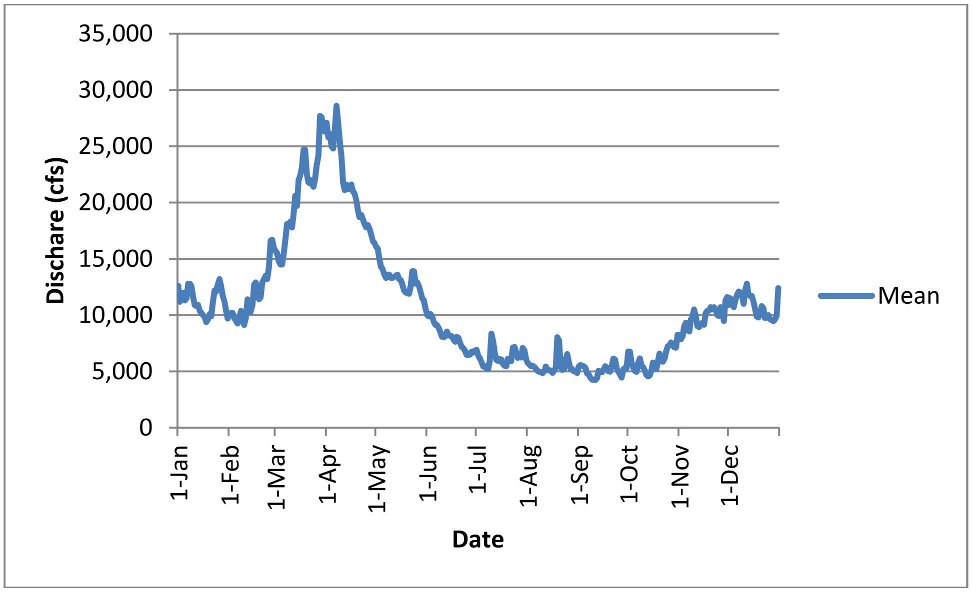


Figure A.9. Mean daily discharge values for the Delaware River at Riegelsville, PA (USGS 01457500) for the period of record from October, 1905 to September, 1971.

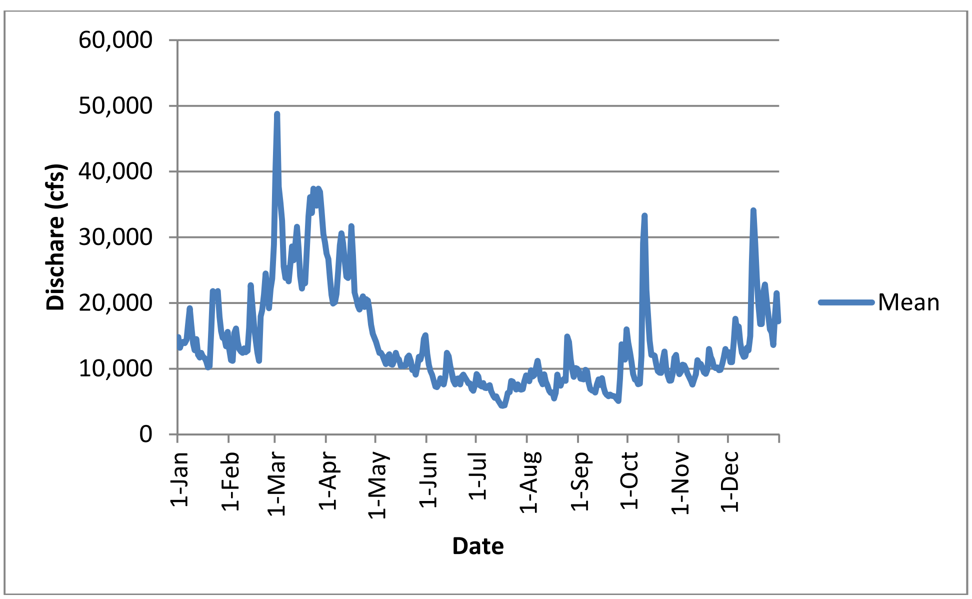


Figure A.10. Mean daily discharge values for the Delaware River at Lambertville, NJ (USGS 01462000) for the period of record from October, 1897 to September, 1906.

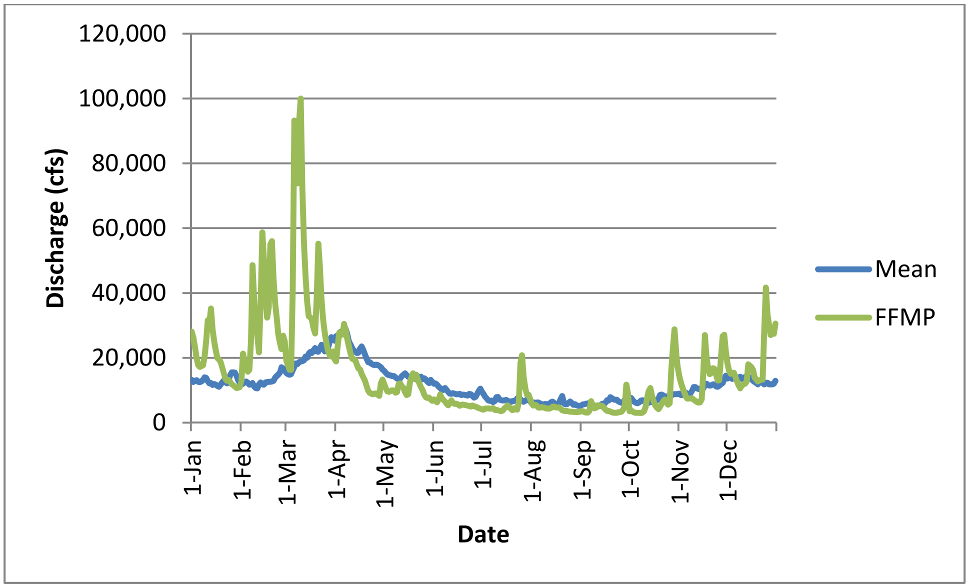


Figure A.11. Mean daily discharge values for the Delaware River at Trenton, NJ (USGS 01463500) for the period of record from October, 1912 to September, 2008. Also included is the discharge during the FFMP water management from Oct 1, 2007 to September 30, 2008.

Appendix B.

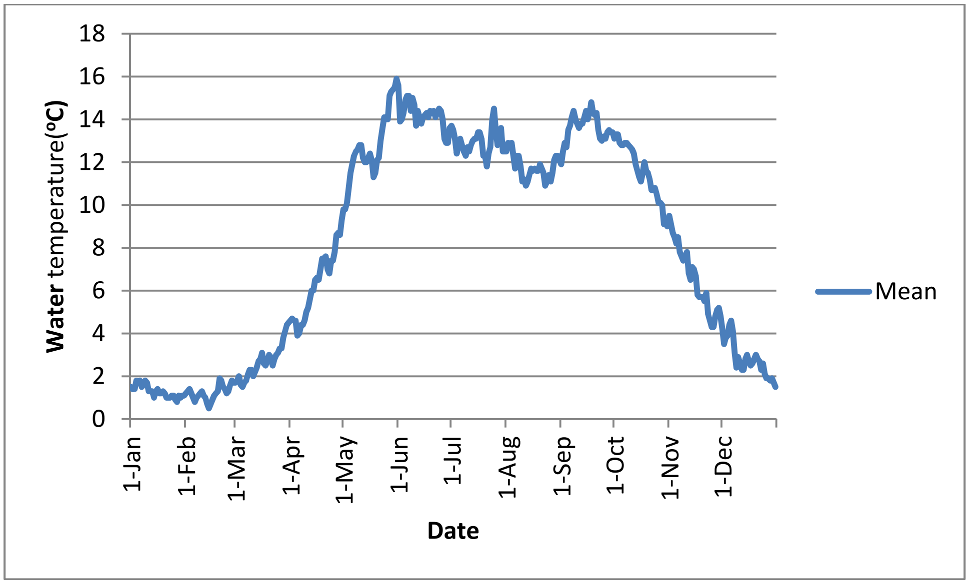


Figure B.1. Mean daily water temperature (°C) values for the West Branch Delaware River at Hale Eddy, NY (USGS 01426500) for the period of record from October, 1984 to September, 2008.

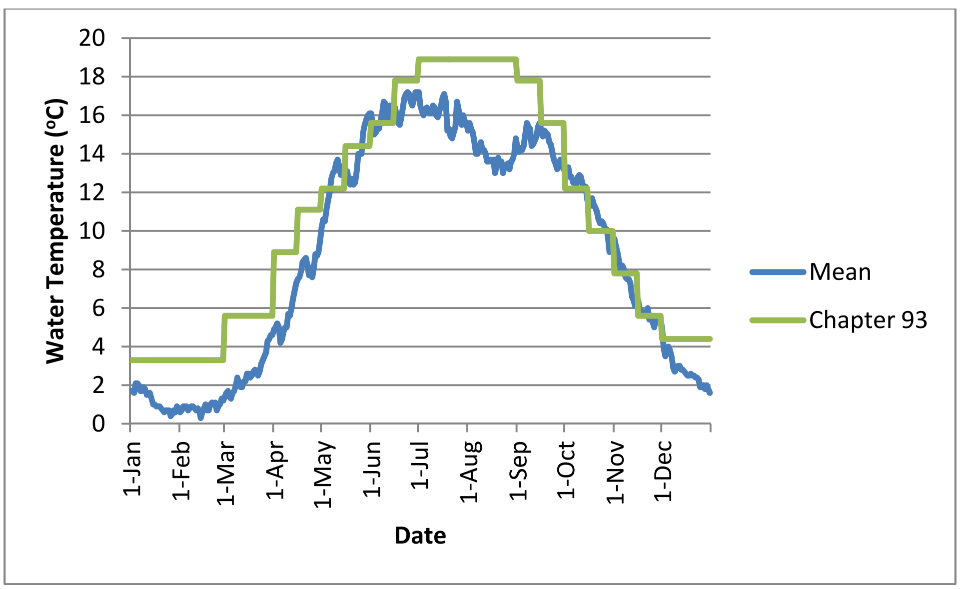


Figure B.2. Mean daily water temperature (°C) values for the West Branch Delaware River at Hancock, NY (USGS 01427000) for the period of record from October, 1996 to September, 2008. Also illustrated is the Pennsylvania Chapter 93 temperature criterion for Cold Water Fishes (CWF).

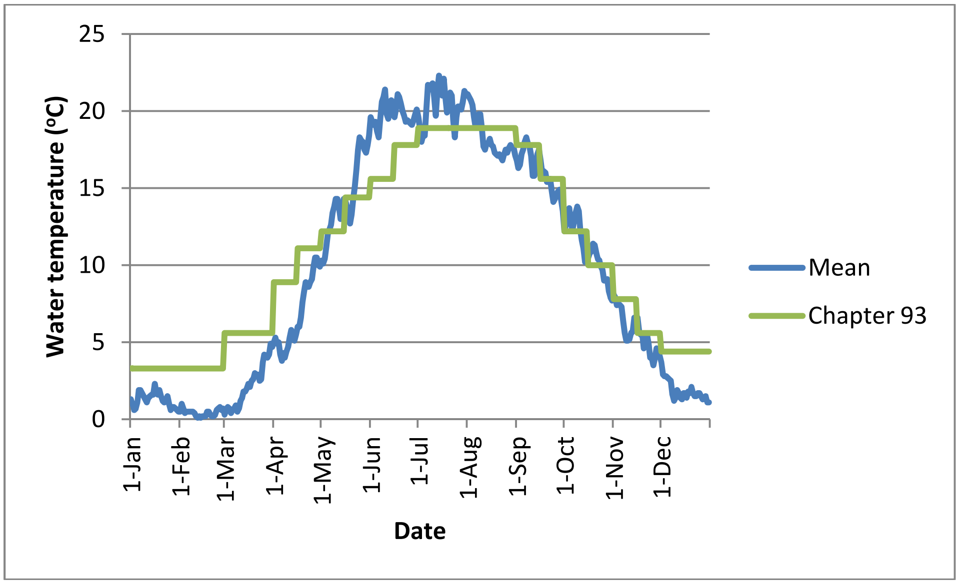


Figure B.3. Mean daily water temperature (°C) values for the Delaware River at Lordville, NY (USGS 01427207) for the period of record from October, 1992 to September, 2008. Also illustrated is the Pennsylvania Chapter 93 temperature criterion for Cold Water Fishes (CWF).

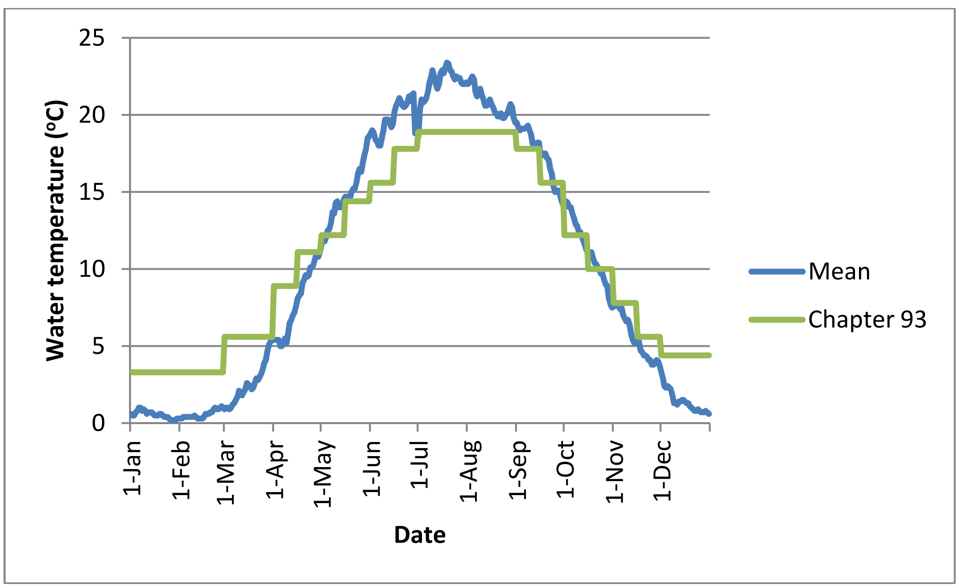


Figure B.4. Mean daily water temperature (°C) values for the Delaware River at Callicoon, NY (USGS 01427510) for the period of record from October, 1974 to September, 2008. Also illustrated is the Pennsylvania Chapter 93 temperature criterion for Cold Water Fishes (CWF).

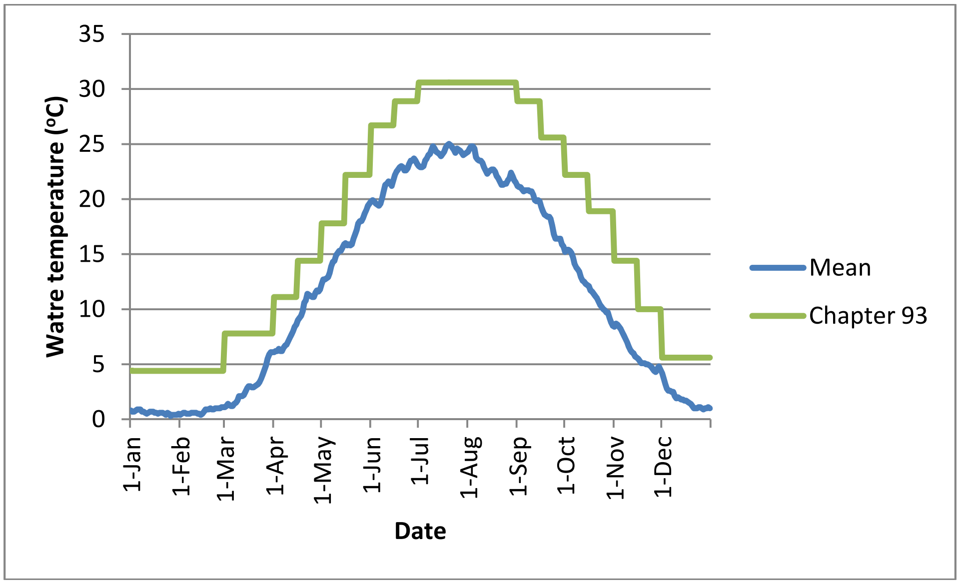


Figure B.5. Mean daily water temperature (°C) values for the Delaware River at Lackawaxen, PA (USGS 01428500) for the period of record from October, 1975 to September, 2008. Also illustrated is the Pennsylvania Chapter 93 temperature criterion for Warm Water Fishes (WWF).

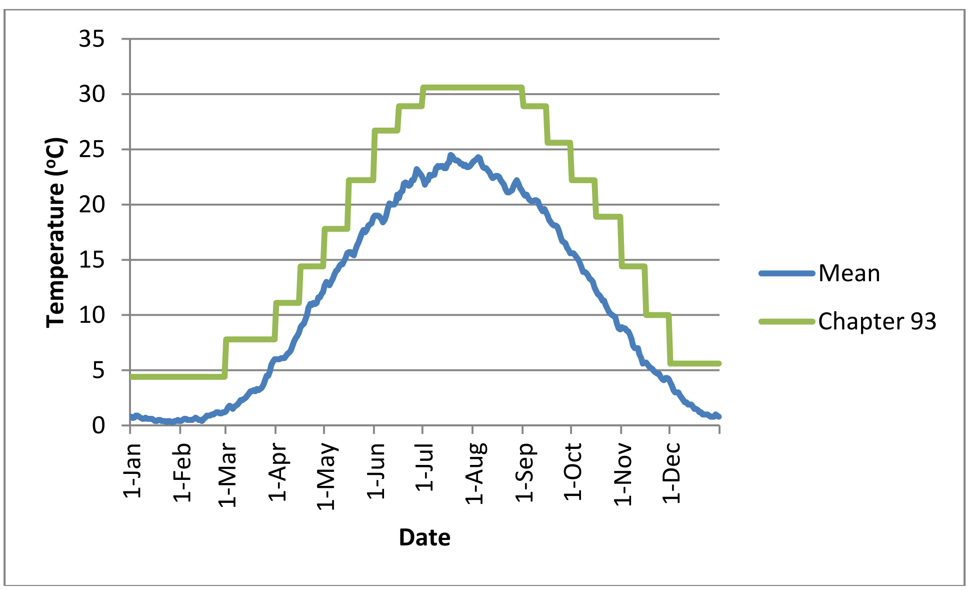


Figure B.6. Mean daily water temperature (°C) values for the Delaware River at Barryville, NY (USGS 01432160) for the period of record from October, 1973 to September, 2008. Also illustrated is the Pennsylvania Chapter 93 temperature criterion for Warm Water Fishes (WWF).

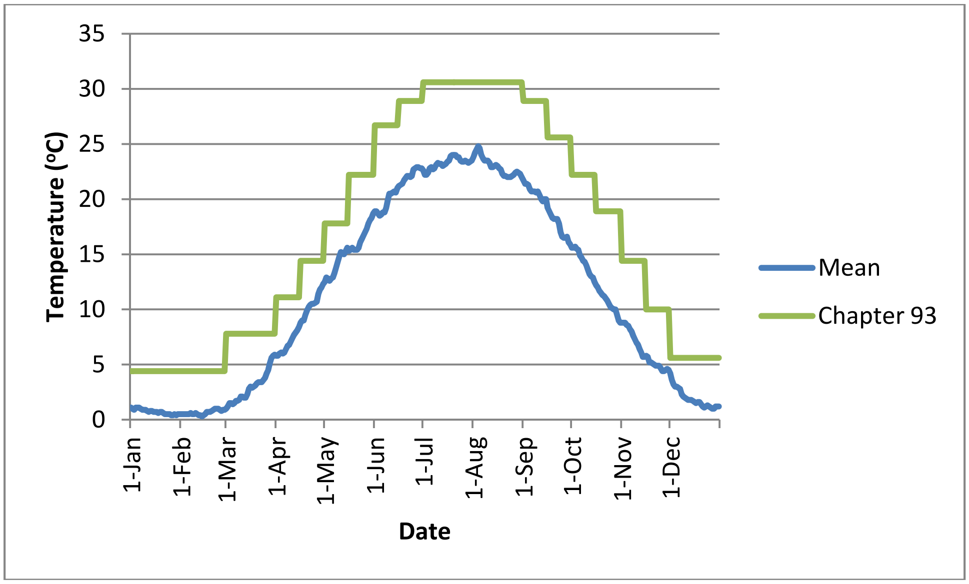


Figure B.7. Mean daily water temperature (°C) values for the Delaware River at Pond Eddy, NY (USGS 01432805) for the period of record from October, 1973 to September, 2008. Also illustrated is the Pennsylvania Chapter 93 temperature criterion for Warm Water Fishes (WWF).

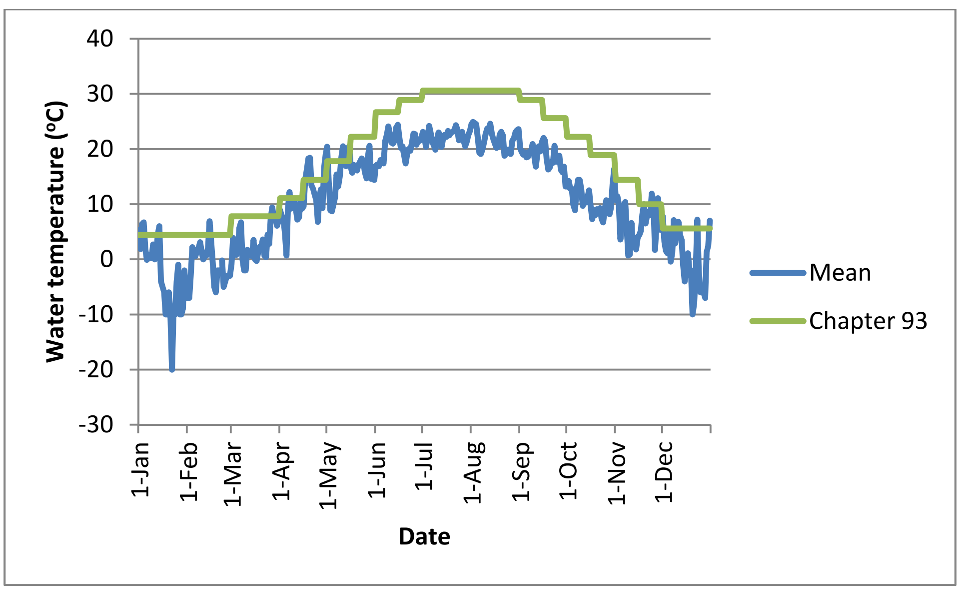


Figure B.8. Mean daily water temperature (°C) values for the Delaware River at Water Gap, PA (USGS 01440200) for the period of record from October, 2003 to September, 2005. Also illustrated is the Pennsylvania Chapter 93 temperature criterion for Warm Water Fishes (WWF).

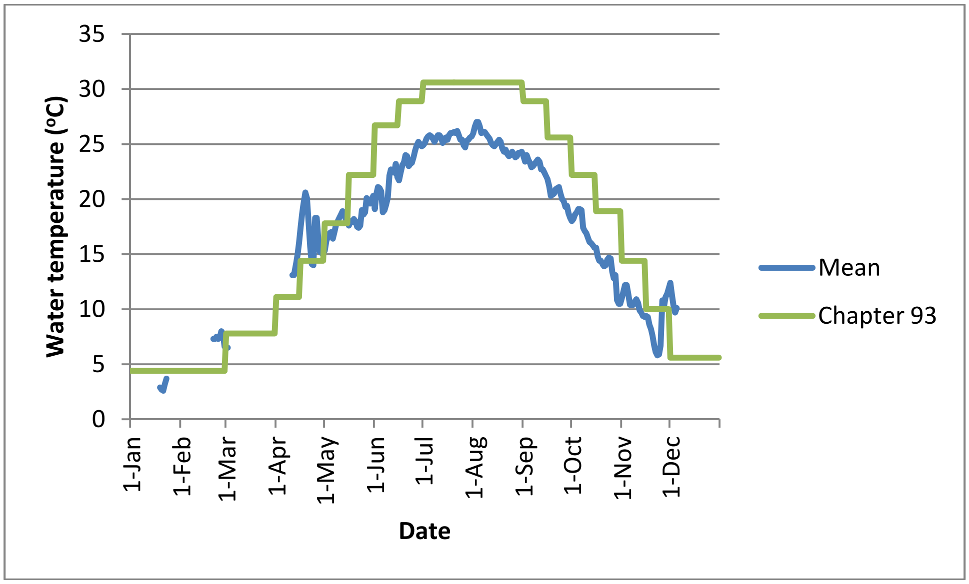


Figure B.9. Mean daily water temperature (°C) values for the Delaware River at Point Pleasant, PA (USGS 01460200) for the period of record from October, 1999 to September, 2005. Also illustrated is the Pennsylvania Chapter 93 temperature criterion for Warm Water Fishes (WWF).

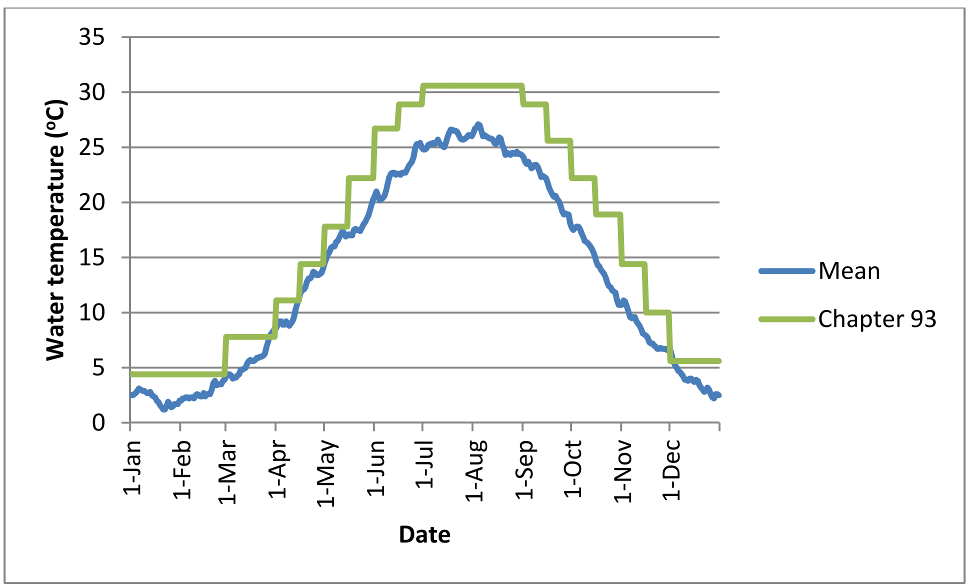


Figure B.10. Mean daily water temperature (°C) values for the Delaware River at Trenton, N.J. (USGS 01463500) for the period of record from October, 1994 to September, 2005. Also illustrated is the Pennsylvania Chapter 93 temperature criterion for Warm Water Fishes (WWF).