# SURFACE WATER AND RIPARIAN AREAS OF THE RARITAN RIVER BASIN

A Technical Report for the Raritan Basin Watershed Management Project

**New Jersey Water Supply Authority**

**Final Report: September 2002**

# SURFACE WATER AND RIPARIAN AREAS OF THE RARITAN RIVER BASIN

# TABLE OF CONTENTS

Acknowledgements .......... vi
Summary .......... 1
Hydrology .......... 2
Surface Waters .......... 2
Hydrology and Topography of the Raritan Basin .......... 2
Hydrologic Cycle .......... 4
Hierarchy of Streams in Watersheds .......... 4
Headwater Streams and Attributes .......... 5
Surface Flows of the Basin .......... 6
Changes in Stream Hydrology .......... 11
Stream Channels .......... 13
Stream Channel Components .......... 13
Stream Morphology Classification .......... 14
High Flow Events .......... 14
Types of Floods .......... 14
Flood Plains .......... 15
Definitions .......... 15
Benefits of Flood Plains .......... 16
Fluvial Versus Tidal Flood Plains .......... 16
Flood Damages .......... 16
Areas of the Basin within 100-Year Flood Prone Areas .......... 16
Preventive Measures .......... 17
Frequency of High Flows .......... 18
Magnitude and Frequency .......... 18
History of Floods in the Basin .......... 18
Flooding Due to Hurricane Floyd .......... 21
Watershed Based Changes in High Flows .......... 22
Effects of Urbanization on Watershed Hydrology .......... 22

Effects of Sewage Treatment Plants ........ 23
Imperviousness and Runoff ........ 23
Increase in Contaminants ........ 23
Population Projections and Shifts within the Raritan Basin ........ 24
Ecological Health ........ 24
Surface Waters ........ 24
General Health ........ 24
Benthic Macroinvertebrates ........ 25
Fisheries/Shellfisheries ........ 34
Eutrophication ........ 37
Wetlands ........ 38
Functions and Values of Wetlands ........ 38
Wetlands Within the Raritan Basin ........ 38
Effects of Urbanization on Wetland Systems ........ 40
Riparian Areas ........ 41
Functions and Values of Riparian Areas ........ 41
Extent of Existing Riparian Areas Within the Basin ........ 43
Health of Existing Riparian Areas Within the Basin ........ 44
Effects of Urbanization on Stream Corridors/Riparian Areas ........ 45
Public Uses ........ 46
Designated Uses Determined by NJDEP Surface Water Classifications ........ 46
Other Recreational Uses in the Basin ........ 54
Management Conclusions of Existing Plans ........ 55
Existing Laws and Regulations ........ 55
Model Stream Corridor Ordinances ........ 57
State Development and Redevelopment Plan ........ 57
Green Brook Flood Control Project ........ 58
South River Flood Control and Ecosystem Restoration Project ........ 58
Millstone River Watershed Protection and Flood Damage Reduction (PL-566) Project ........ 59
United States Army Corps of Engineers Millstone River Watershed Flood Damage Reduction Project ........ 59
Stormwater Watershed Model ........ 60
South Branch Rockaway Creek Stormwater Management Study ........ 60

Critical Needs ........ 60
Conclusions ........ 61
Glossary of Terms ........ 62
Common Acronyms ........ 64
References ........ 65

***List of Tables***

Table 1 - Results of Raritan Basin Headwaters Investigation ........ 6
Table 2 - Flow duration values of mean daily flow, and seven-day ten-year low flows ........ 9
Table 3 - Land Use Classifications within the 100-Year Flood Prone Areas of the Raritan Basin ........ 17
Table 4 - Stations in the Raritan Basin Exhibiting New Peaks of Record ........ 21
Table 5 - Sites Above Flood Stage in the Raritan Basin as a Result of Hurricane Floyd ........ 21
Table 6 – Results of NJDEP 1993-94 Ambient Biomonitoring Network ........ 26
Table 7 – Results of NJDEP 1999 Ambient Biomonitoring Network ........ 26
Table 8 – Comparison of NJDEP 1996 Surface Water Quality Inventory Report (305b) Macroinvertebrate Results with NJDEP 1999 AMNET Report Results ........ 29
Table 9 – South Branch Watershed Association Macroinvertebrate Sampling Results 1994-2001 ........ 31
Table 10 - Results of Stony Brook-Millstone Watershed Association's BAT Data Evaluation 1996-2001 ........ 32
Table 11 – Rockaway Creek Water Quality Monitoring Project Results for 1999-2001 ........ 33
Table 12 - Summary of Fish Consumption Advisories – Mercury ........ 36
Table 13 - Basinwide Conversion of Wetlands to Other Land Uses 1986-1995 ........ 39
Table 14 - Upper Raritan WMA - Conversion of Wetlands to Other Land Uses 1986-1995 ........ 39
Table 15 - Lower Raritan WMA - Conversion of Wetlands to Other Land Uses 1986-1995 ........ 40
Table 16 - Millstone WMA - Conversion of Wetlands to Other Land Uses 1986-1995 ........ 40
Table 17 - Water Bodies Attaining Water Quality Standards with No Known Threats to Designated Uses ........ 47

***List of Figures*** ***Follows Page***

1 First Order and other Streams within the Raritan Basin ........ 5
2 Dams Classified by Height within the Raritan Basin ........ 11
3 Dams Classified by Hazard within the Raritan Basin ........ 11
4 100-Year Floodprone Areas within the Raritan Basin ........ 16
5 1995 General Land Use Classifications in the 100-Year Floodprone Areas within the Raritan Basin ........ 17
6 Municipalities Subject to Flooding Problems (1975) within the Raritan Basin ........ 20
7 South Branch Watershed Association Monitoring Results Above Darts Mill by NJ Impairment Scoring 1994-1999 ........ 30
8 South Branch Watershed Association Monitoring Results Below Darts Mill by NJ Impairment Scoring 1994-1999 ........ 30

***List of Figures Continued*** ***Follows Page***

9 Stony Brook-Millstone Watershed Association Biological Action Team Data for Big Bear Brook and Ten Mile Run by NJ Impairment Scoring 1997-2000 ..... 30
10 Stony Brook-Millstone Watershed Association Biological Action Team Data for Beden Brook by NJ Impairment Scoring 1996-2000 ..... 30
11 Stony Brook-Millstone Watershed Association Biological Action Team Data for Stony Brook by NJ Impairment Scoring 1996-2000 ..... 30
12 Rockaway Creek Water Quality Monitoring Project Macroinvertebrate Results by NJ Impairment Scoring 1999-2000 ..... 33
13 Surface Water Classifications of Streams within the Raritan Basin ..... 35
14 Conversion of Wetlands to other Land Uses between 1986-1995 within the Raritan Basin ..... 38
15 a. 14-Digit Hydrologic Unit Codes within the Raritan Basin ..... 43
b. 14-Digit Hydrologic Unit Codes and Municipalities within the Raritan Basin ..... 43
c. Municipalities and Hydrology within the Raritan Basin ..... 43
16 Riparian Land Cover Conversion in the Upper Raritan WMA ..... 43
17 Riparian Land Cover Conversion in the Lower Raritan WMA ..... 43
18 Riparian Land Cover Conversion in the Millstone WMA ..... 43
19 Degrees of Riparian Land Cover Conversion in the Raritan Basin ..... 43
20 Riparian Area Components in a Subwatershed of the Upper Raritan WMA ..... 44
21 Riparian Area Components in a Subwatershed of the Lower Raritan WMA ..... 44
22 Riparian Area Components in a Subwatershed of the Millstone WMA ..... 44
23 Forested Riparian Area in the Raritan Basin (1995) ..... 45
24 Number of Stream Crossings per Kilometer within the Raritan Basin ..... 45

***List of Figures From "Setting of the Raritan River Basin" Technical Report (not included)***

Figure 4 – Municipalities and Road Network within the Raritan Basin
Figure 6 – Geological Map of New Jersey
Figure 10 – Surface Water Hydrology within the Raritan Basin
Figure 11 - Monitoring Stations and Stream Flows within the Raritan Basin
Figure 23 – Historical Population Estimates within the Raritan Basin
Figure 24 – Historical Population Estimates within the Raritan Basin

***Figure From "Water Availability" Technical Report (not included)***

Figure 1 – Stream Gauging Stations within the Raritan Basin

***List of Figures From "Water Budget" Technical Report (not included)***

Figure 1 – The Hydrologic Cycle of a Watershed – Pre-Development
Figure 2 – The Hydrologic Cycle of a Watershed – Development

*Note: Figures referenced from other technical reports are available at the www.raritanbasin.org web site or by contacting the NJ Water Supply Authority's Watershed Protection Programs Office at (732) 356-9344.*

***Appendices***

Appendix A – Results of Riparian Area Analyses
Appendix B – Stream Morphology of the Raritan Basin

# Acknowledgements

Primary Author:

Deborah J. Newcomb, Watershed Protection Specialist
Watershed Protection Programs, NJ Water Supply Authority

Contributing Authors:

Kathy Hale, Watershed Protection Specialist
Watershed Protection Programs, NJ Water Supply Authority

Caroline R. Phillipuk, GIS Specialist, and Doug Schleifer, GIS Manager
Upper Raritan Watershed Association

Tom J. Stanuikynas, GIS Specialist
Watershed Protection Programs, NJ Water Supply Authority

This report was developed using geographic information system digital data developed under the auspices of the New Jersey Department of Environmental Protection Geographic Information System digital data, but this secondary product has not been verified by NJDEP or the original author(s) of the study.

The NJ Water Supply Authority would like to thank the Characterization Committee, Project Team and Technical Advisory Committee of the Raritan Basin Watershed Management Project for all of their comments, hard work and suggestions. Project Team members include:

- New Jersey Department of Environmental Protection
- New Jersey Water Supply Authority
- North Jersey Resource Conservation and Development Council
- Rutgers Center for Environmental Communication
- South Branch Watershed Association
- Stony Brook-Millstone Watershed Association
- United States Department of Agriculture – Natural Resources Conservation Service
- United States Geological Survey
- Upper Raritan Watershed Association

# SURFACE WATER AND RIPARIAN AREAS OF THE RARITAN RIVER BASIN

## A Technical Report for the Raritan Basin Watershed Management Project

## Summary

The Raritan River Basin includes 16 major watersheds, and comprises approximately 1,100 square miles. The New Jersey Department of Environmental Protection (NJDEP) has aggregated these watersheds into three Watershed Management Areas (WMAs), as shown in Figure 4--Municipalities and Road Network within the Raritan Basin, of the technical report "Setting of the Raritan River Basin." These areas are the North & South Branch Raritan (i.e., Upper Raritan) WMA (WMA 8), the Lower Raritan WMA (WMA 9) and the Millstone WMA (WMA 10).

This technical report focuses on the surface waters and riparian areas of the Raritan River Basin and includes detailed descriptions of stream flows, flood prone areas, wetlands and riparian areas. It describes the ecological health of the surface waters and riparian areas of the Basin and provides a general summary of the existing regulations and plans that aid in the protection of surface waters and riparian areas. Projects that have been undertaken to protect or restore the stream corridors of the Basin are also included in the section on existing plans.

Based on an investigation conducted by a subcommittee of the New Jersey Clean Water Council, approximately 52% of the stream miles in the Basin have been classified as first order streams, and 75% of stream miles are either first or second order. Using data provided by the United States Geological Survey (USGS), low flow data for streams have been listed in the surface flows section of the report. Several areas of the Basin including areas of the Neshanic River, the North Branch of the Raritan River, as well as several tributaries to the Millstone River have experienced low flows close to zero during dry periods based on 7-day 10-year low flow data.

A look at dams in the Basin revealed a number of them in need of repair, particularly in Hunterdon, Mercer, Monmouth and Somerset Counties as well as the need to assess the effects of the 256 dams on surface waters of the Basin. The section on the frequency of high flows provides information on flooding events in the Basin and shows that several areas of the Basin, including areas along the Green Brook and Millstone River have been continually subjected to severe flooding throughout the last century. Although the data show that flood prone areas do not extend much beyond existing wetland boundaries in the Basin, significant areas prone to flooding are evident along the mainstem of the Raritan River in Bridgewater, Manville and Bound Brook, along the tidal portion of the Raritan River near Raritan Bay and along the Millstone River in Millstone Borough, Plainsboro, South Brunswick and in Monroe Township in both the Millstone and Lower Raritan WMAs.

The health of surface waters in the Basin has been assessed primarily by the use of macroinvertebrate data provided by the NJDEP, and the South Branch, Stony Brook-Millstone and Upper Raritan Watershed Associations. Macroinvertebrate data show that the majority of the streams in the Basin have been classified as non-impaired or moderately impaired, with a small percentage of sites classified as severely impaired. Comparison of the NJDEP's AMNET results for 1993-94 and 1999 show a slight decrease in the number of non-impaired sites, a decrease in the number of moderately impaired sites, and an increase in the number of severely impaired sites. Watershed Association data show declines in the macroinvertebrate populations

between 1999 and 2000 (a year of drought followed by flood). Additional baseline data are required to establish long-term trends.

The conversion of wetlands and riparian areas in the Basin was assessed using land use and land cover data from the NJDEP for 1986 and 1995/97. Wetlands converted to other land cover types between 1986 and 1995/97 were converted primarily to urban land uses, with a minimal percentage converted to agricultural land use. Riparian area analyses were conducted using a methodology developed by the Raritan Basin Characterization Committee which identified specific parameters that constitute a riparian area. Parameters used in the analyses included a 150 foot corridor for wildlife passage on each side of all first and second order streams and a 300 foot passage corridor on each side of all third order streams and above, wetlands and wetland transition areas adjacent to stream channels, hydric soils adjacent to stream channels, and 100-year flood prone areas. Results of the riparian area analyses show that approximately 32% of the riparian areas in the Upper Raritan WMA, 31% of the riparian areas in the Lower Raritan WMA and 28% of the historic riparian areas in the Millstone WMA have been converted to other land cover types.

Projects currently being planned or under construction in the Basin include the Green Brook Flood Control Project, the South River Restoration Project, the Millstone River Flood Prevention Project, and the Millstone River Flood Damage Reduction Project. All would will aid in flood damage reduction, and may also affect the protection, restoration or management of stream corridors and surface waters of the Raritan Basin.

# Hydrology

## Surface Waters

Surface water is water on the surface of the land that is visible in lakes, ponds, rivers, streams and other waterways. Water that runs over the land surface after precipitation events (e.g., rainfall, snowfall, sleet, hail) is referred to as surface water runoff. Some of the water that falls to the Earth as precipitation infiltrates (or soaks) into the ground, is lost through the process of evapotranspiration, or runs off the land surface making its way to nearby streams, lakes and rivers. Water that seeps into the ground is referred to as ground water, a concept discussed in greater detail in the Water Budget and Ground Water Technical Reports for the Raritan Basin Project. It is important to note however, that even though surface and ground water are referred to separately, they both come from precipitation.[1]

### Hydrology and Topography of the Raritan Basin

Variations in rock type and geologic history of different regions of the State have created three different physiographic provinces in the Raritan Basin that have unique surface topographies and geologic features. The three physiographic provinces are the Coastal Plain, Piedmont and Highlands. Each province consists of different types of consolidated (i.e., rocks) and unconsolidated (i.e., sand, gravel and silt) deposits with characteristic properties (see Figure 6 of the technical report “Setting of the Raritan Basin”). In the northwest portion of the Basin, glacial deposits cover parts of the Piedmont and Highlands. Each of the physiographic provinces and the glacial deposits are associated with characteristic aquifer units and ground water flow types. The major aquifer units within these physiographic provinces in the Raritan Basin are discussed in the technical report “Setting of the Raritan Basin.” The portions of the Piedmont and Coastal Plain located in the Basin are drained by a number of meandering streams that have well developed flood plains including the Millstone and South Rivers. Large portions of these areas are covered by large tracts of wetlands that formed on poorly drained soils and impermeable bedrock.

Surface water movement is generally from west to east in the central part of the Basin, but from north to south in the northern portion and from south to north in the southern portion of the Basin (see Figure 10 of the technical report “Setting of the Raritan Basin”). Stream flow is monitored at a number of stations within the Basin through a cooperative network operated by the United States Geological Survey (USGS) for the NJDEP (see Figure 1 of the technical report “Water Availability”).

The Raritan River drainage basin covers approximately 1,100 square miles and is the largest river basin located entirely within the State of New Jersey. The Raritan Basin contains approximately 2,000 miles of mapped flowing streams and is divided into 16 large hydrologic units, generally corresponding to individual watersheds (such as the Neshanic River and Lawrence Brook) or subdivisions of larger watersheds. USGS has developed a system of numerical hydrologic unit codes (HUCs), with HUC-11s (i.e., 11-digit HUCs) describing the 16 large hydrologic units.

Major streams within the Raritan River Basin include Spruce Run, Mulhockaway Creek, Neshanic River, Lamington River, Rockaway Creek, Millstone River, Stony Brook, Beden Brook, Matchaponix Brook, Manalapan Brook, Lawrence Brook and Green Brook. Major potable water supply sources within the Basin include Spruce Run Reservoir, Round Valley Reservoir and the Delaware and Raritan Canal (D&R Canal). The D&R Canal brings water from the Delaware River to the eastern part of the Basin and collectively, these three systems provide potable water to approximately 1.2 million people in central New Jersey. [This figure was determined by the NJDEP for the Statewide Water Supply Plan through an analysis of service areas and connections throughout the Basin].

*Upper Raritan Watershed Management Area*

The Upper Raritan Watershed Management Area (WMA) lies within portions of Morris, Hunterdon and Somerset Counties and includes the South Branch and the North Branch of the Raritan River. The North and South Branches of the Raritan River originate in the Highlands physiographic province on or near the Wisconsin glacial moraine.

The South Branch of the Raritan River flows from western Morris County through central Hunterdon County and into western Somerset County where it joins with the North Branch of the Raritan River. The South Branch of the Raritan River is 51 miles long from its source in Budd Lake to the mainstem Raritan River. Major tributaries to the South Branch of the Raritan River include the Neshanic River (11 miles long), Spruce Run Creek (6 miles), Mulhockaway Creek (8 miles), and Cakepoulin Creek (7 miles). Major impoundments along the South Branch include Spruce Run and Round Valley Reservoirs.

The North Branch of the Raritan River originates as a spring-fed stream in Morris County and flows south for approximately 23 miles to its confluence with the South Branch. Tributaries to the North Branch include Dawson’s Brook, Burnetts Brook, Peapack Brook, Tanners Brook, Middle Brook and Mine Brook. The North Branch of the Raritan River joins the Lamington River near Burnt Mills and flows southward to the Piedmont. The South Branch of the Raritan River which originates in Budd Lake west of the North Branch of the Raritan River flows southwesterly and then loops easterly to join the North Branch near Raritan Township. The Lake Cushetunk Dam on the South Branch of the Rockaway Creek and the Ravine Lake Dam on the North Branch of the Raritan River are the only major impoundments associated with the North Branch of the Raritan River.[2]

*Lower Raritan Watershed Management Area*

The Lower Raritan WMA includes the areas draining to the lower portion of the Raritan River, specifically the South River, Manalapan Brook, Matchaponix Brook and Lawrence Brook. The mainstem of the Raritan River originates at the confluence of the South Branch and North Branch in Branchburg Township. It flows for approximately 35 miles in an easterly direction where it discharges into the Raritan Bay. Much of the mainstem of the Raritan River is tidal and the head-of-tide has been identified at a point approximately 2.5 miles downstream from the Fieldville Dam [located on the border of Franklin Township, Somerset County and Piscataway Township, Middlesex County]. This area encompasses parts of Middlesex, Somerset, Monmouth and Union Counties. There are two low dams in the river, Island Farm Weir and Calco. Lakes and ponds in the area include Watchung Lake, Surprise Lake, Spring Lake and Green Brook pond. Dams on the Lawrence Brook are associated with the Lawrence Chain of Lakes and include the Davidson's Mill Pond, Dean's Mills, Farrington, Mill Pond, Weston Mill Pond, and the Westons Arch dams.

The South River is formed by the confluence of the Manalapan Brook (20 miles long) and the Matchaponix Brook (15 miles long) and is tidally influenced from Duhernal Lake to the Raritan River at Sayreville in Middlesex County. Other tributaries to the South River include Deep Run and Tennants Brook.

*Millstone Watershed Management Area*

The Millstone WMA drains the northern Coastal Plain province and includes tributaries such as Beden Brook, Stony Brook, Cranbury Brook and Devils Brook. The Millstone River, moves west across the Coastal Plain, cuts across a ridge of diabase (dark green or black igneous rock often found in dikes) and flows northward into the mainstem of the Raritan River near Manville.[3] The Millstone River is 38 miles long and flows from Millstone Township in Monmouth County to the Raritan River near Manville and Bound Brook. Most of the lower half of the river flows adjacent to the D&R Canal. Carnegie Lake is the largest impoundment in the Millstone WMA.[4]

### Hydrologic Cycle

The hydrologic cycle (commonly referred to as the water cycle) is an endless cycle in which water circulates from the atmosphere to the Earth's surface and then back to the atmosphere. Processes of the hydrologic cycle include precipitation (rainfall, snowfall, sleet and hail, etc.), infiltration of water into the ground, evapotranspiration (the combined loss of water from the atmosphere by evaporation and from growing plants) and surface water runoff. Figure 1 of the Water Budget Technical Report shows a simplified representation of the hydrologic cycle under natural conditions. Figure 2 of the Water Budget Technical Report shows a simplified representation of the hydrologic cycle under "developed" conditions where the water pathways are modified by surface and ground water withdrawals, impervious surfaces, etc. According to national figures, under natural conditions, 50% of precipitation infiltrates into the ground and 10% runs off the land's surface (the remaining 40% is lost via evapotranspiration). These percentages are modified as the landscape becomes developed. Under developed conditions (75-100% impervious cover), 15% infiltrates into the ground and 55% runs off the land's surface (30% is lost via evapotranspiration).[5] According to the Water Budget Technical Report, approximate 16% of the Basin's annual precipitation infiltrates into the ground, 30% runs off the land's surface and 54% is lost to evapotranspiration.

### Hierarchy of Streams in Watersheds

When precipitation reaches the ground, some of the water soaks into the soil and the remainder runs off over the surface. What happens to the water when it hits the ground depends on whether it falls on soil or impervious surfaces such as roadways, parking lots, rooftops, etc. Water that falls on a ridge and does not infiltrate (does not soak into the ground) flows downslope toward stream channels and is referred to as overland flow. Overland flow moves in large sheets or in rivulets and follows the land's contours to the nearest storm drain or stream channel. This surface runoff begins when the rate of precipitation exceeds the rate of infiltration and after certain amounts have been lost to evapotranspiration.[6]

A drainage divide is the ridge on the land surface that separates the land that drains into one stream from the land that drains into another stream. The area enclosed by two divides is called the drainage area or watershed.

Stream order refers to a numbering system where the number increases as streams connect in a downstream direction. For instance, first order streams are the smallest streams and do not have any tributaries. They are generally located at the higher elevations of a watershed, near the drainage divide. Second order streams are formed when two or more first order streams join together. (First order streams may also flow directly into other order streams such as third order or above.) Third order streams are formed when two or more second order streams join together and so on. A watershed therefore, is made up of a single network of streams of varying order that flow from the watershed at a single point, in the highest order stream of the network. At an even larger scale, a basin may constitute many watersheds, where the watersheds all connect as a network and flow out of the basin through a single point. The Raritan River Basin is comprised of many watersheds that combine to form the Raritan River, which leaves the basin at a single point when it enters the Raritan Bay.

Generally, the number of first and second order streams in a basin is significantly greater than the number of large order streams. Of the 2,000 mapped miles of flowing streams in the Raritan Basin, approximately 1,100 miles or 52% are first order streams, 21% are second order streams, 13% are third order, 8% are fourth order, 4% are fifth order and 2% are sixth order. As small order streams join together, the main channel of a river successively increases in size, down stream. Channel geometry varies greatly throughout the Basin. In the headwaters of the Raritan Basin, streams are small and flow is confined to single channels. Further downstream, streams become wider with larger flood plains and meanders.

### Headwater Streams and Attributes

The places where surface waters first begin flowing are often referred to as headwaters, and those streams are first order streams. Some definitions of headwater streams also include second order streams. A stream without tributaries or branches is a first order stream while when two first order streams combine, a second order stream is formed. First order streams may also flow directly into other order streams such as third order or above. Headwater streams are important, as they comprise the majority of streams in a watershed. Approximately 75% of the total stream and river mileage in the United States are headwater streams, when defined as first and second order.[7] As noted above, this is true of the Raritan River Basin as well.

Headwater streams originate from springs, snow melt, lake outlets, or other sources, some of which exist only during heavy storms or wet periods while others exhibit year round flows. These small streams are sometimes only a few feet in width and commonly originate in areas with steep gradients. The middle reaches of a waterway occur further downstream where additional tributaries have added flow to the stream system making them deeper and wider. Middle reaches are characterized as fourth through sixth order streams. The lower reaches of a stream are located even further downstream where more tributaries have joined to create the mainstem of the river. The mainstem of a river typically has an expansive flood plain with a large meandering channel that eventually empties into a larger body of water such as a bay or ocean.[8]

According to May et al. (1997), headwaters have lower stream flows, making them more susceptible to pollutant and stormwater impacts due to their limited dilution and carrying capacity. Streams with degraded headwaters take longer to recover from degradation than do streams with intact headwaters.[9]

In March 2000, the Headwaters Subcommittee of the New Jersey Clean Water Council presented the following definition of headwaters:

> *Headwaters are all first order streams that are delineated as a blue line on a 1:24,000 7.5 minute United States Geological Survey quad map; up to and including their point of origin, such as seeps and springs along with their adjoining riparian corridors.*

According to an investigation of the Raritan Basin by the Headwaters Subcommittee, first order streams comprise approximately 1,148 linear miles or 51.9% of the stream miles in the Basin (Table 1). Figure 1 shows all of the first order streams (those that flow into all order streams) and all of "upper" first order streams (those which only flow into second order streams) in the Basin. "Upper" first order streams constitute approximately 761 linear miles or 34.4% of the total stream miles in the Basin. The subcommittee then calculated the land area that would be included if a 300 foot buffer was placed along each headwater stream, as defined. It should be noted that this definition of a buffer area was for investigational, rather than regulatory, purposes, and that it is not related to the riparian analysis included elsewhere in this report.

**Table 1 - Results of Raritan Basin Headwaters Investigation**

| Land Use | **Order 1 Streams, On Each Land Use** | | | |
|---|---|---|---|---|
| | All Order 1 Streams | | "Upper" Order 1 Streams | |
| | Miles | Buffer (sq mi) | Miles | Buffer (sq mi) |
| Agricultural | 135 | 7.7 | 90 | 5.1 |
| Barren Land | 11 | 0.6 | 8 | 0.5 |
| Forest | 508 | 28.9 | 365 | 20.7 |
| Urban & Suburban | 242 | 13.8 | 164 | 9.3 |
| Water | 68 | 3.9 | 33 | 1.9 |
| Wetlands | 212 | 12.0 | 128 | 7.3 |
| **Total** | 1,176 | 66.8 | 789 | 44.8 |

Notes: Buffers created by multiplying stream length by 300 feet and then dividing by 5,280 feet.
"Upper" order 1 streams are those that flow into order 2 streams.
"Length of order 1 streams increased by 28 miles when it was intersected with land use (i.e., 1,148 to 1,176 linear miles). The reason for this is under investigation."
Source: J.L. Hoffman, NJGS Division of Science, Research and Technology, NJDEP, January 2000.

### Surface Flows of the Basin

Stream flow is defined as the velocity of water as it flows through a cross-sectional area of a stream channel. As the volume of water in a stream or river increases, the water increases in velocity (begins to move faster). The flow of water in a stream also increases with stream order size (e.g., a third order stream flows faster than a first order stream).

As indicated on Figure 11 of the Setting of the Raritan Basin Technical Report, headwaters and small tributaries of the Basin exhibit significantly lower flows than the larger tributaries and rivers of the central portion of the Basin. At the confluence of the mainstem of the Raritan River and the Millstone River in Somerset County, flows are significantly greater than those of upstream tributaries due to the large drainage areas that they encompass. Development of land and conversion of wetlands to urbanized areas have also resulted in higher than normal flows due to the increased rate of surface water runoff from land surfaces.

Below the head-of-tide, discharge and flow of the Raritan River are variable due to tidal influence. Flow also varies depending on season, but approximately 50% of the annual precipitation flows out of the Basin. During the summer when flows are generally lower, about 20% flows out and during early spring when flows are higher, approximately 90% flows out of the Basin. Variable flow conditions during drier months are due to the effect of episodic thunderstorms. Because of high rates of evapotranspiration, extreme low flows generally occur during the summer months. Stream channels in the upper and middle parts of the Basin are generally more narrow and shallow with straight reaches that have large bends. Flow in these straight reaches is relatively rapid.[10]

#### *Low Flows*

To ensure that a stream has an adequate flow of water to support habitat for aquatic species and to meet the demands of water supply users during periods of dry weather flow, data are examined to determine characteristics of low flows. A low flow is defined as the flow of a stream that is less than an average minimum flow for a given number of consecutive days.[11] As water demands increase, planners must look at the magnitude and frequency of available streamflow. Low flow data indicate the occurrence of streamflows is less than what is required to supply water to users and dilute pollutants from wastewater discharges. Low flow data are useful for determining locations for future developments and the placement of septic systems.

Low flows are governed primarily by the geology of a region and underlying geologic formations. Stream flow during dry weather is primarily from ground water supplies, water that is stored underground. In some watersheds of the Sourland Mountains, low flows have been reported as zero. This indicates that during extended dry periods, no water flows in streams because of the minimal amount of ground water that is stored in the underlying bedrock. In other areas, diminished stream flows may be a result of recharge losses and water supply uses related to development.

In order to compute water availability and pollutant loads in streams throughout the Raritan Basin, streamflow is measured at 21 cooperative sites (NJDEP/USGS) throughout the Basin. Seven sites have a continuous 15-minute record of streamflow, while the other 14 sites have instantaneous streamflow measurements that measure flow at the time samples are taken. Low flow conditions, or the seven-day ten-year low-flow statistic (MA7CD10) for the continuous monitoring sites were computed using a USGS database. Sites including the South Branch of the Raritan River at Stanton, the South Branch of the Raritan River at Three Bridges, and the Raritan River sites at Manville and Bound Brook were calculated using streamflow records after 1963 (when streamflow regulation began at Spruce Run and Round Valley Reservoirs) and are denoted in Table 2 with an asterisk.

*Streamflow Characteristics*

Streamflows throughout the Raritan Basin vary according to Physiographic provinces, soils, bedrock, topography, reservoirs, impervious surfaces and other characteristics of the Basin. Stream flows in the Piedmont province are the most variable. Streams in this province yield the lowest flows at baseflow conditions. The yield at the $90^{th}$ percent flow duration (the flow that is exceeded 90 percent of the time) is less than 0.10 cfsm (cubic feet per second per square mile) in the Neshanic River, Stony Brook and Beden Brook watersheds. The yield in the upper portion of the South Branch Raritan River watershed is 0.60cfsm. The highest yield at $90^{th}$ percent flow duration is 0.71 cfsm at South Branch Raritan River at Stanton. Flow at this site is regulated by releases from Spruce Run Reservoir during low flow conditions, and so is unnaturally high. Flow per square mile at the $25^{th}$ percent flow duration (high flow, with only 25 percent of all flows exceeding this value) varies from 1.2 cfsm at Manalapan Brook to 2.5 cfsm at South Branch Raritan River at High Bridge. Flow per square mile is highest at sites on the South Branch Raritan and Lamington Rivers at each flow duration.

Baseflow provides between 38 and 75 percent of mean annual streamflow at gaging stations in the Basin. Baseflow comprises a smaller component of total annual streamflow in streams in the Piedmont than in streams in the Highlands and Coastal Plain physiographic provinces. Baseflow comprises an average of 70 percent of mean annual flow at 5 gages in the Highlands physiographic province; 42 percent of mean annual flow at 6 gages in the Piedmont province; and 62 percent of mean annual flow at 3 gages in the inner Coastal Plain portion of the Raritan Basin. Runoff is a higher percentage of total streamflow in the Piedmont province because of the presence of shallow soils with low permeability.

Differences in flow per unit area between physiographic provinces have an effect on water quality constituent yields that are computed by dividing load by drainage area. Yields normalize the load at sites with varying sizes in drainage area. When the flow per square mile varies between sites with similar drainage areas, yield will vary as a function of flow. Constituent yields at low flow ($90^{th}$ percent flow duration) were found to be influenced more by differences in flow per square mile than at higher flows.

Streamflows vary as a function of season. Highest monthly mean flows occur in the spring and lowest monthly mean flows occur in the fall. Six of the seven gages have highest mean monthly flows in March and lowest monthly flows in October. Mulhockaway Creek, the site with the smallest drainage area, has the lowest monthly flow in August and the highest monthly flow in April.

Streamflows at some of the samplings sites are regulated by releases by water from reservoirs and from the Delaware and Raritan Canal and from a major water withdrawal for municipal supply. Spruce Run Reservoir releases water to South Branch Raritan River and Round Valley releases water to both the South Branch Raritan River and Rockaway Creek in the North Branch Raritan River watershed. Streamflow at sampling sites on the South Branch Raritan River downstream from Spruce Run Reservoir, Rockaway Creek, Lamington River at the mouth and the mainstem Raritan River are affected by releases from these two reservoirs. The Delaware and Raritan Canal diverts water from the Delaware River Basin into the Raritan Basin. The Canal runs through the study area but only effects flows at the sampling site at Raritan River at Bound Brook. The mean daily flow in the Canal coming into the Raritan River Basin at the Basin divide as recorded by the Delaware and Raritan Canal at Port Mercer gaging station was 134 cfs from 1990-97. Water is diverted from the Canal at Ten Mile Lock into the Millstone River near the confluence with the Raritan River. The mean daily flow diverted from the Canal to the Millstone River during 1991-97 was 18.9 cfs. Approximately 170 cfs is withdrawn from the Raritan River for water supply, 3.1 miles upstream from the sampling site at Raritan River at Bound Brook.

*Comparison to Historical Streamflow and Precipitation Data*

The statistics of mean daily stream flow at seven sites with continuous streamflow records for 1991-97 were compared to the long term flow statistics at those sites. The long term statistics for South Branch Raritan River at Stanton and for Raritan River at Manville were based on the period 1964 through 1998. Earlier records of flow at these sites do not reflect the Spruce Run Reservoir releases beginning in September 1963.

In general, flows were slightly higher during 1991-97 than for the longer period of record. The median flow during the period 1991-97 was from 2 to 13 percent higher at South Branch Raritan River at Stanton, Neshanic River, Lamington River, and Millstone River gages. Median flow was the same at Stony Brook, 1 percent lower at Mulhockaway Creek, and 2 percent lower at Raritan River at Manville. The median flow at Raritan River at Bound Brook, as estimated from the Raritan River below Calco dam at Bound Brook gage, during 1991-97 was 5 percent lower than the median for the period 1964-98.

Runoff was higher during 1991-97 at the 5 gages with drainage areas less than 400 square miles and lower at the 2 gages draining over 400 square miles than for the long term period of record. The highest mean daily flows, those exceeded only one percent of the time, were higher at all sites in 1991-97 except at the two sites draining the largest areas; Raritan River at Manville and Raritan River at Bound Brook. The one percent flow duration was 9 percent lower at the Manville gage and 15 percent lower at the Raritan River at Bound Brook site. Neshanic River had the largest rise in one percent flow duration with an increase of 18 percent from the 1922-98 period to the 1991-97 period.

Baseflow was higher during 1991-97 at the 5 sites with drainage areas over 30 square miles and lower at the two gages draining under 30 square miles. Lowest mean daily flows, those exceeded 99 percent of the time, were higher at all sites except the Mulhockaway and Neshanic River sites. The 99 percent flow duration increased 29 to 54 percent at South Branch Raritan River at Stanton, Raritan River at Manville, Stony Brook, Millstone River and Raritan River at Bound Brook sites. The 99 percent flow duration dropped slightly from 2.4 to 2.2 cfs (cubic feet per second) at Mulhockaway Creek and dropped from 0.27 to 0.01 cfs at Neshanic River. The Neshanic River gage recorded no flow past the gage site for 28 consecutive days in August and September 1995. In 1966 no flow passed the gage for 11 consecutive days, 33 days total. Also, in 1965 no flow passed the gage for 5 consecutive days. The occurrence of days with no flow in 1995 rivals the 1965-66 period, however, the extreme low end of the flow duration curve has shown a sharper drop in flow for the period 1991- 97 than during earlier periods. Extreme low flows during dry periods in the late summer have occurred with greater frequency in the 1990’s. This may be an indication that water tables in the area are dropping.

Monthly precipitation records from the National Oceanic and Atmospheric Administration’s National Climatic Data Center were used to compare precipitation from 1991-97 to long-term periods of record. The average annual precipitation in northern New Jersey climate division 1, covering the Piedmont, Highlands and Valley and Ridge physiographic provinces during 1991-97 is close to long-term averages. Precipitation averaged 47.1 inches per year in New Jersey climate division 1 from 1991-97. The precipitation from 1960-99 averages 47.4

inches and the average from 1895-1999 was 46.0 inches. The average annual precipitation in southern New Jersey climate division 2, covering most of the New Jersey Coastal Plain province averaged 45.9 inches from 1991-97. Averages for this climatic division for 1960-99 and 1895-1999 were 44.6 and 44.3 inches, respectively.

**Table 2 - Flow duration values of mean daily flow, and seven-day ten-year low flows**

| Station number (# of samples) | 7-day 10-year low flow (MA7- CD10) cubic ft per second | Mean daily flow cubic ft per second | Flow duration values of mean daily discharge, | | | | | | |
|---|---|---|---|---|---|---|---|---|---|
| | | | 1% | 10% | 25% | median | 75% | 90% | 99% |
| 01396280 – South Branch Raritan River at Middle Vally (35) | 15 | 89 | 530 | 170 | 100 | 65 | 40 | 29 | 16 |
| 01396535 – South Branch Raritan River at Arch Street at High Bridge (37) | 18 | 142 | 1,070 | 290 | 170 | 98 | 57 | 40 | 20 |
| 01396588 – Spruce Run near Glen Gardner (37) | 2.2 | 26 | 300 | 62 | 33 | 17 | 8.7 | 5.7 | 2.5 |
| 01396660 – Mulhockaway Creek at Van Syckelk(37) | 2.2 | 19.8 | 155 | 38 | 21 | 12.8 | 7.0 | 4.1 | 2.2 |
| 01397000 – South Branch Raritan River at Stanton (35) | *46 | 275 | 1,510 | 520 | 300 | 180 | 133 | 105 | 74 |
| 01397400 – South Branch Raritan River at Three Bridges (35) | *46 | 300 | 1,760 | 580 | 330 | 190 | 140 | 110 | 76 |
| 01398000 – Neshanic River at Reaville (56) | 0.27 | 46 | 550 | 89 | 37 | 14.9 | 4.1 | 1.5 | 0.01 |
| 01398260 – North Branch Raritan River near Chester (35) | 0.80 | 10.2 | 120 | 24 | 13 | 6.5 | 3.3 | 2.1 | 0.9 |
| 01399120 – North Branch Raritan River at Burnt Mills (35) | 6.8 | 133 | 1,100 | 280 | 140 | 75 | 27 | 23 | 10 |
| 01399500 – Lamington River near Pottersville (37) | 5.3 | 58.6 | 260 | 120 | 74 | 45 | 27 | 16 | 5.1 |
| 01399700 – Rockaway Creek at Whitehouse (35) | 5.7 | 48.6 | 400 | 100 | 58 | 33 | 19 | 13 | 6.3 |
| 01399780 Lamington (Black) River at Burnt Mills (37) | 12 | 201 | 1,500 | 400 | 210 | 117 | 62 | 39 | 18 |
| 01400500 – Raritan River at Manville (35) | *95 | 821 | 5,700 | 1,730 | 870 | 460 | 280 | 220 | 176 |
| 01400540 – Millstone River near Manalapan (35) | 2.9 | 10.5 | 81 | 20 | 12 | 7.2 | 4.3 | 3.2 | 2.3 |
| 01400650 – Millstone River at Grovers Mill (30) | 4.0 | 75 | 710 | 200 | 92 | 49 | 27 | 18 | 10 |
| 01401000 – Stony Brook at Princeton (59) | 0.22 | 73.4 | 861 | 160 | 63 | 23 | 6.9 | 2.8 | 0.63 |
| 01401600 – Beden Brook near Rocky Hill (37) | 0.13 | 62.7 | 850 | 140 | 54 | 19 | 5.1 | 2.0 | 0.40 |
| 01402000 – Millstone River at Blackwells Mills (31) | 17 | 384 | 3,577 | 919 | 407 | 208 | 110 | 73 | 38 |
| 01403300 – Raritan River at | *74 | 1,190 | 9,390 | 2,700 | 1,250 | 590 | 280 | 180 | 135 |

**Table 2 - Flow duration values of mean daily flow, and seven-day ten-year low flows**

| Station number (# of samples) | 7-day 10-year low flow (MA7- CD10) cubic ft per second | Mean daily flow cubic ft per second | Flow duration values of mean daily discharge, | | | | | | |
|---|---|---|---|---|---|---|---|---|---|
| | | | 1% | 10% | 25% | median | 75% | 90% | 99% |
| Queens Bridge at Bound Brook (56) | | | | | | | | | |
| 01405302 – Matchaponix Brook at Mundy Avenue at Spotswood (35) | 4.5 | 61.6 | 390 | 130 | 74 | 42 | 27 | 18 | 7.0 |
| 01405340 – Manalapan Brook at Federal Road near Manalapan (35) | 5.8 | 23.2 | 150 | 42 | 26 | 16 | 10 | 8.0 | 5.4 |

Notes:

- [Flows are in cubic feet per second, MA7CD10 flows are based on gage records through 1993, flow durations and mean daily flows are based on gage records from 1991 through 1997; *, MA7CD10 flow computed from 1964 through 1993, period representing regulated flow condition].
- 1 cubic foot per second = 0.646317 million gallons per day

Source: Evaluation of Water Quality Status in the Raritan River Basin, Water Years 1991-97, USGS June 2000

*Magnitude and Frequency of Runoff Events*

"Magnitude of flow is simply the amount of water passing a fixed point in the river at a specific point in time. Frequency describes how often a particular condition, such as a large flood, has occurred."[12]

"Hydrologists and engineers have defined reasonably accurate methods for estimating the magnitude and frequency of floods expected from drainage basins in a stable or mostly rural condition based on historical streamflow and flood data. However, the rapid growth of urban and suburban areas in New Jersey has created new and dynamic conditions in many of its basins – conditions for which natural or historical flow-estimating relations are no longer applicable. Urbanization tends to increase peak flow magnitudes through the spread of manmade impervious cover, which increases the volume of runoff, and through drainage alterations such as the addition of curbing, gutters, and storm sewers, which facilitate runoff through the basin."[13]

As referenced in the section on frequency of high flows below, there are a limited number of reports that address the frequency of high flows of streams in the Basin. The reports that exist are dated 1959, 1969 and 1974 respectively. No data exist on the subject after 1974.

*Increased Surface Water Flow Versus Baseflow or Interflow*

Baseflow is the amount of water in a stream that is maintained by ground water contributions during dry periods. Interflow is water that has infiltrated into the ground and moves parallel to the surface as subsurface flow and eventually enters a stream or other waterbody. Interflow may take several hours or several weeks to reach a stream depending on the distance and speed of the underground flow. Interflow is also referred to as runoff "beneath" the surface.

A study conducted by Barringer, et al. (1994) compared the Neshanic River subbasin (4.7% impervious land cover) with the more urbanized Green Brook subbasin (25% impervious land cover) to examine baseflows and overland flows in two subbasins at different stages of development. The study revealed that the Neshanic River subbasin had declining baseflows over time that may have been associated with local climatic changes or been due to increases in development. Baseflow was rising faster than overland runoff until the 1960s, but after that time the rates reversed which may be attributed to increases in development. Results from the same study for the Green Brook subbasin showed that baseflow had fallen until the 1960s at which time it rose until the mid-1980s. Overland runoff for the Green Brook subbasin remained relatively constant during that time. The study predicted that increases in impervious surface areas would undoubtedly increase overland runoff rates in the Green Brook subbasin.[14]

### Changes in Stream Hydrology

Changes in stream hydrology occur as a result of a number of factors. Baseflows may be reduced by increased ground water withdrawals for public and private water supplies and also as a result of development of an area. As an area is developed more impervious cover is added to the landscape. This reduces the amount of water that can infiltrate into the ground thereby reducing ground water levels which supply the baseflow of streams. Increases in surface water runoff may also change the hydrology of a stream by adding more water to the stream following precipitation events. Other changes to stream hydrology are visible where streams have been changed deliberately by water diversions, dam construction or channelization.

#### *Dams*

The construction of dams changes the hydrology of streams by altering the amount of water that passes a particular point on a stream at a particular time and by increasing water levels above them for certain distances. "During flood stages, the water is raised for a greater distance upstream, and the effect of the dam may extend to points so far upstream as to be considerably higher in elevation than the top of the dam."[15] Effects may even extend as far back as the headwaters of a stream. Dams are constructed for various purposes, including water supply, recreation, generation of hydroelectric power, and flood protection of downstream areas.

Major impoundments of the Raritan Basin include Round Valley Reservoir, Spruce Run Reservoir, Carnegie Lake, Manalapan Lake and the Lawrence Chain of Lakes. Round Valley and Spruce Run Reservoirs were constructed in the 1960s to serve as water supply reservoirs for central New Jersey and have the highest dams in the Basin. These two reservoirs store water from the South Branch of the Raritan River which supply water to communities and water companies drawing water from the river further downstream. Water released from the reservoirs is also used to maintain water flows during low-flow periods. Carnegie Lake, an impoundment on the Millstone River in Princeton was built by Princeton University using funds from Andrew Carnegie in 1906. The Lawrence Chain of Lakes was built by the City of New Brunswick as a potable water supply system in the 1800's. The chain consists of a series of lakes along the Lawrence Brook in Middlesex County (Davidson's Mill Pond, Farrington Lake, Weston's Mill Pond). The City is the sole user of this water supply.

There are approximately 254 dams in the Raritan Basin, 57 of which were created as flood control structures. Of the 57, approximately 25 are located in the Upper Raritan WMA, 8 in the Lower Raritan WMA and 24 in the Millstone WMA. According to Figure 2, the majority of the dams in the Basin fall within the 10 to 25 foot height class. Of the dams classified in the "top ten height class" in New Jersey, the Round Valley South Dam (178 feet), the Round Valley North Dam (134 feet), the Spruce Run dam (93 feet) and the Round Valley Dike (80 feet) were included on the list.

Recently, inspection of dams throughout New Jersey has become more of a concern due to the aging of dams. Dams are classified by hazard type based on the level of damage potential, not the likelihood of failure. "High hazard" dams are those that could result in the loss of life as well as property damage if a dam were to fail. State law requires that high hazard dams be inspected every year, however, there are numerous dams that have reportedly not been inspected in decades. Dam owners are the responsible entity for conducting inspections. Figure 3 depicts all of the dams in the Raritan Basin by hazard classification.

In New Jersey, 184 dams are classified as high hazard with 67 of those in need of repair or improvements as of August 17, 2000.[16] Six of the 67 are located in the Raritan Basin and are listed below. An update from the NJDEP Dam Safety section regarding the status of repairs or improvements in August 2002 is noted for each of the high hazard dams.

Hunterdon County:

Clinton Mills Dike: The Dam Safety Section anticipates receipt of a design report for rehabilitation of the structure.

Dam No. 31 (No Name): The Dam Safety Section received a Hydrologic and Hydraulic report for the structure and requested revisions.

Lake Solitude Dam: The Dam Safety Section recently received a design schedule for required studies and repairs.

Mercer County:

Stony Brook Watershed Dam No. 7: The Dam Safety Section recently approved an Emergency Action Plan. The owner of the dam is attempting to sell the property to Mercer County

Monmouth County:

Millhurst Dam: A preliminary design was recently approved by the Dam Safety Section. Revisions to the Emergency Action Plan and the final design/permit application are due by 30 October 2002.

Somerset County:

Skillman Dam: Proposals are under investigation for removal of this structure.

The NJDEP Dam Safety Section inspected over 50 dams several weeks after Hurricane Floyd (September 1999) in an effort to assess the impacts of the storm. Of the 50 dams, three in the Basin were damaged including Watchung Lake Dam in Somerset County, Skillman Dam in Somerset County and Seeley's Pond Dam in Union County. As of August 2002, the Watchung Lake Dam had been repaired and repairs to Seeley's Pond Dam were underway. The Skillman Dam has been proposed for removal; therefore, no repair work has been performed, but the water level has been lowered for safety purposes.

On January 10, 2000, Governor Whitman signed legislation (P.L. 1999 c. 347), which set aside money for the rehabilitation of high hazard dams and additional funding for rehabilitation of dams affected by Hurricane Floyd. Monies are available for private dam owners as co-applicants with local government, in the form of low interest loans. A dam rehabilitation project currently under construction in the Basin includes the Heritage Hunt Dam in Monroe Township, Middlesex County.

A database containing information on dams of the Basin was obtained from the NJDEP Dams Safety Section in July 2000. The database includes information on the hazard classification, purpose, stream association, height, length, surface area, capacity, and drainage area of dams within the Basin. It should be noted however that the data have not been quality checked by the authors of this report. Questions on information contained in the database should be directed to the NJDEP Dams Safety Section. You may contact the Dams Safety Section at (609) 984-0859.

Although dams provide numerous benefits such as reservoirs for water supply, lake habitat for recreational purposes, and flood protection of downstream areas, dams may also have negative effects on streams. For example, dams prevent the movement of leaves and other organic material to downstream areas which are often the source of food and shelter for many aquatic species. Dams also truncate habitats and prevent the movement of anadromous fish to upstream areas where they travel to spawn. The release of water from dams may also negatively affect streams by causing erosion or scouring of the stream channel, and by changing the water temperature of a stream by releasing warmer or colder water than what aquatic species are adapted too. Dams also change the natural patterns of drought and flood which some species rely on during breeding cycles.[17]

Additional information is needed to assess the impacts of dams on streams in the Basin. There are approximately 256 dams on 2,000 miles of streams in the Basin, however, no assessment has been performed to determine the effects of these dams on surface waters. Regarding the passage of anadromous fish, the NJDEP Division of Fish and Wildlife has documented the passage of American shad through the Island Farm Weir (a low dam) along the mainstem of the Raritan River. The Division of Fish and Wildlife documented 48 shad swimming through the fishway in 1996. A total of 3,484 fish were documented using the ladder representing 24 species.[18]

#### *Channelization*

Channelization is the alteration of a stream channel from its natural state to an urbanized condition. Channelization often involves the addition of concrete to the bed and banks of a stream which changes its natural hydrology. A channel made of concrete can no longer absorb water; it can only convey water, which has the potential to increase the frequency of flooding and peak flow volumes as well as change the width and depth of the channel.

Fortunately, the Raritan Basin has a limited number of streams that have been channelized. Channelized streams are primarily limited to the Lower Raritan WMA in the vicinity of Green Brook.

## Stream Channels

### Stream Channel Components

Natural stream channels consist of a number of components including the bed (substrate) and banks (soils) of the channel, slope and vegetation types. The stream channel is the part of the stream that conveys water to downstream areas. As the width and depth of a stream increases, or as the channel becomes wider and shallower, the composition of the stream may change. Generally, the many components of a stream channel operate in balance until disturbed. Natural stream channels migrate laterally by erosion of one bank and deposition on the opposite bank while maintaining a constant channel cross section. The form of the cross section is stable, while the position of the channel is not. Stable, self-maintained streams are said to be operating at their full potential.

Streams in the northern portion of the Basin (i.e., Piedmont and Highlands) have been classified by the 2000 Ambient Biomonitoring Network as “high gradient” streams, or having substrates of rock and cobble of various size with relatively swift flows. Streams of the Coastal Plain have generally been classified as “low gradient” or having slower flows and more homogeneous substrates of sand or gravel and finer sediments.

### Stream Morphology Classification

David Rosgen has developed a stream classification method that has been used by the United States Forest Service for characterizing streams based on morphological (physical structure) characteristics.[19] This classification system, developed in 1994 is widely used and accepted as a method of describing channel conditions and predicting stream behavior. Rosgen's classification system presents 42 major stream types and involves a four level classification hierarchy. The first level describes the geomorphic characteristics of a stream, the second describes its morphological characteristics, the third is an assessment of stream conditions and the fourth is a level of validation.

Currently, stream channels in the Raritan Basin have not been classified based on stream morphology. The application of Rosgen's classification system may be a practical and worthy endeavor if time and resources permit.

Appendix B contains illustrations of various stream morphological components throughout the North & South Branch Raritan, Lower Raritan and Millstone WMAs.

## High Flow Events

The amount of water that is temporarily stored in and flows through a stream channel after heavy rainfall events is referred to as channel storage. Enormous amounts of water can be stored in a stream channel during floods.[20] The constant flow of water in channels affects and shapes the morphology and development of a stream channel. Formation of channels involves the transport and storage of sediment as well as erosive processes that move sediment from one location to another further downstream. Bends or curves in a stream channel occur naturally and affect the manner by which water flows through the channel. High flow events carry more water and sediment and have more of a role in changing the shape and size of streams and flood plains. When a stream is filled up to the top of its banks, it is referred to as "bankfull." Bankfull flows have higher velocities than normal streamflows and a higher potential for changing the morphological and ecological characteristics of a stream. When a stream is at bankfull stage, the channel dimensions, pattern, profile and bed features may be changed. When surface water flows increase, the stream may undergo conspicuous changes in channel width. During bankfull conditions, discharges may move sediment, form or remove bars, form or change bends or meanders overall changing the morphological characteristics of the stream. It is these range of flows that occur throughout the year that govern the shape and size of a channel. Flood flows are those flows that exceed bankfull flows, and actually have slower velocities than bankfull flows, especially within the flood plain. For this reason and the higher frequency of bankfull events, they will cause more erosion than floods in natural streams.

During high flow events, ecological changes may occur within the stream or along the banks of the stream. Bottom-dwelling species such as benthic macroinvertebrates may be scoured from the streambed, and streamside vegetation may become stressed or die from prolonged flooding and associated oxygen deprivation.

### Types of Floods

Flood studies indicate that there is no such thing as a maximum flood. There are however, floods that are expected to occur every year, once in every 10 years, once in every 100 years and so on. "The recurrence interval is the average time, in years, in which a flood of a given magnitude can be expected to be exceeded once. Recurrence intervals are average figures based on historical data; because the occurrence of floods is erratic, a flood of a given recurrence interval may occur in any year, even in successive years, or it may not occur for a period much greater than the designated recurrence interval. The recurrence interval is inversely related to the chance of a specific flood discharge being exceeded in any one year. Thus a flood with a 100-

year recurrence interval would have 1 chance in 100, or a 1% chance of being exceeded in any one year. A flood with a 25-year recurrence interval has a 4% chance of being exceed in any given year."[21]

There are various types of floods that occur as a result of varying precipitation events. Flash floods occur as a result of very intense rainfalls and the insufficient time for water to be absorbed into the ground. When this happens, rainwater becomes stormwater runoff which causes sudden rises in stream height. Small watersheds with steep slopes and those with soils that have very limited infiltration capacity are particularly susceptible to flash flooding.[22]

Prolonged precipitation events can also cause flooding. When the ground becomes saturated and additional water can no longer be absorbed, the rainfall becomes runoff and flooding can occur. In essence, the ground becomes as impermeable as roads. Flooding caused by prolonged precipitation can usually be predicted so that sufficient warning may be given to residents.[23]

Localized flooding occurs when water backs up at downstream locations. If a river or stream does not have sufficient capacity to carry the flood waters, water may backflow into upstream tributaries. This type of flooding often occurs when culverts and bridges become blocked and cannot allow water to pass, or when storm drains or sewers back up.[24]

A fourth cause of flooding occurs when dams or other flood control structures are overtopped or when a structure fails. Overtopping occurs when a flood of a certain magnitude exceeds the flood used to design the structure.[25]

## Flood Plains

### Definitions

A flood plain is the area of land adjacent to a stream, lake or pond that sometimes becomes covered by floodwaters from the stream during heavy rains. This area may vary in size depending on the natural landscape. The flood plain is made up of two parts known distinctly as the floodway and the flood fringe. The floodway contains the bed and bank of a stream where water normally flows. The flood fringe is the area that extends from the top of the streambank outward and holds water when streambanks overflow. Flood plains are defined by the storm frequency that affects them, from frequent to very rare (such as Hurricane Floyd). In general, the regulated flood plain is the area that would be covered by water during the "100 year storm" (a storm which has a 1 in 100 chance of occurring in any given year). According to the NJDEP Land Use Regulation Program, a flood plain is defined as "the area adjacent to a stream, lake or pond, which is covered by floodwater when it rains." The NJDEP also regulates areas designated as floodways. A floodway is defined by the NJDEP as "the channel and portions of the flood plain adjoining the channel which are reasonably required to carry and discharge the regulatory flood."

Flood prone areas are defined as areas that are associated with relatively frequent flood events that generally include the active flood plain and low terrace (abandoned flood plain or are subject to occasional flooding). According to the NJDEP Geographic Information System metadata, "flood prone area documentation has been taken directly from USGS flood prone maps. There is on average about 1 chance in 100 that the designated areas will be inundated in any year. The flood prone areas have been delineated through the use of readily available information on past floods rather than from detailed surveys and inspections. In general, the delineated areas are for natural conditions and do not take into consideration the possible effects of existing or proposed flood control structures except where those effects could be evaluated."[26]

### Benefits of Flood Plains

Undeveloped flood plains provide storage for floodwaters which reduce the height and velocity of floodwaters downstream. Flood plains also serve as natural reservoirs, by slowly releasing stored water to a stream.[27] Vegetated flood plains also help reduce the potential for erosion of stream banks and adjoining land areas which prevents sedimentation of the stream.[28]

In addition to economical benefits, vegetated flood plains also provide a number of ecological benefits including habitat for aquatic and terrestrial wildlife, maintenance of cool instream temperatures by providing shade over the stream, and aesthetic values.

### Fluvial Versus Tidal Flood Plains

A fluvial flood is defined by the NJDEP as a flood which is caused entirely by runoff from rainfall in the upstream drainage area and is not influenced by the tide or tidal surge. Conversely, a tidal flood is defined as a flood caused by a storm surge or tide backing up a channel (NJAC 7:13).

New Jersey's geography and location along the Atlantic coastline subjects the State to both tidal and fluvial flooding. Tidal flooding is the result of higher than normal tides that inundate low lying coastal areas. The lower reach of a watercourse that flows into a tidal water body is subject to the same flooding characteristics as the tidal water body, particularly the lower portions of the mainstem Raritan River and the South River. The remaining areas in the Basin are subject to fluvial flooding.

## Flood Damages

As flood plains become developed or filled in, the waterway is reduced and the flow of water becomes obstructed. As a result, water elevations of future flood flows increase both upstream and downstream and can result in significant flood damages. These flood damages are shared by the local community, the region, and state and federal governments. Floods are natural occurrences, but flood damages occur as a result of improper development or increased size of flood hazard areas.

Damages from floods may affect small areas or may be much more devastating depending on the type and magnitude of the flood. Damages from flash floods are generally limited to a small area, but are sometimes quite severe due to the inability to warn residents. Flooding from prolonged precipitation events often results in extensive property damage due to the widespread areas that become inundated with substantial volumes of water. Rain falling on land surfaces that have been covered with impervious surfaces (surfaces that prevent absorption of water such as parking lots or buildings) contribute to local flooding by sending more water downstream at a quicker rate.[29]

## Areas of the Basin within 100-Year Flood Prone Areas

In contrast to many states in the nation, New Jersey experiences a significant number of flood producing storms. Storms include those that originate from tropical hurricanes that move north along the east coast, storms that move northeast from the Gulf of Mexico, storms that originate over the continental United States and move east, and storms that move southeast from Canada and the polar regions. As a result of being located in a "corridor" of storm paths, New Jersey is subject to many flood producing storms. A report prepared by the NJDEP Division of Water Resources in 1973 stated that "New Jersey's flood experience during the past 60 years *(1910-1970)* is far below its potential, a fact which must not be overlooked."[30]

Figure 4 shows the 100-year flood prone areas for the Raritan Basin as defined by the NJDEP and the Federal Emergency Management Agency (FEMA). As compared with Figure 14 of this report (Wetlands in the Basin), the 100-year flood prone areas do not extend much beyond the wetland boundaries, which indicates that the wetlands absorb a significant amount of runoff during flooding events. This signifies the importance of protecting wetlands to prevent flooding of widespread areas and to provide protection of adjacent developed areas. Significant areas prone to flooding in the Basin occur along the mainstem of the Raritan River, particularly in the areas of Bound Brook, Manville and Bridgewater, and along the tidal portion of the Raritan River. The lower reaches of the Basin in the Lower Raritan and the Millstone WMAs also have extensive flood prone areas, particularly in the area of Plainsboro, South Brunswick and Monroe Townships.

Figure 5 shows the existing land uses within the flood prone areas of the Basin. According to Table 3 below, over half (65%) of the flood prone areas in the Basin occur as wetlands or water areas, while urban and agricultural land uses occupy 13% and 7% of flood prone areas, respectively. As seen on Figure 5, urban areas are evident within many of the flood prone areas of the Basin, but are particularly obvious along the mainstem of the Raritan River near the Raritan Bay, along the mainstem in Bound Brook and Bridgewater, and along the Stony Brook in Princeton. Agricultural areas are predominant along the North and South Branches of the Raritan River and along the mainstem of the Raritan River in Raritan and Somerville.

**Table 3 - Land Use Classifications within the 100-Year Flood Prone Areas of the Raritan Basin**

| Land Use | Land Area (Acres) | Percent |
|---|---|---|
| Agriculture | 6,144 | 6.55% |
| Barren Land | 1,254 | 1.34% |
| Forest | 12,909 | 13.77% |
| Urban | 12,314 | 13.13% |
| Water | 12,621 | 13.46% |
| Wetlands | 48,538 | 51.76% |
| **Total** | **93,780** | **100%** |

Source: NJDEP, 2000

### Preventive Measures

Measures to minimize flood damages not only include structural measures, but also involve the wise utilization of flood prone areas and the implementation of land use regulations. Public awareness and proper development also significantly reduce potential flood damages and broad-based community planning helps prevent regional problems by considering flood impacts on upstream and downstream communities. Municipal zoning ordinances also ensure that only permissible types of land use activities occur within flood hazard areas.[31]

Only those uses that are compatible with the threat of flooding should be designed in flood plains. Historically, flood plains were used to access rivers which were used to transport material goods to major cities such as New York City and Philadelphia. Today however, legitimate flood plain uses for development purposes are few.

Structural measures such as detention and retention basins are typically designed to capture and retain stormwater runoff from impervious surfaces during storms. The basins capture runoff and then depending on the basin's function, the water is either infiltrated into the ground or slowly released to an adjacent water body.

Detention basins are designed to reduce peak flows to predevelopment levels by altering the time of basin discharge. However, detention basins do not significantly reduce the volume of runoff caused by development. In order to reduce the volume, the runoff would have to be infiltrated or evaporated which usually is not possible with large flood producing storms due to large amounts of water and limitations of the detention pond holding area. Although stormwater management measures help mitigate the adverse effects of impervious cover, no stormwater management measure can reproduce the runoff conditions that exist prior to dense development.

The Freehold Soil Conservation District has a database containing all of the detention basins under its jurisdiction for the Middlesex and Monmouth County regions of the Basin. This information would be useful for determining the location of detention basins with regard to old and new developments (old developments many not have any basins, whereas newer developments are required to have them). Similar information is needed for the remaining five counties of the Basin to determine the effects of detention basins on streams. This information would also be useful for determining the number of detention basins or outfall structures that exist on a given stream and may help local planners avoid the placement of detention basins on streams that cannot handle additional flows.

## Frequency of High Flows

### Magnitude and Frequency

Although the greatest floods usually occur in late winter and early spring, there is also a period during fall when floods often occur due to tropical storms. Melting snows are primarily responsible for winter and spring floods which do not have extreme flow peaks and have rather long durations, while autumn floods exhibit high flow rates over a relatively short time. Destructive floods of large magnitude are generally produced by large storms, which are relatively rare.

Because large floods occur relatively infrequently, residents who move to an area may not be aware of the inherent danger of moving onto a flood plain. Old residents move away, levees are built, fills are made, warehouses and new developments come in and damaged structures are rebuilt or demolished. Since large floods usually come at longer intervals than small floods, assumptions that another large flood may not occur for another century are too often made. In fact, a large flood may occur at any time despite a 100-year or 500-year designation.[32]

### History of Floods in the Basin

Although floods are experienced at various times throughout the year, historically the most significant floods have occurred during late summer and fall due to tropical storms that have moved north along the coastline. Major floods in the Raritan Basin were associated with hurricanes of 1903, 1938, 1955 and 1971. More recent floods in the Basin include those of 1984, 1996 and 1999. Prior to 1900, major floods occurred in 1810, 1865, 1882 and 1896.[33]

In 1931, a conference was held in Plainfield to discuss corrective measures for flooding problems associated with Green Brook in the counties of Middlesex, Somerset and Union. As a result of the meeting, the Green Brook Flood Control Committee was formed to “investigate methods and costs of controlling floods on Green Brook and to take action toward the construction of proper flood control works.” A study conducted by the Committee revealed that slopes of the Watchung Mountains in the Green Brook and Stony Brook (Lower Raritan WMA) watersheds were responsible for large and sudden flood flows. The valley of Green Brook was where the real problem was determined to be. “It is quite evident from a study of the physical conditions and surveys of the channel that the flooding along Green Brook and Stony Brook is caused by the insufficiency and irregularity of the existing channels which are badly clogged with debris and vegetation. The worst condition of this sort is at Siebring’s Mills, where a railroad has been built across the valley. The capacity of the raceway, bridge and culvert together are entirely insufficient to handle even the smallest flood flows of the stream at this point. As a result, the roadway acts as a dam behind which the waters pile up until they overflow and interrupt traffic.” “The problem along Green Brook below Siebring’s Mills differs from the problem on the rest of the stream in that this area is subject to flooding not only by the waters of Green Brook, but by the back water of the Raritan River when the latter stream is at flood stage. This condition can be prevented only by the control of floods on the Raritan River.”[34]

The following statements taken from a 1932 report by the State Water Policy Commission provide evidence of the flooding that has occurred in the Green Brook area for more than a century. The following quotes are excerpts from files of the Plainfield Courier-News:

| | |
|---|---|
| April 16, 1888 | "Low land between Plainfield and Fanwood submerged." |
| Feb. 6, 1896 | ".......storm one of the worst ever known. Frost in ground increased runoff. Green Brook overflowed in Plainfield, where water rose so high as to flow through its old course into Cedar Brook." |
| March 20, 1896 | "Water within 8 inches of Central Railroad tracks in Bound Brook." |
| March 3, 1902 | "Green Brook has been a raging torrent for three days. Logs, stumps and telephone poles floating in the river. Bound Brook, the 'Venice of America' in state of panic." |
| Oct. 9, 1903 | "Rain started at 3 P.M. yesterday……Somerset Street completely under water and bridge threatened. Water in Green Brook reached the bridge floors at Elm Street and Westervelt Avenue, the highest stage noted in years." |
| Oct. 10, 1903 | "Green Brook, Stony Brook and Cedar Brook are raging torrents…. All bridges stood up, but some were weakened….Houses along Green Brook from Sanford Avenue to Grove Street had water up to the first floors." |
| Oct. 11, 1903 | "Water never so high in New Market Pond." |

Reports of conversations with local residents at the time of these floods indicate that the most serious floods occurred after heavy thunderstorms. At the time the 1932 report was prepared, the flood of October 1903 was recorded as the largest on record with the flood of March 1902 being only slightly smaller. In addition, the storm of February 1896 was reported as having the heaviest rainfall known up to that time. Field investigations conducted during preparation of the 1932 report revealed that "Green Brook and Stony Brook are quick-acting, flashy streams subject to high rates of runoff and quick response to excessive rainfall. Bound Brook is a slow-acting stream yielding only a small portion of its rainfall as flood runoff, owing to the relative flatness of the watershed and the existence of numerous ponds and swamps."[35]

The headwaters of the Green Brook watershed in the Lower Raritan WMA originate on the steep slopes of the Watchung Mountains. Stormwater runs off the Watchung Mountains relatively quickly and slows as it reaches the valley bottom where numerous commercial, industrial and residential developments are located. According to the 1977 flood study, the flat channels in the valley are incapable of handling these flows, and flooding occurs relatively quickly during excessive rainfall events. At Plainfield, the Green Brook channel acts like a funnel, causing water to backup with severe overflows resulting. The 1977 study indicated: "Below Plainfield, the Green Brook is fed by streams that build to a crest over a longer time period. Bound Brook takes approximately 24 hours to reach its peak and does not reach the flood stage until the first peak has receded on Green Brook. Bound Brook is backed up frequently due to channel restrictions, inadequately sized culverts and bridges, and high water levels in the Raritan River. Bonygutt Brook is also constricted by inadequately sized drainage facilities and causes frequent flooding in Dunellen. Ambrose Brook also spills over its banks in heavy storms, thus adding to the concentration of waters at the confluence of the Green Brook and the Raritan River, which back up and inundate the municipality of Bound Brook.[36]"

According to a 1959 open-file report prepared by Richard Tice of the USGS, the flood of February 1896 was recorded as having been the highest flood since 1810, reaching a stage of 34.6 feet above mean sea level (MSL) in Bound Brook. According to Tice, "the Annual Report of the State Geologist for 1896 gives the level of the February 6, 1896 flood as 64 feet above MSL at the confluence of the North and South Branches of the Raritan River. The 1955 flood was 61.2 feet above MSL at the same location. The 1896 flood was given as 23 feet above the normal level at Raritan whereas the 1955 flood was only 18 feet above low water. At South Branch, the 1896 flood was given as 20.5 feet above the ordinary level below the mill dam whereas the 1955 flood was only 14 feet above low water. Since 1896, the flood of August 19, 1955 was the highest in the vicinity of the Raritan, although the flood of September 22, 1938 was as high or higher downstream from Raritan Township."

Hurricane Doria, which hit New Jersey in August 1971, caused the State to be declared a natural disaster area. Approximately $242,000 of flood damages occurred along the South Branch of the Raritan River alone. The flood stage was 37.5 feet above MSL at Bound Brook and exceeded the 1896 flood stage of 34.6 feet above MSL. Hurricane Doria caused approximately $140 million of damages statewide.

An intense cold front which moved north-eastward across New Jersey caused devastating floods in Somerset, Union and northern Middlesex counties in August 1973. The total rainfall in a 5-hour period averaged approximately 7 inches in a relatively narrow band across north-central New Jersey. Overall, 1,000 people were evacuated from their homes or places of business and Middlesex, Somerset, Union and Essex Counties were declared federal disaster areas. Public and private damages were estimated in excess of $67 million.[37] The highest total precipitation of 8.78 inches in the 5-hour period was recorded at Bound Brook. The greatest rainfall intensity of 4 inches in one hour was recorded in Plainfield.

Figure 6, a re-creation from the County and Municipal Government Study Commission 1977 flood study illustrates municipalities within the Basin that have historically been subject to flooding problems. The figure shows municipalities subject to recurrent and serious flooding problems and those which experience occasional flooding problems. Other areas subject to localized flooding from coastal storms, hurricanes and major storms may not be indicated on the map.[38]

According to several USGS flood studies from the 1960s, areas in the Millstone WMA that have experienced extensive flooding include Rock Brook at the toe of slope of the Sourland Mountains near Skillman; the confluence of Rock Brook and Beden Brook; Pike Run north of its confluence with Back Brook; and the area along River Road at the confluence of Beden Brook and Pike Run.[39] Between 1921 and 1967, the highest flood on the Millstone River occurred at Blackwells Mills in 1938. Prior to 1921, the largest floods occurred on the Millstone River in 1810, 1882 and 1896. Flooding along Beden Brook near Rocky Hill and Pike Run at Bridgepoint have traditionally occurred from backwater on the Millstone while peak discharges at Blackwells Mills have been caused by flood runoff from Beden Brook, Ten Mile Run and Six Mile Run. USGS mapping of floods in the Upper Millstone Basin show extensive flooding from 1938 along the Millstone River, Rocky Brook, Big Bear Brook and Cranbury Brook in the vicinity of Plainsboro and Princeton Junction.[40]

The Millstone River has a history of flooding problems that has been well documented since the early twentieth century. These flooding problems range from chronic overtopping of low-lying roadways that traverse the River and its floodplain to severe but less frequent flooding of residential, commercial, and institutional structures. Most of these structures are located in older communities, some of which have historic status. Similar flooding problems occur along the River's major tributaries, including the Stony Brook, Beden Brook, and Six and Ten Mile Run. In studies to date, urbanization has not been identified as a significant reason for the flooding problems described above. Instead, the primary cause of the flooding problems is the location of these structures and roadways, which were constructed in the Millstone River's natural floodplain prior to our current understanding of floodplain hydrology and hydraulics. However, urbanization may become a more significant factor in the future if watershed development continues without adequate runoff controls.

The Natural Resources Conservation Service through their PL-566 Millstone River Watershed Protection and Flood Damage Reduction Project have identified 66 flood damage locations throughout the Millstone WMA. These locations have been identified and prioritized by frequency of flooding. NRCS is investigating flood damage reduction measures in the watershed. More information on the Millstone PL-566 project is available on the Raritan Basin project web site at www.raritanbasin.org. The US Army Corps of Engineers has also begun a flood damage reduction that is focused mostly on the Manville-to-Millstone Borough area, and the two projects are sharing information and concepts.

## Flooding Due to Hurricane Floyd

According to the USGS, the Raritan Basin was the hardest hit by Hurricane Floyd across the State of New Jersey. The Basin was reported as having received between 7 and 11 inches of rain in less than 24 hours. The mainstem of the Raritan River at Bound Brook set a new peak of record on September 17, 1999 at 42.13 feet above MSL, the highest stage since at least 1800. This stage was higher than the stage following Tropical Storm Doria in 1971. Tables 4 and 5 below illustrate the new peaks of record and sites above flood stage that occurred as a result of Hurricane Floyd.

**Table 4 - Stations in the Raritan Basin Exhibiting New Peaks of Record**

| **Station Name** | **Old Peak of Record** | | **New Peak of Record** | |
|---|---|---|---|---|
| | **Gage Height (ft)** | **Date** | **Gage Height (ft)** | **Date** |
| Spruce Run at Glen Gardner | 7.96 | 10/19/96 | 9.37 | 9/16/99 |
| Neshanic River at Reaville | 13.84 | 8/28/71 | 15.3 | 9/16/99 |
| North Branch Raritan River at North Branch | 19.31 | 7/7/84 | 21.53 | 9/16/99 |
| North Branch Raritan River near Raritan | 15.57 | 10/19/96 | 18.78 | 9/16/99 |
| North Branch Raritan River at South Branch (Old York Road) | 18.0 | August 1896 | 18.98 | 9/16/99 |
| Raritan River at Manville | 23.8 | 8/28/71 | 27.5 | 9/17/99 |
| Beden Brook near Rocky Hill | 16.83 | 8/28/71 | 18.61 | 9/16/99 |
| Pike Run at Belle Mead | 12.17 | 10/19/96 | 13.56 | 9/17/99 |
| Millstone River at Blackwells Mills | 18.68 | 8/28/71 | 20.97 | 9/17/99 |
| Raritan River below Calco Dam at Bound Br. | 37.47 | 8/28/71 | 42.13 | 9/17/99 |
| Green Brook at Seeley Mills | 7.05 | 10/19/96 | 8.25 | 9/16/99 |

Source: Flooding Due to Hurricane Flood, September 1999 – Prepared by USGS, 2000b.

**Table 5 - Sites Above Flood Stage in the Raritan Basin as a Result of Hurricane Floyd**

| **Station Name** | **Feet Above Flood Stage** |
|---|---|
| South Branch Raritan River near High Bridge | 10.87 |
| South Branch Raritan River at Stanton | 13.89 |
| Lamington River at Pottersville | 4.64 |
| Stony Brook at Princeton | 14.0 |

Source: Flooding Due to Hurricane Flood, September 1999 – Prepared by USGS, 2000b.

As a result of flooding caused by Hurricane Floyd, the Federal Emergency Management Agency (FEMA) is buying and demolishing approximately 42 homes in a section of Manville known as Lost Valley; the largest buyout in a single town in New Jersey. Although flooding occurred in 1996 during two storms, residents had not witnessed any severe flooding since Hurricane Doria in 1971, more than 25 years ago. For many residents, this was their first flood.[41]

As stated in the March 15, 2000 edition of the Courier News, “Hurricane Floyd became a wake-up call for the stalled Green Brook project.” The Green Brook flood control project includes dredging and the placement of levees in a 65 square mile area in 14 towns. The project started in November 2000 and the first phase is expected to be completed by December 2004. The plan was first proposed in the 1980s, however “delays revolved around state permits and getting congressional funding for the project.”[42] The project was approved by the Army Corps of Engineers in 1997. Some upstream communities are concerned that the project is a local solution to a regional problem.[43]

Results of the "Great Raritan Flood Project" conducted by the Rutgers University Geography Department reported that "rainfall upstream from Bound Brook and Manville was 2 inches more than from Doria, and it fell in a shorter period of time." "Anyone wanting to hang their hat on development as the primary cause of Floyd's flooding has no peg,"[44] primarily because the amount of rain that fell during Floyd would have caused flooding despite the amount of development that has occurred throughout the region.

Other areas that experienced flooding as a result of Hurricane Floyd included Lambertville, Warren, Bound Brook, South Bound Brook, Green Brook, Franklin Township in Somerset County, Hillsborough, North Plainfield, Branchburg, Bridgewater and Flemington. "Floyd swamped some buildings along the Millstone River corridor and along the Raritan and its tributaries in South Branch, Flagtown, Green Hills and Neshanic." According to the Center for Urban Policy Research, 9 counties in New Jersey were declared major disaster areas, 6 of which are located in the Raritan Basin (i.e., Hunterdon, Mercer, Middlesex, Morris, Somerset and Union). The Borough of Bound Brook "suffered catastrophic flooding in its downtown business district where the Raritan River peaked at 42 feet above MSL," according to the USGS. "Some downtown storefronts were under 20 feet of water before the flood receded; police rescuers traversing Main Street by boat were able to reach up and touch the tops of traffic lights."[45]

Despite the severe flooding, many people are moving into the flood-prone areas of Manville and Bound Brook due to low costs for homes and because surrounding municipalities are costly and are among the fastest rising in the nation. In Bound Brook alone, "the flood destroyed nearly $50 million in taxable properties in the 200-acre flood zone." Some real estate agents said the "flood has affected prospective home buyers' view of the town, but they have not had trouble selling homes anywhere in the community" despite the concerns.[46]

## Watershed Based Changes in High Flows

### Effects of Urbanization on Watershed Hydrology

Changes in land use and alterations to stream channels in a watershed can affect the hydrologic regime of a stream by increasing the magnitude and frequency of runoff events of all sizes; delivering more of a stream's annual flow as surface storm runoff rather than base flow; and increasing the velocity of flow during storms.[47]

Urbanization has many effects on the water quality and quantity of streams by increasing pollutant loads, increasing water temperature, degrading aquatic habitat, and reducing recreational uses. Human activities have substantially altered river flow regimes in many areas of the United States insomuch as only two percent of U.S. rivers remain relatively free-flowing and undeveloped.[48] One of the more obvious forms of flow alteration results from the construction of dams and reservoirs. The operation of dams for flood control, water supply, barge navigation, hydroelectric power generation, or recreation affect the timing and amount of water releases from a dam and have an effect on downstream areas.

Hydrologic systems are very sensitive to changes in the landscape. Urbanization decreases soil infiltration and increases evapotranspiration rates which may explain why intensive land uses can significantly increase flood peaks and exacerbate low flow conditions.

Urbanization affects flood runoff in at least two ways: 1) the volume of water available for runoff increases because of reduced infiltration of rainfall over manmade impervious areas, and 2) changes in hydraulic efficiency associated with artificial stream channels, curbing, gutters, drains and storm sewers increase the magnitudes of flood peaks because runoff time is shorter. The combined effect of these two changes increases peak discharges.[49]

The effects of development on a watershed are two-fold and interfere with low flow and high flow processes. When natural land areas are developed and covered with impervious surfaces including parking lots, roads and buildings, the ground can no longer absorb water. [50] Therefore, the post-development volume of water entering a stream is significantly greater than before the areas were developed. Under natural conditions, the ground absorbs and stores water that is released to streams during dry periods. The same is true when comparing small and large storms. Small storms allow water to infiltrate into the soil, but during larger storms, soils become waterlogged and water can no longer infiltrate into the ground. The excess water runs off the land surface, similar to water running over an impervious surface. Thus, the larger the storm, the less difference the amount of impervious cover in a watershed makes.

In an effort to determine the effects that development has on flooding, the Natural Resources Conservation Service (NRCS) is conducting an analysis as part of the Millstone River Watershed Protection and Flood Damage Reduction (PL-566) project (see section on Management Plans) to assess the impacts of flooding on areas along the Millstone River. Results of this project are available on the Raritan Basin Project web site at http://www.raritanbasin.org/nrcs_millstone.htm.

### Effects of Sewage Treatment Plants

During periods of low flow, discharges from sewage treatment plants (STPs) may provide the majority of stream baseflow in some locations. On the Raritan River alone, there are approximately 50 municipal or industrial wastewater treatment discharge facilities. Although the STPs may be maintaining baseflow during certain periods, the quality of the discharge may vary from natural stream conditions due to higher pollutant concentrations or higher temperatures of the discharge. At the peak of the 1999 summer drought, about 20 percent of water drawn from the Raritan River had been discharged from wastewater treatment plants.[51] For comparison, the Passaic River at Little Falls in the Passaic River Basin has been comprised of well over 85% treated wastewater discharge at times.

### Imperviousness and Runoff

Increased amounts of impervious cover in a watershed makes it virtually impossible for rainwater to recharge ground water. As impervious cover amounts reach 10-15% in a watershed, the rate and volume of runoff dramatically increases especially in the smaller, more erosive storms. Research by the Center for Watershed Protection has demonstrated that an imperviousness of 10% in a watershed results in unstable and eroding channels. Research on the effects of impervious cover on a watershed in the Raritan Basin has been conducted by faculty at the Department of Ecology, Evolution and Natural Resources at Cook College, Rutgers University. Study results were not available at the time this report was completed.

Other key changes that occur as impervious levels increase include an increase in magnitude and frequency of floods, higher flow rates, channel enlargement, increased sedimentation, declination of baseflow levels, degradation of instream habitats, loss of large woody debris important for habitat diversity, more treefalls from eroded banks, increases in the number of stream crossings and potential fish barriers, riparian forest fragmentation, declination in water quality, increases in stream temperatures and a overall reduction in aquatic diversity.[52]

Specific information on imperviousness and its effect on streams in the Basin is discussed in the Landscape Technical Report.

### Increase in Contaminants

New construction can affect streams by increasing the amount of sediment to the stream from upland construction sites and also from contaminants that have been deposited on impervious surfaces that are carried to streams during storms. Generally, constituent concentrations in urbanized streams are one or two orders of magnitude greater than forested watersheds. Water quality problems typically associated with urban areas include turbidity, nutrient enrichment, bacterial contamination, organic matter loads, toxic compounds, temperature increases and increased instances of trash or debris.[53] The Surface Water Quality and Pollutant Loadings Technical Report addresses the effect of pollutants and associated land uses on water quality.

#### Population Projections and Shifts within the Raritan Basin

Population trends from 1930 to 1990 (Figures 23 and 24 of the Setting of the Raritan Basin Technical Report) show that the Basin has seen significant population growth in the last 70 years. Population in some areas is projected to grow at a very high rate in the immediate future with much of that growth occurring in the southern and western (i.e., more rural) parts of the Basin.[54] It is also expected that populations will continue to "shift" from urban to rural areas as the road and rail networks allow people to move farther from employment centers and still be within an acceptable commuting distance of their work. The population growth and shifts will result in changes to many watersheds in the Basin. It is not known at this time what the ultimate impact on flooding will be, but NRCS (Natural Resources Conservation Service) is assessing future impacts as part of its Millstone project. However, it can be predicted that new development will reduce ground water recharge, and in areas reliant on public or domestic wells, result in more ground water demands.

## Ecological Health

### Surface Waters

#### General Health

This section provides a brief overview of stream health based on the NJDEP 1996 Water Quality Inventory Report. (Results of the 2000 Surface Water Quality Inventory Report are not available at this time). Further discussion of pollutant loadings will be discussed in the Surface Water Quality and Pollutant Loadings Technical Report.

In 1996, the South Branch of the Raritan River and its associated watershed were documented as containing a variety of potential point source pollution problems, but concerns about nonpoint source pollution issues were on the rise. Currently runoff from suburban sources and storm drains are causing increased sedimentation to streams, and septic tanks are also a severe problem due to the large number of failing systems, particularly in High Bridge and Califon. Runoff from agricultural land, surface mining activities and general road runoff are also causes for concern in some areas.

Problems in the North Branch of the Raritan River are associated primarily with nonpoint source pollution from suburban development as opposed to point sources. Conversion of farmlands to residential housing developments has affected the Lamington River by contributing nutrients and sediment to the River. Other sources of nonpoint source pollution include runoff from storm sewers and land clearing and leachate from faulty septic systems. Agricultural activities including poorly managed pasture lands and livestock feedlots have also degraded water quality in the North Branch.[55]

Nonpoint sources on the mainstem of the Raritan River have been identified as leachate from landfills in the lower portions of the River as well as from construction activities from urban and suburban development throughout the length of the River. Hazardous waste sites are also prevalent in this region, many of which are on the USEPA National Priority List.

Nonpoint source pollution from developed lands is also a significant concern in the South River. This River is also believed to be threatened with toxic contamination from the Burnt Fly Bog waste disposal site located near Deep Run, a tributary to the South River. This region also contains a large number of hazardous waste sites which are on the USEPA National Priority List and the NJDEP's Known Contaminated Sites List.

Nonpoint source pollution and failing septic systems associated with suburban development are a major cause of impairment in the Millstone WMA. Nonpoint sources associated with agriculture are also a problem in the region drained by Etra and Peddie Lakes, Cranbury Brook, and the lower reaches of the Millstone River near its confluence with the Raritan River. Fuel oil spills have caused fish kills in the Upper Millstone, and landfills have caused problems in South Brunswick where leachate from a municipal landfill has been noted by local authorities. Treatment plant effluents from plants in Hightstown and East Windsor had been major point source contributors to dissolved oxygen and nutrient problems in the Millstone River, however, the Hightstown plant has undergone an upgrade and the East Windsor plant was replaced by a new facility. [56]

### Benthic Macroinvertebrates

Benthic macroinvertebrates are macroscopic (visible to the unaided eye) organisms found in the bottom (substrate) of streams. They are commonly used as indicators of water quality, because they are relatively immobile and therefore useful for identifying site specific pollution impacts. Different species of macroinvertebrates have varying degrees of tolerance to different environmental factors including sedimentation, temperature changes, and pollutants. Some are very tolerant, while others cannot even tolerate minimal amounts of pollution. Through the collection and identification of individual species, the relative health of a stream can be determined (i.e., the greater diversity of pollution intolerant species present, the "healthier" the stream).

According to the USEPA, benthic macroinvertebrates are used as indicators of water quality for the following reasons:

- They are good indicators of localized conditions because of their limited migration patterns, which makes them well suited for assessing site specific impacts.
- Benthic macroinvertebrate communities integrate the effects of short-term environmental variations.
- Degraded stream conditions are easily detectable because macroinvertebrates are relatively easy to identify to family or order.
- Benthic macroinvertebrates are abundant in most streams.
- NJDEP and USEPA utilize benthic macroinvertebrate sampling in their statewide monitoring programs.
- Sampling methods (using a kick net on a cobble substrate) have shown good statistical replication.

#### *NJDEP Biological Monitoring Results*

In 1991, the NJDEP Bureau of Water Monitoring reconvened its monitoring efforts and established the Ambient Biomonitoring Network (AMNET). This program was established so that long-term monitoring data could be evaluated to support environmental policy decisions in watershed management and permitting activities. Of the 144 sites that were sampling between 1993 and 1994 in the Raritan Basin, 37.5% were rated as non-impaired, 56.9% were rated as moderately impaired and 5.6% were rated as severely impaired. 1993-94 results for specific drainage areas of the Basin are indicated below in Table 6.

| **Table 6 – Results of NJDEP 1993-94 Ambient Biomonitoring Network Benthic Macroinvertebrate Study** | | | |
|---|---|---|---|
| | **Attributes** | | |
| **Drainage Area** | **Non-Impaired** | **Moderately Impaired** | **Severely Impaired** |
| Lamington River | 80% | 20% | 0% |
| North Branch Raritan River | 81.3% | 18.8% | 0% |
| South Branch Raritan River | 64.7% | 35.3% | 0% |
| Millstone River | 10.8% | 83.8% | 5.4% |
| Lawrence Brook | 0% | 100% | 0% |
| South River | 5.9% | 70.6% | 23.5% |
| Raritan River (mainstem) | 10.5% | 79% | 10.5% |
| **Overall Raritan Basin** | **37.5%** | **56.9%** | **5.6%** |

Source: NJDEP, 1995a

The 1999 NJDEP Ambient Biomonitoring Network Report for the Raritan Region presents the results from the second round of AMNET monitoring in the Raritan. In order to compare the 1999 results with the 1993-94 results, sites that were sampled along the Elizabeth, Rahway and Woodbridge Rivers (WMA 7) as part of the 1999 study were extracted and the percentages were recalculated for the Raritan Basin.

Of the 150 monitoring stations sampled during the 1999 study in the Basin, 37.3% were rated as non-impaired, 54.7% were rated as moderately impaired, and 8.0% were rated as severely impaired (Table 7). As compared with the 1993-94 results for the Basin, there was little change in the number of non-impaired sites (37.5% in 1994 to 37.3% in 1999). The number of moderately impaired sites decreased slightly from 56.9% in 1994 to 54.7% in 1999, and the number of severely impaired sites increased from 5.6% in 1994 to 8.0% in 1999.

| **Table 7 – Results of NJDEP 1999 Ambient Biomonitoring Network Benthic Macroinvertebrate Study** | | | |
|---|---|---|---|
| | **Attributes** | | |
| **Drainage Area** | **Non-Impaired** | **Moderately Impaired** | **Severely Impaired** |
| Lamington River | 86.7% | 13.3% | 0% |
| North Branch Raritan River | 82.3% | 11.8% | 5.9% |
| South Branch Raritan River | 62.9% | 37.1% | 0% |
| Millstone River | 5.4% | 81.1% | 13.5% |
| Lawrence Brook | 0% | 83.3% | 16.7% |
| South River | 10% | 75% | 15% |
| Raritan River (mainstem) | 15% | 75% | 10% |
| **Overall Raritan Basin** | **37.3%** | **54.7%** | **8.0%** |

Source: NJDEP, 1999

The 1999 report also evaluated the results of the biological monitoring by Watershed Management Area. For the Upper Raritan WMA, results showed that although some of the localized degradation may be from agricultural or residential sources, stream biotic integrity was found to be quite favorable. For the Lower Raritan WMA, a significant improvement was seen at seven sites and significant decline at three sites, indicating an increasing improvement of water quality progressively downstream. The Millstone WMA experienced a significant improvement at three sites and a significant decline at six sites, indicating that stream quality is primarily a function of habitat quality in the area due to the increase in moderately impaired sites and sub-optimal habitat from upstream to downstream.[57] A comparison of scores for 1993-94 and 1999 is available on http://www.state.nj.us/dep/watershedmgt/bfbm/downloads.html, the NJDEP Bureau of Freshwater and Biological Monitoring web site.

The NJDEP's definitions for impairment of waterways are as follows:

- *Non-impaired*: Benthic community comparable to other undisturbed streams within the region. A community characterized by maximum taxa richness (number of different families in a sample), balanced taxa groups and good representation of intolerant individuals.

- *Moderately impaired*: Macroinvertebrate richness is reduced, in particular EPT taxa (*Ephemeroptera*, *Plecoptera* and *Tricoptera* orders). Taxa composition changes results in reduced community balance and pollutant intolerant taxa become absent.

- *Severely impaired*: A dramatic change in the benthic community has occurred. Macroinvertebrates are dominated by a few taxa which are very abundant. Tolerant taxa are the only individuals present.

"While biological monitoring using benthic macroinvertebrate community structure is an excellent water quality monitoring tool, it is only a branch of water quality monitoring. Additional tools include water column chemistry, sediment chemistry, toxicity testing, fish tissue analysis, and fish community analysis. The most comprehensive evaluation would incorporate all of these elements. However, financial constraints make such monitoring difficult to perform. The frugality of benthic macroinvertebrate analysis provides the water pollution control professional with a holistic assessment of water quality at a reasonable cost."[58]

*NJDEP Results for the South Branch of the Raritan River*

According to the NJDEP 1996 Surface Water Quality Inventory Report, an extensive amount of macroinvertebrate analysis has been performed in the South Branch of the Raritan River. At its source (near Budd Lake), the South Branch was classified as moderately impaired, which improved further downstream. Results between Long Valley and Clinton indicated a non-impaired status. Farther downstream at Three Bridges, conditions declined to a moderately impaired status. Other tributaries to the South Branch varied between non-impaired and moderately impaired. In the upper regions, Drakes Brook was moderately impaired at its upstream-most location and non-impaired before its confluence with the South Branch. Spruce Run, Mulhockaway Creek, Cakepoulin Creek, Prescott Brook and the upper half of Beaver Brook were all rated as non-impaired, however, the lower portion of Beaver Brook was moderately impaired.

Tributaries to the lower reaches of the South Branch include Pleasant Run which ranged from moderately impaired at its upper-most reach to non-impaired at its lower-most reach. Holland Brook was rated as non-impaired along its entire length whereas the Neshanic River and Black Creek were both moderately impaired. Comparison of the 1996 305b results with the 1999 AMNET results (Table 8) show no change in impairment status at any of the sites along the South Branch of the Raritan River. The status of Pleasant Run changed from moderately impaired to non-impaired at its upper-most reach, and from non-impaired to moderately impaired at its lower-most reach. In addition, Holland Brook degraded from a non-impaired to a moderately impaired status between 1996 and 1999.

*NJDEP Results for the North Branch of the Raritan River*

The 1996 NJDEP data assessed the entire length of the North Branch of the Raritan River as non-impaired. Although one reach of the Lamington River was assessed as moderately impaired, the remainder of the River had a rating of non-impaired. Assessments of the Rockaway Creek varied, while the confluence of the South Branch and North Branch of the Raritan River was rated as moderately impaired. Tributaries to the North Branch of the Raritan River including Dawson's Brook, Burnetts Brook, Peapack Brook and Tanners Brook were all non-impaired, while Middle Brook was non-impaired in its upper half but moderately impaired in its downstream reaches. Mine Brook was moderately impaired in its upper reaches, but non-impaired in its lower reaches. Comparison of the 1996 305b results with the 1999 AMNET results showed that both reaches of the Middle Brook improved to a status of non-impaired, while the upper reaches of Mine Brook declined to a status of severely impaired and the lower reaches declined to a moderately impaired status (Table 8).

*NJDEP Results for the Mainstem of the Raritan River*

Macroinvertebrate samples taken at Millville and Piscataway were assessed as moderately impaired. Many of the tributaries to the mainstem also exhibited moderately impaired conditions including Dukes Brook, Peters Brook and Middle Brook. In Watchung, the Green Brook was assessed as severely impaired, but improved to moderately impaired at Seeley's Mill. Comparison of the 1996 305b results with the 1999 AMNET results showed that the impairment status of the Green Brook improved from severely impaired to moderately impaired between 1996 and 1999 (Table 8).

*NJDEP Results for the South River*

The majority of the streams associated with the South River including the Matchaponix Brook, Pine Brook, Barclay Brook, Deep Run, Millford Brook and Tepehemus Brook were assessed as moderately impaired. The central section of Manalapan Brook in the vicinity of Monroe Township was severely impaired, while portions of McGellairds Brook and Weamaconk Creek were severely impaired in some reaches. Comparison of the 1996 305b results with the 1999 AMNET results showed that Deep Run and Pine Brook declined from a status of moderately impaired to severely impaired. Conversely, Manalapan Brook and Weamaconk Creek improved from a severely impaired status to a moderately impaired status (Table 8).

*NJDEP Results for the Millstone River*

Almost the entire Millstone WMA was assessed as moderately impaired. Non-impaired streams included the Millstone River at Bergen Mills, Camp Harmony Brook, and Cruser and Back Brooks. The lower end of Heathcote Brook and Duck Pond Run were assessed as severely impaired. Comparison of the 1996 305b results with the 1999 AMNET results showed that Camp Harmony Brook, Cruser Brook and Back Brook all declined from a non-impaired status to a moderately impaired status, while the lower end of Heathcote Brook and Duck Pond Run improved to a non-impaired and moderately impaired status, respectively (Table 8).

**Table 8 – Comparison of NJDEP 1996 Surface Water Quality Inventory Report (305b) Macroinvertebrate Results with NJDEP 1999 AMNET Report Results**

| Watershed | Attributes | |
|---|---|---|
| | **1996** | **1999** |
| South Branch Raritan River | | |
| o At Budd Lake | Mod | Mod |
| o Between Long Valley and Clinton | Non | Non |
| o At Three Bridges | Mod | Mod |
| o Upstream portion of Drakes Brook | Mod | Mod |
| o Downstream portion of Drakes Brook | Non | Non |
| o Spruce Run | Non | Non |
| o Mulhockaway Creek | Non | Non |
| o Cakepoulin Creek | Non | Non |
| o Prescott Brook | Non | Non |
| o Upper half of Beaver Brook | Non | Non |
| o Lower half of Beaver Brook | Mod | Mod |
| o Upper portion of Pleasant Run | Mod | Non |
| o Lower portion of Pleasant Run | Non | Mod |
| o Holland Brook | Non | Mod |
| o Neshanic River | Mod | Mod |
| o Black Creek | Mod | Mod |
| North Branch Raritan River | | |
| o Lamington River | Non | Non |
| o Confluence of North Branch and South Branch | Mod | Mod |
| o Dawsons Brook | Mod | Mod |
| o Burnetts Brook | Non | Non |
| o Peapack Brook | Non | Non |
| o Tanners Brook | Non | Non |
| o Upper portion of Middle Brook | Non | Non |
| o Lower portion of Middle Brook | Mod | Non |
| o Upper portion of Mine Brook | Mod | Sev |
| o Lower portion of Mine Brook | Non | Mod |
| Mainstem Raritan River | | |
| o Dukes Brook | Mod | Mod |
| o Peters Brook | Mod | Mod |
| o Middle Brook | Mod | Mod |
| o Green Brook at Watchung | Sev | Mod |
| o Green Brook at Seeley's Mill | Mod | Mod |
| South River | | |
| o Matchaponix Brook | Mod | Mod |
| o Pine Brook | Mod | Sev |
| o Barclay Brook | Mod | Mod |
| o Deep Run | Mod | Sev |
| o Millford Brook | Mod | Mod |
| o Tepehemus Brook | Mod | Mod |
| o Manalapan Brook at Monroe Township | Sev | Mod |
| o McGellairds Brook | Sev | Sev |
| o Weamaconk Creek | Sev | Mod |
| Millstone River | | |
| o Millstone River at Bergen Mills | Non | Non |
| o Camp Harmony Brook | Non | Mod |
| o Cruser Brook | Non | Mod |
| o Back Brook | Non | Mod |
| o Lower end of Heathcote Brook | Sev | Non |
| o Lower end of Duck Pond Run | Sev | Mod |

Sources: NJDEP Surface Water Quality Inventory Report – 305(b).
NJDEP 1999 Ambient Biomonitoring Network Report.
Notes: "Non" indicates an impairment status of non-impaired.
"Mod" indicates an impairment status of moderately impaired.
"Sev" indicates an impairment status of severely impaired.

*South Branch Watershed Association Results*

In 1994, the South Branch Watershed Association (SBWA) established a biological monitoring program in an effort to obtain baseline water quality data for the South Branch of the Raritan River. By 1999, trained volunteers monitored 20 sites along the main river and major tributary streams.

According to the SBWA 1999 Benthic Macroinvertebrate Sampling Report, the mainstem of the South Branch of the Raritan River was reported as having a "non-impaired" status with all samples from tributary streams showing "moderate impairment." Data compiled in 1999 were compared with data collected since 1994. Results were comparable on a site-by-site basis. Monitoring results for 2000 indicate an overall decrease in macroinvertebrate scores throughout the South Branch Watershed tentatively attributed to natural causes related to drought followed immediately by Hurricane Floyd flooding during late 1999. 2001 results show additional decreases at five sites and increases at four sites from 2000. Annual monitoring will continue in order to verify current water quality data and to establish additional monitoring sites along the mainstem and tributaries of the River.[59] Results from samples collected by SBWA's Water Stewards between 1994 and 2001 are reported in Table 9 and illustrated on Figures 7 and 8. Figures 7 and 8 show the macroinvertebrate results by New Jersey Impairment Score (NJIS). A score of 24-30 indicates an impairment status of non-impaired, a score of 9-21 indicates an impairment status of moderately impaired and a score of 0-6 indicates an impairment status of severely impaired.

Of the South Branch Watershed Association's sampling sites along the South Branch of the Raritan and its tributaries, approximately seven of the SBWA's sites are located at the same location or proximate to a NJDEP AMNET monitoring site. The SBWA sites and the NJDEP sites for 1999 were assigned the same impairment status by both organizations.

*Stony Brook-Millstone Watershed Association Results*

The Stony Brook-Millstone Watershed Association's Water Monitoring Program was established in 1996 in an effort to help improve the overall quality of the waters in the Stony Brook-Millstone watershed region which were reported as "fair" (meaning that pollution varies from moderate to high) in a 1992 NJDEP Report. SBMWA's biological monitoring program conducts benthic macroinvertebrate sampling at eight sites on Stony Brook, Beden Brook, Big Bear Brook and Ten Mile Run. Sampling is conducted annually in March, July and October. Results from samples collected by SBMWA's Biological Action Teams (BATs) between 1996 and 2001 are reported in Table 10 below and illustrated on Figures 9-11. Figures 9, 10 and 11 show the macroinvertebrate results by New Jersey Impairment Score (NJIS).

Of the SBMWA's sampling sites, approximately five of the sites are located at the same location or proximate to a NJDEP AMNET monitoring site. Results varied between SBMWA and NJDEP for three sites including Beden Brook (BD1), Stony Brook (SB1) and Ten Mile Run (TM1). Comparison of SBMWA's 1999 results with NJDEP's 1999 results show that site BD1 was scored as moderately impaired while the NJDEP scored its corresponding site #405 as severely impaired. At SB1, the SBMWA reported a non-impaired status while the NJDEP assigned corresponding site #393 a moderately impaired status. Finally, at the Ten Mile Run site, SBMWA scored the site as non-impaired while the NJDEP scored corresponding site #407 as moderately impaired.

**Table 9 – South Branch Watershed Association Macroinvertebrate Sampling Results 1994-2001**

| Site | 1994 | 1995 | 1996 | 1997 | 1998 | 1999 | 2000 | 2001 |
|---|---|---|---|---|---|---|---|---|
| South Branch Raritan River - Below Confluence with Turkey Brook, Mt Olive Twp (Site I) | Non | Non | Non | Non | Non | Non | Non | Non |
| South Branch Raritan River - Clairmont Stretch, Washington Township (Site II) | Non | Non | Non | Non | Non | Non | Non | Non |
| South Branch Raritan River - One Eighth of a Mile Below Vernoy Road, Tewksbury Township (Site III) | Non | Non | Non | Non | Non | Non | Mod | Mod |
| South Branch Raritan River - Hamden Road Bridge, Franklin/Clinton Townships (Site IV) | Mod | Non | Mod | Mod*<br>Non** | Non | Non | Non | Non |
| South Branch Raritan River - Packer's Island, Border of Readington/Raritan Townships (Site V) | Non | Mod | Mod | Mod*<br>Non** | Non***<br>Mod**** | Non | Mod | Mod |
| South Branch Raritan River - Dart's Mill, Readington/Raritan Townships (Site VI) | Non | Non | Non | Non | Non | Non | Mod | Mod |
| South Branch Raritan River - Higginsville Road Bridge, Readington Township (Site VII) | Non | Non | Non | Non | Non | Non | Non | Non |
| South Branch Raritan River - Route 567 Bridge, Neshanic Station, Branchburg Township (Site VIII) | Non | Non | Non | Non | Non | Non | Mod | Mod |
| South Branch Raritan River - Orchard Drive, Branchburg/Hillsborough Township Boundary (Site IX) | Non | Non | Non | Non | Non | Non | Non | Mod |
| Neshanic River - Rainbow Hill Road Bridge, East Amwell Township (Site X) | Non | Non | Mod | Mod | Non | Non | Non | Mod |
| South Branch Raritan River - Below Clinton Township Sewage Treatment Plant, Clinton Township (Site XI) | -- | Non | Non | Non | Non | Non | Mod | Non |
| Drake's Brook – Above Bartley Road Bridge, Mount Olive Township (Site XII) | -- | -- | Mod | Non | Non | Non | Non | Mod |
| South Branch Raritan River above Route 24 (Schooley's Mountain Road) Bridge in Long Valley (Site XIII) | -- | -- | -- | -- | Non | Non | Non | Mod |
| South Branch Raritan River at Rowlands Mills, at the Boundary of Readington and Raritan Townships (Site XIV) | -- | -- | -- | -- | Non | Mod | Mod | Non |
| Pleasant Run Brook – Off Pleasant Run Road at Craig Road (Site XV) | -- | -- | -- | -- | -- | Mod | Mod | Non |
| Pleasant Run Brook – At 629 Bridge, Branchburg Township (Site XVI) | -- | -- | -- | -- | -- | Mod | Mod | Non |
| Holland Brook – At Brookview Drive, Readington Township (Site XVII) | -- | -- | -- | -- | -- | Mod | Non | Non |
| Back Brook – Off Van Lieu's Road (Site XVIII) | -- | -- | -- | -- | -- | Mod | Non | Mod |
| Third Neshanic River at Kuster Farm (Site XIX) | -- | -- | -- | -- | -- | Mod | Sev | -- |
| Neshanic River off of Reaville Road at the gasline access (Site XX) | -- | -- | -- | -- | -- | Mod | Mod | -- |

Source: South Branch Watershed Association Annual Benthic Macroinvertebrate Sampling Reports 1994-20001
Notes: "Non" indicates an impairment status of non-impaired.
"Mod" indicates an impairment status of moderately impaired.
"Sev" indicates an impairment status of severely impaired.
-- Indicates no data available for that given year
*Sample identified by RMC Laboratories shows "moderate impairment" at this site.
**Sample identified by SBWA "Water Stewards" shows a "non-impaired" status.
*** Sample identified by RMC Laboratories shows "non-impairment" at this site.
**** Sample identified by SBWA "Water Stewards" shows a "moderately impaired" status.

**Table 10 - Results of Stony Brook-Millstone Watershed Association's BAT Data Evaluation 1996-2001**

| Site | 1996 | 1997 | 1998 | 1999 | 2000 | 2001 |
|---|---|---|---|---|---|---|
| Big Bear Brook at Cranbury Road, near the confluence with the Millstone River (BB1) | -- | Mod | -- | -- | Mod | Mod (7/20/01) |
| | | | | | | Mod (10/20/01) |
| Beden Brook at River Road, North of Route 206 (BD1) | Mod | Sev (3/97) | Mod | Mod | Mod (7/22/00) | Mod (7/21/01) |
| | | Mod (8/97) | | | Mod (10/21/00) | Mod (10/20/01) |
| Beden Brook at Great Road, near Cherry Valley Country Club (BD3) | -- | Mod | Mod | Mod | -- | Mod (7/21/01) |
| | | | | | | Mod (10/20/01) |
| Beden Brook at Aunt Molly Road (BD4) | Mod | Mod | Non (4/98) | Sev (7/99) | Mod (3/25/00) | Mod (3/24/01) |
| | | | | | Mod (7/22/00) | Mod (7/21/01) |
| | | | Mod (7/98 & 11/98) | Mod (10/99) | Mod (10/21/00) | Mod (10/20/01) |
| Back Brook where Route 206 crosses the stream (BK1) | -- | -- | -- | -- | -- | Non (7/21/01) |
| | | | | | | Mod (10/20/01) |
| Duck Pond Run, on Route 1, sample from Chili's restaurant parking lot | -- | -- | -- | -- | -- | Mod (7/21/01) |
| Stony Brook at Route 206, 10 feet downstream of the 206 bridge (SB1) | Mod (9/96) | Mod | Mod (7/98) | Non | -- | -- |
| | Non (12/96) | | Non (10/98) | | | |
| Stony Brook at Province Line Road at the closed bridge, hike downstream (SB2) | Mod | Mod | -- | -- | Sev (3/25/00) | Mod (3/24/01) |
| | | | | | Mod (7/22/00) | Mod (7/21/01) |
| | | | | | Non (10/21/00) | Mod (10/20/01) |
| Stony Brook at Pretty Brook Rd (SB3) | -- | -- | -- | -- | -- | Mod (10/20/01) |
| Stony Brook at upper reaches, near the Mine Road bridge (SB5) | Non | Mod | Non | Mod | Mod | Mod (7/21/01) |
| | | | | | | Mod (10/20/01) |
| Six Mile Run, sample near canal | -- | -- | -- | -- | -- | Mod (7/21/01) |
| | | | | | | Mod (10/20/01) |
| Ten Mile Run, b/t big rock and wing wall of bridge (TM1) | -- | -- | -- | Non | Mod (3/25/00) | Mod (3/24/01) |
| | | | | | Mod (7/22/00) | Mod (7/21/01) |
| | | | | | Mod (10/21/00) | Mod (10/20/01) |

Sources: SBMWA 11/23/99 Detailed BAT Data Evaluation
SBMWA 11/20/00 Detailed BAT Data Evaluation

Note: "Non" indicates an impairment status of non-impaired.
"Mod" indicates an impairment status of moderately impaired.
"Sev" indicates an impairment status of severely impaired.
A "—" indicates that the sample did not include enough organisms for statistical evaluation.

*Upper Raritan Watershed Association*

The Upper Raritan Watershed Association (URWA) has been providing technical assistance to the Readington and Tewksbury Township Environmental Commissions on the Rockaway Creek biological and chemical water quality monitoring project in the Upper Raritan Watershed Management Area. The purpose of the project which is funded by Merck and Co., Inc., is to protect water quality within the Rockaway Creek subwatershed. Results of the samples collected for 1999, 2000 and 2001are reported in Table 11 below and on Figure 12. Figure 12 shows the macroinvertebrate results by New Jersey Impairment Score (NJIS).

Of the Rockaway Creek project sampling sites, approximately four of the sites are located at the same location or proximate to a NJDEP AMNET monitoring site. Results for the Rockaway Creek project were the same as the NJDEP results for 1999 for three of the four sites, however Site #15 for the Rockaway Creek project was reported as having a non-impaired status, while the NJDEP reported corresponding site #368 as moderately impaired.

**Table 11 – Rockaway Creek Water Quality Monitoring Project Results for 1999-2001**

| Site | 1999 | 2000 | 2001 |
|---|---|---|---|
| Unnamed Tributary that flows through Sutton Farm, North of Farmersville Road, Farmersville (Tewksbury Township) (Site 1) | Mod | Non | Non |
| Unnamed Tributary that flows along Guinea Hollow prior to confluence with North Branch Rockaway Creek, Mountainville (Tewskbury Township) (Site 2) | Non | Non | Non |
| Unnamed Tributary that flows along Water Street prior to confluence with North Branch Rockaway Creek, Mountainville (Tewksbury Township) (Site 3) | Non | Non | Non |
| North Branch Rockaway Creek (flows along Rockaway Road), Mountainville (Tewksbury Township) (Site 4) | Non | Non | Non |
| North Branch Rockaway Creek Rockaway Road at Bissell Road (Tewksbury Township) (Site 5) | Non | Mod | Non |
| North Branch Rockaway Creek, Whittemore property, Oldwick (Tewksbury Township) (Site 6) | Non | Mod | Non |
| North Branch Rockaway Creek, Wagner property, West of Route 523, Whitehouse Station (Tewksbury Township) (Site 7) | Non | Non | Non |
| Unnamed Tributary, Merck Property at Potterstown Road, South of the Cold Brook School, Potterstown (Readington Township) (Site 8) | Mod | Mod | Mod |
| Unnamed Tributary, Merck Property East of Route 523, just above confluence with Mainstem North Branch Rockaway Creek, Whitehouse Station (Readington Township) (Site 9) | Mod | Mod | Non |
| North Branch Rockaway Creek, Merck Property East of Route 523, Whitehouse Station (Readington Township) (Site 10) | Non | Non | Non |
| Unnamed Tributary, South of Overlook Drive, Lebanon (Clinton Township) (Site 11) | Non | Non | Non |
| South Branch Rockaway Creek, NJ Department of Fish, Game and Wildlife, Lebanon (Clinton Township) (Site 12) | Non | Non | Non |
| South Branch Rockaway Creek, Readington Lebanon Sewer Authority, South of Main Street, Lebanon (Lebanon Borough) (Site 13) | Non | Mod | Non |
| South Branch Rockaway Creek, East of Mountain Road, South of Route 22, Lebanon (Readington Township) (Site 14) | Non | Non | Non |
| South Branch Rockaway Creek, Nelson Street, Whitehouse Station (Readington Township) (Site 15) | Non | Mod | Mod |
| Mainstem Rockaway Creek, North of Old Highway 28, East Whitehouse (Readington Township) (Site 16) | Non | Non | Non |

Source: Rockaway Creek Water Quality Monitoring Project – 1999, 2000 and 2001 Findings.
Notes: “Non” indicates an impairment status of non-impaired.
“Mod” indicates an impairment status of moderately impaired.

### Fisheries/Shellfisheries

The NJDEP Surface Water Classifications as defined at NJAC 7:9B, provide a basis for water quality and uses of surface waters throughout the State.

Trout production (TP) waters are defined as "waters designated for use by trout for spawning or nursery purposes during the first summer" (NJAC 7:9B-1.4). Category 1 (C1) designations indicate that the waters are to be protected from "measurable changes in water quality characteristics because of their clarity, color, scenic setting, other characteristics of aesthetic value, exceptional ecological significance, exceptional recreational significance, exceptional water supply significance, or exceptional fisheries resource(s) (NJAC 7:9B-1.4). A category of a surface water describes a stream's surface water classification in terms of its general surface water class, its antidegradation status and its trout water status."

Trout maintenance (TM) means "waters designated for the support of trout throughout the year" (NJAC 7:9B-1.4). In addition, "water quality characteristics that are generally better than, or equal to, the water quality standards shall be maintained within a range of quality that shall protect the existing/designated uses. Water quality shall be protected from changes that might be detrimental to the attainment of the designated uses or maintenance of the existing uses. Water quality characteristics that are generally worse than the water quality criteria shall be improved to meet the water quality criteria" (NJAC 7:9B-1.5).

Non-trout waters are defined as "fresh waters that have not been designated as trout production or trout maintenance. These waters are generally not suitable for trout because of their physical, chemical, or biological characteristics, but are suitable for a wide variety of other fish species" (NJAC 7:9B-1.4).[60]

Freshwater 1 (FW-1) "means those fresh waters that are to be maintained in their natural state of quality and not subjected to any man-made wastewater discharges or increases in runoff from anthropogenic activities. These waters are set aside for aesthetic value, unique ecological significance, exceptional recreational significance, exceptional water supply significance, or exceptional fisheries resource(s). Uses of FW-1 waters in accordance with NJAC 7:9B-1.12 include:

- Primary and secondary contact recreation;
- Maintenance, migration and propagation of the natural and established aquatic biota; and
- Any other reasonable uses.

Freshwater 2 (FW-2) means "the general surface water classification applied to those fresh waters that are not designated as FW-1 or Pinelands Waters." FW-2 uses include:

- Maintenance, migration and propagation of the natural and established aquatic biota;
- Primary and secondary contact recreation;
- Industrial and agricultural water supply; and
- Public potable water supply after conventional filtration treatment (a series of processes including filtration, flocculation, coagulation, and sedimentation, resulting in substantial particulate removal but no consistent removal of chemical constituents) and disinfection; and
- Any other reasonable use.

Saline Estuarine 1 (SE-1) means "saline estuarine waters whose designated uses are listed in NJAC 7:9b-1.12(d)." SE-1 uses include:

- Shellfish harvesting in accordance with NJAC 7:12;
- Maintenance, migration and propagation of the natural and established aquatic biota;
- Primary and secondary contact recreation; and
- Any other reasonable use.

Streams associated with the North Branch of the Raritan River are classified as FW-2 Trout Production, FW-2 Trout Maintenance and FW-2 Nontrout. The North Branch of the Rockaway Creek upstream of the Route 523 road crossing is classified by the NJDEP as FW-2, Trout Production, Category 1 waters. Lower reaches of the

North Branch of the Rockaway Creek as well as the entire South Branch of the Rockaway Creek are classified as FW-2, Trout Maintenance. The mainstem of the Rockaway Creek which begins at the confluence of the North and South Branches where it joins the Lamington River is classified as FW-2, Non-trout by the NJDEP. During the summer months, warm in-stream temperatures associated with the North Branch and the Lamington Rivers are concern for the trout production reaches of the river. Low dissolved oxygen levels during low flow periods are also a concern for aquatic species.

According to Figure 13, the Upper South Branch Watershed is classified as FW-2 Trout Maintenance, FW-2 Trout Production and FW-2 Nontrout in various areas. Although overall water quality has been rated as good in much of the South Branch, some problems are still evident. Warm summertime temperatures threaten the aquatic life, particularly in the trout designated portions of the river.

The majority of the waters within the central and southern portions of the Basin are classified as FW Non-Trout as seen on Figure 13. SE-1 waters are evident in the eastern portion of the Basin along the tidal portion of the mainstem of the Raritan River and its tributaries.[61]

Waters associated with the Lower Raritan are classified as FW-2 Trout Maintenance, FW-2 Nontrout and SE-1. Waters associated with the South River have been classified as FW-2 Nontrout and SE-1. The entire Millstone WMA is classified as FW-2 Nontrout.

*Fishery Resources*

According to the New Jersey Division of Fish and Wildlife, sportfish reared and stocked throughout the Raritan Basin between 1994-1998 included trout, channel catfish, largemouth and smallmouth bass, striped bass, northern pike and tiger muskellunge. Other common freshwater sportfish in the Basin include but are not limited to bluegill, carp, crappie, perch and trout.

Historical fisheries that were once common in the tidal portion of the Raritan River included oysters, perch, sunfish, smallmouth bass, carp, catfish, eel and shad. In the late 1800s, shad, bluefish, weakfish, eel, menhaden, fluke, croaker, cunner, kingfish, mullet, sculpin, mackeral, spot, tomcod and silver hake were also common in the lower Raritan River. Abundant sportfish of the time included bluefish, croakers, eel, fluke, kingfish, porgies, sheepshead, spot, weakfish, winter flounder and an occasional salmon.[62] According to the New York-New Jersey Harbor Estuary Program Final Comprehensive Conservation and Management Plan, today there is a “very large and active recreational fishery in the Raritan Bay for such species as striped bass, bluefish, fluke and winter flounder.” However, no commercial quantities of oysters exist. Commercial fisheries in the Bay “exist for species such as blue crab, winter flounder, menhaden, bluefish, weakfish and baitfish."[63]

Natural trout populations in the northwestern part of the Basin represent a valuable sport fishery. Brook, brown and rainbow trout may all be present; the brook trout being the only native trout species (listed as a threatened species) to occur in New Jersey.

*Fishery Health Advisories*

Health concerns associated with fisheries in the Basin include elevated concentrations of mercury, a toxic heavy metal that accumulates in fish tissue. Although it is very unlikely that the level of mercury found in fish would cause immediate health effects, repeated consumption of contaminated fish could cause adverse health effects. Consumption advisories were issued in June 1997 for largemouth bass and chain pickerel for freshwaters in the State of New Jersey including Round Valley and Spruce Run Reservoirs. These advisories were updated in July 2002 as detailed in Table 12.

| Table 12 - Summary of Fish Consumption Advisories - Mercury | | | |
|---|---|---|---|
| Water body | Fish species | General population | High risk individuals |
| Statewide (unless specified below) | Largemouth bass | 1 meal per week | 1 meal per month |
| | Smallmouth bass | 1 meal per week | 1 meal per month |
| | Chain pickerel | 1 meal per week | 1 meal per month |
| | Yellow bullhead | No restrictions | 1 meal per month |
| | Sunfish | No restrictions | 1 meal per month |
| | Brown bullhead | No restrictions | 1 meal per week |
| Budd Lake | Northern pike | No restrictions | 1 meal per week |
| | White catfish | No restrictions | 1 meal per week |
| Carnegie Lake | Largemouth bass | 1 meal per week | Do not eat |
| | Channel catfish | No restrictions | 1 meal per month |
| | White perch | No restrictions | 1 meal per month |
| | Brown bullhead | No restrictions | 1 meal per week |
| Devoe Lake | Chain pickerel | No restrictions | 1 meal per month |
| | Largemouth bass | No restrictions | 1 meal per month |
| | Brown bullhead | No restrictions | 1 meal per week |
| Delaware & Raritan Canal @ Bound Brook | Channel catfish | 1 meal per week | Do not eat |
| Grovers Mill Pond | Brown bullhead | 1 meal per week | 1 meal per month |
| | Largemouth bass | 1 meal per week | 1 meal per month |
| | Chain pickerel | No restrictions | 1 meal per week |
| Raritan River @ Neshanic Station | Largemouth bass | No restrictions | 1 meal per week |
| | Smallmouth bass | No restrictions | 1 meal per week |
| | Red breast sunfish | No restrictions | 1 meal per week |
| | Brown bullhead | No restrictions | 1 meal per week |
| | Rock bass | No restrictions | 1 meal per week |
| Raritan River @ Millstone | Largemouth bass | 1 meal per week | 1 meal per month |
| | Channel catfish | No restrictions | 1 meal per week |
| Raritan River @ Route 1 | White perch | No restrictions | 1 meal per week |
| Round Valley Reservoir | Largemouth bass | No restrictions | 1 meal per month |
| | Lake trout | No restrictions | 1 meal per week |
| Spruce Run Reservoir | Largemouth bass | 1 meal per week | 1 meal per month |
| | Northern pike | 1 meal per week | 1 meal per month |
| | Hybrid striped bass | No restrictions | Do not eat |

Note: Sunfish includes bluegill, pumpkinseed and red breast sunfish. High risk individuals include pregnant women, women planning on becoming pregnant within one year, nursing mothers and children under the age of five.

Fish consumption advisories for PCBs, Dioxin and Chlordane contamination in the Raritan Bay and tidal portions of the Raritan River (downstream of the Route 1 bridge in New Brunswick) and the tidal portions of all rivers and streams that feed into these water bodies are as follows: the general population should not consume striped bass, bluefish (over 6 lbs.), white perch, American eel or white catfish more than once a week. High-risk individuals are advised to not eat any of the above-mentioned species at all. In addition, the general population is advised not to consume fish from the Bound Brook and its tributaries due to PCB contamination.

For more information on fish advisories or related concerns, visit the NJDEP Division of Science and Research website at www.njmainfish.htm.

### *Shellfisheries*

The NJDEP Shellfish Inventory Program is responsible for determining the distribution and abundance of the important molluscan species which occur in New Jersey's estuaries. Baseline data are necessary for the development of management strategies designed to preserve shellfish habitat and enhance shellfish resources. The National Shellfish Sanitation Program is based on regular monitoring of water quality, field surveys of shoreline conditions, and the study of water currents and flows.

Shellfish including oysters, mud crab, blue crab, hard clam, soft clam and horseshoe crab were also common in the Bay. The decline in shellfish abundance occurred as a result of heavy fishing off the east coast, and an increase of commercial fishery vessels in the Raritan Bay and lower Raritan River.[64]

According to a 1962 survey, hard clams were abundant in the Raritan Bay channel, west of the Navy Pier. Although other areas of the bay south and east of the Navy Pier contained clam populations, much of those areas had trashy bottoms which were not conducive to healthy hard clam populations. Clams in those areas were found to be covered with burrowing arthropods and mussels.[65] According to the 1998 NJDEP Bureau of Freshwater and Biological Monitoring - Water Quality Monitoring Network Report, the harvest and consumption of shellfish from the Raritan Bay and the tidal portion of the Raritan River is prohibited, meaning that harvest is not allowed under any conditions.

Shellfish consumption advisories for PCBs, Dioxin and Chlordane contamination in the Raritan Bay and tidal portions of the Raritan River and the tidal portions of all rivers and streams that feed into these water bodies are as follows: the general population and high-risk individuals should not consume the green gland of the blue crab or the American lobster.

### Eutrophication

Excessive nutrients (usually phosphorus) in a stream can lead to an overgrowth of algae and macrophytes (aquatic plants). These plants generate very high levels of dissolved oxygen during the day, but at night they deplete streams of the dissolved oxygen necessary for the survival of other aquatic species. The increase in algae or other aquatic vegetation is referred to as eutrophication, a process that adversely affects water quality. Eutrophication interferes with the amount of light reaching the bottom of the stream thereby causing submerged aquatic plants to die. Also, the bacteria that decompose the dying plants maintain a high oxygen demand, the dissolved oxygen levels in the stream drop abruptly, which causes fish and other aquatic life to die or relocate.

Nitrogen is another nutrient that can lead to eutrophication problems since it does not attach to soil particles (as phosphorus does) and can leach into ground water and streams. Nitrogen is generally not considered a problematic nutrient in fresh waters; however, excessive nitrates in a stream can sometimes contribute to eutrophication. As a contaminant, nitrates can increase water treatment costs.[66] Nitrogen is also the main contributor to eutrophication in saline waters and is an issue for the lower Raritan River and Raritan Bay.

Eutrophication problems have been documented to varying degrees in waterways throughout the Basin. According to Omni Environmental Consultants[67], the Millstone River between the Township of Plainsboro and Carnegie Lake in Princeton contains an abundance of rooted macrophytes and algae. Visually this section of the Millstone has been characterized as one of the worst sites in the watershed. Impoundments in the Beden Brook subwatershed have also been reported as having severe eutrophication problems and have been known to turn the water green during summer months. In the Millstone River and Beden Brook, large accumulations of algae and macrophytes may be responsible for low dissolved oxygen levels. There has not been any evidence of problems with algae or macrophytes along the mainstem of the Raritan River.

Omni's report is consistent with the results of the Stony Brook-Millstone Watershed Association's Draft Characterization and Assessment of the Beden Brook Subwatershed. According to the SBMWA

Characterization and Assessment, two sections along Beden Brook, one section along Rock Brook, and two sections along Pike Run have been identified as having algal problems. Assessments were conducted by SBWMA's river action teams between May and July 2000.

Other areas noted by Omni as having problems with rooted macrophytes include several pockets along the North Branch and South Branch of the Raritan River. A study conducted in July 1993 revealed pockets of rooted macrophytes growing in the slow moving sections of the river downstream of the Clinton Mill dike in the town of Clinton, south to Stanton Station Road in Raritan Township. A site visit by NJWSA staff in August 2000 revealed severe eutrophication problems in stretches of the South River near Route 535 upstream to Duhernal Lake. It is believed that growth of the macrophytes may be a result of nonpoint source pollutants from adjacent land areas. Pockets of rooted macrophytes were also observed along sections of the North Branch of the Raritan River, but not to a significant extent. According to Omni, algae is not a significant concern in the North and South Branches of the Raritan River, although rooted macrophytes have been known to cause large swings in dissolved oxygen counts. According to NJ Water Supply Authority staff, the Spruce Run Reservoir has also experienced eutrophication problems in previous years.

## Wetlands

### Functions and Values of Wetlands

Wetlands are the swamps, marshes, bogs or similar areas found in flat vegetated areas or depressions in the landscape along streams, rivers lakes and coastal areas. Wetlands contribute to the social, economic and environmental health of the environment by providing habitat for fish and wildlife, providing natural flood control by soaking up stormwater runoff, storing and gradually releasing stored flood waters, and by providing open space for recreation and tourism.[68] Other functions that wetlands provide include erosion control, removal of sediment and nutrients, ground water discharge (or storage in some cases), natural area buffers, and commercial uses (e.g., shellfishing or timber).[69]

### Wetlands Within the Raritan Basin

Wetland areas in New Jersey listed as USEPA Priority Wetlands are those wetlands that have been identified by the USEPA as areas that are important and vulnerable wetlands in the State. Listed areas include:

- Spruce Run Reservoir Tributary Wetlands - Hunterdon County
- Dismal Swamp - Middlesex County
- Helmetta - Helmetta Borough, Middlesex County
- Pigeon Swamp - South Brunswick Township, Middlesex County
- Raritan Bay Estuary Wetlands - Middlesex, Monmouth and Union Counties
- Raritan Center - Edison Township, Middlesex County
- Lamington River Watershed - Roxbury Township to Chester Township, Morris County

The USEPA Priority Wetlands are discussed in more detail in the Landscape Report.

According to Figure 14 which depicts the areas of the Basin where wetlands have been converted to other land uses, it is evident that some of the larger wetland systems in the Basin have been losing wetlands around their fringes, particularly in the Lower Raritan and Millstone WMAs where there are extensive systems to be lost. In the Upper Raritan WMA, there are not as many evident losses, perhaps because there is not as much to lose due to the natural topography of the area. Tables 12 through 15 below illustrate the land uses to which wetlands have been converted.

Historically, because most wetlands were too wet to farm and too shallow for swimming, they were often regarded as wastelands and breeding grounds for insects, pests and disease and were considered impediments to development and progress. As a result, wetlands were readily converted to other land uses and approximately half of the nation's wetlands have been lost since the 1700s. In most parts of the Basin, conversion to agriculture was common over the centuries, but has been followed by conversion of those agricultural lands and additional wetlands to urban land uses. Although wetlands conversion to agriculture is still common nationally, this is no longer a common practice in New Jersey as indicated by Tables 13 through 16.

**Table 13 - Basinwide Conversion of Wetlands to Other Land Uses 1986-1995**

| Land Use Type - 1995 | Acres Converted | Percent Converted |
|---|---|---|
| Urban | 4,426 | 92.7% |
| Water | 233 | 4.9% |
| Barren Land | 72 | 1.5% |
| Agriculture | 36 | 0.8% |
| Forest | 6 | 0.1% |
| **Total Loss** | 4,773 | 100% |

Source: NJDEP - Bureau of Geographic Information Analysis, 2000

**Table 14 - Upper Raritan WMA - Conversion of Wetlands to Other Land Uses 1986-1995**

| Land Use Type - 1995 | Acres Converted | Percent Converted |
|---|---|---|
| Urban | 394 | 91.4% |
| Water | 23 | 5.3% |
| Barren Land | 8 | 1.9% |
| Agriculture | 6 | 1.4% |
| **Total Loss** | 431 | 100% |

Source: NJDEP - Bureau of Geographic Information Analysis, 2000

| Table 15 - Lower Raritan WMA - Conversion of Wetlands to Other Land Uses 1986-1995 | | |
|---|---|---|
| **Land Use Type - 1995** | **Acres Converted** | **Percent Converted** |
| Urban | 2,982 | 93.3% |
| Water | 133 | 4.2% |
| Barren Land | 56 | 1.8% |
| Agriculture | 20 | 0.6% |
| Forest | 4 | 0.1% |
| **Total Loss** | 3,195 | 100% |

Source: NJDEP - Bureau of Geographic Information Analysis, 2000

| Table 16 - Millstone WMA - Conversion of Wetlands to Other Land Uses 1986-1995 | | |
|---|---|---|
| **Land Use Type - 1995** | **Acres Converted** | **Percent Converted** |
| Urban | 1,056 | 91.5% |
| Water | 77 | 6.7% |
| Barren Land | 10 | 0.9% |
| Agriculture | 8 | 0.7% |
| Forest | 2 | 0.2% |
| **Total Loss** | 1,154 | 100% |

Source: NJDEP - Bureau of Geographic Information Analysis, 2000

### Effects of Urbanization on Wetland Systems

Wetlands that have been drained, filled or otherwise altered as a result of urbanization undergo changes as wetlands species are replaced by upland species. As wetlands are fragmented, populations of species are reduced and wildlife and vegetation species that can tolerate disturbed environments increase in number.

Urbanization impairs wetlands through direct losses of wetland acreages and by degrading the quality of wetlands. Degradation of wetlands results from changes in water quality, quantity, and flow rates; increases in pollutant inputs; and changes in species composition as a result of the introduction of non-native species. Excessive nutrient inputs due to urbanization can lead to eutrophication or result in the release of pollutants from a wetland into adjacent water resources. Runoff from paved surfaces may cause water temperatures to increase thereby reducing the level of dissolved oxygen needed by aquatic species. Rises in water temperature also promote the release of nutrients from wetland sediment. Impervious surfaces also prevent ground water recharge therefore increasing surface runoff and decreasing ground water supply to wetlands.

Over time, wetlands in the Raritan Basin have been subjected to pollution and modification as a result of agriculture and urbanization. Tidal marshes have been dredged and filled, with a negative effect on aquatic resources. Wetlands near the Bay provided hay for cattle in colonial times but later on, the wetlands were regarded as wastelands and served as landfill areas. However, despite the loss of wetlands in the Basin, the remaining wetlands still provide many functions and values and essential habitat for important fishery and aquatic communities. As referenced in the section on flood prone areas in this report, wetlands also act as storage areas for flood waters. Without these wetlands, flood waters would impact a much more extensive area than what has occurred throughout the Basin. The marshes along the estuarine portion of the Raritan River are an important resource that have been neglected in the past, but are improving today.[70]

## Riparian Areas

Riparian areas are transitional land areas between uplands and streams that serve a wide variety of functions. They support surface water ecosystems, and help protect streams, lakes, rivers and other waterways from environmental degradation. The destruction of riparian areas and the removal of riparian vegetation for urbanization, agriculture and development projects can result in the deterioration of aquatic ecosystems and contribute to the impairment of healthy streams and waterways.

Stream channels with impaired riparian zones or those entirely without riparian areas do not receive protection from negative influences such as polluted surface water runoff or stream bank erosion. Riparian areas that have been damaged or replaced by impervious surfaces do not provide any benefits to the stream channel or its existing biota. The condition of vegetation along streams is a major component in determining the integrity of riparian ecosystems.

Riparian areas are "complex ecosystems that help provide optimum food and habitat for stream communities as well as aid in the control and mitigation of nonpoint source pollution."[71] Riparian areas facilitate the removal of excess nutrients and sediment from surface water runoff. They shade streams to optimize light and temperature conditions for aquatic plants and animals. Streamside riparian areas have been found to improve the quality of water resources by removing harmful pollutants in stormwater runoff and increase the biological diversity and productivity of stream communities.[72]

Defining riparian areas is a difficult task due to the large number of influencing factors that require consideration, including soil characteristics, hydrology, and landscape features. Riparian areas vary in width, shape, and character and do not stop at a uniform distance away from a stream or watercourse.[73] Natural riparian areas (or those that are fully functional) are comprised of grasses, trees, or both types of vegetation that exist within natural, agricultural, forested, suburban, and urban landscapes.[74]

### Functions and Values of Riparian Areas

Riparian areas perform a wide range of functions with respect to stream health, wildlife uses, and the economic and social values of people. Functions and values of riparian areas include, but are not limited to the following:

- Maintaining habitat for fish and other aquatic organisms by moderating water temperatures and providing woody debris;
- Storing and absorbing the energy of flood waters, thereby decreasing damage to property;
- Stabilizing stream banks and reducing channel erosion;
- Offering recreational and educational opportunities;
- Providing habitat for terrestrial organisms;
- Improving the aesthetics of stream corridors (which can increase property values);
- Trapping/removing sediment from runoff;
- Trapping/removing phosphorus, nitrogen, and other nutrients from runoff that can lead to eutrophication of aquatic ecosystems; and
- Trapping/removing other contaminants from runoff, such as pesticides, heavy metals and petroleum products.

In addition to maintaining all of the abovementioned "services," properly functioning, natural riparian areas help preserve land areas along streams, rivers and other water bodies that are frequently unsuitable or less suitable for other uses. The benefits of natural riparian areas relate to how the areas function to protect air, land, water quality and animal habitat. While the benefits of riparian areas can be grouped into broad categories, many interrelationships exist between them.[75]

Riparian areas and associated wetlands provide a number of ecological benefits to aquatic ecosystems including protection of streams, rivers and lakes as well as providing habitat for an array of plant and animal species that are dependent on those aquatic ecosystems. Wetlands adjacent to streams afford treatment of the greatest possible drainage area and are very effective at removing pollutants from stormwater runoff in the absence of concentrated flow. Concentrated flow consists of surface water runoff that is generally piped or channeled directly from a developed area to a stream channel. When runoff is discharged to a stream in this manner, the resulting concentrated flow bypasses the natural filtration system of the riparian area and therefore receives no pre-treatment or decrease in velocity prior to entering the stream. Bypassing the riparian area not only results in an increased pollutant load to the stream, but also increases the potential for stream bank erosion, sedimentation of the stream and degradation of overall stream health.

Wetlands, riparian corridors, and adjacent lands are particularly valuable habitats for wildlife, which rely on access to rivers and streams for foraging and breeding purposes. Riparian areas are especially important to amphibians and many reptiles, due to the fact that their lifecycle requires access to water. Vegetated riparian areas also function as corridors for wildlife movement by providing connectivity between a wide array of habitats promoting safe travel from one habitat to another. Habitat fragmentation results in the loss of wildlife habitat and movement corridors, which in turn results in wildlife decline and extirpation (eventual loss of the species). It has been estimated that approximately 80% of all natural riparian communities within North America and Europe have been lost due to development and fragmentation.[76] Habitats that become isolated islands surrounded by development lose much of their ecological value even though the habitat may not be directly affected.[77]

Riparian areas with undeveloped floodplains provide overbank storage for floodwaters and help attenuate large magnitude floods by reducing the height and velocity of floodwaters downstream.[78] Natural riparian areas also reduce the potential for erosion of stream banks and adjoining floodplains, which helps in preventing sedimentation of the stream.[79] Accelerated upland erosion can increase sediment deposition in riparian and wetland areas because of downslope movement of dislodged soil material. Such deposition changes the soils, drainage, and vegetation associated with riparian or wetland areas. Riparian vegetation also reduces sediment and nutrient transport in a number of ways. Roots, especially those of woody vegetation, help stabilize stream banks by holding soil intact.[80] Vegetated riparian areas and adjacent wetlands also operate as filter zones that can prevent the direct flow of sediment, phosphorus and nitrogen into streams. Excessive nutrients such as phosphorus and nitrogen compounds cause an excessive growth of algae and rooted aquatic vegetation, the subsequent death of which can kill aquatic organisms and change an existing ecosystem.

According to Wenger (1999), "soil characteristics determine in large part whether or not overland flow occurs, how fast water and contaminants move to the stream and other factors relevant to the effectiveness of the riparian zone."[81] Soils consisting of silt or clay particles that have not been compacted are typically ideal for vegetative growth. Soils with granular or crumb-like consistencies promote percolation of water and air and help reduce erosion. Conversely, compacted soils slow or prevent surface water infiltration which is a limiting factor for plant growth, and in turn affects the amount of food and cover available for wildlife.[82]

Factors contributing to decreased oxygen levels in streams include the excessive deposits of silt and sediment contained in surface water runoff. Streams containing shallow areas with a rocky or gravelly substrate (i.e., riffles) generally are well oxygenated due to mechanical absorption of oxygen into the water. However, when increased sediment loads enter the stream, the consistency of the substrate changes, which decreases dissolved oxygen levels and eliminates instream habitats utilized by macroinvertebrates and other aquatic species. Another factor affecting the amount of dissolved oxygen in a stream is water temperature. Cold water is able to hold more dissolved oxygen than warmer water. Therefore, increases in water temperature can have a negative effect on aquatic life. Shading of the stream by a vegetated riparian corridor help keep streams cool, which increases dissolved oxygen levels and lowers the stress on aquatic life.

Finally, the trees and plants that make up the riparian area also contribute to the health of the stream by providing food to aquatic organisms. Detritus that accumulates on the bottom of streams provide food for bacteria, fungi, and macroinvertebrates (cumulatively called benthic detritivores), which form a basis of the aquatic food chain. Studies have found that detritus from native plant species may be beneficial to aquatic species but that leaves from foreign species sometimes have an adverse effect on the survival of certain leaf-eating species such as mayfly larvae.[83]

### Extent of Existing Riparian Areas Within the Basin

Riparian areas for the Raritan Basin were defined by a number of distinct parameters as discussed in the Riparian Area Methodology prepared for the Raritan Basin project and in the preceding section. Since riparian areas do not have sharply definable boundaries and are not a set width along every stream channel, the Raritan Basin Characterization Committee developed a scientifically based methodology that encompasses the factors known to contribute to the function and benefits of riparian areas.

Figures 16, 17 and 18 illustrate the riparian areas for the Upper Raritan, Lower Raritan and Millstone Watershed Management Areas as defined by the parameters discussed above. Each figure shows the estimated historical riparian area based on the width of the 100-year flood prone areas, streamside hydric soils, streamside wetlands and associated transition areas, and a 150 foot or 300 foot wildlife passage corridor (dependent on stream order) as presented in the Riparian Area Methodology. Figure 15a (Hydrologic Unit Codes in the Raritan Basin) was prepared for use in identifying the Hydrologic Units with 14-digit Hydrologic Unit Codes (HUCs) as shown on the riparian area figures (Figures 16-23). Figure 15b shows the same HUC-14 areas with municipal boundaries, while Figure 15c shows municipal boundaries and surface waters.

Although significant historical riparian area in the Basin has been converted to land cover other than natural (vegetated) cover, the riparian areas indicated on the maps provide a representation of what these areas may have looked like prior to conversion. Figures 16, 17 and 18 depict riparian areas of the Basin that were historically converted to agricultural and urban land cover (pre-1986) as well as the riparian areas converted to agricultural and urban land cover between 1986 and 1995. As seen in the pie chart on Figure 16, approximately 32% of the riparian land cover for the Upper Raritan WMA had been converted to agricultural (16%) and urban (16%) land uses by 1995. Historically, riparian areas comprised approximately 28% of the WMA; as of 1995 that percentage dropped to 19%. As seen on Figure 17, the Lower Raritan WMA had approximately 31% of its riparian area converted to agricultural (4%) and urban (27%) land uses by 1995. Historically, riparian areas comprised approximately 37% of the WMA; as of 1995 riparian areas dropped to 26%. Figure 18 shows that the Millstone WMA has had 28% of its riparian areas converted to agricultural (12%) and urban (16%) land uses by 1995. Historically, 35% of the WMA consisted of riparian area; by 1995, riparian areas dropped to 25%. Tables A-1, A-2 and A-3 in Appendix A include a detailed breakdown of the conversion of riparian areas to other land cover types including conversion prior to 1986, between 1986 and 1995, and up to 1995 by subwatershed (HUC-14) for the entire Basin.

Figure 19, a color-graduated map, shows the degree of riparian area conversion for each of the subwatersheds (HUC-14s) for the Basin. The lighter the color, the lesser the percentage of converted riparian area. As seen on Figure 19, the Upper Raritan WMA has several light cream-colored HUC-14s, illustrating historical conversions of less than 20%. However, these HUC-14s contain large water bodies such as Spruce Run Reservoir, Round Valley Reservoir, and Budd Lake which make up a significant portion of the subwatershed. The remaining cream colored area is located along the Lamington River in Chester and Bedminster Townships. The medium orange colors on the map illustrate conversions between 20-29.99%, 30-39.99% and 40-49.99%, while the dark brown illustrates conversions of more than 50%. The only dark brown HUC-14s in the Upper Raritan WMA are located in the central part of the WMA in Tewksbury Township (a tributary to the North Branch Rockaway Creek) and along a tributary to the North Branch Raritan River in Chester Township & Peapack-Gladstone, both of which have converted almost half of their respective riparian areas to agricultural and urban land uses.

The Lower Raritan WMA as shown on Figure 19, contain several dark brown HUC-14s. According to the bar chart on Figure 19, approximately 20% of the subwatersheds in the Lower Raritan WMA have converted greater than 50% of their riparian areas to non-natural land cover types. HUC-14s with greater than 50% conversions appear in developed or developing areas of this WMA, particularly along Chambers Brook in Somerville and Bridgewater, along Green Brook and Bound Brook, along tributaries to the mainstem of the Raritan River near New Brunswick and Franklin Township (Somerset County), and in the highly urbanized Woodbridge/Edison Township area. Most of the Lower Raritan WMA has experienced conversions ranging between 20% and 40%.

The Millstone WMA also has a high number of subwatersheds that have converted between 20 and 40% of their riparian areas to other land cover types. There are no HUC-14s in the Millstone that have converted more than 50% of their riparian areas. Most conversions have occurred in the northern part of the Millstone WMA in Hillsborough Township, and in the southeastern part of the WMA along Cranbury Brook in Cranbury and Plainsboro Townships. Conversions have also occurred along the D&R Canal and the Millstone River in Princeton Township/West Windsor Township, and in the vicinity of the Route 1 corridor. The subwatershed that lost between 40-49.99% is located in the Beden Brook subwatershed in the vicinity of Hopewell Township. The areas that have converted the least amount of riparian area in this WMA are located along a tributary to the Beden Brook in the Sourland Mountains in Montgomery and Hillsborough Townships and to the east in the South Brunswick/Plainsboro area.

The bar chart on Figure 19 compares the subwatershed status for the three WMAs. The majority of the Upper Raritan, Lower Raritan and Millstone WMAs have seen conversions between 20 and 40%.

Although each watershed management area has had significant amounts of its riparian areas converted to non-natural land cover types, it is important to consider how much of the HUC originally contained riparian area for each WMA. For example, Figure 20 shows that the riparian area of a particular subwatershed along the South Branch of the Raritan River (HUC 02030105020080) in Hunterdon County is comprised of 100-year flood prone areas, wetlands, hydric and alluvial (riparian) soils and a corridor for wildlife passage and that 23.7% of the total subwatershed area is considered historic riparian land. Conversely, for a subwatershed of the mainstem of the Raritan River (HUC 02030105160100) proximate to the Raritan Bay, the same method estimates that almost 45% of the subwatershed was historic riparian land as shown on Figure 21. In addition, for a subwatershed in the lower Millstone WMA (HUC 02030105100070) approximately 57.5% of the total subwatershed is considered part of the historical riparian area. Differences in the composition of subwatersheds are attributed to differences in topography, geology and elevation of the seasonal high water table. Wetlands and hydric soils have a major impact on riparian area estimates.

A more detailed look at the riparian area component maps (Figures 20-22) show significant overlap among the parameters that constitute the riparian areas. For instance, the composite riparian area is comprised of four parameters (wildlife passage corridor, wetlands and wetland transition areas, flood prone areas, hydric (riparian) soils), all of which overlap significantly and make a strong case that the riparian areas have been accurately defined using the Raritan Basin Riparian Area Methodology.

Tables A-1, A-2 and A-3 in Appendix A show a summary of the conversion of riparian areas in each HUC-14 (subwatershed) for all three WMAs in the Basin. In addition, Tables A-4, A-5 and A-6 (Appendix A) show the conversion of riparian areas to agricultural and urban land cover types for each WMA.

### Health of Existing Riparian Areas Within the Basin

In a broad sense, the "health" or "integrity" of a riparian area may be defined as its ability to perform its normal functions. These functions include nutrient and sediment filtration, stream bank stabilization, water storage, aquifer recharge, habitat for fish and wildlife, protection against erosion, maintenance of proper stream temperature and dissolved oxygen content, and preservation of open space. Evaluating riparian integrity also requires consideration of upstream and adjacent land use areas.[84]

Stream channels with impaired riparian zones or those entirely without riparian areas suffer tremendously. Riparian areas that have been ecologically damaged, bisected with ditches or pipelines, or replaced by impervious surfaces do not provide any benefits to the stream channel or its existing biota. According to the Center for Watershed Protection, it has been estimated that "sensitive stream elements" (i.e., aquatic habitat, channel stability, aquatic species) are lost from a system when impervious cover amounts in a watershed reach 10%.[85] A majority of landowners with streams and ponds within their property boundaries simply do not know the warning signs of a stressed riparian area or what can be done to improve the areas.

Indicators of a healthy stream ecosystem include evidence of both aquatic and terrestrial life. Healthy streams are generally cool, clean and oxygenated and are not cloudy or choked with sediment or algae; they have vegetated flood plain areas and stream banks that do not appear to be eroded or undercut with exposed soil; and if left to their own accord, need little or no intervention.[86]

As part of the riparian area analyses that have been conducted, Tables A-7, A-8 and A-9 in Appendix A present a summary of the "riparian health" components by WMA for the Basin. Figure 23 illustrates the percentage of forested area (those areas with crown closure[87] greater than 10%) within the riparian area for each of the subwatersheds in the Basin. As seen on Figure 23, the Upper Raritan WMA contains the greatest percentage of subwatersheds with crown closure greater than 10%. The majority of the subwatersheds in the Upper Raritan WMA contain between 20 and 30% crown closure, while less than 20% of the subwatersheds in the Lower Raritan and Millstone WMAs have greater than 30% crown closure.

### Effects of Urbanization on Stream Corridors/Riparian Areas

The fragmentation and alteration of streams by humans have dramatic effects on ecosystem integrity and biological diversity.[88] Human-created barriers including dams fragment aquatic ecosystems by blocking the access of migratory fish and other aquatic species to upstream spawning areas as well as by blocking the movement of macroinvertebrate species downstream where populations are reseeded. Instream fragmentation contributes to losses of aquatic species and loss of integrity of aquatic ecosystems. Water impoundments such as dams not only fragment habitats, but also contribute to local extirpation of species and a reduction in genetic diversity.

Road crossings are one of the most potentially damaging barriers to riparian corridors due to the breaks they cause in streamside vegetative cover. The more fragmented a riparian area, the wider the area needs to be in order to perform its desired functions. The length or connectivity of the riparian corridor is as important as its width.[89]

Roads can be significant barriers to the movement of small vertebrates and invertebrates in terrestrial ecosystems as well as to aquatic life. Wildlife species that attempt to cross highways are often struck and killed by automobiles – a major source of mortality for many species. Instream culverts constructed for road crossings can impede the passage of aquatic life. In addition, culverts constructed as part of a road crossing also impede passage of aquatic life due to faster flows, unsuitable substrate, poor lighting conditions and the size and/or positioning of the culvert. Due to increased development along streams, individual species are less able to travel from one habitat to another.[90]

Figure 24 illustrates the number of stream crossings per kilometer for the Basin by WMA. As defined by May et al. (1997), it is recommended that road crossings be limited to less than two crossings per kilometer (two per 0.62 miles) of stream length so that a nearly continuous riparian corridor can be maintained. (The red dashed line on Figure 24 depicts this recommendation). As seen on Figure 24, the Lower Raritan WMA has the greatest number of stream crossings per kilometer with several subwatersheds having up to four crossings per kilometer. The Millstone WMA does not have any subwatersheds with greater than two stream crossings per kilometer, while the Upper Raritan WMA has slightly more than two stream crossings per kilometer for several subwatersheds.

Approximately 98% of all streams in the United States have been altered in some way, either by fragmentation due to dam construction or by water diversion projects.[91] Segments of streams throughout the Raritan Basin have been subject to managed flows, discharges and substantial water withdrawals. Specific streams with managed flows in the Basin include the lower Spruce Run, South Branch of the Raritan River downstream of Spruce Run Creek, Rockaway Creek, the Lower Lamington River, North Branch of the Raritan River below the Lamington, the mainstem of the Raritan River (below the confluence of the North Branch and South Branch of the Raritan River), and the Delaware and Raritan Canal.

## Public Uses

### Designated Uses Determined by NJDEP Surface Water Classifications

The NJDEP Surface Water Classifications set uses for waterways in accordance with NJAC 7:9B-1.12. "Full support" means that waters are non-impaired and can fully support the designated uses listed above in the section on fisheries and surface water classifications. "No support" means waters are severely impaired (e.g., contaminated with fecal coliform bacteria or too low of a pH) and cannot support the designated uses. Formerly, the NJDEP reported whether or not water bodies met their designated uses in a water quality inventory, known as the 305b report and required by the Clean Water Act. The USEPA has recommended that states combine their water quality inventories (305b) with their impaired water bodies list (303d), also required by the Clean Water Act, into an Integrated List. On May 20, 2002, NJDEP issued their 2002 Integrated List in draft. The Integrated List is divided into 5 categories that indicate whether or not the water bodies are meeting their intended uses. In New Jersey's List, Categories 1 and 2 have been combined and contain water bodies without impairments. Category 3 contains water bodies where impairments are known but causal agents are not, and generally are near AMNET stations indicating impairments. Category 4 contains water bodies where remedial work is being performed to alleviate the impairment. Category 5 contains impaired water bodies where remedial work, including the development of TMDLs, is needed but not yet performed. At the writing of this report, the Integrated List was only issued in draft.

Table 17 is a reproduction of Category 1 of the Integrated List and indicates the water bodies in the Raritan Basin that attain water quality standards and are meeting their designated uses. Please refer to NJDEP's web site for the most recent or final version of the 2002 Integrated List Category 1 to determine which water bodies in the Raritan Basin are meeting their designated uses. The current list can be located at www.state.nj.us.dep/dsr/watershed/integratedlist

| Table 17 - Water Bodies Attaining Water Quality Standards with No Known Threats to Designated Uses | | | | |
|---|---|---|---|---|
| **WMA** | Site Description | **Site ID** | **Parameters Fully Attaining** | **Data Source** |
| 8 | Assiscong Creek at River Rd in Raritan Twp | AN0328 | Aquatic Life | NJDEP AMNET |
| 8 | Beaver Brook at Herman Thau Rd in Clinton Twp | AN0323 | Aquatic Life | NJDEP AMNET |
| 8 | Budd Lake- 08 | Budd Lake | Aquatic Life | |
| 8 | Burnett Brook at Old Mill Rd in Mendham Twp | AN0348 | Aquatic Life | NJDEP AMNET |
| 8 | Cakepoulin Creek at Lansdown Rd in Franklin Twp | AN0325 | Aquatic Life | NJDEP AMNET |
| 8 | CakepoulIn Creek at Rt 513 in Franklin Twp | AN0325B | Aquatic Life | NJDEP AMNET |
| 8 | Chambers Brook A at Coddington Rd in Readington Twp | AN0372 | Aquatic Life | NJDEP AMNET |
| 8 | Chambers Brook A at Station Rd in Branchburg Twp | AN0373 | Aquatic Life | NJDEP AMNET |
| 8 | Chambers Brook at North Branch Depot | 01399900 | Nitrate, Dissolved Solids, Unionized Ammonia | NJDEP/ USGS Data |
| 8 | Cold Brook at Vliettown Rd in Tewksbury Twp | AN0362 | Aquatic Life | NJDEP AMNET |
| 8 | Dawsons Brook at S Rd & Ironia Rd in Mendham Twp | AN0347 | Aquatic Life | NJDEP AMNET |
| 8 | Dawsons Brook near Ironia | 01398300 | Phosphorus, pH, Nitrate, Dissolved Solids, TSS, Unionized Ammonia | NJDEP/ USGS Data |
| 8 | Drakes Brook at Bartley Long Valley Rd in Washington Twp | AN0312 | Aquatic Life | NJDEP AMNET |
| 8 | Electric Brook at Fairview Ave in Washington Twp | AN0314 | Aquatic Life | NJDEP AMNET |
| 8 | Furmans Brook at Welisewitz Rd in East Amwell Twp | AN0336 | Aquatic Life | NJDEP AMNET |
| 8 | Holland Brook at Holland Brook Rd in Readington Twp | AN0342 | Aquatic Life | NJDEP AMNET |
| 8 | Horseshoe Lake- 08 and Lake 2 | | Fecal Coliform- Recreation | Roxbury Township Board of Health |
| 8 | India Brook at Calais Rd BR# 733 in Randolph Twp | AN0344A | Aquatic Life | NJDEP AMNET |
| 8 | India Brook at Mountainside Rd in Mendham | AN0345 | Aquatic Life | NJDEP AMNET |
| 8 | India Brook UNK Trib at Calais Rd in Randolph Twp | AN0344 | Aquatic Life | NJDEP AMNET |
| 8 | Lamington River at Burnt Mills | 01399780 | pH, Temperature, Dissolved Oxygen, Nitrate, Dissolved Solids, TSS, Unionized Ammonia | NJDEP/ USGS Data |
| 8 | Lamington River at Rt 24 in Chester Twp | AN0358 | Aquatic Life | NJDEP AMNET |

**Table 17 - Water Bodies Attaining Water Quality Standards with No Known Threats to Designated Uses**

| **WMA** | Site Description | **Site ID** | **Parameters Fully Attaining** | **Data Source** |
|---|---|---|---|---|
| 8 | Lamington River at Rt 512 in Tewksbury Twp | AN0360 | Aquatic Life | NJDEP AMNET |
| 8 | Lamington River at Rt 523 in Tewksbury Twp | AN0363 | Aquatic Life | NJDEP AMNET |
| 8 | Lamington River at Walsh Rd in Bedminster Twp | AN0370 | Aquatic Life | NJDEP AMNET |
| 8 | Lamington River near Pottersville | 01399500 | pH, Temperature, Dissolved Oxygen, Nitrate, Dissolved Solids, TSS, Unionized Ammonia | NJDEP/ USGS Data |
| 8 | Lamington River (unnamed tributary) at Black River Rd in Bedminster Twp | AN0361 | Aquatic Life | NJDEP AMNET |
| 8 | Lingerts Pond- 08 | Demott Pond | Aquatic Life | |
| 8 | Marine Lake- 08 | Springs | Fecal Coliform- Recreation | Roxbury Township Board of Health |
| 8 | Middle Brook at Burnt Mills | 01399100 | Nitrate, Dissolved Solids, Unionized Ammonia | NJDEP/ USGS Data |
| 8 | Middle Brook at River Rd in Bedminster Twp | AN0355 | Aquatic Life | NJDEP AMNET |
| 8 | Middle Brook at Spook Hollow Rd in Bedminster Twp | AN0354 | Aquatic Life | NJDEP AMNET |
| 8 | Mine Hill Lake- 08 | Mine Hill Beach | Fecal Coliform- Recreation | Madison Boro Board of Health |
| 8 | Mulhockaway Creek at Rt 635 in Union Twp | AN0321 | Aquatic Life | NJDEP AMNET |
| 8 | Mulhockaway Creek at Van Syckel Road | 01396660, 8- MU- 1 | Dissolved Oxygen, Nitrate, Dissolved Solids, TSS, Unionized Ammonia, Chromium, Copper, Lead, Nickel, Selenium, Zinc | NJDEP/ USGS Data |
| 8 | Neshanic River at Reaville | 01398000 | Nitrate, Dissolved Solids, Unionized Ammonia | NJDEP/ USGS Data |
| 8 | Peapack Brook at Fox Chase Rd in Chester Twp | AN0349 | Aquatic Life | NJDEP AMNET |
| 8 | Peapack Brook at Old Dutch Rd in Bedminster Twp | AN0350 | Aquatic Life | NJDEP AMNET |
| 8 | Pleasant Run at Pleasant Run Rd in Readington Twp | AN0339 | Aquatic Life | NJDEP AMNET |
| 8 | Prescott Brook at Station Rd in Readington Twp | AN0327 | Aquatic Life | NJDEP AMNET |
| 8 | Raritan River North Branch at Burnt Mills | 01399120 | Dissolved Oxygen, Nitrate, Dissolved Solids, TSS, Unionized Ammonia | NJDEP/ USGS Data |
| 8 | Raritan River North Branch at Rt 202 in Bedminster Twp | AN0351 | Aquatic Life | NJDEP AMNET |
| 8 | Raritan River North Branch at Rt 202 in Branchburg Twp | AN0374 | Aquatic Life | NJDEP AMNET |

| Table 17 - Water Bodies Attaining Water Quality Standards with No Known Threats to Designated Uses | | | | |
|---|---|---|---|---|
| **WMA** | Site Description | **Site ID** | **Parameters Fully Attaining** | **Data Source** |
| 8 | Raritan River North Branch at Rt 24 in Mendham Twp | AN0346 | Aquatic Life | NJDEP AMNET |
| 8 | Raritan River North Branch near Chester | 01398260 | Dissolved Oxygen, Nitrate, Dissolved Solids, TSS, Unionized Ammonia | NJDEP/ USGS Data |
| 8 | Raritan River North Branch near Raritan | 01400000 | pH, Temperature, Dissolved Oxygen, Nitrate, Dissolved Solids, TSS, Unionized Ammonia | NJDEP/ USGS Data |
| 8 | Raritan River South Branch Arch St at High Bridge | 01396535, 8- SB- 2 | Nitrate, Dissolved Solids, TSS, Unionized Ammonia, Chromium, Copper, Lead, Nickel, Selenium, Zinc | NJDEP/ USGS Data |
| 8 | Raritan River South Branch at Elm St in Branchburg Twp | AN0338 | Aquatic Life | NJDEP AMNET |
| 8 | Raritan River S Br at Middle Valley | 01396280, 8- SB- 1 | Dissolved Solids, TSS, Unionized Ammonia, Chromium, Copper, Lead, Nickel, Selenium, Zinc | NJDEP/ USGS Data |
| 8 | Raritan River South Branch at Neshanic Station | 01398070 | Nitrate, Dissolved Solids, TSS, Unionized Ammonia | NJDEP/ USGS Data |
| 8 | Raritan River South Branch at River Rd (downstream of Rt 512) in Califon | AN0316 | Aquatic Life | NJDEP AMNET |
| 8 | Raritan River South Branch at River Rd (Ken Lockwood Gorge) in Lebanon Twp | AN0317 | Aquatic Life | NJDEP AMNET |
| 8 | Raritan River South Branch at Rt 173 & Rt 513 in Clinton | AN0322 | Aquatic Life | NJDEP AMNET |
| 8 | Raritan River South Branch at Rt 517 in Washington Twp | AN0315 | Aquatic Life | NJDEP AMNET |
| 8 | Raritan River South Branch at Rt 613 in Raritan Twp | AN0329 | Aquatic Life | NJDEP AMNET |
| 8 | Raritan River South Branch at South Branch | 01398102 | Nitrate, Dissolved Solids, TSS, Unionized Ammonia | NJDEP/ USGS |
| 8 | Raritan River South Branch at Stanton Station | 8- SB- 3 | Chromium, Copper, Lead, Nickel, Selenium, Zinc | NJDEP Metal Recon |
| 8 | Raritan River South Branch at Studdiford Dr in Branchburg Twp | AN0341 | Aquatic Life | NJDEP AMNET |
| 8 | Raritan River South Branch at Three Bridges | 01397400, 8- SB- 4 | Oxygen, Nitrate, Dissolved Solids, TSS, Unionized Ammonia, Chromium, Copper, Lead, Nickel, Selenium, Zinc | NJDEP/ USGS Data |
| 8 | Rockaway Creek at Island Rd in Readington Twp | AN0369 | Aquatic Life | NJDEP AMNET |
| 8 | Rockaway Creek at Whitehouse | 01399700 | Nitrate, Dissolved Solids, TSS, Unionized Ammonia | NJDEP/ USGS Data |

**Table 17 - Water Bodies Attaining Water Quality Standards with No Known Threats to Designated Uses**

| **WMA** | Site Description | **Site ID** | **Parameters Fully Attaining** | **Data Source** |
|---|---|---|---|---|
| 8 | Rockaway Creek North Branch at Rockaway Rd in Tewksbury Twp | AN0365 | Aquatic Life | NJDEP AMNET |
| 8 | Rockaway Creek North Branch at Rockaway Rd in Tewksbury Twp | AN0366 | Aquatic Life | NJDEP AMNET |
| 8 | Rockaway Creek North Branch at Rt 512 in Tewksbury Twp | AN0364 | Aquatic Life | NJDEP AMNET |
| 8 | Rockaway Creek South Branch at Windy Acres Farm in Clinton Twp | AN0367 | Aquatic Life | NJDEP AMNET |
| 8 | Rogerene Lake- 08 | Civic Assoc. | Fecal Coliform- Recreation | Madison Boro Board of Health |
| 8 | Round Valley Reservoir- 0 8 | Reservoir | Aquatic Life | |
| 8 | Shongum Lake- 08 | Shongum Lake | Fecal Coliform- Recreation | Roxbury Township Board of Health |
| 8 | Spruce Run at Newport | 01396550 | Nitrate, Dissolved Solids, TSS, Unionized Ammonia | NJDEP/ USGS Data |
| 8 | Spruce Run at Newport Rd in Lebanon Twp | AN0318 | Aquatic Life | NJDEP AMNET |
| 8 | Spruce Run at Rt 31 in Glen Gardner | AN0319 | Aquatic Life | NJDEP AMNET |
| 8 | Spruce Run near Glen Gardner | 01396588, 8- SP- 2 | Nitrate, Dissolved Solids, TSS, Unionized Ammonia, Chromium, Copper, Lead, Nickel, Selenium, Zinc | NJDEP/ USGS Data |
| 8 | Spruce Run Reservoir- 08 | (East Beach) and (West Beach) | Fecal Coliform- Recreation | Central Region |
| 8 | Stony Brook at Fairview Ave in Washington Twp | AN0313 | Aquatic Life | NJDEP AMNET |
| 8 | Stony Brook at Fairview Avenue at Naughright | 01396219 | pH, Temperature, Dissolved Oxygen, Nitrate, Dissolved Solids, TSS, Unionized Ammonia | NJDEP/ USGS Data |
| 8 | Tanners Brook at Tanners Brook Rd in Chester Twp | AN0357 | Aquatic Life | NJDEP AMNET |
| 8 | Trout Brook at Hacklebarney Rd in Washington Twp | AN0359 | Aquatic Life | NJDEP AMNET |
| 8 | Willoughby Brook at Rt 31 in Lebanon Twp | AN0320 | Aquatic Life | NJDEP AMNET |
| 8 | | Conf. Ctr. | Fecal Coliform- Recreation | Hunterdon County Health Department |
| 8 | | Outdoor Ministries (Camp Beisler) | Fecal Coliform- Recreation | Bergen County Health Department |
| 8 | | Outlet | Fecal Coliform- Recreation | Mount Olive Health Department |

**Table 17 - Water Bodies Attaining Water Quality Standards with No Known Threats to Designated Uses**

| **WMA** | Site Description | **Site ID** | **Parameters Fully Attaining** | **Data Source** |
|---|---|---|---|---|
| 8 | | Beach | Fecal Coliform- Recreation | Mount Olive Health Department |
| 9 | Barclay Brook near Englishtown | 01405285 | Phosphorus, Temperature, Nitrate, Unionized Ammonia | NJDEP/ USGS Data |
| 9 | Bound Brook at Middlesex | 01403900 | pH, Temperature, Dissolved Oxygen, Nitrate, Dissolved Solids, Unionized Ammonia | NJDEP/ USGS Data |
| 9 | Bound Brook at Route 28 at Middlesex | 01403385 | pH, Temperature, Dissolved Oxygen, Nitrate, Dissolved Solids, TSS, Unionized Ammonia | NJDEP/ USGS Data |
| 9 | Farrington Lake- 09 | Lake Farrington | Aquatic Life | |
| 9 | Green Brook at North Plainfield | 01403470 | Ammonia | NJDEP/ USGS Data |
| 9 | Green Brook at North Plainfield | 01403470 | Ammonia | NJDEP/ USGS Data |
| 9 | Ireland Brook at Patricks Corners | 01404470 | Nitrate, Dissolved Solids, Unionized Ammonia | NJDEP/ USGS Data |
| 9 | Lake Topanemus at Pond Rd in Freehold | 61 | Nitrate | Monmouth Co. HD |
| 9 | Manalapan Brook at Federal Rd near Manalapan | 01405340 | Nitrate, Dissolved Solids, TSS, Unionized Ammonia | NJDEP/ USGS Data |
| 9 | Manalapan Brook at Rt 33 in Manalapan Twp | AN0438 | Aquatic Life | NJDEP AMNET |
| 9 | Manalapan Brook at Rt 524 in Millstone Twp | AN0437 | Aquatic Life | NJDEP AMNET |
| 9 | Matchaponix Brook at Englishtown | 01405195 | Nitrate, Dissolved Solids, TSS, Unionized Ammonia | NJDEP/ USGS Data |
| 9 | Matchaponix Brook at Spotswood | 01405302, 9- MAN -2 | Temperature, Dissolved Oxygen, Nitrate, Dissolved Solids, TSS, Unionized Ammonia, Mercury | NJDEP/ USGS Data |
| 9 | McGolliard Brook at Main St in Englishtown | 22 | Nitrate | Monmouth Co. HD |
| 9 | Middle Brook at Talmage Ave in Bridgewater Twp | AN0420 | Aquatic Life | NJDEP AMNET |
| 9 | Middle Brook East Branch at Gilbride Rd in Bridgewater Twp | AN0419 | Aquatic Life | NJDEP AMNET |
| 9 | Peters Brook at Rt 28 at Somerville | 01400395 | Temperature, Dissolved Oxygen, Nitrate, TSS, Unionized Ammonia | NJDEP/ USGS Data |
| 9 | Raritan Bay | 26A 63B, 66, RB3 | Dissolved Oxygen | Coastal Water Quality Monitoring-DEP-BMWM |
| 9 | Raritan Bay & Estuary | | Chromium, Copper, Lead, Mercury | NJDEP/ USGS Metal Recon. |

**Table 17 - Water Bodies Attaining Water Quality Standards with No Known Threats to Designated Uses**

| **WMA** | Site Description | **Site ID** | **Parameters Fully Attaining** | **Data Source** |
|---|---|---|---|---|
| 9 | Raritan Bay & Estuary | | Chromium, Copper, Lead, Mercury | NJDEP/ USGS Data |
| 9 | Raritan Bay & Estuary | | Nickel | |
| 9 | Raritan River | | Chromium, Copper, Mercury | |
| 9 | Raritan River at Fieldville Dam (I287) in Piscataway Twp | AN0428 | Aquatic Life | NJDEP AMNET |
| 9 | Raritan River at Manville | 01400500 | Nitrate, Dissolved Solids, TSS, Unionized Ammonia | NJDEP/ USGS Data |
| 9 | Raritan River at Queens Bridge | 01403300 | pH, Temperature, Dissolved Oxygen, Nitrate, Dissolved Solids, Unionized Ammonia | NJDEP/ USGS Data |
| 9 | Raritan River Estuary | | Chromium, Copper, Mercury | |
| 9 | Sandy Hook Bay | | Chromium, Copper, Lead, Mercury | NJDEP/ USGS Metal Recon. |
| 9 | Washington Valley Reservoir- 09 | Reservoir | Aquatic Life | |
| 9 | Weemaconk Creek at Main St in Manalapan | 9 | Nitrate | Monmouth Co. HD |
| 9 | Wemrock Brook at Rt #9 (After 1St Pipe) in Freehold | 69 | Nitrate | Monmouth Co. HD |
| 9 | Wemrock Brook at Rt #9 (Before Pipes) in Freehold | 68 | Nitrate | Monmouth Co. HD |
| 9 | | Hercules Pond | Fecal Coliform- Recreation | Middlesex County Public Health Department |
| 10 | Bear Brook at Stobbe Ln in West Windsor Twp | AN0384 | Aquatic Life | NJDEP AMNET |
| 10 | Bedens Brook near Rocky Hill | 01401600 | pH, Temperature, Dissolved Oxygen, Nitrate, Dissolved Solids, TSS, Unionized Ammonia | NJDEP/ USGS Data |
| 10 | Brainard Lake- 10 | Brainerd Lake | Aquatic Life | |
| 10 | Cranbury Book near Prospect Plains | 01400690 | Dissolved Oxygen, Nitrate, Dissolved Solids, TSS, Unionized Ammonia | NJDEP/ USGS Data |
| 10 | Duck Pond Run at Clarksville | 01401200 | Ammonia | NJDEP/ USGS Data |
| 10 | Heathcote Brook at Academy St in South Brunswick Twp | AN0396 | Aquatic Life | NJDEP AMNET |
| 10 | Heathcote Brook at Kingston | 01401400 | Dissolved Oxygen, Nitrate, Dissolved Solids, TSS, Unionized Ammonia | NJDEP/ USGS Data |
| 10 | Millstone River above Raritan River confluence in Manville | 10- MIL- 3 | Chromium, Copper, Lead, Nickel, Selenium, Zinc | NJDEP AMNET |

**Table 17 - Water Bodies Attaining Water Quality Standards with No Known Threats to Designated Uses**

| WMA | Site Description | Site ID | Parameters Fully Attaining | Data Source |
|---|---|---|---|---|
| 10 | Millstone River at Blackwells Mills | 01402000 10- MIL -5, 10- MIL- 6, 10-MIL- 3 | Oxygen, Nitrate, Dissolved Solids, TSS, Unionized Ammonia, Chromium, Copper, Lead, Nickel, Selenium, Zinc | NJDEP/ USGS Data |
| 10 | Millstone River at Corner of Rt 33 & Millstone Rd in Millstone | MB- MILL1 | Aquatic Life | Monmouth Co. HD |
| 10 | Millstone River at Corner of Rt 33 & Millstone Rd in Millstone | MILL1 | Aquatic Life | Monmouth Co. HD |
| 10 | Millstone River at Grovers Mill | 01400650 | pH, Temperature, Dissolved Oxygen, Nitrate, Dissolved Solids, TSS, Unionized Ammonia | NJDEP/ USGS Data |
| 10 | Millstone River at Roberts Rd in Millstone | MB- MILL6 | Aquatic Life | |
| 10 | Millstone River near Grovers Mill | 01400640 | pH, Temperature, Dissolved Oxygen, Nitrate, Dissolved Solids, TSS, Unionized Ammonia | NJDEP/ USGS Data |
| 10 | Millstone River near Manalapan | 01400540, 10- MIL -1 | Nitrate, Dissolved Solids, Unionized Ammonia, Chromium, Copper, Nickel, Selenium, Zinc | NJDEP/ USGS Data |
| 10 | Millstone River off Rte 1, Plainsboro | 10- MIL- 7 | Cadmium, Chromium, Copper, Nickel, Selenium, Zinc | NJDEP Metal Recon |
| 10 | Peddie Lake- 10 | Peddie Lake | Aquatic Life | |
| 10 | Pike Run near Rocky Hill | 01401700 | Oxygen, Nitrate, TSS, Unionized Ammonia | NJDEP/ USGS Data |
| 10 | Rocky Brook at Bitner Rd in Millstone | MB- PARK5 | Aquatic Life | |
| 10 | Rocky Brook at Perrineville | 01400585 | Temperature, Dissolved Oxygen, Nitrate, Dissolved Solids, TSS, Unionized Ammonia | NJDEP/ USGS Data |
| 10 | Stony Brook at PrInceton | 01401000, 10-STO- 1, 10- STO- 4 | Nitrate, Dissolved Solids, Unionized Ammonia, Chromium, Nickel, Selenium, Zinc | NJDEP/ USGS Data |
| 10 | Sturbridge Lake- 10 | Foxview Beach | Fecal Coliform- Recreation | Camden County Health Department |
| 10 | | Wilson Park Lake | Aquatic Life | |

Source: NJDEP's Draft 2002 Integrated List, Categories 1&2 issued May 20, 2002.
www.state.nj.us.dep/dsr/watershed/integratedlist

According to the NJDEP 1996 305b Report, several sites along the South Branch of the Raritan River partially supported primary contact recreation (swimming) based upon fecal coliform bacterial data. Spruce Run and Mulhockaway Creek also partially supported the use, while the Neshanic River did not. The upper and central portions of the South Branch fully supported the designated use for aquatic life. Tributaries to the South Branch including Drakes Brook varied between partially and fully supportive for aquatic life support whereas Spruce Run, Mulhockaway Creek, Cakepoulin Creek, Prescott Brook and the upper half of Beaver Brook were fully supported to aquatic life. The upper reach of Pleasant Run as well as the Neshanic River and Black Creek partially supported the aquatic life use, while the lower end of Pleasant Run and Holland Brook fully supported the use. Due to elevated fecal coliform bacteria counts as recorded in the 1996 report, primary contact recreation was not supported on the Raritan River at Bound Brook. However, the Raritan River at Manville fully supported this use.

According to the 1996 NJDEP 305b report, primary contact recreation (swimming) was partially supported within the North Branch of the Raritan River, with the exception of Burnt Mills which did not support the use. The upper portion of the Lamington River near Pottersville fully supported the use, while the lower end near Burnt Mills only partially supported it. Rockaway Creek at Whitehouse Station did not support the use. Overall, the North Branch of the Raritan and its tributaries generally exhibit healthy macroinvertebrate and fish communities with some limited exceptions. Recreational fishing for trout and smallmouth bass are common in many streams associated with the North Branch. There are however, some concerns with water quality in some sections of the Lamington and the North Branch where if left unmanaged, may threaten the quality of the fisheries and overall biota in those reaches.

A major threat to fishery resources associated with the Manalapan and Matchaponix Brooks is runoff from acid-producing soils of the region which can reduce the pH in streams and have deleterious effects on aquatic communities. Runoff from construction sites as well as leachate from septic tanks and stream bank destabilization are other concerns in the South River region. Both Manalapan Brook at Manalapan Township, and the Matchaponix Brook at Spotswood Borough fully support the primary contact (swimming) designated use. The South River is partially supporting of the aquatic life designated use.

Chronic fish kills have occurred in the East Windsor Township area and degraded fish communities have been evident in the upper Millstone River. The waters of the Millstone have been classified as partially supportive of primary contact recreation (swimming) near Manalapan and at Grovers Mill. The Millstone River does not support the use at Blackwells Mills because of excessive fecal coliform bacteria concentrations. Beden Brook near Rocky Hill and Stony Brook at Princeton both partially support the use. The entire Millstone watershed partially supports the aquatic life designated use with the exception of the Millstone at Bergen Mills where it is non-impaired.

### Other Recreational Uses in the Basin

Recreational uses in the Raritan Basin are extensive and include such activities as boating, fishing, hiking and camping. The Round Valley and Spruce Run Reservoir Recreation Areas in Hunterdon County offer opportunities to picnic, swim, bike, hunt, fish, boat, and camp as well as hike a number of trails ideal for bird watching or wildlife viewing. The South Branch, Stony Brook-Millstone and the Upper Raritan Watershed Associations offer some of the same amenities (excludes camping, swimming and boating) and are open year round to the public. Other large public recreation areas in the Basin include the Lawrence Chain of Lakes, Devoe Lake, Thompson Park, D&R Canal State Park, Carnegie Lake in Princeton, the Black River wildlife management area, the South Branch Reservation, Sourland Mountain Nature Preserve, Pigeon Swamp and Monmouth Battlefield.

The NJDEP Division of Parks and Forestry also provides a list of parks for the State. The follow link contains a list of the parks by county: http://www.state.nj.us/dep/forestry/parknj/divhome.htm

The Raritan Project contracted with TRC Omni Environmental Corporation, which prepared an inventory of water-based recreation opportunities and open space areas in the Basin. The inventory identified nearly 200 water-based recreation and open space areas. Field assessments of the sites identified recreation activities/access, resource impacts associated with recreational activities, priority needs (e.g. infrastructure improvements, riparian restoration, aquatic habitat preservation) and recommended improvement projects/management recommendations. The information collected for the inventory was entered into a database available from the Raritan Project.

## Management Conclusions of Existing Plans

This section provides a general summary and states the applicability of existing regulations and plans that aid in the protection of surface waters and riparian areas, with specific applicability to the development of stream corridors or surface waters in the Raritan Basin.

### Existing Laws and Regulations

Numerous laws and municipal and county ordinances regulate activities within and adjacent to wetlands, stream corridors, flood plains and stream channels in the State of New Jersey. Regulations that aid in the protection of stream flows and riparian areas are summarized below.

#### *Stormwater Management Act of 1981*

The purpose of stormwater management is to control surface water runoff as close to its point of origin as possible to prevent flood damage due to new development. Stormwater management measures also provide water quality control and enhancement of ground water infiltration in some cases. The Stormwater Management Act (P.L. 1981, c.32; NJAC 7:8) requires that all municipalities develop stormwater management plans and ordinances in accordance with regulations adopted by the NJDEP if a grant for 90% of the costs for the preparation of the plan has been made available by the NJDEP. The State regulations detail municipal stormwater management planning procedures and set forth minimum standards for water quality, flood and erosion control.

The New Jersey Stormwater Management Act establishes minimum requirements and controls to compensate for the differences in the hydrologic response of a watershed from undeveloped to developed conditions. This Act supplements the Water Pollution Control Act (NJSA 58:10A-1; NJAC 7:14A-1) and the Municipal Land Use Laws of New Jersey (NJSA 40:55D-1). Under the Municipal Land Use Law, counties and municipalities are responsible for approval of two phases of stormwater management provisions. The Phase 1 plan requires that short-term preventive measures be addressed, while the Phase 2 plan requires the consideration of alternative prevention measures in conjunction with remedial stormwater management measures. This program was established to mitigate flooding and nonpoint source pollution, and protect environmentally critical areas including flood plains and wetlands.

#### *Soil Erosion and Sediment Control Act*

The State Soil Erosion and Sediment Control Act (NJSA 4:24-1; NJAC 2:90-1.1) administered by the State Soil Conservation Districts mandates onsite erosion control during the construction period of development projects in an effort to prevent sediment from entering streams. According to the Act, sediment is a source of pollution and rapid shifts in land use from agricultural and rural to nonagricultural and urbanizing uses, construction of housing, industrial and commercial developments, and other land disturbing activities have accelerated the process of soil erosion and sediment deposition. The deposition has resulted in pollution of the waters of the State and damage to domestic, agricultural, industrial, recreational, fish and wildlife, and other resource uses. It is, therefore, declared to be the policy that the State reduce the danger from stormwater runoff, to retard nonpoint pollution from sediment and to conserve and protect the land, water, air and other environmental resources of the State.

A stormwater construction general permit is also required under the NJDEP New Jersey Pollutant Discharge Elimination System program but is obtained through the local Soil Conservation District. It applies to point source surface water discharges for construction activities in accordance with NJSA 58:19A-1; NJAC 7:14A-1.

*Freshwater Wetlands Protection Act*

The Freshwater Wetlands Protection Act Rules (FWPA) at NJAC 7:7A (NJSA 13:9B) regulate activities in and around freshwater wetlands of the State and the discharge of dredged or fill material into State open waters. In 1994, in accordance with the Section (g)(1) of Clean Water Act, the United States Environmental Protection Agency (USEPA) authorized the State of New Jersey to assume the responsibility from the United States Army Corps of Engineers (USACE) to administer its own individual and general wetlands permit program for the discharge of dredged or fill material into State regulated waters within its jurisdiction. This enabled the NJDEP to become the lead agency for regulating the discharge of dredged and fill material into certain waters/wetlands in the State. Waters used as a means to transport interstate or foreign commerce shoreward to their ordinary high water mark (navigable waters) including all waters subject to the ebb and flow of the time shoreward to their mean high water mark would continue to be regulated by the USACE.

The Land Use Regulation Program of the NJDEP reviews applications for development that would affect environmentally sensitive lands such as freshwater wetlands, coastal areas or flood plains. The regulations have been designed to prevent pollution, destruction of vital wildlife habitat, increases in runoff, and destruction of aesthetic resources. The Wetlands Act of 1970 (NJSA 13:9A) regulates development in coastal wetlands, the Waterfront Development Law (NJSA 12:5-3) regulates construction within existing navigation channels and tidally influenced waterways in New Jersey and the Tidelands Act (NJSA 12:3) regulates lands that are now or were formerly influenced by the tide of a natural waterway. The Coastal Area Facility Review Act (NJSA 13:19) regulates construction in coastal areas.

*Flood Hazard Area Control Act (NJAC 7:13)*

Flood plain management regulations (also referred to as Stream Encroachment regulations by the NJDEP – NJAC 7:13A; NJSA 58:16A), control the type, location and elevation of structures proposed in flood plains or floodways. The regulations control new construction, but not existing structures. Permits are generally granted if an applicant can demonstrate that the proposed structure will not increase the 100-year flood elevation. Flood-proofed structures are generally permitted above the 100-year flood plain elevation. Local governments also regulate flood plains so that they are eligible to receive money from the National Flood Insurance Program in the event of an emergency. The Flood Hazard Area Control Act limits developments in flood plain areas and requires permits for specific activities in flood plains, category 1, and trout associated waters or those that support threatened and endangered species.

*Delaware and Raritan Canal Commission Certificate of Approval*

The Delaware and Raritan Canal Commission reviews development applications for projects that would have an effect on storm drainage and water quality, visual and natural quality, stream corridor or traffic impacts associated with the D&R Canal Park. Municipalities in parts of Hunterdon, Mercer, Middlesex, Monmouth and Somerset County are subject to the requirements of the Commission, which is a State agency.

*Residential Site Plan Improvement Standards*

The Residential Site Plan Improvement Standards (NJSA 40:55D-40) set uniform standards for residential developments with respect to streets, parking, water supply, sanitary sewers and stormwater management. The Standards, formed by the Site Improvement Advisory Board and adopted by the Department of Community Affairs, require that developments be designed to reduce flood damages, minimize stormwater runoff from new land developments, reduce soil erosion from construction projects, assure adequacy of culverts and bridges, induce water recharge, prevent an increase in nonpoint source pollution, maintain integrity of stream channels and minimize safety concerns from stormwater detention facilities.

### Model Stream Corridor Ordinances

In 1994, the Urban Forestry Advisory Committee of the Middlesex County Planning Board prepared a Model Stream Corridor Protection and Management Overlay Zone Ordinance. The overlay zone requires an amendment to municipal master plans and zoning ordinances to include development standards and criteria and buffer/easement requirements. Uses of these zones relate to special environmental features that restrain development and protect environmentally sensitive areas. It is recommended in the Ordinance that the stream corridor should extend at least 200 feet from the top of the streambank, or 100 feet from the 100-year flood zone (whichever is greater) and include provisions for a conservation easement to protect a buffer at least 50 feet from the top of bank or 100-year flood zone and the first 25 feet of steep slopes greater than 12 percent; (whichever is greater).[92] The Township of South Brunswick expressed an interest in adopting this ordinance for Heathcote Brook. A report (Stream Corridor Protection and Management Overlay Zone Ordinance – An Implementation Assessment: South Brunswick Township Case Study) was developed by Louis Berger & Associates, Inc. to determine how the ordinance could be revised to incorporate the specific aspects of Heathcote Brook.[93] In 1996, Princeton Township also established a stream corridor buffer which regulates activities along stream corridors.[94]

In 1996, the Stony Brook-Millstone Watershed Association (SBWMA) developed a Model Stream Corridor Ordinance in an effort to provide greater protection of water quality and ecologically sensitive areas of the region. SBMWA developed a boilerplate document that could be modified for the specific needs of individual municipalities. The ordinance was developed to maintain the quality of streams and improve impaired streams, protect significant ecological components, prevent flood damages to existing communities and complement state, regional, county and municipal stream corridor protection efforts. The ordinance draws on the Delaware and Raritan Canal Commission regulations and the Middlesex County proposal as models.

In 1977, West Windsor Township adopted a Green Belt Plan in an effort to protect stream corridors and wildlife habitat in the Township. The plan was developed in an effort to protect the Township's environmental resources and ensure the availability of resources for years to come. The plan recommends a minimum belt width of 400 feet (200 feet on each side of the stream edge). In 1977, the West Windsor Planning Board accepted the Plan, included it in the Master Plan and adopted it as a policy of the Planning Board.

### State Development and Redevelopment Plan

The State Planning Act (NJSA 52:18A 196 et seq.) adopted by the State of New Jersey in 1985, declared that New Jersey needed to implement a statewide planning initiative to:

> *"…conserve its natural resources, revitalize its urban centers, protect the quality of its environment, and provide needed housing and adequate public services at a reasonable cost while promoting beneficial economic growth, development and renewal…"*

Under the Act, the State Development and Redevelopment Plan should establish statewide planning objectives that would encourage State and local governments to guide future growth into compact forms of development and redevelopment. This would support and maintain the capacities of infrastructure, environmental, natural resource, fiscal, economic and other systems. Although the State Plan is not a regulation, "it is a policy guide for State, regional and local agencies to use when they exercise their delegated authority."[95] County and municipal master plans should be modified to incorporate the provisions of the Plan.

The State Development and Redevelopment Plan calls for the protection and preservation of large, continuous tracts and corridors of open space land which contain important biological resources, potentially through the establishment of greenway networks. The Plan also calls for the maintenance of stream corridor buffers adequate for the protection of water quality, wildlife corridors and opportunities for recreational activities.[96]

### Green Brook Flood Control Project

Due to a series of flood events in the Green Brook area of Middlesex, Somerset and Union Counties over many decades, the Green Brook Flood Control Project has been established in an effort to prevent continual damages to the area in the future. Suggestions made by the Green Brook Flood Control Commission in 1977 to reduce flood flows included improvements to the channel to provide complete protection for a typical based flood of 4,000 cubic feet per second at Sebring's Mills, and the inauguration of a park on the adjoining lands. It was assured that these two measures would effectively solve the flood problem.

The Green Brook Flood Control Project will be funded primarily by the Federal Government which has agreed to contribute 75% of the total cost of approximately $400 million. The State of New Jersey and the three counties have agreed to pay the remaining 25% of the cost. The first segment of the project will cost approximately $331 million of which the Federal Government will pay 75%, the State of New Jersey will be paying 19%, and Middlesex and Somerset counties will be contributing the remaining 6% of the cost, with Middlesex contributing $9.6 million and Somerset contributing $11 million. The first segment of the project will take place from the confluence of the Stony Brook with the Green Brook in Plainfield and North Plainfield, and extend down to the Raritan River.[97]

The project has been designed to provide flood protection, protect the environment, enhance national economics, preserve recreation and open spaces and meet federal principles and guidelines. Structural alternatives including channelization to lower flood depths, construction of levees/flood wall to contain floods and dry detention basins to reduce flows downstream have been considered, as have non-structural alternatives including flood proofing to eliminate damages to homes and businesses, and the buyout of structures. The recommended plan involves the construction of 78,000 linear feet of levees/floodwalls, 21 bridge/road modifications, 21,000 linear feet of channel modifications, 8 closure structures (gates that serve to hold back water), 2 dry detention basins, 166 flood proofs (raising or moving the building, constructing ring levees/walls, modification of the structure to minimize flood damage) and 16 pump stations. In the Lower Portion of the Green Brook watershed, the recommended plan will provide protection for the 150-year flood. A lesser degree of protection will be provided in the remainder of the Green Brook watershed.

The Lower and Stony Brook portions of the Green Brook Project were authorized for construction, which began in 2001. The authorization for construction of the Upper portion of the project has been on hold pending potential relocation of the detention basins.

### South River Flood Control and Ecosystem Restoration Project

The United States Army Corps of Engineers (USACE) Flood Control and Ecosystem Restoration project for the South River which is expected to begin construction in 2005, will restore and diversify existing ecosystems in the South River watershed and protect communities against flood problems. A reconnaissance report completed in May 1995 by the USACE identified a plan of improvement consisting of two levees along the South River that would protect the communities of South River and Sayreville from the 100-year flood. Restoration efforts include a plan to restore the quality of the salt marsh near Washington Canal by replacing low quality vegetation in 250 acres of wetlands. The project will provide flood control protection to South River, Sayreville and East Brunswick. Work performed in 2000 included selection of a work plan, development of mitigation and restoration plans, preparation of geotechnical and hydraulic analysis.[98]

A Draft Feasibility Report and Environmental Impact Statement for the project was published in June 2002. The project consists of two components: hurricane and storm damage reduction and ecosystem restoration. The objective of the storm damage reduction portion of the project is to reduce the threat of potential future damages due to the effects of tidal flooding from the mouth of the South River to the Duhernal Lake Dam. The objectives of the ecosystem restoration portion of the project are to increase the diversity and function of existing monotypic and/or disturbed communities by: diversifying habitat, creating underrepresented habitat, creating habitat for rare or special interest wildlife, increasing the net wetland acreage, increasing tidal flushing, stabilizing/protecting existing wetland habitats, reducing the extent of Phragmites, enhancing water quality, and increasing recreational opportunities.

Studies showed that there are no widespread flooding problems in the South River watershed upstream of the Duhernal Lake Dam; the project therefore focused on the river reaches below the dam. A wide range of alternative plans incorporating structural and non-structural measures were considered. Several potential measures were eliminated based on economic feasibility and/or anticipated environmental impacts. The recommended plan was selected as it provided the greatest net benefit with respect to economic analysis and level of storm damage protection.

The recommended storm damage reduction plan will provide hurricane and storm damage protection for a 500-year storm event. Structural protection will be provided through a combination of levees, floodwalls and a storm surge barrier. The plan includes 10,712 feet of levees and 1,655 feet of floodwalls. The 320-foot long storm surge barrier is designed to span the South River. A clear opening of 80 feet is included in the surge barrier. The recommended plan also includes a mitigation plan to restore 11 acres of degraded wetland to offset impacts from construction of the recommended plan.

The recommended ecosystem restoration plan will involve restoration of 380 acres of wetlands that have been severely degraded by Phragmites colonization. The areas will be restored to wetland forest/scrub/shrub, upland forest/scrub-shrub, lower emergent marsh, mudflat and open water (tidal creek and tidal pond).

The storm damage reduction portion of the project is estimated to cost approximately $62.5 million, and the ecosystem restoration portion of the project is estimated to cost approximately $50.8 million. The federal government will pay 75% of the total project cost and the State of New Jersey will pay the remaining 25% of the total project cost. Construction is anticipated to begin in 2005.

### Millstone River Watershed Protection and Flood Damage Reduction (PL-566) Project

Following flooding from Hurricane Floyd, the Natural Resources Conservation Service began meeting with representatives of counties, soil conservation districts, municipalities and other organizations to develop a watershed protection and flood damage reduction program for the Millstone River Watershed. The project has incorporated concerns and objectives such as flood damage reduction, soil erosion reduction, water quality improvement, public recreation development, public fish and wildlife development, ground water recharge protection and agricultural water management. The plan will include identification of problems, determination of local citizen's objectives, inventory of existing resources, analysis of the resource data, development and evaluation of the various alternatives for solution of the locally identified problems, and a decision by the local people regarding which alternative would offer the best solution to the problems. The plan is expected to be completed in 2002 and followed by implementation of the selected alternative.[99]

### United States Army Corps of Engineers Millstone River Watershed Flood Damage Reduction Project

The United States Army Corps of Engineers (USACE) completed a draft Reconnaissance Study in October 2000 for its Millstone River Watershed Flood Damage Reduction project. The Reconnaissance Study identified possible flood control and ecosystem restoration projects that could be undertaken in the Millstone Basin. The next step of the project is to develop a feasibility study which would identify a recommended plan and include the design of an alternative to reduce flood damages in the Millstone Basin. The study will take approximately 3-4 years, beginning in 2002, and will focus on flood damage reduction activities primarily from Millstone Borough to the mouth of the Millstone River. The USACE will also be involved in planning major ecological restoration activities in the upper watershed.

### Stormwater Watershed Model

In compliance with the New Jersey Stormwater Management Act, the Middlesex County Planning Board developed a Phase 1 Stormwater Management Plan and Ordinance Review Guide which was prepared by Killam Associates in 1991. The document contains a checklist of stormwater management criteria for use by Middlesex County in the review of municipal Phase 1 stormwater management plans and ordinances prepared in accordance with the State Stormwater Management Act. It lists the minimum requirements and controls needed to compensate for the differences in hydrologic response of watersheds from the undeveloped to the developed condition.

### South Branch Rockaway Creek Stormwater Management Study

The South Branch Rockaway Creek Stormwater Management Study was conducted in 1986 to document existing land uses and recommend a stormwater management plan for the South Branch Rockaway Creek in Hunterdon County. Objectives of the study were to "field test" the stormwater management regulations and to test different approaches to try and reduce downstream flooding. Objectives also included development of a strategy for implementing the recommended stormwater management plan and documentation of the planning process. The purpose of the study was to assess the benefits of a watershed level stormwater management plan in a developing area. The recommended plan would allow the development potential of the watershed to be fully realized with a minimum level of adverse impacts on flooding, erosion and water quality and at the least possible cost to developers, the municipalities and the public. Recommendations of the study required that all site plan and subdivision proposals that would create one acre of more of impervious cover would be required to provide flood, erosion and water quality controls as mandated by state regulations.

The study recommended that the plan be implemented into each affected municipalities stormwater ordinance, the county stormwater resolution, and municipal and county master plans. A sample ordinance prepared as part of the study included three sections stating the minimum requirements of the State's stormwater management regulations dealing with applicability, design standards and maintenance of stormwater management facilities to ensure consistency throughout the watershed.

## Critical Needs

In order to perform a more complete assessment of the "health" of the surface waters and riparian areas of the Raritan Basin, the following information would be required:

- Updated low flow data from USGS (in progress through an agreement with NJDEP)
- Revised FEMA flood plain maps (planned by FEMA by 2006, nationwide)
- Results of USGS field studies on extent of flooding caused by Hurricane Floyd
- Additional macroinvertebrate sampling data to better establish baseline and trends
- A documentation of floods that have occurred between 1970 and 1999
- 100-Year Flood Plain vs. Areas Flooded by Hurricane Floyd
- Effects of Pre and Post-Development on Floods
- Research on the effects of impervious cover on wetlands in urban areas (on-going study by Cook College, Rutgers University)
- Application of the Rosgen classification for determining stream behavior and channel conditions of streams in the Basin

## Conclusions

The topography and geology of the Highlands, Piedmont and Coastal Plain physiographic provinces constitute the primary differences between streams within the Raritan Basin. Tributaries to larger waterways in the Highlands are generally small and fast flowing, many of which flow between steeply sloping areas. Conversely, streams of the Piedmont are generally larger and flatter with more expansive flood plains. Streams of the Coastal Plain are also relatively flat and contain sandy or gravelly substrates and have expansive flood plains along the larger streams. Of the 2,000 mapped stream miles in the Basin, approximately 52% are first order streams, 21% are second order, 13% are third order, 8% are fourth order, 4% are fifth order and 2% are sixth order.

The construction of dams and the channelization of streams changes the physical and ecological characteristics of streams by altering stream flows and the natural functions of streams. Dams can also cause erosion problems, change the substrate of a stream and adversely affect the organisms living in the stream. Of the 254 dams in the Basin, 57 were created as flood control structures and most dams fall within the 10 to 25 foot height class. The largest dams, however, are reservoir dams. Seven of the high hazard dams are in need of repair and three dams in the Basin were damaged by Hurricane Floyd in 1999. Further study to determine the effects of the 256 dams on the 2,000 miles of streams in the Basin needs to be conducted. Channelized streams are primarily limited to the Lower Raritan WMA in the vicinity of the Green Brook which indicates that the majority of streams in the Basin still contain their natural components and function naturally.

The proximity of the Basin to the Atlantic coastline subjects it to both tidal and fluvial flooding. The lower reaches of the mainstem of the Raritan River and the South River are subject to tidal flooding, while the remaining areas in the Basin are subject to fluvial flooding. Flood prone areas within the Basin do not extend much beyond the wetland boundaries, which exemplifies the need to protect wetland systems from development. Significant areas prone to flooding in the Basin exist in areas of Bound Brook, Manville and Bridgewater, and in other areas along the tidal portion of the Raritan River in the Lower Raritan WMA. The lower reaches of the Basin in the Millstone WMA also have extensive flood prone areas, particularly in Plainsboro, South Brunswick and Monroe Townships.

The slopes of the Watchung Mountains in combination with the insufficiency and irregularity of existing channels in the Green Brook and Stony Brook watersheds have historically been responsible for large and sudden flood flows. In addition, the flat channels in the Green Brook valley are incapable of handling these flows, and flooding occurs relatively quickly during excessive rainfall events. Backwater effects from the Raritan River have also caused problems in this area. Other areas that have flooded extensively in the past have been areas in the Upper Millstone River Watershed in the vicinity of Hightstown, Rock Brook near Skillman, the confluence of Rock Brook and Beden Brook, Pike Run north of its confluence with Back Brook, and along River Road at the confluence of Beden Brook and Pike Run. Floods in the Millstone Watershed have also occurred along the Millstone River, Rocky Brook, Big Bear Brook and Cranbury Brook in the vicinity of Plainsboro and Princeton Junction.

The 1999 NJDEP Ambient Biomonitoring Network results for the Raritan Basin showed 37.3% of the monitoring locations as non-impaired, 54.7% as moderately impaired, and 8.0% as severely impaired. As compared with the results from the 1993-94 report, the number of non-impaired sites remained relatively the same (about 37% both times), there were fewer moderately impaired sites in 1999 than in 1994 (57% and 55% respectively), but the number of severely impaired sites increased from 5.6% to 8.0%. 1999 was a drought year in the Basin and is reflected in the macroinvertebrate data collected by the South Branch, Stony Brook-Millstone and Upper Raritan Watershed Associations for 2000. Overall results for 2000 indicate a decline in the number of macroinvertebrates observed in streams throughout the Basin. Additional data is required to establish a baseline trend and determine whether declines in macroinvertebrate populations are a result of natural causes (i.e., drought or flood) or stream degradation.

Consumption advisories for mercury were issued in 1997 and updated in July 2002 for the general population and high-risk individuals for several fish species and water bodies in the Basin, including largemouth bass and chain pickerel. Fish and crab consumption advisories for PCBs, dioxin or chlordane contamination in the Raritan Bay and tidal portions of the Raritan River and all of the rivers and streams that feed into these water bodies have been issued for striped bass, bluefish white perch, or white catfish, blue crab for high-risk individuals. In addition, the harvest and consumption of shellfish from the Raritan Bay and the tidal portion of the Raritan River is prohibited.

Eutrophication problems have been documented in the Millstone River between the Township of Plainsboro and Carnegie Lake in Princeton Township, within impoundments in the Beden Brook subwatershed, in several pockets along the North Branch and South Branch of the Raritan River, within stretches of the South River and in the lower stretch of the mainstem of the Raritan River and the Raritan Bay. Specific causes of eutrophication problems in the Basin are unknown, however, problems are usually attributed to excessive phosphorus and nitrate contributions.

Riparian area results for the Upper Raritan WMA show that 32% of the historical riparian land cover has been converted to agricultural (16%) and urban (16%) land uses by 1995. The Lower Raritan WMA has had approximately 31% of its historical riparian area converted to agricultural (4%) and urban (27%) land uses by 1995, while the Millstone WMA has had 28% of its historical riparian areas converted to agricultural (12%) and urban (16%) land uses. The greatest conversions have occurred in Tewksbury Township in the Upper Raritan WMA, along Chambers Brook in Somerville and Bridgewater Township, along Green Brook and Bound Brook, along tributaries to the mainstem of the Raritan River near New Brunswick and Franklin Township (Somerset County), in the highly urbanized Woodbridge/Edison Township area, along the headwaters of Deep Run in Marlboro and along the headwaters of the Matchaponix Brook in the vicinity of Manalapan Township and Marlboro Township in the Lower Raritan WMA. In the Millstone WMA, extensive conversions have occurred in Hillsborough Township, Cranbury and Plainsboro Townships. Other significant conversions in the Millstone WMA have occurred along the D&R Canal and the Millstone River in Princeton Township, in the vicinity of the Route 1 corridor, and in the vicinity of Hopewell Township.

The conversion of approximately 30% of the Basin’s historical riparian areas to urban and agricultural land uses suggest a need for better protection of stream corridors to prevent future degradation of the Basin’s surface waters and continued loss of this valuable habitat. Between 1986 and 1995, 2.0% of the Upper Raritan WMA’s, 3.0% of the Lower Raritan WMA’s and 3.0% of the Millstone WMA’s riparian areas were converted to urban land uses.

Despite federal, state and local regulations that have been established to protect surface waters and riparian areas, continued degradation of habitats and conversion of these natural features to other land cover types is evident throughout the Raritan Basin. Projects such as streambank restorations, wetland creation and enhancement, and flood mitigation help restore degraded habitats, but efforts to prevent further destruction or loss of these habitats need to be established. More stringent regulations such as the proposed wetlands regulations and the water quality and watershed management rule and proper planning may guide future growth patterns, but more needs to be done to maintain and improve the quality and quantity of these ecosystems.

## Glossary of Terms

“Alluvium” means material, such as sand, silt, or clay, deposited on land by streams.

“Anadromous fish" means fish which travel from salt water to fresh water or up waterways to spawn.

“Bank” means the inclined sides of the stream channel.

“Bed” means the floor of the stream channel.

“Channel” means the well-defined bed and banks of a watercourse which confine and conduct flowing water continuously or intermittently.

“Crown closure” means the amount of shading provided by the tree canopy over land or water surfaces.

“Detention basin” means an impoundment area made by constructing an embankment, or excavating a pit, or both, for the purpose of temporarily storing water.

“Evapotranspiration” means the combined loss of water to the atmosphere by evaporation and from growing plants.

“Exceptional resource value wetlands” means freshwater wetlands exhibiting any of the following characteristics: those which discharge into FW-1 waters or FW-2 trout production waters or their tributaries; or those which are present habitats for threatened or endangered species, or those which are documented habitats for threatened or endangered species, and which remain suitable for breeding, resting, or feeding by these species during the normal period these species would use the habitat.

“Erosion” means the detachment and movement of soil or rock fragments by water, wind, ice or gravity.

“Flood hazard areas” means the floodway and flood fringe areas determined by the NJDEP under Section 3 of the Flood Hazard Areas Control Act (P.L. 1979, c.359).

“Flood plain” means the areas adjacent to a stream or river that are subject to flooding or inundation during severe storm events. [Often referred to as a 100-year floodplain, it would include the area or flooding that occurs, on average, once every 100 years].

“Flood prone areas” means those areas that frequently flood but are not necessarily part of the regulated 100-year flood plain.

“Floodway” means the channel of a natural stream and portions of the flood hazard areas adjoining the channel, which are reasonably required to carry and discharge the flood water or flood flow of any natural stream.

“Flow, natural” means the flow of a stream as it occurs under natural conditions; that is, not subjected to any regulation or diversions.

“Flow, regulated” means the flow of a stream that has been subjected to any artificial or man-made storage, augmentation or diversions.

“Ground water” means that portion of water beneath the land surface that is within the zone of saturation (below the water table) where pore spaces are filled with water.

“Headwaters” means the beginnings or sources for water courses. Typically the land surrounding the point in the landscape where sufficient runoff collects to form an intermittent stream.

“HUC System” means the national hydrologic unit code system used by the United States Geological Survey as a way to identify individual watershed areas.

“Hydric soils” means a soil that in its undrained condition is saturated, flooded, or ponded long enough during the growing season to develop anaerobic conditions that favor the growth and regeneration of hydrophytic vegetation.

“Hydrologic cycle” means the continuous movement of water from the Earth’s surface into the atmosphere (via evaporation, transpiration and condensation) and back to the earth’s surface again (via precipitation, runoff and infiltration).

“Impervious cover” means any surface in the urban landscape that cannot effectively absorb or infiltrate rainfall.

“Impoundment” means a body of water confined by a dam, dike, floodgate or other barrier.

“Infiltration” means the soaking of water into the ground.

“Intermediate resource value wetlands” means freshwater wetlands not defined as exceptional or ordinary.

“Moraine” means a thick glacial deposit consisting of a heterogeneous mixture of rocks and gravel.

“Ordinary resource value wetlands” means freshwater wetlands which are isolated wetlands which are more than 50 percent surrounded by development and less than 5,000 square feet in size.

“Physiographic provinces” means the distribution of land area in New Jersey into distinct land divisions that have been determined by New Jersey’s geologic history.

“Retention basin” means an impoundment area with a permanent pool made by constructing an embankment, or excavating a pit, or both for the purpose of temporarily storing stormwater.

“Riparian area” means streamside land areas that are generally transitional areas between the stream and upland areas.

“Stormwater runoff" means flow on the surface of the ground, resulting from precipitation

“Stream order” means the number assigned to a stream based on the size and shape of the channel.

“Subwatershed” means a smaller geographic section of a larger watershed that comprises the drainage area for a tributary stream within the watershed or a section of the primary stream.

“Surface waters” means water at or above the land’s surface which is neither ground water nor contained within the unsaturated zone. Surface waters include, but are not limited to, the ocean and its tributaries, all springs, streams, rivers, lakes, ponds, wetlands, and artificial water bodies.

“Watershed” means a hydrologic unit in which all surface water runoff egresses through a single, natural hydrologic outlet, and as delineated in the Statewide Water Quality Management Plan. [Often referred to as all the land area which contributes runoff to a particular point along a waterway].

“Watershed Management Area” means one of the areas incorporating one or more contiguous watersheds as delineated in the Statewide Water Quality Management Plan. A watershed management area is used as a planning area for the watershed management process.

“Wetland transition area” means an area of land adjacent to a freshwater wetland which minimizes adverse impacts on the wetland or serves as an integral component of the wetlands ecosystem.

## Common Acronyms

AMNET - Ambient Biomonitoring Network
D&R Canal – Delaware and Raritan Canal

FEMA – Federal Emergency Management Agency
HUC – Hydrologic Unit Code
MSL – Mean Sea Level
NJDEP – New Jersey Department of Environmental Protection
NRCS – Natural Resources Conservation Service
WMA – Watershed Management Area
USACE – United States Army Corps of Engineers
USDA – United States Department of Agriculture
USFWS – United States Fish and Wildlife Service
USGS – United States Geological Survey

## References

Ashley, Gail M., Gary H. Haag, Robert T. Pavlowsky and William H. Renwick. 1992a. River Geomorphology, Sedimentology and Surface Hydrology of the Raritan River. Excerpt from Environmental Geology of the Raritan River Basin. Ninth Annual Meeting of the Geological Association of New Jersey. October 30-31, 1992. Field Guide and Proceedings. Supported in part by, Jersey City State College and Rutgers University.

Ashley, Gail M. 1992b. Geology, Geomorphology and Land Use of the Raritan River. Excerpt from Environmental Geology of the Raritan River Basin. Ninth Annual Meeting of the Geological Association of New Jersey. October 30-31, 1992. Field Guide and Proceedings. Supported in part by, Jersey City State College and Rutgers University.

Baker, N., P.J. Brown, C. Durgin, R.D. Pfister. 1997. Montana Forest and Conservation Experiment Station. Classification and Management of Montana's Riparian and Wetland Sites.

Barringer, Thomas H., Robert G. Reiser, and Curtis V. Price. 1994. Potential Effects on Development on Flow Characteristics on Two New Jersey Streams. Water Resources Bulletin – American Water Resources Association. Volume 30, No. 2.

Brandywine Valley Association. 1999. 1998 Brandywine Valley - State of the Watershed Report. West Chester, PA.

Center for Environmental Education. 2000. Streams and River Classification. Washington State University. Internet site: http://www.hrc.wsu.edu/enviroed/watersheds/Watershed_Education/river_stream.htm

Center for Watershed Protection. 1998. Rapid Watershed Planning Handbook – A Comprehensive Guide for Managing Urbanizing Watersheds. Ellicott City, Maryland.

Center for Urban Policy Research (CUPR). 2000. A Publication of the Center for Urban Policy Research. Volume 11, No. 1. Spring 2000.

Cosgrove, Jim. Omni Environmental Consultants, Inc. Princeton, NJ. Personal Communication, October 3, 2000.

Courier News. 2000a. "After flood, home prices, taxes still on the rise." Article written by Terri Needham, published in March 15, 2000 edition.

Courier News. 2000b. "Rutgers project examines disaster." Article written by Leslie Boyd, published in March 15, 2000 edition.

Farlekas, George M. 1969. Extent and Frequency of Floods in Upper Millstone River Basin in the Vicinity of Hightstown, NJ. United States Department of the Interior Geological Survey. Prepared in Cooperation with the State of New Jersey Department of Conservation and Economic Development Division of Water Policy and Supply. Open-file report.

Gilliam, J.W., D.L. Osmond, and R.O. Evans. 1997. Selected Agricultural Best Management Practices to Control Nitrogen in the Neuse River Basin. North Carolina Agricultural Research Service Technical Bulletin 311, North Carolina State University, Raleigh, NC.

Gordon, Stuart. 1996. Instructor's Guide Eastern – Forested Wetland and Streamside Forest Management. In cooperation with the National Association of State Foresters and the National Association of Conservation District.

Green Brook Flood Control Commission. 2000a. May Newsletter, Volume XIV, Number 3.

Green Brook Flood Control Commission. 2000b. July Newsletter, Volume XIV, Number 4.

Haskin, Harold H. 1962. The Hard Clam Population of Raritan Bay, Survey of April 9-13, 1962. New Jersey Agricultural Experiment Station. Rutgers – The State University. New Brunswick, New Jersey.

Hazen, Allen. 1930. Flood Flows – A Study of Frequencies and Magnitudes. John Wiley & Sons, Inc. New York.

Home News Tribune. 2000. "NJ Thirsty for Cleaner Water Supply – Battle to Block Pollution Continues." Article written by Rick Malwitz, published in Mary 15, 2000 edition.

Horne, Alexander J. and Charles R. Goldman. 1994. Limnology – Second Edition. McGraw-Hill Inc.

Leopold, Luna B. 1974. Water – A Primer. University of California, Berkeley. W.H. Freeman and Company, San Francisco.

Lima, Dewey. New Jersey Department of Environmental Protection, Dam Safety Section. Personal Communication. 7 August 20002.

Livio, Susan K. 2000. "In a Manville Neighborhood Where Strangers Were Rare, Hurricane Floyd Was the Most Unwelcome of All." March 12, 2000 Edition – Star Ledger.

Louis Berger & Associates, Inc. 1994. Model Stream Corridor Protection and Management Overlay Zone Ordinance. Prepared for the Urban Forestry Advisory Committee - Middlesex County Planning Board. New Brunswick, NJ

Louis Berger & Associates, Inc. 1995. Model Stream Corridor Protection and Management Overlay Zone Ordinance – An Implementation Assessment: South Brunswick Township Case Study. Prepared for the Urban Forestry Advisory Committee - Middlesex County. New Brunswick, NJ

MacKenzie, Jr., Clyde L. 1931. The Fisheries of Raritan Bay. Rutgers University Press. New Brunswick, New Jersey.

Malwitz, Rick. 2000. N.J. Thirsty for Cleaner Water Supply – Battle to Block Pollution Continues. Home News Tribune, May 15, 2000 edition, East Brunswick, New Jersey.

Manning, John C. 1992. Applied Principles of Hydrology – Second Edition. Macmillan Publishing Company. New York.

Maryland Department of Natural Resources Forest Service. Riparian Forest Buffers. Function and Design for Protection and Enhancement of Water Resources. Internet site: http://www.dnr.state.md.us/forests/publications/buffers.html

Meffe, Gary K. and C. Ronald Carroll. 1997. Principles of Conservation Biology – Second Edition. Sinauer Associates, Inc. Publishers. Sunderland, MA.

Massachusetts Department of Fisheries, Wildlife and Environmental Law Enforcement. 1997. Fact Sheet #3: Functions of Riparian Areas for Wildlife Habitat. MA Riverways Program.

May, Christopher W. and Richard R. Horner, James R. Karr, Brian W. Mar, and Eugene B. Welch. 1997. Effects of Urbanization on Small Streams in the Puget Sound Lowland Ecoregion. Watershed Protection Techniques. Volume 2, No. 4.

Montgomery County Planning Commission. 1997. Guidebook for Riparian Corridor Preservation. Norristown, Pennsylvania.

Natural Resources Defense Council. 2000. Stormwater Strategies - Community Responses to Runoff Pollution. August 2000 slide presentation. New York, New York.

NJDEP, 1972. Delineation of Flood Hazard Areas in the Raritan Basin. Flood Hazard Report No. 2, Raritan River. Department of Environmental Protection, Division of Water Resources.

NJDEP, 1973. Delineation of Flood Hazard Areas in the Raritan River Basin. Flood Hazard Report No. 11, South Branch Raritan River. Department of Environmental Protection, Division of Water Resources.

New Jersey Department of Environmental Protection (NJDEP). 1995a. Ambient Biomonitoring Network – Raritan River Drainage Basin. 1993-94 Benthic Macroinvertebrate Data.

NJDEP. 1995b. Survey of Surface Source Waters for Giardia and Cryptosporidium and Water Treatment Efficiency Evaluation. Division of Science and Research.

NJDEP. 1996. Surface Water Quality Inventory Report – 305b Report.

NJDEP. 1996. Office of Information Resources Management, Bureau of Geographic and Information Analysis, Geographic Information System Digital Data CD-ROM, Volumes 2 & 3.

NJDEP. 1998. Water Quality Monitoring Networks - Water Monitoring Report. Bureau of Freshwater and Biological Monitoring.

New Jersey Department of Environmental Protection. 1999. Fish and Crab Consumption Advisories Based on PCBs, Dioxin or Chlordane Contamination. http://www.state.nj.us/dep/dsr/fish-crab.htm

NJDEP, 2000a. Ambient Biomonitoring Network – Watershed Management Areas 7, 8, 9 and 10 - Raritan Region. 1999 Benthic Macroinvertebrate Data.

NJDEP. 2000. Division of Watershed Management, "Exploring New Jersey's Watersheds," Series 2 Volume 2.

NJDEP. 2000b. Land Use Regulation Freshwater Wetlands Program. Internet site: http://www.state.nj.us/dep/landuse/fww/fww.html

New Jersey Department of Environmental Protection. 2002. Guide to Mercury Health Advisories for Eating Fish from New Jersey Freshwaters – 2002 Update. http://www.state.nj.us/dep/dsr/advisory-updates-2002.htm.

NJDEP. Hunterdon County and USDA Soil Conservation Service. 1986. South Branch Rockaway Creek Stormwater Management Study. A Report of the Work Study Group. State of NJDEP/Division of Water Resources. Trenton, New Jersey.

New Jersey Department of Transportation. 1996. Geographic Information Systems.

New Jersey Office of State Planning. Internet site: http://www.state.nj.us/osp/plan/sdrpsumm.htm

NJOSP. 1997. Tomorrow's New Jersey Data Profiles CD-ROM. Trenton, New Jersey. http://www.state.nj.us/osp

New York-New Jersey Harbor Estuary Program. 1996. Final Comprehensive Conservation and Management Plan - Including the Bight Restoration Plan.

North Carolina State University (NCSU). 2000. Major Causes of Wetland Loss and Degradation. Water Quality Group. Internet site: http://h2osparc.wq.ncsu.edu/info/wetlands/wetloss.html

Powley, Van. R. 1987. Soil Survey of Middlesex County, New Jersey. United States Department of Agriculture - Soil Conservation Service, in Cooperation with the New Jersey Agricultural Experiment Station and the New Jersey Department of Agriculture. New Jersey Department of Agriculture. Trenton, NJ.

Rosgen, Dave, 1996. Applied River Morphology. Wildlife Hydology, Pagosa Springs, CO.

Ross, Thomas G. 1969. Extent and Frequency of Floods in the Beden Brook Basin in Somerset and Mercer Counties, New Jersey. United States Department of the Interior Geological Survey. Prepared in cooperation with New Jersey Department of Conservation and Economic Development Division of Water Policy and Supply.

South Branch Watershed Association. 1994-1996, 1997, 1998 and 1999 Annual Reports - South Branch Watershed Association Water Quality Monitoring Program, Benthic Macroinvertebrate Sampling.

Stankowski, Stephen J. and Anthony J. Velnich. 1973. A Summary of Peak Stages and Discharges For the Flood of August 1973 in New Jersey.

State of New Jersey - County and Municipal Government Study Commission. 1977. Flood Control Management – An Overview of Issues and Responses. Fourteenth Report.

Stankowski, Stephen J. 1974. Magnitudes and Frequency of Floods in New Jersey with Effects of Urbanization. Special Report 38. Prepared by the United States Geological Survey in cooperation with the State of New Jersey – Department of Environmental Protection Division of Water Resources.

Star Ledger, The. 2000. "Gambling With Dams." Article written by Brian T. Murray and Wayne Woolley, published in August 17, 2000 edition.

Stony Brook-Millstone Watershed Association. 1996. The Model Stream Corridor Protection Ordinance and the Basis and Background. Prepared by Imali D. Seneviratne in conjunction with Gerald J. Muller, Esq. and the extensive contributions of The Stream Corridor Ordinance Resource Group.

State Water Policy Commission. 1932. Control of Floods on Green Brook in the Counties of Middlesex, Somerset and Union. Special Report 4. State of New Jersey.

Tewksbury and Readington Township Environmental Commissions and the Upper Raritan Watershed Association. 2000. Rockaway Creek Water Quality Monitoring Project – 1999 Findings.

Tice, Richard. 1959. Extent and Frequency of Inundation of Flood Plain Near Raritan, New Jersey. Open-file report. United States Department of the Interior Geological Survey. Prepared in Cooperation with New Jersey Department of Conservation and Economic Development Division of Water Policy and Supply.

TRC Omni Environmental Corporation. 2001. Raritan River Basin Water-Based Recreation Study. Raritan Basin Watershed Management Project, South Bound Brook, NJ.

United States Army Corps of Engineers. 2002a. Draft Integrated Feasibility Report and Environmental Impact Statement, Hurricane and Storm Damage Reduction and Ecosystem Restoration Project, South River, Raritan River Basin.

United States Army Corps of Engineers. 2002b. Raritan River Basin, Green Brook Sub Basin, NJ – Flood Damage Reduction Project Fact Sheet. Prepared by the New York District, May 2002.

United States Army Corps of Engineers (USACE). 2000a. South River, Raritan River Basin, New Jersey – Flood Damage Reduction and Ecosystem Restoration Fact Sheet. Prepared by the New York District, July 2000.

United States Army Corps of Engineers. 2000b. Draft South River Restoration Screening Report Executive Summary. Flood Control and Ecosystem Restoration Project, South River, New Jersey.

United States Department of Agriculture (USDA) Forest Service, Natural Resources Conservation Service (NRCS), and Cooperative State Research, Education and Extensive Service. 1998. Chesapeake Bay Riparian Handbook: A Guide for Establishing and Maintaining Riparian Forest Buffers.

USDA – NRCS. 2000. Millstone River Watershed Protection and Flood Prevention (PL-566) Locally-Led Planning and Implementation Effort.

United States Environmental Protection Agency (USEPA). 1994. Priority Wetlands for the State of New Jersey. USEPA Region 2. Marine Wetlands Protection Branch.

USEPA. 2000. Academy 2000 - Distance Learning Modules on Key Watershed Management Topics. Office of Water. Internet site: http://www.epa.gov/owow/watershed/wacademy/acad2000/

United States Environmental Protection Agency. 2001. 2001 National Listing of Fish and Wildlife Advisories. http://www.epa.gov/waterscience/fish/.

United States Geological Survey (USGS). 1999. CD-ROM. Department of the Interior.

USGS. 2000a. Evaluation of Water Quality Status in the Raritan River Basin, Water Years 1991-1997.

USGS. 2000b. Flooding Due to Hurricane Floyd, September 1999. Internet site: http://nj.usgs.gov/floyd.html

USGS. 2000c. Water Resources Data New Jersey, Water Year 1999. Volume 1. Surface-Water Data. Water-Data Report NJ-99-1.

USGS. 1982. Low-Flow Characteristics and Flow Duration of New Jersey Streams. Open-File Report 81-1110. Prepared in Cooperation with the New Jersey Department of Environmental Protection Division of Water Resources.

Walsh, Richard J. 1928. Save the Raritan. New Brunswick, New Jersey.

Water Environment Federation and American Society of Civil Engineers. 1998. Urban Runoff Quality Management. WEF Manual of Practice No. 23, ASCE Manual and Report on Engineering Practice No. 87.

Welsch, David. 1991. Riparian Forest Buffers – Function and Design for Protection and Enhancement of Water Resources. USDA Forest Service, Northeastern Area – State and Private Forestry, Radnor, PA. NA-PR-07-91.

Wenger, Seth. 1999. A Review of the Scientific Literature on Riparian Buffer Width, Extent and Vegetation. Office of Public Service and Outreach, Institute of Ecology, University of Georgia.

West Windsor Township. 1977. Green Belt Plan. Prepared by the West Windsor Environmental Commission.

Wistendahl, Warren Arthur. 1955. The Flood Plain of the Raritan River, New Jersey. A Thesis Submitted to the Graduate School of Rutgers University The State University of New Jersey. New Brunswick, New Jersey.

# APPENDIX A

# RESULTS OF RIPARIAN AREA ANALYSES

# APPENDIX B

# STREAM MORPHOLOGY OF THE RARITAN BASIN

[1] Leopold, Luna B., 1974
[2] NJDEP, 1996
[3] Wistendahl, 1955
[4] NJDEP, 1996
[5] NRDC, 2000
[6] Leopold, Luna B., 1974
[7] Center for Watershed Protection, 1999
[8] Center for Environmental Education, 2000
[9] May et al., 1997
[10] Ashley, Gail, M., etal. 1992a
[11] USGS, 1982
[12] http://www.epa.gov/owow/watershed/wacademy/acad2000/river/river6.html
[13] Stankowski, Stephen J.,,1974
[14] Barringer, Thomas H., et al., 1994
[15] Hazen, Allen, 1930
[16] The Star-Ledger, 2000
[17] Horne and Goldman, 1994
[18] http://www.state.nj.us/dep/fgw/anadfish.htm
[19] Rosgen, David, 1996
[20] Leopold, Luna B., 1974
[21] Stankowski, Stephen J., 1974
[22] State of NJ - County and Municipal Government Study Commission, 1977
[23] State of NJ - County and Municipal Government Study Commission, 1977
[24] State of NJ - County and Municipal Government Study Commission, 1977
[25] State of NJ - County and Municipal Government Study Commission, 1977
[26] http://www.state.nj.us/dep/gis/appendixa.html
[27] Montgomery County Planning Commission, 1997
[28] Gordon, S., 1996
[29] State of NJ - County and Municipal Government Study Commission, 1977
[30] NJDEP, 1973
[31] NJDEP, 1973
[32] Hazen, Allen, 1930
[33] NJDEP, 1973
[34] State Water Policy Commission, 1932
[35] State Water Policy Commission, 1932
[36] State of NJ - County and Municipal Government Study Commission, 1977
[37] Stankowski S. J., and A. J. Velnich, 1973
[38] State of NJ - County and Municipal Government Study Commission, 1977
[39] Farlekas, George M., 1969
[40] Ross, Thomas G., 1969
[41] Livio, Susan K., 2000
[42] Courier News, 2000a
[43] Courier News, 2000a
[44] Courier News, 2000b
[45] CUPR, 2000
[46] Courier News, 2000a
[47] Water Environment Federation and American Society of Civil Engineers, 1998
[48] http://www.epa.gov/owow/watershed/wacademy/acad2000/river/right5.html
[49] Stankowski, Stephen J., 1974
[50] NJDEP, Hunterdon County and USDA-SCS, 1986
[51] Home News Tribune, 2000
[52] Center for Watershed Protection, 1999
[53] Water Environment Federation and American Society of Civil Engineers, 1998
[54] NJOSP, 1997
[55] NJDEP, 1996
[56] NJDEP, 1996
[57] NJDEP, 2000a
[58] NJDEP, 1995a
[59] SBWA, 1999
[60] Tewksbury and Readington Twp Environmental Commissions and the Upper Raritan Watershed Association, 2000

[61] Tewksbury and Readington Twp Environmental Commissions and the Upper Raritan Watershed Association, 2000
[62] MacKenzie, Jr., Clyde L., 1931
[63] NY-NJ Harbor Estuary Program, 1996
[64] MacKenzie, Jr., Clyde L., 1931
[65] Haskin, H., 1962
[66] Montgomery County Planning Commission, 1997
[67] Cosgrove, J., Correspondence 2000
[68] NJDEP, 2000b
[69] NCSU, 2000
[70] Ashley, Gail M., 1992b
[71] Welsch, D., 1991
[72] Maryland Department of Natural Resources Forest Service
[73] USDA, 1998
[74] Gilliam, J.W., D.L. Osmond, and R.O. Evans, 1997
[75] Montgomery County Planning Commission, 1997
[76] Wenger, 1999
[77] MA Department of Fisheries, Wildlife and Environmental Law Enforcement, 1997
[78] Montgomery County Planning Commission, 1997
[79] Gordon, S., 1996
[80] Wenger, 1999
[81] Wenger, 1999
[82] Powley, Van R., 1987
[83] Montgomery County Planning Commission, 1997
[84] Baker N., et al, 1997
[85] Center for Watershed Protection, 1998
[86] Brandywine Valley Association, 1999
[87] "Crown closure" means the amount of shading provided by the tree canopy over land or water surfaces.
[88] Meffe, Gary K. and C. Ronald Carroll, 1997
[89] May, Christopher W., et al., 1997
[90] Meffe, Gary K. and C. Ronald Carroll, 1997
[91] Meffe, Gary K. and C. Ronald Carroll, 1997
[92] Louis Berger & Associates, Inc., 1994
[93] Louis Berger & Associates, Inc., 1995
[94] Stony Brook-Millstone Watershed Association, 1996
[95] http://www.state.nj.us/osp/plan/sdrpsumm.htm
[96] Stony Brook-Millstone Watershed Association, 1996
[97] Green Brook Flood Control Commission, 2000b
[98] United States Army Corps of Engineers, 2000a
[99] USDA-NRCS, 2000