SETTING OF THE RARITAN RIVER BASIN

A Technical Report for the Raritan Basin Watershed Management Project

New Jersey Water Supply Authority

July 2000

Raritan Basin

Central to New Jersey

SETTING OF THE RARITAN RIVER BASIN

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Summary

This technical report provides an overview of the setting of the Raritan River Basin, including a description of the physical and ecological characteristics of the Basin. Geological features and landforms of the northern end of the Basin vary greatly in composition and physical appearance from those of the southern end, all of which contributes to the differences in climate, land use and development patterns throughout the 1,100 square mile Basin. This report summarizes these characteristics and provides a general understanding of the land use development patterns and trends that have occurred throughout the Basin over the years.

Basin Summary

The Raritan Basin is located within three of New Jersey's physiographic land provinces – the Highlands, Piedmont and Coastal Plain. The three provinces exhibit distinct characteristics which affect soil drainage capabilities, surface water runoff, ground water recharge potential, variations in precipitation and temperature patterns, and land use and land cover development patterns throughout the Basin. Differences among the New Jersey Department of Environmental Protection's designated Watershed Management Areas are summarized below.

Watershed Management Area Summaries

Upper Raritan Watershed Management Area (WMA 8)

The northern half of the Upper Raritan Watershed Management Area (WMA) is characterized by the Highlands physiographic province, which reaches elevations of approximately 1,400 feet in some areas. Ridges associated with these elevations were formed from hard rock material that resisted erosion, while valleys in the lower elevations are comprised of softer materials of limestone and shale. Soils of this WMA are moderately well-drained and have moderate infiltration rates. The Upper Raritan WMA encompasses many of the headwater streams that exhibit lower flows than the larger streams located in the central portion of the Basin, particularly in the vicinity of the Raritan Bay. Limestone and glacial aquifers of the Highlands contribute to this WMA's moderate to high infiltration rates. The Upper Raritan WMA contains a larger percentage of forested area than the Lower Raritan and Millstone WMAs.

Lower Raritan Watershed Management Area (WMA 9)

The Lower Raritan Watershed Management Area contains the lowest elevations of the Basin (often less than 100 feet and close to sea level in some areas), particularly in the area surrounding Raritan Bay. This WMA is characterized by a significant amount of development and large streams that result in high flows during periods of extended rainfall. Soils of the northern half of this WMA are somewhat poorly drained and have low infiltration rates, while soils of the southern half of the WMA have high recharge capabilities as compared with the rest of the Basin. The Lower Raritan WMA includes many of the larger streams of the Basin that exhibit much higher flows than streams located to the north and west.

Millstone Watershed Management Area (WMA 10)

The Millstone Watershed Management Area contains many of the soils that contribute to ground water recharge within the Basin, especially in Middlesex, Mercer and Monmouth counties. Comparison of land uses for the Raritan Basin illustrate that the Millstone WMA contains a high percentage of agricultural land and ranks the second highest in the urban land use/land cover category as compared with the Upper and Lower Raritan WMAs. The Millstone WMA also had the largest increase in urban land areas between 1986 and 1995 than the other WMAs in the Basin.

Location

The Raritan River Basin is located in north-central New Jersey, approximately midway between New York City and Philadelphia (Figure 1). The Raritan Basin is the largest river basin located entirely within the State of New Jersey, and is surrounded by the Upper Delaware Watershed Management Area to the northwest, the Central Delaware Watershed Management Area to the west and southwest, the Passaic Water Region to the north, the Arthur Kill Watershed Management Area to the northeast, and the Atlantic Coastal Water Region to the southeast. The Basin encompasses approximately 1,100 square miles and is located within parts of seven counties including Hunterdon, Mercer, Middlesex, Monmouth, Morris, Somerset and Union counties (Figure 2).

According to the New Jersey Department of Environmental Protection (NJDEP) Division of Watershed Management, http://www.state.nj.us/dep/watershedmgt/ "[a] watershed is the area of land that drains into a body of water such as a river, lake, stream or bay. It is separated from other systems by high points in the area such as hills or slopes. It includes not only the waterway itself but also the entire land area that drains to it. For example, the watershed of a lake would include not only the streams entering that lake but also the land area that drains into those streams and eventually the lake. Drainage basins generally refer to large watersheds that encompass the watersheds of many smaller rivers and streams.[1]"

There are 141 watersheds in New Jersey, which the NJDEP has grouped into 20 watershed management areas (WMAs) and 5 water regions. The Raritan River Basin encompasses 3 of the 20 NJDEP listed WMAs and is located within the Raritan water region, as indicated on Figure 3. The Basin comprises WMAs 8 (North and South Branch Raritan), 9 (Lower Raritan, South River, Lawrence Brook) and 10 (Millstone River). The 3 WMAs will be referred to as the Upper Raritan (WMA 8), the Lower Raritan (WMA 9) and the Millstone (WMA 10) from hereon. There are approximately 2,000 mapped miles of flowing streams within the Basin, all of which flow to the Raritan Bay located at Perth Amboy and South Amboy in the easternmost portion of Middlesex County.

Major waterways in the Basin include the North Branch and South Branch of the Raritan River (known collectively as the Upper Raritan River), the Lower Raritan River, South River, Green Brook, Lawrence Brook and the Millstone River, along with all their many feeder streams. Some of these watersheds are among the healthiest in New Jersey, while others are considerably degraded. The Delaware & Raritan Canal, which brings water from the Delaware River to the eastern part of the Basin, augments Raritan water supplies. In addition, ground water underlies the entire Basin. This ground water system receives water from land surfaces and gradually releases the water to surface waters and to wells. All in all, the Basin covers approximately 1,100 square miles and includes all or parts of 100 municipalities (Figure 4).

The Raritan Basin provides water to approximately 1.2 million people in central New Jersey, including drinking water, irrigation water for farms, nurseries and golf courses, and processing water for industries. In addition, the Basin is also used for many recreational activities including boating, fishing and hiking and provides habitat for many aquatic and terrestrial organisms. Each of the seven counties and 100 municipalities brings unique administrative, economic, demographic and physical attributes to the Basin which will be discussed in detail in the following sections.

Topography, Geology and Soils

Topography

The topography of the Raritan Basin ranges from sea level to less than 100 feet above mean sea level (msl) near the Raritan Bay and to elevations of approximately 1,400 feet near Budd Lake in the headwater areas of Morris County. The area in the northern-most part of the Basin includes steeply sloping incised stream valleys with more modest slopes along ridgelines. This area's scenic qualities are closely related to the hills and valleys formed by stream channels. Figure 5 provides an indication of the elevations and contours that contribute to sloping land throughout the Basin.

The Raritan Basin exhibits a considerable variation in its landforms, surface and bedrock materials, and in the soils derived from them. Variations in rock type and geologic history of different regions of the State have created four different physiographic provinces which include the Valley and Ridge, Highlands, Piedmont, and Coastal Plain provinces. The Raritan Basin is located within portions of the Highlands, Piedmont and Coastal Plain provinces as indicated on Figure 5.

Elevations within the Highlands range from 300 to 1410 feet, while elevations in the hills and swamps of the Piedmont province range from 160 to 600 feet. Some of the highest elevations in the State occur in the Highlands because of the Precambrian rocks resistance to erosion.[2] Waters within the Coastal Plain portion of the Basin flow northward toward the Raritan Bay where elevations range from a high of 250 to 500 feet in the southeastern corner of the Basin, to a low of less than 100 feet (and close to sea level in some places), particularly near the Raritan Bay.

Each of the three provinces within the Basin consist of different types of rock and deposits of sand, gravel and silt with characteristic properties. These properties are associated with characteristic aquifer units and ground water flow types that will be discussed in further detail in the section on ground water hydrology.

Geology

Highlands

The present surface features of northern New Jersey are due almost entirely to erosion of older and higher land masses and the effects of the Wisconsinan glaciation that left behind the terminal moraine which constitutes a narrow band of the Highlands region. A small area of the terminal moraine intersects the very northern portion of the Upper Raritan WMA in the Basin.[3] The greater hills and the mountains of the Highlands (including the Allamuchy Mountains), and northern New Jersey have their present elevation because they are made of harder rock and have been eroded less rapidly than other areas. Present surface features are the result of long-continued weathering and erosion over hundreds of millions of years, on rocks of different degrees of resistance and of different modes of arrangement.[4]

The Highlands physiographic province is located within the northern portion of the State and covers approximately 12% of New Jersey's land area and 17% of the Raritan Basin (Table 1). The geologic formations of the Highlands region are estimated to be approximately 1 billion years old. Elevations in the northern part of the Basin in the Highlands average approximately 1,000 feet above msl, while the southern part of the Highlands shows valley contours reaching a low of 350 feet. Ridges of the Highlands have resisted erosion due to the very hard rock, (sandstone, gneiss, granite, marble, quartzite, igneous and metamorphic material) of which they are made. Highland valleys consist of much softer materials of limestone or shale, making them less resistant to erosion. The soils of the Highlands have been weathered from glacial till deposits and eroding bedrock and are generally shallow and stony, with frequent rock outcrops.[5]

Piedmont

The Piedmont physiographic province is located in the northcentral part of New Jersey and covers approximately 20% of the State's land area and 61% of the Raritan Basin (Table 1). The bedrock of the Piedmont is comprised primarily of consolidated shales, siltstones, sandstones, conglomerates and igneous rocks. Sedimentary units include the Stockton and Lockatong Formations and the Brunswick Group. Other formations in the Piedmont include igneous diabase that makes up the Sourland Mountains and basalt flows which comprise the Watchung Mountains (Figure 6).

The Piedmont is comprised of gently rolling terrain, which is dissected by a series of broad, winding river valleys. The gentle contour of the landscape is interrupted by a number of distinctly higher, rocky ridges and hills, including Cushetunk Mountain which surrounds Round Valley Reservoir, the Sourland Mountains and the Watchung Mountains, all of which formed from the diabase or basaltic rocks which are much harder than the shale and sandstone of the Piedmont lowlands (Figure 7).

Exposed rock and soil at the surface of the Piedmont is the product of intense weathering of local bedrock and the influence that glacial ice sheets had on the landscape. Continuous cycles of freezing and thawing in the rocks and soils produced landform characteristics consisting of subsurface depressions and uneven ground. Boulder fields, like those found on the Rocky Hill Ridge, were heaved to the surface by the expanding and contracting of the permafrost during glacial periods. Meltwater streams deposited sediment on the landscape and subsequent weathering and erosion have continued to shape and reshape the surface and produce the modern soil profile of the Piedmont province.

Coastal Plain

The Coastal Plain, which covers approximately 60% of the State's land and 22% of the Raritan Basin, is located in the southeastern portion of the Basin and is comprised primarily of deposits of clay, silts, sands and gravels (Table 1). Lower elevations of the Coastal Plain consist mostly of unconsolidated materials (particles that are not cemented together). Changes in sea level between glacial and interglacial periods, combined with continuing wave erosion and deposition, have sculpted the coastal area of New Jersey.[6]

The portion of the Coastal Plain that is located within the Raritan Basin consists of sand-sized aggregates of glauconite and contains a wide variation of drainage conditions. In some areas, a high water table has resulted in the formation of extensive areas of wetlands. Underlying geologic strata of the Coastal Plain consist of sediments deposited during the Tertiary and Cretaceous periods. These sediments include sands, silts, and clays of marine and continental origin that were deposited in cyclical transgressions and regressions of the sea throughout this time resulting in permeable sands overlying layers of relatively impermeable clays and silts.[7]

Table 1 - Summary of Geological Features of the Raritan Basin

Physiographic Province	Composition	% of New Jersey's Land Area	% of Raritan Basin
Highlands	Ridges comprised of hard rock materials including sandstone, gneiss, granite, marble, quartzite, and igneous and metamorphic material; Limestone valleys consist of softer materials of limestone and shale.	12%	17% (Northwest portion of Basin)
Piedmont	Comprised primarily of consolidated shales, siltstones, sandstones, conglomerates and igneous rocks.	20%	61% (Central portion of Basin)
Coastal Plain	Comprised primarily of deposits of clay, silts, sands and gravels.	60%	22% (Southeast portion of Basin)

Source: Wilber, Charles, P., and Johnson, Meredith E., 1940 and Tedrow, John, C.F. 1986.

Soils

Highlands

The dominant soils within the Highlands region of the Basin (Figure 8) consist of the Parker and Gladstone (formerly Edneyville) series. These are well-drained, gravelly sandy loams and loams formed in weathered gneissic bedrock in the uplands. Annandale soils, formed in old glacial till, are also extensive on broad undulating ridgetops. These soils are well-drained but contain a water restrictive horizon (fragipan) in the subsoil.

Bartley, a moderately well-drained soil formed in old glacial till or colluvium, is important in the limestone valleys. Poorly drained Cokesbury soils, also formed in old glacial till or colluvium, are found in depressions and waterways.

Some very poorly drained soils, also found in depressions or along low-gradient streams, are formed in organic deposits (Carlisle series).

Piedmont

The most extensive soil in the Piedmont area is the Penn series (Figure 8). This is a moderately deep (20 to 40 inches to bedrock), well-drained, silty soil formed in weathered red shale. Other important well-drained, deep soils formed from sedimentary rocks include Bucks (red shale), Quakertown and Hazleton (sandstone), and Pattenburg (red conglomerate). Areas of shallow soils, (less than 20 inches to bedrock), Klinesville, and poorly drained soils, Croton are also found on uplands.

Soils associated with Round Valley, and the Watchung and Sourland Mountains formed in weathered igneous rocks, diabase or basalt. The important series are the well-drained Neshaminy and moderately well-drained Mt. Lucas.

On outwash terraces, the well-drained, moderately coarse textured Dunellen soils are extensive.

Soils associated with floodplains of the Piedmont consist of silty soils that formed in recent alluvium. A variety of drainage conditions are encountered here.

Several soil associations in the eastern part of the Basin have been designated as urban land areas. According to the United States Department of Agriculture – Natural Resources Conservation Service (USDA-NRCS), urban lands are defined as areas in which 80% or more of the ground surface is covered by asphalt, concrete, buildings, or other impervious surfaces; most unpaved sections have been cut or filled. Examples include city centers, parking lots, shopping centers, industrial parks, and high-density housing. Slopes range from nearly level to gently sloping (0 to 8 percent). According to Figure 8, there are several large areas to the north of the Raritan River (proximate to the Raritan Bay) in Middlesex and Union Counties that have been designated as urban land associations.

Coastal Plain

The most common soils in the Coastal Plain area of the Basin include Sassafras (well-drained) and Woodstown (moderately well-drained), formed in moderately fine textured sediments (Figure 8). Other important soils include Downer, a well-drained, moderately coarse textured soil, and Keyport, a moderately well-drained soil formed in fine textured materials, as well as some sandy soils including Evesboro (well-drained) and Klej (moderately well-drained to somewhat poorly drained).

There are considerable areas of moderately fine textured Fallsington soils in low-lying, poorly drained areas.

Soils with high amounts of organic matter are common on floodplains (Manahawkin, Humaquepts) and tidal marshes (Sulfihemists).

Soil Surveys

Soils in the Raritan Basin have been surveyed and mapped by the USDA. A soil survey contains soil maps, descriptions of the soils, and soil interpretations. Soil interpretations are developed to predict soil behavior for specific soil uses and under specified management practices. Interpretations can be used to plan broad categories of land use (cropland, urban development) and to plan specific management practices (irrigation, equipment use). Soil behavior is predicted by observing and recording soil responses to specific uses and management practices.

Soil surveys place soil into hydrologic groups according to runoff potential. This is done according to the minimum infiltration rate for bare soil after prolonged wetting. Soil properties that influence runoff potential include depth to water table, infiltration and permeability, and depth to slowly permeable layers.

The USDA has placed soil series into four basic hydrologic groups with the following characteristics:

- Group A soils are deep, well to excessively drained, sandy and gravelly soils which have a low runoff potential, high infiltration rate and a water transmission rate greater than 8.0 inches/hour.

- Group B soils are moderately deep, to deep, moderately well to well-drained, fine to moderately coarse textured soils with moderate infiltration rates and a water transmission rate of 0.8 to 8.0 inches/hour.

- Group C soils are moderately fine to fine textured soils, with an impeded downward movement of water, low infiltration rates and a water transmission rate of 0.08 to 0.8 inches/hour.

- Group D soils are shallow with a high permanent water table or a claypan or clay layer near the surface. These soils have a high swelling potential, high runoff potential, low infiltration rates and a water transmission rate of less than 0.08 inches/hour.

Dual hydrologic groups are given for certain wet soils that can be adequately drained. The first letter applies to the drained condition, the second to the undrained:

- Group A/D
- Group B/D
- Group C/D

Within the Basin, the majority of soils are classified as Hydrologic Groups B and C which are indicative of moderately well-drained soils with moderate to low infiltration rates (Figure 9). The Highlands portion of the Basin consists mostly of Group B soils, Parker and Gladstone, while the Piedmont portion consists primarily of Group C soils, mostly Penn soils. These groupings are due in part to the underlying geology of the provinces and its effect on soil properties, and in part to soil drainage conditions throughout the Basin. Group A soils, which are evident along streams and in some low-lying topographic areas, are very important for their surface and ground water recharge capabilities. As indicated on Figure 9, Group A soils are limited to the southeastern corner of the Basin (i.e., the Coastal Plain) where they occur in areas associated with the South River and its tributaries. These include sandier, well-drained soils such as Evesboro.

In the northwestern portion of the Upper Raritan WMA, soils consist mostly of Group C, while the southeastern portion of the watershed is comprised of a mix of Groups B and B/C. Soils within the Coastal Plain and the lower reaches of the Lower Raritan and Millstone watershed areas are the most diverse in the Basin, and are comprised mostly of Group C/D with a mix of Groups A, B and B/D. The Lower Raritan WMA contains a mix of all 7 combinations of soils, but consists mostly of Class D soils in the lower elevations of the Basin, particularly tidal marsh soils (Sulfihemists and Sulfaquents) in the vicinity of the Raritan Bay and adjacent low-lying areas.

Surface Water Hydrology

The Raritan Basin encompasses three Watershed Management Areas within the State which include the Upper Raritan (WMA 8) that encompasses 43% of the Basin, the Lower Raritan (WMA 9) which encompasses 33% of the Basin, and the Millstone (WMA 10) which encompasses 24% of the Basin. These three WMAs include a number of major watersheds and contain approximately 2,000 mapped miles of flowing streams within the Basin (Figure 10).[8] According to the NJDEP, the major streams in the Basin have been identified as the North Branch of the Raritan River, the South Branch of the Raritan River, the Lower Raritan River (including Green Brook), the Millstone River, the Lawrence Brook and the South River. Also indicated on Figure 10 is the “HUC System” which is the national hydrologic unit code system used by the United States Geological Survey and the NJDEP as a way to identify individual watershed areas. There are 16 designated HUC-11 (i.e., 11-digit code) watersheds within the Basin.

The mainstem of the Raritan River originates at the confluence of the South Branch and North Branch in Branchburg Township, flows for 35 miles in an easterly direction, and discharges into the Raritan Bay. Much of the mainstem of the Raritan River is tidal, and influenced by the Raritan Bay. Based on a tidal study conducted by Omni Environmental Consultants in 1991 and confirmed by the NJDEP, the Head of Tide in the Raritan River 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). Measurements conducted by Omni at the Landing Lane Bridge over the mainstem of the Raritan River in New Brunswick indicated 4-foot elevation changes, but no reversal in the direction of flow at this location.

The South Branch of the Raritan River is 51 miles long from its source in Budd Lake to its confluence with the North Branch. 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. The Raritan River drainage basin covers approximately 1,100 square miles, making it the largest river basin located entirely within the State of New Jersey.

Major streams within the Raritan River Basin (other than those noted above) include Spruce Run, Mulhockaway Creek, Neshanic River, Lamington River, Rockaway Creek, Millstone River, Stony Brook, Bedens Brook, Matchaponix Brook, and Manalapan Brook. Major impoundments in the Basin include Spruce Run Reservoir, Budd Lake, and Round Valley Reservoir.[9]

Major potable water systems within the Basin include Spruce Run Reservoir, Round Valley Reservoir and the Delaware and Raritan 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 an analysis of service areas and connections throughout the Basin). The D&R Canal is used also for augmenting water to the Raritan River in the City of New Brunswick and the Millstone River in the Township of Somerset. According to the New Jersey Statewide Water Supply Plan prepared by the NJDEP Office of Environmental Planning in 1996, the total water use in the Basin in 1990 was approximated at 202 million gallons per day (MGD) with 122 MGD (60%) of the total water use being supplied by surface water resources.

The Highlands Region contains numerous wetlands and mountain streams that flow down through rocky ravines south and east to the Piedmont, and comprise many of the headwaters for the Raritan Region. These streams and wetlands provide important habitat for a broad array of animal and plant species and are critical for the survival of more than 20 species of threatened and endangered animals.[10] Streams of the Highlands are well oxygenated and of high quality as indicated by high populations of aquatic insects and pollution-intolerant macroinvertebrates.[11]

The portions of the Piedmont and Coastal Plain that are located in the Basin are drained by a number of meandering streams that have well developed floodplains. Large portions of these areas are covered by large tracts of wetlands which formed on poorly drained soils and impermeable bedrock. However, due to heavy development in the region, surface waters have become impaired and natural drainage patterns have been altered due to damming, diversions and drainage.

As indicated on Figure 11, 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 larger 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.

Ground Water Hydrology

The geology and soils of an area directly affect the quantity and quality of surface and ground water in a watershed. Certain properties of geologic formations, such as permeability or depth to bedrock, determine the potential for well yield or ground water contamination.[12]

Due to the differences in geology, topography and the location of major waterways throughout the State, the ratio between ground water and surface water use varies considerably. Underlying geologic formations determine the capacity for ground water storage, while natural topography has an influence on above-ground storage areas such as lakes and reservoirs. Although the southern half of the State generally relies more heavily on ground water resources than does the northern half, approximately 40% of the total daily water use in the Raritan Basin (i.e., 80 MGD of the 202 MGD total use in 1990) is supplied by ground water resources.

Aquifers

Highlands

The Highlands province contains some formations that are among the oldest in New Jersey. Bedrock in the Highlands consists of Precambrian gneiss, igneous rocks and the Green Pond Outlier, a belt of Paleozoic age sedimentary rocks (Figure 6). Water movement in the Highlands occurs primarily through joints, fractures and bedding planes in the formations on a very local scale. The Precambrian aquifers do not generally produce large yields, except near streams or where wells intercept major fault zones and are often hydraulically connected with surface waters, particularly in the lower-lying limestone valleys. Some areas in the Highlands section of the Basin are underlain by carbonate rocks (e.g., limestone valleys) that are water soluble and very prolific aquifers.[13] These areas have high water yield potentials and are found in several areas of the Basin, specifically in Hunterdon and Morris Counties. Recent modeling by the United States Geological Survey has shown that carbonate aquifers are capable of regional water movements.

The range of stream flow values for the Highlands is comparatively large. The high baseflow reflects the high total streamflow, which in turn, appears to be correlated with generally higher precipitation found in this area of high elevation and the high recharge capacity of soils in the limestone valleys.[14]

Piedmont

The Piedmont is composed of consolidated shales, siltstones, sandstones, conglomerates and igneous rocks. Sedimentary units include the Stockton and Lockatong Formations and the Brunswick Group. Other formations in the Piedmont which have limited water bearing potential include igneous diabase sill deposits (i.e., the Sourland Mountains) and basalt flows which comprise the Watchung Mountains. Water movement in the consolidated rocks is primarily through channels called joints and bedding planes which were created by the original deposition and subsequent movement of the rock formations. Water movement also occurs in fractures which formed as a result of tectonic stresses that occurred after consolidation of the rock material. This type of flow allows relatively limited movement of water through the aquifer system, though some wells in the Brunswick Group can produce large volumes of water. Formations of the Piedmont are hydraulically connected with local streams, except where covered by semiconfining glacial deposits in the northern parts of the Basin.

Ground water in the fractured bedrock of the Piedmont provides an important source of water for domestic, industrial and public supply wells.

The Piedmont, where glacial cover is thin or absent, such as in the Upper Raritan WMA, tends to contain "flashy" streams. These streams have extremely high flows during precipitation events but very low flows between precipitation events, reflecting poor recharge rates for Piedmont aquifers.

Coastal Plain

The Basin includes four major aquifer systems of the Coastal Plain province as indicated on Figure 7. These four major aquifers include the Potomac-Raritan-Magothy, Englishtown, Mount Laurel-Wenonah, and the Kirkwood-Cohansey, which are separated by clay or silt layers that act as confining or semi-confining barriers to separate them. While these units exist within the Basin, the major portion of each aquifer extends beyond the Basin boundaries. Water withdrawals from these confined coastal plain aquifers in the Lower Raritan WMA is partially restricted by the NJDEP as part of the critical areas program of the water supply element. Restrictions have been implemented to prevent salt-water intrusion into these very productive aquifers.

The Raritan-Potomac-Magothy, Englishtown, and Wenonah-Mount Laurel aquifers are present at depths ranging from exposed areas along the ground's surface to approximately 1,500 feet below msl. The Kirkwood-Cohansey formation is exposed in several locations of the southern portion of the Basin. The Englishtown aquifer in the vicinity of the Millstone and South Rivers is approximately 100 feet thick, and has a recharge area of about 50 square miles. Ground water recharge in the Basin occurs primarily along the Middlesex - Monmouth County line in the Coastal Plain.[15]

The Wenonah-Mount Laurel aquifer system averages a thickness of approximately 40 feet and has a 48 square mile outcrop area along the border of Middlesex and Monmouth counties. Recharge to the aquifer occurs as a result of vertical leakage through the overlying Navesink, Red Bank Sand and Hornerstown Sand formations that are situated to the east of the Wenonah-Mount Laurel outcrop area.[16]

The Kirkwood-Cohansey aquifer which is located in the Kirkwood Formation and overlain by patches of Cohansey Sand, ranges from a depth of several feet to approximately 80 feet below msl and is the uppermost aquifer in the formation. Water levels in the aquifer range from at or near the ground's surface to a depth of 20 feet below msl. This aquifer is significant for its high recharge capabilities due to the perviousness and composition of the Upper Kirkwood Formation.[17]

Climate

Precipitation Patterns

Water continuously recycles itself through a natural process referred to as the hydrologic cycle. Stated simply, precipitation that falls to the earth either evaporates or transpires (a process known as evapotranspiration), runs off the land into surface water bodies, falls directly into surface waters, or infiltrates into the ground. Evapotranspiration refers to the loss of water from soil or other land surfaces by evaporation and the release of water vapor from plants. Runoff is that portion of the water that enters our streams, lakes and oceans by overland flow. Infiltration is the process by which water enters the ground and either recharges ground water or contributes to stream flow. All water eventually re-enters the atmosphere and the cycle repeats itself. Measurements of precipitation, stream flows, and ground water levels are useful in estimating water supplies and provide much needed information about the movement of water through the environment.[18]

The physiographic provinces provide a pattern for the geographic distribution of rainfall throughout the State, with the greatest rainfall amounts falling in northern New Jersey. According to information obtained from the United States Department of Agriculture/Office of the Chief Economist Middle Atlantic River Forecast Center, the mean annual precipitation for the Highlands region averaged 49 inches, the Piedmont averaged 45 inches and the Coastal Plain region averaged 46 inches over a 30-year period between 1961 and 1990. Precipitation amounts average approximately 44 inches annually for the State of New Jersey and are distributed fairly uniformly throughout the year.

While the Basin receives a significant amount of rain, averaging approximately 47 inches a year, the pattern and frequency of the precipitation (as rain and snow) can cause serious problems both to natural systems and society. Moderate amounts of rainfall generally assist in the recovery of ground water during dry periods; however, heavy rains for extended periods of time can result in an increase of surface water runoff which can result in severe flooding problems.

Nearly every year however, there are periods when rainfall is not enough to supply moisture for high-value crops and other water supply demands. Extended dry weather patterns result in the lowering of water supply reservoirs and excessive declines in ground water levels which puts a stress on major water supply sources. While precipitation is relatively even throughout the year (on average), evapotranspiration is by far the highest during the warmer months. This phenomenon results in significant reductions in stream flow during summer months and compounds the effects of drought.

As noted above, precipitation levels throughout the Basin also vary from the northern end to the southern end due to major geographical features that alter precipitation patterns. Differences in the amount of runoff between sections of New Jersey are due to varying precipitation, the water-holding capacity of different soil types and varying water tables. Runoff varies both geographically and seasonally throughout the State, with March and April exhibiting periods of highest runoff. Generally, northern New Jersey has a greater amount of runoff than southern New Jersey due to high slopes, thin soils with lower infiltration rates and larger amounts of snow during winter months.[19]

Of the 50 rain gage stations monitored by the Office of the New Jersey State Climatologist at Rutgers University, there are 8 monitoring stations located within the Raritan Basin (Figure 12). According to available data for November 1997 through December 1999, precipitation levels for 4 of the 8 stations in the Basin (Table 2) indicate precipitation amounts above average for the end of 1997 and the first six months of 1998 and below average for the last six months of 1998. With the exception of January and March, the first several months of 1999 were also relatively low as compared with 1961-1990 averages.

Table 2 - Precipitation Averages for the Raritan Basin
Comparison of 1961-1990 Averages to 1997-1999 Totals (in inches)

Station Location	**Month**											
	J	**F**	**M**	**A**	**M**	**J**	**J**	**A**	**S**	**O**	**N**	**D**
Flemington												
1961-1990 Average	3.71	3.14	3.79	4.09	4.61	4.17	4.86	3.91	3.93	3.45	4.03	3.87
1997 Total	--	--	--	--	--	--	--	--	--	--	3.33	3.83
1998 Total	4.23	4.72	4.13	6.44	--	--	--	1.28	--	--	--	--
1999 Total	7.38	2.64	3.24	2.94	2.71	0.77	0.69	4.54	12.41	3.08	--	--
Freehold												
1961-1990 Average	3.45	3.17	3.96	3.92	4.02	3.59	4.71	4.37	3.84	3.23	4.17	3.78
1997 Total	--	--	--	--	--	--	--	--	--	--	5.43	4.41
1998 Total	5.35	6.3	6.57	5.0	5.82	4.93	2.15	2.24	2.88	1.75	1.07	0.94
1999 Total	8.6	2.57	5.3	--	--	1.1	1.27	--	--	--	--	--
Hightstown												
1961-1990 Average	3.28	2.94	3.65	3.95	4.23	3.53	5.08	4.5	4.11	3.15	3.83	3.63
1997 Total	--	--	--	--	--	--	--	--	--	--	3.28	4.08
1998 Total	4.47	3.3	4.67	4.51	6.07	4.48	1.53	6.33	2.11	1.71	1.4	--
1999 Total	4.9	2.65	--	2.72	4.16	0.77	1.76	7.16	10.09	3.51	2.36	3.25
New Brunswick												
1961-1990 Average	3.51	2.94	3.8	3.99	4.54	3.49	4.96	4.26	4.4	3.2	4.11	3.82
1997 Total	--	--	--	--	--	--	--	--	--	--	3.81	4.05
1998 Total	4.65	5.26	4.53	5.92	6.16	6.69	1.11	2.1	2.62	2.68	1.18	0.93
1999 Total	7.18	2.74	4.79	2.47	4.21	1.08	0.99	5.40	9.63	2.77	2.36	3.08

Source: Office of the State Climatologist, Rutgers University, Precipitation Amounts 1961-1990 and Monthly Climate Maps November 1997 - June 1999.

Note: -- indicates data not available.

Heavy rainfall in November and December of 1997 and the first six months of 1998 preceded a dry summer, fall and winter. At the end of June 1998, most of the Basin had received approximately 32 inches of precipitation, 10 inches above the 22-inch average for the first half of the year. The last 6 months of 1998, however, received only about 11 inches of precipitation compared to the 24 inches that usually occur. The first six months of 1999 also showed significant precipitation lows, with averages from January through June being several inches below normal (Figure 12). The summer of 1999 (June and July) experienced significant precipitation lows which caused reservoir levels, surface water flows and ground water levels to drop considerably below normal. This pattern resulted in a severe drought and water restrictions throughout much of the State.

Record amounts of rainfall for September (approximately 7 inches above the monthly norm) were attributed to Hurricane Floyd. According to Figure 12, the highest rainfall amounts during Hurricane Floyd were recorded in Bridgewater and Flemington and the central region of the Basin. The remainder of 1999 received precipitation amounts slightly below normal. Assessment of precipitation levels, ground water levels and stream flows determine short term needs and long term trends that are used to make recommendations to better prepare for future conditions such as flooding and drought.

Temperature Variability

Mean annual temperature within the State is approximately 54 degrees Fahrenheit (12 degrees Celsius), with lower temperatures occurring in the northern mountains. Average annual temperatures are shown in Figure 13. The start of the vegetative growing season ranges from mid-March in the southern part of the State to early April in the northern part. Climate may be highly affected by land elevations and varying topography throughout the State.[20]

New Jersey has a climate with four distinct seasons and five distinct climate zones: north, central, pine barrens, southwest, and coastal. Their geology, distance from the Atlantic Ocean, and prevailing atmospheric flow patterns produce distinct variations in the daily weather between these regions.[21] Temperature differences between the northern and southern parts of the State are greatest in winter and least in summer. All 5 climate zones have registered readings of 100 degrees Fahrenheit (38 degrees Celsius) or higher and have records of 0 degrees Fahrenheit (-18 degrees Celsius) or below. The Raritan River Basin is located in portions of the north, central and coastal climate zones.

The northern climate zone normally exhibits a colder temperature regime than other climate regions of the State. The difference is most dramatic in winter when average temperatures are sometimes 10 degrees Fahrenheit cooler than in the coastal zone. Annual snowfall averages 40 to 50 inches in the northern zone as compared with an average of 10-15 inches in the extreme southern portion of the State. The mountains of the Highlands play a role in making the climate of the northern zone different from the remainder of the State. Following the passage of a cold front, air that is forced to rise over the mountains produces clouds and precipitation while the rest of the State observes clear skies. During the warm season, thunderstorms moving east from Pennsylvania and the mid-west often move into the northern part of the State, where they reach maximum development in the evening. This region has approximately twice the number of thunderstorms as the coastal zone, due to stabilized atmospheric conditions near the ocean.[22]

The northern edge of the central zone forms a common boundary between freezing and non-freezing precipitation during wintertime. In summer, areas in the southern portion of the central zone tend to have twice as many days with temperatures above 90 degrees Fahrenheit (32 degrees Celsius) than the 15-20 commonly observed areas in the central portion of the State.[23]

In the coastal climate zone, continental and oceanic influences can dominate conditions. In autumn and early winter, the ocean is generally warmer than the land surface, and the coastal zone experiences warmer temperatures than interior regions of the state. In spring, ocean breezes keep temperatures along the coast cooler. Because the ocean has a higher heat capacity compared to the land, seasonal temperature fluctuations tend to be more gradual and less prone to extremes in this region.[24]

In the Raritan Basin, the annual mean temperature for 1998 was approximately 38 degrees Fahrenheit (3 degrees Celsius) in January, and 72 degrees Fahrenheit (22 degrees Celsius) in July. In 1999, the annual mean temperatures for January and July were 32 degrees Fahrenheit (0 degrees Celsius) and 80 degrees Fahrenheit (27 degrees Celsius), respectively. Winter variations between the northern and southern region of the Basin as indicated on Figure 13, are due primarily to the influence of the mountains in the Highlands, and the proximity of the Atlantic Ocean in the coastal plain where temperatures are moderated by ocean currents. Over the last 30 years, temperatures for the north, southwest and coastal regions of the State during the month of January have averaged 27.9, 31.5 and 33.2 degrees Fahrenheit (-2, -0.3 and 0.7 degrees Celsius) respectively, whereas July temperatures have averaged 73.2 degrees Fahrenheit (23 degrees Celsius) for the north, 75.1 degrees Fahrenheit (24 degrees Celsius) for the southwest and 74.6 degrees Fahrenheit (24 degrees Celsius) for the coastal region. [25]

Variations between winter and summer are also particularly important to vegetation and the length of the growing season. The vegetative growing season is referred to as the number of consecutive days on which the average temperature is above 43 degrees Fahrenheit (6 degrees Celsius), the point above which it is believed that most plant growth starts. The length of the growing season varies between approximately 225 days in the Highlands to a length of 245 days in the Coastal Plain, a difference of approximately 3 weeks within the Basin.[26]

Other temperature variations also exist between urban and rural areas of the Basin. Temperatures in cities and other developed areas generally exhibit higher overall temperatures than in rural areas due to the large number of buildings and impervious surfaces that exist in urban areas. Urban areas generally contain a concentration of heat-creating sources such as residences, businesses, vehicles and industrial plants. This heat, in addition to solar radiation, is reflected and stored by pavement and building structures. Elevated temperatures in urban areas are particularly noticeable during the summer months. Temperature differentials between developed and less developed surrounding areas have increased continuously over the last 50 years and will continue to increase as the landscape becomes more developed. In addition, cites tend to have 10% more precipitation, 10% more cloudiness, 30% more fog in summer and 100% more fog in winter than surrounding areas that are less developed.[27]

Land Use

Historic Land Use Patterns

European settlers began to colonize the central areas of the Raritan Basin in the middle of the seventeenth century, especially in the fertile lowlands and valleys. Large areas of forest were slowly cleared throughout colonial expansions for timber and fuel and were replaced with fields and pastures.

By the early 1800s, New Jersey had developed into an industrialized state. New factories cut down and used most of the surrounding forests for making charcoal. Soon after the depletion of New Jersey's forests, people in Pennsylvania discovered coal and began mining for it. Trenton and New Brunswick became important commercial river ports and the Delaware and Raritan Canal system was eventually built in 1834 to connect the two cities and establish a faster route across the center of the State. The canal system became an important trade corridor in Central New Jersey due to the high expense to transport coal by rail. Towns and farmers along the route benefited from the traffic generated by the Canal until operations ceased in 1932 when traveling by rail became faster and less expensive. The canal system was eventually replaced by railways and then the modern highways which now crisscross the landscape (Figure 14). U.S. Route 1 which was one of the major highways constructed during the early part of the century, extends from northeast to southwest directly across the heart of the Raritan Basin, along the boundary between the Piedmont and Coastal Plain provinces.

Early industry of the central region of the Basin consisted of brick making from the deep clay beds of the Raritan River. In 1825, the biggest clay manufacturer was started, and by 1878, 54 million bricks were produced annually by 8 brick yards along the Raritan River. Other industries of the central Raritan Basin included agriculture, transportation and industries that specialized in the production of organic chemicals, petroleums and primary metals. Today, major industries in the region are involved in the production of pharmaceuticals, plastics, adhesives, coatings and solvents. In the late 1980s, more than 100 of the country's largest industries had facilities located in Middlesex County.[28]

Over the past several decades, the Raritan Basin has experienced a shift in its development pattern and has been subjected to an unprecedented amount of development in rural areas. For New Jersey as a whole, employment opportunities have nearly doubled in recent years, while jobs in urban areas and the major cities of the State have declined by approximately 35 percent. Since the 1950s, hundreds of thousands of acres of rural and agricultural lands have been converted to sprawling subdivisions which has resulted in increased traffic congestion, loss of agricultural lands, polluted streams, loss of wetlands, deteriorating urban centers, and other impacts of poorly planned growth.[29]

Since the early 1950's New Jersey's population has grown at a moderate pace, but the pattern of land use has changed far more dramatically, resulting in a sprawl of urban and suburban areas. Even as early as the mid 1960's these changes heightened the public's awareness and appreciation of the benefits of open space preservation. Concern over the impacts of sprawl and the public's burgeoning desire for outdoor recreation opportunities ultimately resulted in the passage in 1961 of New Jersey's first Green Acres Bond Referendum. Despite New Jersey's strong record of open space preservation, the state has lost more than half the farmland it had in 1950, and new developments continue to consume thousands of acres of open lands each year.[30]

Modern Trends

Today, land uses along the mainstem of the Raritan River consist primarily of urban and suburban developments with a number of industrial and commercial centers. Land uses along the South Branch of the Raritan River are mostly agricultural, but suburban and industrial developments are increasing at a rapid rate. Land use along the North Branch of the Raritan River is primarily rural and consists of large woodland tracts and agricultural lands. Commercial and residential areas are scattered along the North Branch of the Raritan River, and development is notably increasing along major roads. Land uses along the Millstone River consist primarily of suburban developments and a number of scattered agricultural areas.[31]

Land uses in the northern portion of the Basin consist primarily of residential development, with large areas devoted to public water supply and outdoor recreation. In recent years residential development has increased dramatically, and its environmental impact on watersheds has been a constant source of political controversy.[32]

Over the past few decades many of the dairy, horse and poultry farms located in the western portion of the Basin have been lost and the land rapidly developed, although many farms are still in operation. Corporate parks, specializing in industrial research and development, have become common, especially in the areas surrounding Princeton and New Brunswick. Residential developments have replaced old fields and pastures in newly expanded suburbs. Parks, forests and small areas on steep rocky ridges contain the remnants of remaining open space.

According to the 1986 land use and land cover data for the Basin (Table 3), approximately 23.0% (253.77 square miles) of the Basin consisted of agricultural land, 1.5% (16.21 square miles) of barren land, 27.3% (301.88 square miles) of forest, 30.5% (337.15 square miles) of urban land, 1.9% (20.55 square miles) of water areas, and 15.8% (174.96 square miles) consisted of wetlands.

Table 3 - Comparison of Land Use Types 1986-1995 for the Raritan Basin

Land Use Type	1986 Total for Basin		1995 Total for Basin		Change between 1986-1995	
	mi^2	%	mi^2	%	mi^2	%
Agriculture	253.77	23.0	211.93	19.2	-41.84	-20
Barren Land	16.21	1.5	15.27	1.4	-0.94	-6
Forest	301.88	27.3	293.84	26.6	-8.04	-3
Urban	337.15	30.5	394.12	35.7	56.97	+14
Water	20.55	1.9	21.0	1.9	0.45	+2
Wetlands	174.96	15.8	168.36	15.2	-6.6	-4

Source: NJDEP, Office of Information Resources Management, Bureau of Geographic and Information Analysis, 1996.

For clarification purposes, definitions for each of the land use and land cover categories as defined by the NJDEP Geographic Information System Digital Data are provided below:

- "Agricultural land includes all lands used primarily for the production of food and fiber and some of the structures associated with this production. Categories of agricultural land include: cropland and pastureland; orchards; vineyards; nurseries and horticultural areas; and confined feeding operations."

- "Barren lands are characterized by thin soil, sand or rocks and a lack of vegetative cover in a non-urban setting. Barren land such as beaches and rock faces are found in nature, but also result as a product of human activities. Extraction mining operations, landfills and other disposal sites compose the majority of human-altered barren lands."

- "Forest land contains any lands covered by woody vegetation other than wetlands. These areas are capable of producing timber and other wood products, and of supporting many kinds of outdoor recreation. Land use categories under forest land are deciduous; coniferous; mixed deciduous-coniferous; and brushland."

- "Urban land is characterized by intensive land use where the landscape has been altered by human activities. Although structures are usually present, this category is not restricted to traditional urban uses. Urban land includes the following categories: residential; commercial and service; industrial; transportation; communication and utilities; industrial and commercial complexes; mixed urban or built-up; other urban or built-up; and recreational areas."

- "Water areas are all areas that are periodically covered by water including streams and canals, natural lakes, artificial lakes, bays and estuaries. Not included in this category are water treatment and sewage treatment facilities."

- "Wetlands are those areas that are inundated or saturated by surface or ground waters at a frequency and duration sufficient to support vegetation adapted for life in saturated soil conditions. Included in this category are naturally vegetated swamps, marshes, bogs and savannas which are normally associated with topographically low elevations but may be located at any elevation where a perched water table is present. Wetlands that have been modified for recreation, agriculture or industry are not included in this definition."

Figure 15 illustrates the 1986 land use percentages by HUC-11 (i.e., watershed areas determined by the United States Geological Survey) within the Basin. According to Figure 15, urban land uses are significantly greater in the eastern portion of the Basin than in the north and west due to the historic concentration of development in the eastern counties. Figure 16 provides a detailed breakdown of the land use percentages by each HUC-11 watershed.

Land use totals for 1995 (Table 3) were approximately 19.2% (211.93 square miles) agricultural land, 1.4% (15.27 square miles) barren land, 26.6% (293.84 square miles) forest, 35.7% (394.12 square miles) urban, 1.9% (21.0 square miles) open water, and 15.2% (168.36 square miles) consisted of wetlands.

Figure 17 illustrates the 1995 land use percentages by HUC-11 within the Basin. Similar to Figure 15 (1986 land use percentages by HUC-11), urban land uses have remained high in the eastern part of the Basin, but have increased in other parts of the Basin, with the greatest increase having occurred in the Millstone WMA. Figure 18 provides a detailed breakdown of the land use percentages by each HUC-11 watershed for 1995, while Figures 19 and 20 illustrate the general and detailed land use/land cover classifications within the Basin.

Comparison of land use conditions in 1995 with those of 1986 reveal significant losses in agricultural land and increases in urban land as indicated in Table 3 above and Table 4 below. Figure 21 illustrates specific land cover areas that have changed to urban land since 1986. As seen in Figure 21, significant losses of agricultural land have occurred along the U.S. Route 1 corridor in the West Windsor/Plainsboro area of Mercer County, as well as in Raritan and Readington Townships in eastern Hunterdon County. Urban development has rapidly replaced agricultural land uses in many other areas of the Basin as well.

Figure 21 also depicts the greatest loss of wetlands in the Basin in the Lower Raritan WMA in northern Middlesex and eastern Somerset Counties. Loss of forested land has been greatest in the Upper Raritan WMA, especially in Morris County. Other changes that have occurred in the Basin since 1986 include an expansion of developed areas in western Monmouth County in the vicinity of Freehold Township, and along the Neshanic River in Hillsborough Township in Somerset County. Although the areas surrounding Green Brook and the South River have experienced minimal growth since 1986 (due in part to their already developed nature), there is still a noticeable decline in agricultural land uses in these areas.

Table 4 - Comparison of Land Use Types 1986-1995 (by WMA) For the Raritan Basin

Land Use Type	1986			1995		
	Upper Raritan WMA %	Lower Raritan WMA %	Millstone WMA %	Upper Raritan WMA %	Lower Raritan WMA %	Millstone WMA %
Agriculture	28.9	9.0	30.5	25.1	7.0	24.5
Barren Land	0.7	2.5	1.6	0.7	2.1	1.6
Forest	37.2	18.9	21.6	36.2	17.5	22.0
Urban	22.0	46.4	24.9	26.8	51.3	31.0
Water	2.0	2.3	1.1	2.0	2.4	1.1
Wetlands	9.3	20.9	20.4	9.1	19.7	19.9

Source: NJDEP, Office of Information Resources Management, Bureau of Geographic and Information Analysis, 1996.

Farmland

The data presented in Table 5 below provide information on how the agriculture sector is changing within the Basin. The information presented in the table is for the entirety of all seven counties, but reflects a general indication of change in the Basin. As the data indicate, the total number of farms in the 7 counties has decreased from 3,667 in 1987 to 3,586 in 1997; the amount of farmland has decreased from 328,345 acres in

1987 to 289,735 acres in 1997; and the average farm size has also decreased. This represents a loss of 11.8% of the total land in the agricultural sector, which exceeds the 6.9% loss for the State of New Jersey since 1987, indicating that the causes of farm loss are more intense in the Basin.

A possible reason for the losses indicated in Table 5 is that farmers are having a difficult time earning a living. Real estate property taxes have risen, and younger generations have less interest in farming than was the case in years past. Many existing farmers are retiring and frequently decide to sell part of, or their entire farm to land developers in order to make a profit. Many farmers are having a difficult time making a living because their relatively small farms do not afford the same economies of larger farms in other parts of the United States.[33]

Table 5 - Agriculture Census for the Seven Counties of the Raritan Basin

County	Total Number of Farms			Land in Farms (Acres)		
	1987	1997	% Change 1987-1997	1987	1997	% Change 1987-1997
Hunterdon	1,398	1,313	-6.1%	123,698	105,230	-15.0%
Mercer	309	285	-7.8%	41,303	28,391	-31.3%
Middlesex	252	275	+9.1%	25,222	28,100	+11.4%
Monmouth	840	874	+4.0%	65,846	59,405	-9.8%
Morris	430	383	-11.0%	27,086	22,351	-17.5%
Somerset	407	437	+7.4%	45,190	46,258	+2.4%
Union	31	19	-38.7%	449	(D)	--
Total for 7 Counties	**3,667**	**3,586**	**-0.2%**	**328,345***	**289,735***	**-11.8%**
Total for New Jersey	**9,032**	**9,101**	**+0.8%**	**894,426**	**832,600**	**-6.9%**

Source: USDA, Census of Agriculture 1999.
Notes: (D) indicates information withheld to avoid disclosing data for individual farms.
A +/- indicate gains or losses over the 10-year period.
An * indicates total calculated without Union County acreage

Open Space

Open space areas provide valuable habitat for wildlife, parklands for recreation, and aesthetic benefits for humans. As land development trends continue to increase in suburban areas throughout the Basin, the need to preserve open space has become more prevalent. Not only have state agencies and citizens of New Jersey realized the need to preserve the State's natural, historic and cultural heritage, they have also recognized the importance of acquiring and managing open space areas for use by wildlife and humans. In order to acquire open space areas, the NJDEP Office of Green Acres collaborates with other public and private organizations including municipal and county governments, nonprofit organizations, and the State Farmland Preservation Program to assist in buying and managing open space areas throughout the State. The Office of Green Acres also accepts donations of conservation and recreational lands that become part of the State's system of parks, forests, natural areas and wildlife management areas. Since the 1980s, private citizens interested in land preservation have donated more than 5,400 acres of land.[34]

Areas that have been designated for open space preservation within the Basin consist of state, county and municipal parkland areas, NJDEP Green Acres encumbrances, Division of Fish and Wildlife Management Areas, NJDEP Natural Land Areas[35] as well as privately owned nature preserves and wildlife management areas. Although there are a number of open space areas designated for preservation within the Basin, only those areas encompassing 500 acres of land or more have been included in Table 6 below. Figure 22 illustrates all of the Basin's open space areas that are listed in the NJDEP Green Acres Inventory.

Table 6 - Open Space Land Areas Greater than 500 Acres within the Raritan Basin		
Land Area	**Land Area in Acres**	**Watershed Management Area**
County and Municipal Green Acres Open Space Inventory		
Jamesburg Park	1,363	Lower Raritan
Northwest Mercer Park	804	Millstone
Runyon Water Supply Management Area	1,224	Lower Raritan
Sayreville Water Supply Management Area	564	Lower Raritan
Sourland Mountains	1,615	Upper Raritan/ Millstone
South Branch Reservation	783	Upper Raritan
Thompson Park	689	Lower Raritan
State Owned Land		
Black River	3,195	Upper Raritan
Clinton Wildlife Management Area	1,660	Upper Raritan
Delaware and Raritan Canal	2,340	Lower Raritan/ Millstone
Hacklebarney	1,040	Upper Raritan
Monmouth Battlefield	1,836	Lower Raritan
Pigeon Swamp	977	Lower Raritan
Round Valley	1,571	Upper Raritan
Six Mile Run	3,000	Millstone
Spruce Run	678	Upper Raritan
Voorhees	617	Upper Raritan

Source: NJDEP, Office of Green Acres
Note: Land acreages in this table do not include all open space areas within the Raritan Basin.

Vegetation and Wildlife

This section provides a brief overview of the vegetation and wildlife species most commonly associated with the three physiographic provinces of the Raritan Basin. A more comprehensive list of species (albeit not all-encompassing) is included in the table in Appendix A.

Highlands

Vegetative communities of the ridgetops, steep slopes and rock outcroppings of the Highlands are dominated primarily by Chestnut-Oak forests. Species occupying this forest type include chestnut oak, red oak, black birch, tulip tree, white ash, basswood and sugar maple. Smaller trees and saplings that constitute the understory include flowering dogwood. An array of herbs, ferns and mosses provide ground cover. Grasses, sedges and annuals are abundant on drier slopes.[36]

Upland vegetative communities of the Highlands consist primarily of three forest types which include the Mixed-Oak forest, the Hemlock-Mixed Hardwood forest and the Sugar Maple-Mixed Hardwood forest. Mixed-Oak forests consist of varying mixtures of large trees including red, white and black oak, hickory, maple, ash, beech, and elm to name a few. Smaller trees, shrubs and vines comprise much of the understory.[37]

Slopes of the Highlands underlain by gneiss formations contain a different forest type called the Hemlock-Mixed Hardwood forest. This vegetative community occurs in cool, moist ravines and on steep, lower, north-facing slopes. Dominant species in the tree canopy include hemlock, oak, birch, maple, beech, and scattered individuals of several other species.[38]

Many of the fertile limestone valleys of the Highlands have been cleared of their natural vegetation which included the Sugar Maple-Mixed Hardwood forest which consisted of various species of oak and hickory, as well as ash, birch, maple, basswood, and beech. Scattered trees of hemlock, white pine, American elm and black walnut are found in some of the remaining wooded areas of the limestone valleys.[39]

Forests of the Highlands provide habitat for approximately 23 threatened and endangered species and 120 resident bird species. The forested ridges provide critical nesting habitat and migration corridors for migratory songbirds and other avian species.[40] Large contiguous forests provide nesting and foraging opportunities for several species of hawks and owls (birds of prey).

Wetlands, lakes and streams of the Highlands region support endangered and threatened species including bog turtle and wood turtle as well as large populations of small mammals, butterflies, moths and dragonflies.[41] Other wildlife species of the Highlands include black bear, beaver, coyote, river otter, wild turkey, white-tailed deer and an occasional bobcat.[42]

Piedmont

Mixed-Oak forests typically found in the Highlands also occur in the Piedmont, particularly on flat expanses of sandstone and shale and on the slopes of the diabase and basalt ridges of the Watchungs and Sourlands. Dominant trees of the Piedmont include white oak which is more abundant than black or red oak, hickory, maple, beech, ash, and cherry. Maple-leaved viburnum and black haw are the common shrubs of well-drained areas, while moist forests include an abundance of spicebush and arrowwood and a diversity of common herbs.[43]

Lowlands of the Piedmont consist of hardwood swamp communities and a number of species commonly found on floodplains. Meadowland communities are dominated by cattail and a number of flood tolerant shrubs, grasses and herbs.[44]

Although the heavily developed U.S. Route 1 corridor passes through the southern edge of the Piedmont, the Piedmont province is still dominated primarily by farm fields, pastures, woodlands, swamps, and rocky ridges. Fortunately, large tracts of land within this area have been preserved as public open space.[45] Abandoned farm fields of the Piedmont consist of pioneer species or species that have occurred as a result of natural succession.

Wildlife species of the Piedmont region are typically found in forested areas and fallow fields. Uncultivated fields provide valuable habitat for many edge-dwelling species and endangered grassland birds. Field edges containing sassafras, dogwood, viburnum, gray birch, blackberry and raspberry brambles provide shelter and foraging opportunities for an array of wildlife species including white-tailed deer and red fox. Migratory songbirds rely on the interior of Piedmont forests, and a variety of toads and turtles reside in drier soils of higher elevations. Commonly seen mammals consist of eastern chipmunk, gray squirrel, eastern cottontail, woodchuck and white-tailed deer. Flowering plants attract an array of insects and birds and loose soils attract small mammals, which attract red fox, hawks and owls.[46]

Coastal Plain

Differences in elevation, soil moisture and climate between the Piedmont and Coastal Plain produce considerable differences between vegetation types of north and south Jersey. Vegetation of the upland areas of the Coastal Plain consist of two forest types including a Mixed-Oak forest and a Beech-Oak forest. Various species of oaks are abundant throughout the region and two long-lived successional species including the Virginia pine and sweet gum are also common.

Beech dominated forests are common in Monmouth County and along the transition zone of the Piedmont and Coastal Plain provinces. American beech is dominant in this forest type and other common species include black birch, tulip tree, black oak, red oak, sweet gum and sassafras.[47]

The most commonly seen wildlife species of the Coastal Plain include opossum, gray squirrel, eastern chipmunk, raccoon, striped skunk, eastern cottontail, red and gray fox, voles, shrews and white-tailed deer and an array of small mammals.[48] Commonly seen avian species include a diversity of shorebirds including gulls, terns and rails; wading birds including egrets and herons; waterfowl; and birds of prey.[49]

Wetlands

Although government agencies have recently recognized the importance of freshwater wetlands for the purification and recharge of surface and ground water, flood and storm damage protection, soil erosion control, and critical habitat for fish and wildlife, New Jersey's wetlands have been historically viewed as natural lands best suited for conversion to other uses such as agriculture, industrial sites and residential housing. Human activities including drainage for agriculture; channelization for flood control; filling for housing developments, highways, industrial activities and sanitary landfills; dredging for navigation channels; timber harvest; ground water extraction; and various forms of water pollution and waste disposal have resulted in the destruction of the majority of the State's wetlands. Fortunately, due to Federal and State wetland regulations, wetlands are being maintained and enhanced despite mounting pressures to convert them to other uses.

Since the mid-1900s, it has been estimated that at least 20% of the State's wetlands have been lost. While agriculture may have played the primary role in wetland alteration in the past, the most significant recent cause is urbanization. Filling wetlands for housing developments, industry, and commercial businesses has been accelerating since the 1950s.[50]

The filling and dredging of wetlands between the 1940s and 1970s resulted in a loss of more than 25% of the wetlands in Middlesex, Morris, Somerset and Union counties, while Hunterdon, Mercer and Monmouth counties lost more than half of their wetlands. Since the 1970s, wetland losses throughout the State have been greatly reduced by the adoption of the New Jersey Wetlands Act of 1970, the Federal Clean Water Act and the Freshwater Wetlands Protection Act. Prior to 1970, wetland losses averaged approximately 3,200 acres per year.[51]

Due to differences in topography, wetlands in the Highlands region of the Basin are not as extensive as the wetlands that exist in the lower elevations of the Piedmont and Coastal Plain. Most of the natural wetlands in the Highlands formed during the last Ice Age when glaciers scoured out basins that were then filled by water from glacial melt or from streams whose drainage was altered by glacial deposits. The majority of the lakes that formed during the last glacial period have been naturally filled in over time by silt and organic material, and are now covered by forested land. Limestone bedrock that lies close to the surface in the Highlands formed the calcareous fens of the region. Natural freshwater wetlands that have remained in the northern part of the Basin consist primarily of swamps, marshlands, bogs and fens; and floodplains located adjacent to streams and lakes. The differences between these wetland types are particularly vague due to their various stages of succession and therefore similar vegetative types may develop on all of them.[52]

Although several areas of saline marsh (i.e., wetlands influenced by tidal waters from an influx of brackish water [a mix of fresh and salt water] from the Raritan Bay) exist along the mainstem of the Raritan River, the majority of wetlands throughout the Raritan Basin are freshwater in nature.

Wetlands in the southern portion of the Basin exhibit relatively similar ecological qualities to those in the northern part. However, due to the flat terrain and sandy soils of the Coastal Plain, wetland types including marshes, swamps and peatlands have different vegetation types from those of North Jersey. Since the Coastal Plain was never glaciated and typically has well-drained soils, there are no true bogs in this region of the Basin. For the same reasons, very few natural lakes or ponds exist and freshwater marshes that typically exist adjacent to ponds and lakes are very uncommon in the Coastal Plain.[53]

According to Table 4, differences in wetland percentages between the three WMAs are due partly to the development patterns of the Basin (e.g., wetland losses in the eastern portion associated with the high percentage of urban land), but are also contributed to the geologic differences in the Basin's physiographic provinces. Losses in wetlands varied throughout the Basin between 1986 and 1995, with the greatest loss of 6% having occurred in the Lower Raritan WMA. The Upper Raritan and the Millstone WMAs each lost 2% of the their reported wetlands since 1986. Figures 15 and 17 depict changes in land cover (wetland losses) by HUC-11 between 1986 and 1995.

Population

Historic Trends 1930-1990

Historically, population growth in the Raritan Basin has been largely influenced by industrialization and rail expansion in Central New Jersey (Figure 14). However, since the invention of the automobile, residential growth has expanded significantly outside urban centers such as New Brunswick, Plainfield, Perth Amboy, Somerville, Freehold and Princeton. The development pattern today is one of increasing suburbanization in proximity to old and new employment centers and urban concentrations.[54] As illustrated on Figures 23 and 24, population in the Basin increased significantly between 1930 and 1990, with a high percentage of the population surrounding the urban centers referenced above.

Present Conditions

Population trends from 1930 to 1990 (Figures 23 and 24) illustrate that the Basin has seen significant population growth in the past. Population in some areas is projected to grow at a very high rate in the immediate future. The 1997 population density figures for the eastern half of the Basin (Figure 25) illustrate that the majority of Middlesex County and areas along the U.S. Route 1 corridor are continuing to see increases in population densities. According to the population change estimates within the Raritan Basin between 1990 and 1997 (Figure 26), while much of the western half of the Basin is exhibiting population growth rates up to 25%, many of the urban centers, particularly in the eastern half of the Basin are reporting a loss of people, or "shifts" in population from urban areas to rural areas.[55]

The projected population densities for the years 2000, 2010 and 2020 continue the trends from past decades. Increasing population densities are projected to follow the major transportation corridors such as I-78, I-287, U.S. Route 1 and U.S. Route 9, the New Jersey Turnpike and the Garden State Parkway as the road and rail networks allow people to move farther from the employment centers and still be within a reasonable commuting distance of their work.[56]

Housing Trends

Economic growth is linked with population growth in a number of ways. Expansion of service utilities and support industries are needed to accommodate increased numbers of people. There is also continuing pressure to increase employment opportunities. State and local officials as well as private business owners, particularly land developers, builders and realtors, are continually trying to lure new industry and commerce into the State, which will attract new residents thereby requiring new housing developments. Figure 27 illustrates household densities within the Basin for 1990. Although the western portion of the Basin contains fewer households per square mile than the eastern portion of the Basin, increasing population densities over the last several years have resulted in an increased demand for households in this area. Therefore, as housing developments are continually constructed, household densities in the western half of the Basin will begin to show similar trends to those that have been exhibited in the eastern half of the Basin; an increase of households surrounding major roadways and growing cities (Figure 27). In addition, 90% of new housing developments today are comprised of single-family homes which use more land than a multi-family home (i.e., multi-family housing developments provide housing for more individuals per unit of land area).

According to information obtained from the New Jersey Department of Labor (Figure 28), the number of residential housing units (new homes and/or additions) authorized by building permits between 1990 and 1998 reveals a steady upward trend in most counties throughout the Basin. With the exception of Union County which is mostly developed, counties in the Basin showed a steady upward trend of the number of permits issued during the 8 year period. Despite a slight decline in the number of permits issued for Middlesex and Mercer counties between 1990 and 1992, Middlesex, Monmouth, Morris and Somerset counties showed the greatest increase over the 8 year period. Information recorded in Figure 28 is consistent with the increase of new housing development trends discussed above.[57]

Employment Trends

Review of the employment density map for 1990 (Figure 29) indicates that a significant amount of the development that has occurred in the Basin has centered around primary cities including Perth Amboy, New Brunswick, Freehold, Princeton and Somerville.

The 1980s was a decade of unprecedented suburban growth, with a shift from older industrial centers to more rural areas. Industries seeking less expensive land and relatively lower taxes have located corporate office complexes and high-technology industries throughout the Basin, particularly within Hunterdon and Somerset counties. Networks of highways, particularly the U.S. Route 1 corridor, have spawned huge amounts of corporate developments along their corridors. In the 1980s, more square footage of office space was built along 13 square miles of U.S. Route 1 than existed in downtown Indianapolis, the thirteenth largest city in the country.[58]

Due to sprawling development in rural areas, thousands of workers are required to commute to and from their places of employment by automobile instead of traveling by mass transit. As a result, traffic congestion has increased drastically across the State, particularly in the central and easternmost portions of the Basin.

Figure 30 compares the total employment by economic sector for the 7 counties in the Basin for 1970 and 1995. While the majority of employment sectors have experienced increases throughout the region over the last 25 years, the most noticeable increase between the 1970s and the 1990s was a 12% increase in the service sector. Conversely, the manufacturing sector experienced a significant decrease of 18% over the 25-year span. It should be noted however that the figures depicted in Figure 30 are representative of the 7 counties in their entirety, and not just the Raritan Basin.

Income

According to information obtained from the New Jersey State Data Center, the median household income for the State of New Jersey increased from $22,906 in 1980 to $47,589 in 1990, an overall change of 108%. The seven counties in the Basin also experienced increases as seen in Table 7 below. It should be noted however, that these changes are representative for each county in its entirety, not solely for the portions of the counties included in the Raritan Basin.

Table 7 - Median Incomes for the Seven Counties of the Raritan Basin (1980-1990)			
County	**1980**	**1990**	**Percent (%) Change 1980-1990**
Hunterdon	$26,618	$61,132	130
Mercer	$22,972	$48,490	111
Middlesex	$25,603	$51,835	103
Monmouth	$24,526	$53,590	119
Morris	$29,283	$62,749	114
Somerset	$29,172	$62,255	113
Union	$25,266	$48,862	93

Figure 31 illustrates the distribution of median household incomes by census tract for the Raritan Basin. As portrayed in Figure 31, incomes are variable throughout the Basin, with high-income areas (greater than $75,000) concentrated in lower Morris and upper Somerset Counties (particularly in Mendham, Chester, Bernards and Branchburg Townships), and several areas of Mercer (e.g., West Windsor Township) and Monmouth Counties (e.g., Marlboro Township). Conversely, 1990 median income classifications for areas in eastern Middlesex and western Hunterdon Counties averaged approximately $60,000 or less, especially in areas associated with industrial and agricultural land use activities. Figure 32 shows the range of incomes by census tract (e.g., how many census tracts in the Basin fall into a particular income range). According to Figure 32, most households within the Basin averaged between $45,000 and $55,000 per year in 1990, which is consistent with the 1990 State average of $47,589.

Future Trends

Population Projections

By the year 2030, it has been estimated that New Jersey will provide homes for approximately 9.6 million people, which is about 23 percent higher than the current population. The population density (already the highest in the United States) would therefore average approximately 1,279 persons per square mile by 2030.[59]

Trends over the past several decades have resulted not only in an increase in the total population, but also a shift in the population from urban to rural areas. This trend is expected to continue in future years as more housing developments and roadway networks are constructed in rural areas of the Basin. Counties within the Basin that are expected to experience the highest population growth rates include Hunterdon (42 percent) and Somerset (40 percent). In contrast, the older, more urbanized counties are expected to have minimal growth as more and more people move out of the cities and into the country.[60]

Future Centers and Redevelopment

The shift in population from urban areas to rural areas will inadvertently result in the exploitation of undeveloped land including open space, farmland and forested areas. As indicated on Figure 33, population projections for 2010 and 2020 continue to show increases in the already heavily developed municipalities in the eastern portion of the Basin with continued sprawl development throughout the entire Basin.[61]

Continuation of current development trends will undoubtedly result in a “shift” of population from urban areas to rural areas, thereby resulting in increased traffic congestion, continued aging and deterioration of urban infrastructure, and new demands for expensive infrastructure. Farmland and open space areas will continue to be lost, and natural elements including aquifers, surface and ground water resources and wildlife habitats will rapidly diminish.[62]

In order to address the issues of suburban sprawl and problems associated with current development patterns, the New Jersey State Planning Commission has prepared and adopted a State Development and Redevelopment Plan according to the requirements of the State Planning Act of 1985 (N.J.S.A. 52:18A 196 et seq.) The State Plan has been adopted to guide State agencies and local governments in effective planning efforts that will support economic growth and development in the State in a sustainable manner.[63]

Figure 34 which was recreated using the resource planning and management map from the New Jersey State Development and Redevelopment Plan, illustrates the location of the designated planning areas of New Jersey which range from the most densely populated areas of the State [e.g., Metropolitan (PA1)] to the least densely populated areas of the State [e.g., Environmentally Sensitive (PA5)]. For additional information on New Jersey's development and redevelopment areas, please refer to the New Jersey Office of State Planning web site at http://www.state.nj.us/osp/ospplan.htm

Conclusions

The setting of the Raritan Basin is influenced by the topography, geology and soil characteristics of the Highlands, Piedmont and Coastal Plain Physiographic provinces in which it is located. Limestone valleys and glacial aquifers of the Highlands contribute to high infiltration rates in the Upper Raritan WMA, while urban land soils in the eastern portion of the Basin inhibit surface and ground water recharge potential. Headwater streams of all three watershed management areas exhibit lower flows than the larger streams of the central Basin.

Development trends over the last several decades have resulted in a significant amount of development in rural areas that has therefore resulted in a loss of open space, agricultural land, wetlands and critical wildlife habitat. According to information from the United States Census Bureau and the New Jersey Department of Labor, population and housing totals are continuing to rise and by 2030, New Jersey is expected to house 23% more people than currently reside in the State. Hunterdon and Somerset counties are expected to experience the highest growth rates in the Basin with a 40% anticipated increase.

Significant increases in population and sprawl development are just several of the reasons for characterizing and assessing the current trends of the Basin. The characterization and assessment will be used in the development of a management plan that will help guide future land use practices and development throughout the Raritan Basin.

Glossary of Terms

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

"Aquifer" means any water-saturated zone in sedimentary or rock stratum which is significantly permeable so that it may yield sufficient quantities of water from wells or springs in order to serve as a practical source of water supply.

"Colluvium" means soil material, rock fragments, or both moved by creep, slide or local wash and deposited at the base of steep slopes.

"Consolidated deposits" means deposits of sand, gravel, silt or clay that have been compressed to form solid material or rock.

"Erosion" means the weathering away of the land by water, wind, ice or other geologic agents and processes.

"Floodplain" 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].

"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.

"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.

"Physiographic Provinces" means the distribution of land area in New Jersey into distinct physiographic land divisions that have been determined by New Jersey's geologic history.

"Subwatershed" means a smaller geographic section of a larger watershed.

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

"Unconsolidated deposits" means recent deposits of clays, silts, sands and gravels that are not cemented together.

"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.

Common Acronyms

D&R Canal – Delaware and Raritan Canal
HUC – Hydrologic Unit Code
msl – Mean Sea Level
NJDEP – New Jersey Department of Environmental Protection
NRCS – Natural Resources Conservation Service
WMA – Watershed Management Area
USDA – United States Department of Agriculture
USGS – United States Geological Survey

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APPENDIX A

Representative List of Vegetative Communities and Wildlife Species By Physiographic Province for the Raritan Basin

HIGHLANDS

Vegetative Communities

Chestnut Oak Forest

Chestnut oak
Red oak
Back birch
Tulip tree
White ash
Basswood
Sugar maple
Flowering dogwood
Wild ginger
Wild sarsaparilla
Black snakeroot
Columbine
Ferns and mosses
Grasses, sedges and annuals

Mixed-Oak Forest

Red oak
White oak
Black oak
Hickory
Red maple
Sugar maple
White ash
Tulip tree
American beech
Black cherry
Black birch
Sour gum
American elm
Flowering dogwood
Hop hornbeam
Sassafras
Ironwood
Maple-leaved viburnum
Black haw
Arrowwood
Spicebush
Witch hazel
Blueberry
Huckleberry
Poison ivy
Virginia creeper
Japanese honeysuckle
Wild grape

Hemlock-Mixed Hardwood Forest

Eastern hemlock
Red oak
Black birch
Chestnut oak
Black oak
Red maple
American beech
Yellow birch
White ash
Striped maple
Hop hornbeam
Flowering dogwood

Sugar Maple-Mixed Hardwood Forest

White oak
Black oak
Red oak
White ash
Tulip tree
Black birch
Yellow birch
Red maple
Basswood
American beech
Hickory
White pine
American elm
Black walnut

Wildlife Species

Cooper's hawk
Northern goshawk
Barred owl
Red-shouldered hawk
Wild turkey
Black bear
Beaver
Bobcat
Coyote
River otter
White-tailed deer
Diversity of small mammals
Butterflies
Moths
Dragonflies
Bog turtle
Wood turtle

PIEDMONT

Vegetative Communities

Mixed-Oak Forest
White oak
Black oak
Red oak
Pignut hickory
Sugar maple
Red maple
American beech
White ash
Norway maple
Pin oak
Sour gum
Black cherry
Sweet cherry
Flowering dogwood
Maple-leaved viburnum
Black haw
Spicebush
Arrowwood

Herbs of Moist Woodlands
Mayapple
Jack-in-the-pulpit
Solomon's-seal
Aster
Goldenrod
New York fern
Christmas fern

Hardwood Swamp Communities
Red maple
Pin oak
Black willow
Swamp white oak
American elm
White ash
Silver maple
Basswood
Green ash
Boxelder maple

Meadowland Communities
Cattail
Flood tolerant shrubs, grasses and herbs

Abandoned Farm Fields
Eastern red cedar
Sassafras
Big-toothed aspen
Tulip tree

Abandoned Farm Fields Continued
Sweet gum
Gray birch
Black locust
Black cherry
Red maple
Crabgrass
Wintercress
Common mullein
Canada thistle
Yarrow
Butter-and-eggs
Orchard grass

Mowed Roadside Fields
Common cinquefoil
Wild strawberry
Common dandelion
English plantain
Chichory
Hawkweed
Goldenrod
Common ragweed
Variety of grasses

Wildlife Species
White-tailed deer
Red fox
Variety of toads and turtles
Eastern chipmunk
Gray squirrel
Eastern cottontail
Woodchuck
White-tailed deer
Endangered avian grassland species

COASTAL PLAIN

Vegetative Communities

Mixed-Oak Forest

Virginia pine
Sweet gum
Persimmon
Sweet gum
Virginia pine
American holly
Flowering dogwood
Ironwood
Black cherry
Sassafras
Heath shrubs
Japanese honeysuckle
Virginia creeper
Wild grape
Poison ivy

Beech Dominated Forests

American beech
Black birch
Tulip tree
Black oak
Red oak
Sweet gum
Sassafras
Flowering dogwood
Maple-leaved viburnum
Arrowwood
Spicebush
Black cherry
Greenbrier
Poison ivy
Japanese honeysuckle
Agrimony
Partridgeberry
Wild licorice
Other herbs and vines

Wildlife Species

Opossum
Gray squirrel
Eastern chipmunk
Raccoon
Striped skunk
Eastern cottontail
Red and gray fox
Vole
Shrew
White-tailed deer
Gulls
Terns

Wildlife Species Continued

Rails
Egrets and herons
Northern harrier
Osprey
Owls
Gray tree frog
Wood frog

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