STATE OF THE RARITAN REPORT

Volume 1

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State of the Raritan Report, Volume 1

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About the Sustainable Raritan River Initiative

The Sustainable Raritan River Initiative, a joint program of Rutgers' Edward J. Bloustein School of Planning and Public Policy and the School of Environmental and Biological Science, works with stakeholders around the Raritan region to balance social, economic and environmental objectives towards the common goal of restoring the Raritan River, its tributaries and its estuary for current and future generations. The Initiative in turn partners with the Sustainable Raritan River Collaborative, which is a network of over 130 organizations, governmental entities and businesses in the Raritan region, and with the Rutgers Raritan River Consortium. The Consortium is comprised of multiple schools, programs and departments of Rutgers University that have joined together to apply university-based educational programming and research to advance improvements in planning, policy and decision-making for a more sustainable Raritan. We work together to restore and protect this valuable regional resource.

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Executive Summary

This report updates key indicators of water quality and watershed health for the Raritan Basin that were originally assessed in the *2002 Raritan Basin: Portrait of a Watershed* as developed by the New Jersey Water Supply Authority. The objective of that original report, as well as this update, is to inform watershed management and water supply protection needs in the Raritan Basin. This new assessment uses the same eleven key indicators and updates the original data – most from 1986 and 1995 – with data from 2002, 2007 and 2012 in order to determine trends over the past 26 years and to identify data gaps for development of future more comprehensive assessments.

Eleven key indicators were assessed for this report including: population; housing units; urban land use; impervious surface cover; forested, coastal and emergent wetlands; upland forest cover; prime agricultural land; groundwater recharge; fish and macroinvertebrate bioassessments; riparian area integrity; and known contaminant sites and groundwater contamination.

Overall comparison of this updated analysis with the prior 2002 report (Table 1) shows that trends evident between 1986 and 1995 are continuing in the same general direction though the rate has varied over the longer time period. Trends increased for population, housing units, urban land use and impervious surface cover. An increasing trend for these indicators adds stress on water quality and supplies with potential negative impacts for the watershed. Trends declined for all of the wetland land covers assessed as well as for upland forest, prime agricultural land and groundwater recharge. Downward trends for these indicators suggests that the watershed is losing its natural filtering capacity with attendant negative impacts to water quality. The bioassessment and riparian areas trends were mixed and there was not sufficient data to determine trends for the known contaminated sites and groundwater contamination indicators.

This report is the first in a series that will eventually assess a broad array of metrics of watershed health for the Raritan Basin. The intent is to inform watershed management planning in concert with remediation, restoration and protection efforts at the state, regional and local levels.

Table 1 below, summarizes the eleven indicators assessed for the Raritan and the current status and trend for each. These are described in more detail in the corresponding sections that follow.

Key Indicators	2002 Trend*	2016 Trend**	2016 Trend Impact
Population	Increasing	Increasing	Negative
Housing units	Increasing	Increasing	Negative
Urban land use	Increasing	Increasing	Negative
Impervious surface	Not sufficient data	Increasing	Negative
Wetlands	Decreasing	Decreasing	Negative
Upland forest	Decreasing	Decreasing	Negative
Prime agricultural land	Decreasing	Decreasing	Negative
Groundwater recharge	Decreasing	Decreasing	Negative
Bioassessment (stream integrity)	Mixed	Mixed	Undetermined
Riparian areas	Decreasing	Mixed	Undetermined
Known contaminated sites and groundwater contamination	Not sufficient data	Not sufficient data	Undetermined
* *2002 Trend from Portrait of a Watershed data* ** *2016 Trend from this analysis*			

Table 1. Trends in Key Indicators for 2002 and 2016 reports on the Raritan Basin

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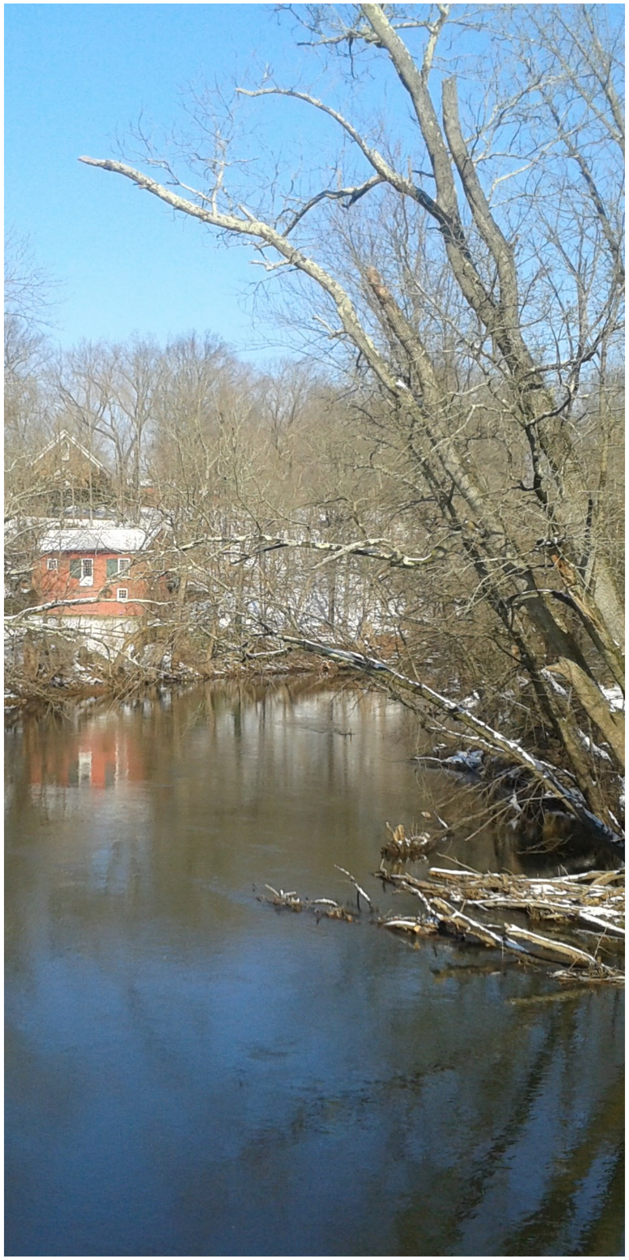


Background

In 1999, the New Jersey Department of Environmental Protection (NJDEP) provided funding to the Raritan Basin Watershed Management Project – a partnership of government, regional, and non-profit entities, academia, and watershed groups – to coordinate and develop a watershed management plan for the Raritan Basin that the NJDEP could adopt and endorse (NJWSA, 2002). The New Jersey Water Supply Authority (NJWSA) led the project. The resulting seven characterization and assessment technical reports and two background reports provided a baseline of the status of the Raritan basin with a focus on assessing water supply and to provide a baseline for a watershed management plan.

The technical and background reports were summarized in a question-and-answer-format report entitled, *Raritan Basin, Portrait of a Watershed* (2002). In addition to an overview of the issues noted above, the report addressed questions directed towards general public education that defined watersheds, discussed their function and importance, and described the sources of pollution affecting the Raritan. The *Portrait of a Watershed* and associated technical reports were based primarily on data from 1986 and 1995 and served to document the baseline condition of watershed health against which subsequent degradation or improvements could be compared. The summary of issues impacting the basin that were explored in those reports included population growth, land use, riparian areas, aquatic habitat, water supply, groundwater, surface water quality and pollutant loading.

Purpose of this Report

Rutgers University's Sustainable Raritan River Initiative, with input from watershed partners throughout the basin, has undertaken to update the NJWSA's earlier assessment employing similar methodology using more recent data from 2002, 2007 and 2012. With the resulting twenty-five plus year record of data, we have analyzed the status and trends of the same suite of key indicators of watershed health used in the *2002 Portrait* and produced this *2016 State of the Raritan Report.*

This current volume is the foundation for a future basin-wide assessment that goes beyond the eleven key indicators for water quality and water supply and explores a broader set of indicators that will measure overall watershed health. We intend to develop this assessment through a series of reports that will build upon each other. This first report is an update of the key indicators that were used by NJWSA in their 2002 assessment and for which we could secure more current data in order to update trends.

In early 2017, following discussions with area stakeholders to identify a broader set of indicators of watershed health, we will develop a second more comprehensive report. Together, the two volumes will provide critical data to inform planning and decision-making in the basin as well as identify data gaps and research needs that will set priorities for university-based efforts. Our ultimate goal is to develop a baseline of metrics that can be used in the coming years to identify strengths and weaknesses in efforts to restore and protect Raritan resources and to help inform basin-wide stewardship of the Raritan.

About the Raritan

The Raritan River basin, located in north-central New Jersey, is the largest watershed located entirely within the State of New Jersey. The total watershed area is approximately 1,105 square miles (706,900 acres) and is located in all or part of Hunterdon, Mercer, Middlesex, Monmouth, Morris, Somerset, and Union counties. The watershed is divided into three water management areas (WMAs): the Upper Raritan, the Lower Raritan, and the Millstone (Figure 1). The Upper Raritan (WMA 08), covers approximately 470 square miles and includes the North and South Branches of the Raritan that join to form the main stem of the Raritan near Branchburg Township at the top of the Lower Raritan watershed (WMA 09). The Millstone (WMA 10) encompasses approximately 285 square miles and includes the Stony Brook and Millstone River watersheds as well as a significant section of the Delaware and Raritan Canal that enters the watershed near the confluence of the Stony Brook and Carnegie Lake in Princeton Borough. The Millstone joins the main stem in the Lower Raritan watershed at Manville Borough just above the Island Weir (aka Confluence) dam. The Lower Raritan watershed covers approximately 352 square miles and includes the Green Brook, Lawrence

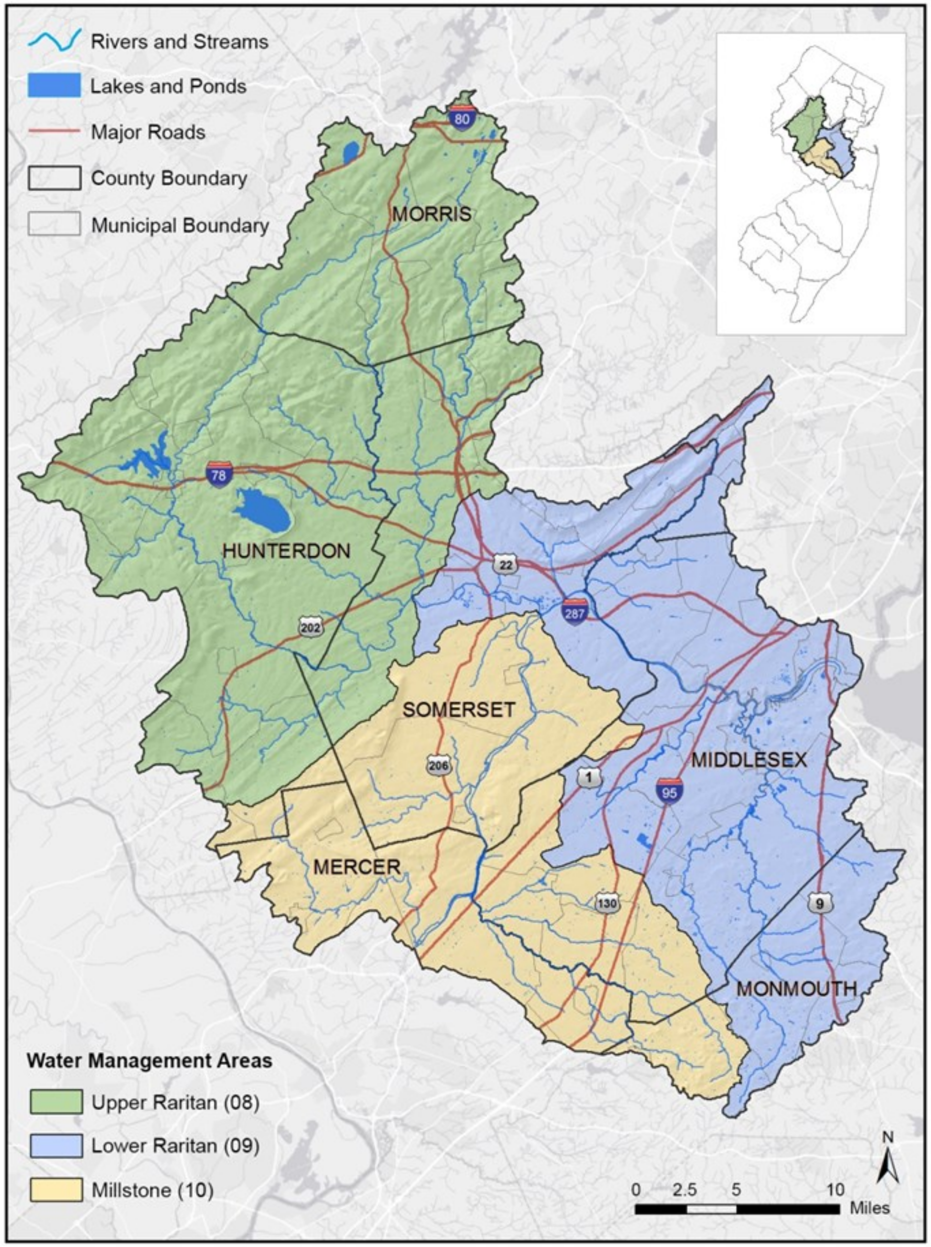


Figure 1. Location of Raritan River watershed in New Jersey

Brook, and South River. The Lower Raritan drains to Raritan Bay on the mid-Atlantic Coast south of Staten Island. The tidal reach of the Raritan is approximately 12 nautical miles from Raritan Bay and extends to just upstream of Landing Lane Bridge in New Brunswick.

The Raritan Basin includes portions of three of New Jersey's physiographic provinces (Figure 2). The Highlands province to the north is characterized by rugged topography and discontinuous rounded ridges separated by narrow valleys comprised of predominately igneous and sedimentary rock (NJGS, 2006). The beautiful Ken Lockwood Gorge and some of the best trout fishing in the state are located in the Highlands region, as are Budd Lake and the headwaters of the Raritan. The Piedmont province, at the southern contact of the Highlands, is mostly low rolling plains divided by higher ridges underlain by folded and faulted sedimentary and igneous rocks. This area is characterized by the Watchung Mountains to the east and the Sourland Mountains to the west, with good farmland in-between, and includes Spruce Run and Round Valley Reservoirs. The Raritan's upper and lower branches converge in the central section of the Piedmont. The

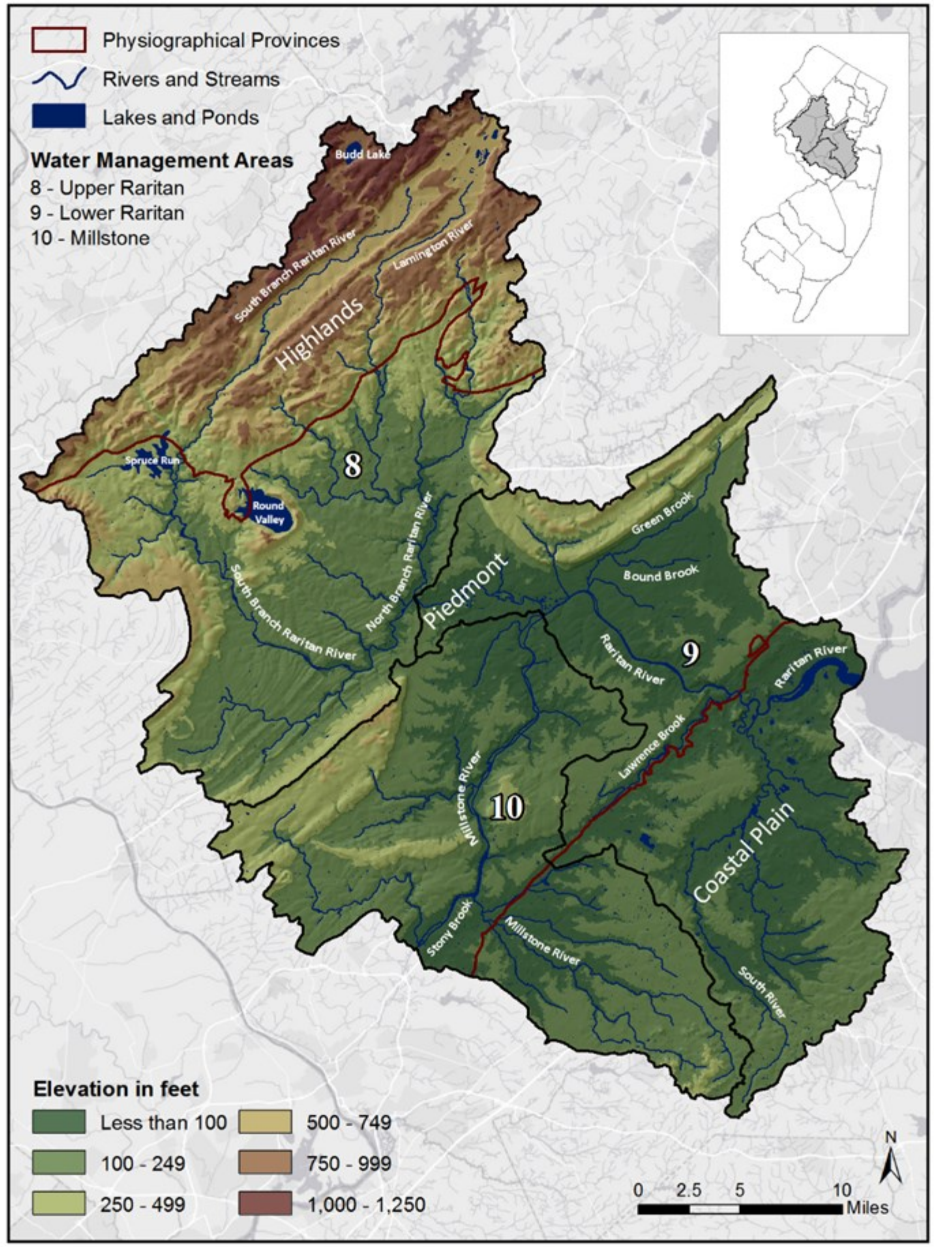


Figure 2. Streams, elevation and physiographic provinces in the Raritan River watershed

Coastal Plain, at the southern contact of the Piedmont, is predominately unconsolidated deposits in low relief. The headwaters of the Millstone and South Rivers are in the Coastal Plain; both rivers flow north to join the main stem. The Lawrence Brook flows east along the contact between the Piedmont and Coastal Plain provinces. Raritan Bay is also in the Coastal Plain. Elevations in the Raritan Basin range from 1,250 feet in the Highlands province to mean sea level in the Coastal Plain province.

Approximately 1.3 million people live in the Raritan Basin's 98 municipalities (US Census, 2010) and more than 793,000 people work here (NJDOL, 2014). The integrity of the Raritan complex is central to quality of life in the region as a valuable source of drinking water, for its role in commerce and industry, for its myriad of recreational opportunities and the associated health benefits of access to aesthetic/open space, and as a natural wildlife corridor offering refuge to numerous threatened and endangered species.

Measuring the Health of a Watershed

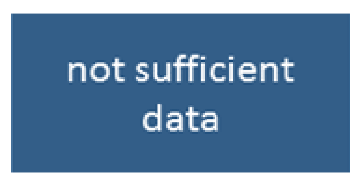
Eleven indicators were evaluated in this assessment of the health of the Raritan (Table 1). The selected indicators reflect certain aspects of water quality and watershed health and represent some driver (e.g., human population or urban land use) or reflect on the resulting consequences (e.g., groundwater recharge). For each indicator, the current status (i.e., condition based on the most recent data available in the public domain) and the temporal trends (as reflected by the measured change in the longest dataset available) have been characterized. For each indicator, a background, status, and trends are described. Indicator trends are graphically identified as increasing, decreasing, mixed, or not sufficient data and are represented throughout the text by the symbols to the right.

Further, the symbols are color-coded to indicate if the trend has a positive impact on water quality (**green color**) or has a negative impact on water quality (**red color**). If the trend was mixed and/or the impact was undetermined, the symbol is **grey**.

An increasing trend suggests that the trend of that indicator is increasing based on the analysis of longest period of data available in the public domain.

Conversely, a decreasing trend is the opposite. A decreasing trend, however, doesn't necessarily represent a decline in watershed health. For example, a decrease in impervious surface would actually represent a positive change for watershed health.

Mixed trends indicate both increasing and decreasing trends are observed from the analysis so no conclusive direction can be determined.



Not sufficient data means no analysis was performed due to lack of data or insufficient data.

Key Indicator

Population

Background

The impact of population on water quality is inevitable as people use water to bathe, cook, wash clothes, process waste, water lawns and gardens, for recreation, in agriculture, and for industry. Water quality degrades after most uses. As populations grow, water usage increases leading to further negative impacts on water quality. Additionally, population increase tends to coincide with increases in housing stocks and the development of new roads, shopping centers, and commercial areas that are often associated with increases in impervious surface cover leading to more

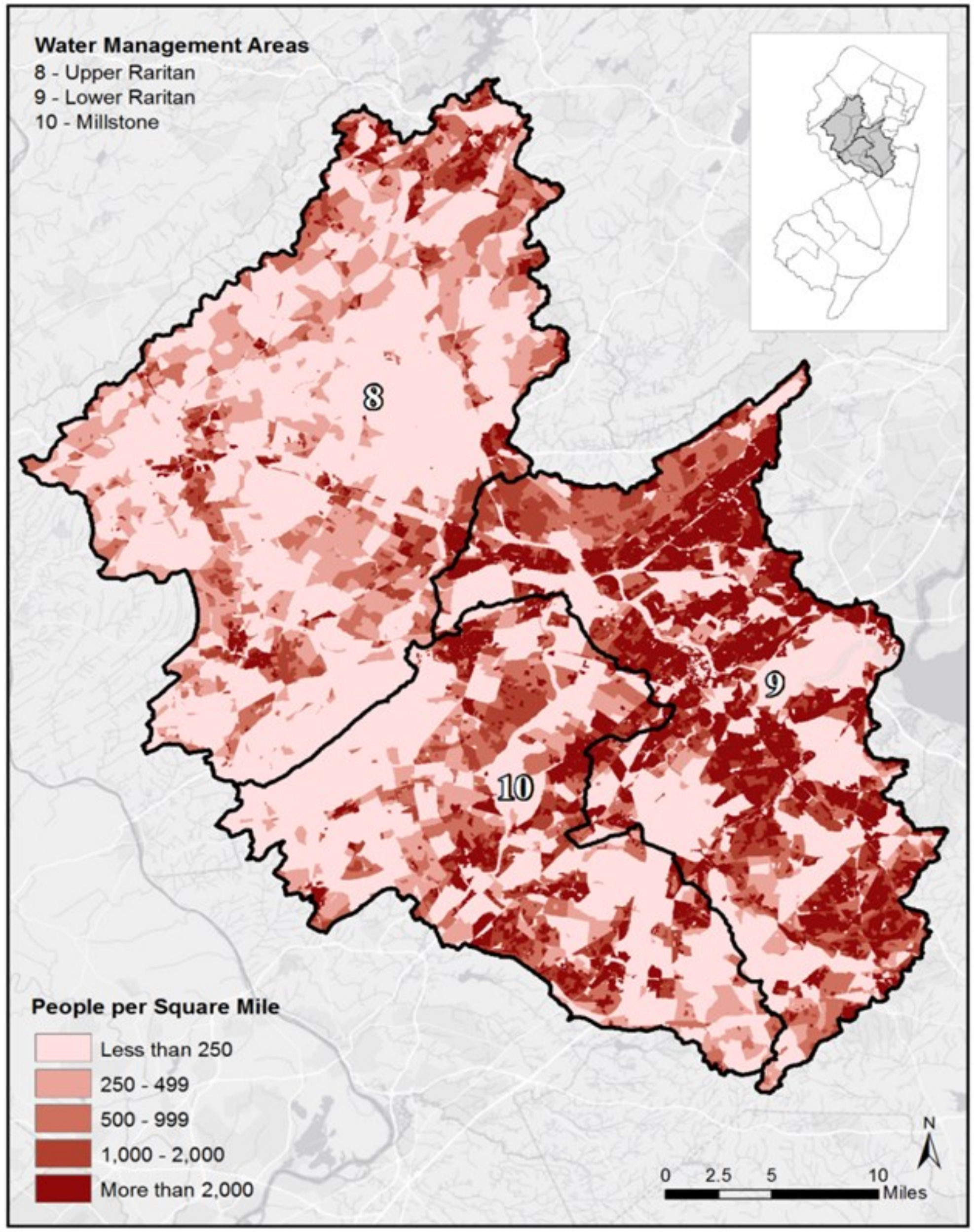


Figure 3. Population density in the Raritan River watershed based on 2010 census

	1990 Population	2000 Population	2010 Population	20 Year Population Change	20 Year Percent Population Change
Total Raritan (1,104.5 sq mi)	1,040,996	1,213,862	1,307,003	266,077	25.6
Upper Raritan (468.3 sq mi)	174,516	212,375	223,002	48,485	27.8
Lower Raritan (351.6 sq mi)	684,472	764,792	819,136	134,663	19.7
Millstone (284.6 sq mi)	182,007	236,694	264,864	82,858	45.5

Table 2. Population in the Raritan River Watershed from 1990 to 2010

runoff and further degradation of water quality. Consumptive demands on water in the region also result in transport of water resources from one watershed to another with impacts on local water budgets. The Raritan River is located in the middle of one of the most densely populated states in the nation. Increases in population density compound the effects of population and can have a significant impact on watershed health. Population growth and housing units, therefore, were analyzed in this study to consider their effect on water quality in the Raritan.

Methodology

Population data were obtained from the United States Census Bureau for the years 1990, 2000 and 2010 and clipped based on the Raritan and WMA boundaries. As the census tract boundaries do not exactly match WMA boundaries, a simple ratio method was applied to estimate the total population in the Raritan basin (i.e., a ratio of land area inside the WMA vs. total census tract area). The population density in the watershed was also calculated on a per census tract basis (i.e., population was divided by area of each census tract polygon in square miles).

Status and Trends

From 1990 to 2010, the Raritan gained over a quarter of a million new residents for a total population of approximately 1,307,003 (US Census, 2010) (Table 2). Density increased by 244 people per square mile (PPSM) to 1,183 PPSM in 2010. This represents a region-wide increase of 25.6 percent. The Lower Raritan had the highest total population as well as the highest density in 2010, though it had the slowest population growth rate of the three watershed management areas with 19.7 percent. The Upper Raritan's population grew by 27.8 percent between 1990 and 2010 to 223,002, while the Millstone experienced a 45.5 percent population growth rate. The corresponding population density per square mile was 2,327 for the Lower Raritan, 929 for the Millstone, and 476 for the Upper Raritan (Table 2, Figure 3).

While populations have increased throughout the region, the rate of growth has declined for the latter time period. Overall, the increase in population growth rate in the Raritan was 25.6 percent during the 20 years between 1990 to 2010 (Table 2), though the mean annual population growth rate was higher during 1990 to 2000 than it was during 2000 to 2010 on both a basin-wide as well as a WMA basis (Figure 4). The population grew 21.7 percent in the Upper Raritan between 1990 and 2000 but slowed to five percent in the following decade. Similarly, the Lower Raritan grew 11.7 percent from 1990 to 2000 and slowed to 7.1 percent growth rate between 2000 and 2010, while the Millstone grew 30.0 percent between 1990 and 2000 and slowed to 11.9 percent growth rate in the following ten years.

Many factors play into future population projections and an in-depth analysis of estimates is beyond the scope of this report. We do note, however, that New Jersey Department of Labor estimates that populations will continue to grow across the region (NJDOL, 2016). By 2034, the population in the Upper Raritan is expected to grow by 7.4 percent to just under a quarter of a million people (242,225), the Lower Raritan's population will increase by 13.9

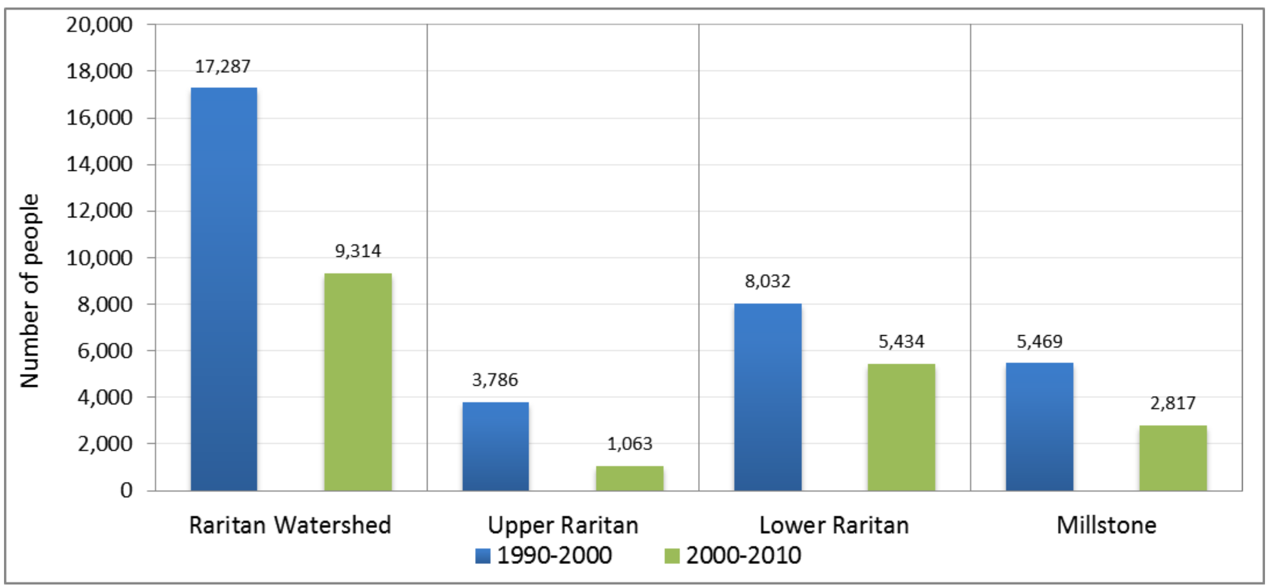


Figure 4. Mean annual population growth in the Raritan River watershed between 1990 and 2010

	2014 Population estimate	2024 Population projection	2034 Population projection	20 Year Population Change	20 Year Percent Population Change
Total Raritan (1,104.5 sq mi)	1,338,857	1,422,317	1,506,610	167,753	12.5
Upper Raritan (468.3 sq mi)	225,474	233,741	242,225	16,750	7.4
Lower Raritan (351.6 sq mi)	842,367	900,886	959,641	117,274	13.9
Millstone (284.6 sq mi)	271,016	287,690	304,744	33,728	12.4

Table 3. Population projections in the Raritan River Watershed from 2014 to 2034

percent to 959,641 people, and the Millstone will grow 12.5 percent to 304,744 people (Table 3). If factors used in those estimates bear out, the Raritan region would need to accommodate an additional 115,314 people by 2024 (over the 2010 census totals) and by 2034, the Raritan basin population could exceed 1,506,600.

Summary—Population

Population trends throughout the Raritan are increasing, which can increase numerous stresses on the watershed including increasing associated urban land uses such as housing, transportation, and commercial uses that can increase the potential for contaminated runoff into streams that degrades water quality. Increasing population trends have a negative impact on watershed health.

Housing Units

Background

Increases in population often coincide with increases in housing units that can increase impervious surface cover in the form of new roads, parking lots, and residential rooftops. During rainfall, these areas generate runoff quicker than undeveloped surfaces and can transport nonpoint source pollutants into the nearest waterbody. Increases in nonpoint source pollutants pose a threat to both aquatic as well as terrestrial ecosystems. Therefore, in this study housing units were analyzed to evaluate water quality status and trends in the Raritan.

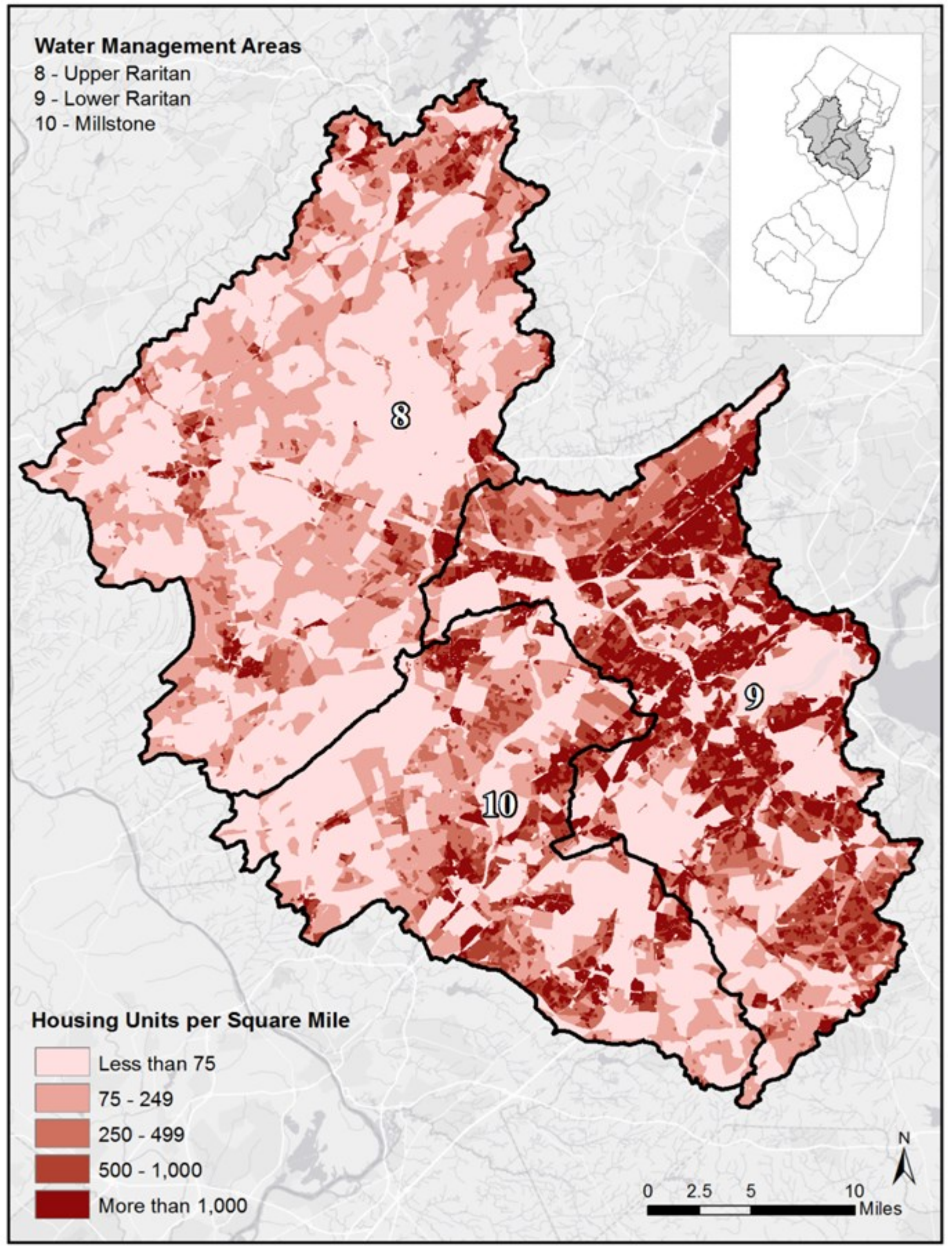


Figure 5. Distribution of housing density in the Raritan River watershed based on 2010 census

	1990 Housing Units	2000 Housing Units	2010 Housing Units	20 Year Change	20 Year Change (percent)
Total Raritan	386,551	441,584	481,332	94,781	+24.5
Upper Raritan	63,786	77,637	84,243	20,457	+32.1
Lower Raritan	248,239	272,105	291,772	43,533	+17.5
Millstone	74,526	91,842	105,317	30,791	+41.3

Table 4. Total housing units in the Raritan River watershed from 1990 to 2010

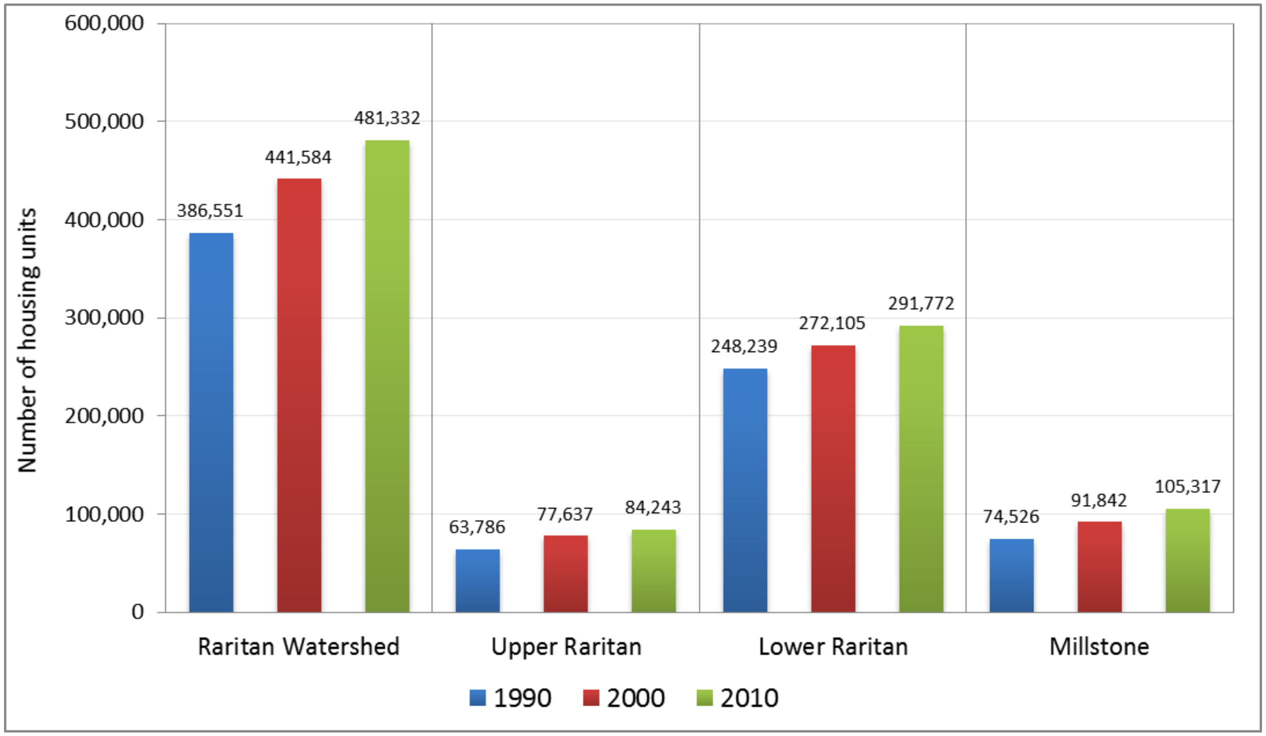


Figure 6. Total housing units in the Raritan River watershed from 1990 to 2010

Methodology

The housing units data were obtained from the United States Census Bureau for the years 1990, 2000 and 2010 and processed similar to the population data as previously outlined.

Status and Trends

Based on the 2010 Census, the Raritan contained a total of 481,332 housing units for a density of 436 housing units per square mile. The Lower Raritan had the highest number of housing units (291,772) followed by the Millstone (105,317) and Upper Raritan (84,243) (Table 4, Figures 5 and 6).

The overall increase in housing units in the Raritan was 24.5 percent during the 20 year time period (Table 4).

The increase in housing units was highest in the Lower Raritan while it was lowest in the Upper Raritan during the 20 year study period (Table 4; Figure 7). As with population, the highest percent increase in housing units was found in the Millstone. The mean annual growth in number of housing units slowed during the 2000 to 2010 time period, both across the entire watershed as well as on a watershed management area basis (Figure 7).

Since population growth and housing units are correlated with each other, a comparison chart was prepared for change in population and housing units from 1990 to 2010 (Figure 8). Housing units closely matched with the population growth for the basin as a whole, which indicated little change in the type of housing development in terms of low, medium or high density housing. In the Upper

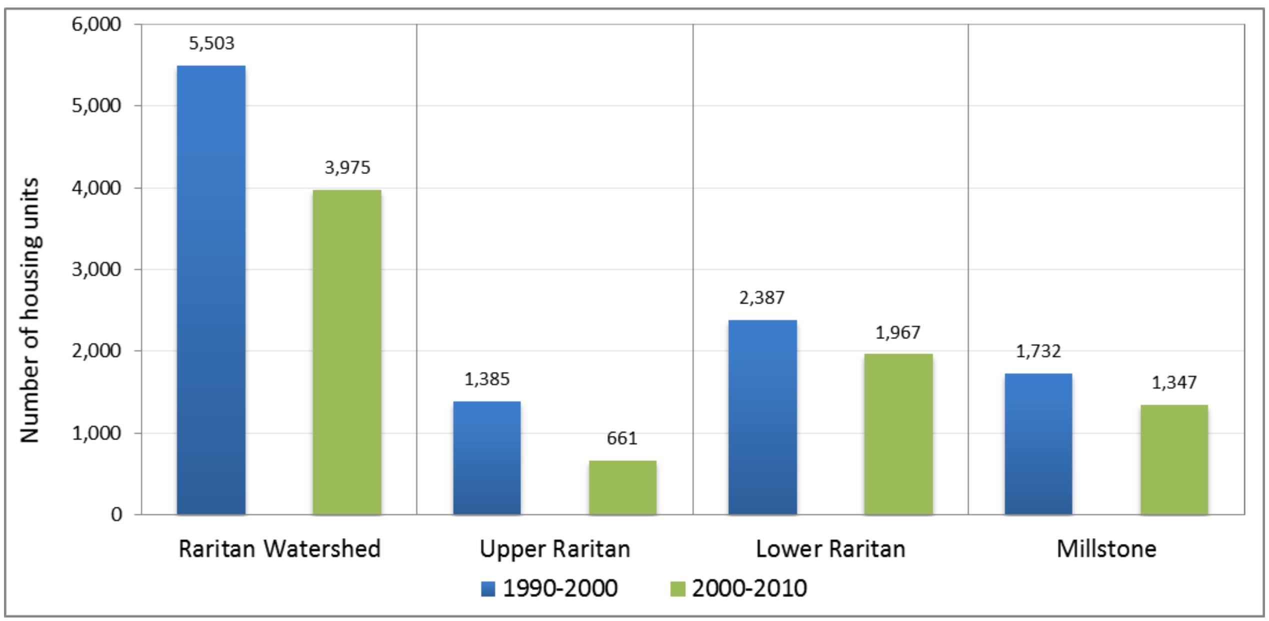


Figure 7. Mean annual growth in housing units in the Raritan River watershed from 1990 to 2010

Raritan, housing units grew at a rate of four percent greater than the population indicating an increase in lower density housing which is less likely to represent "smart growth". Conversely, the Millstone and Lower Raritan indicated that population growth outpaced housing unit growth by five percent and two percent, respectively. This suggests a shift toward higher density housing which may be attributed to "smart growth" and/or that much of these areas are nearly built-out.

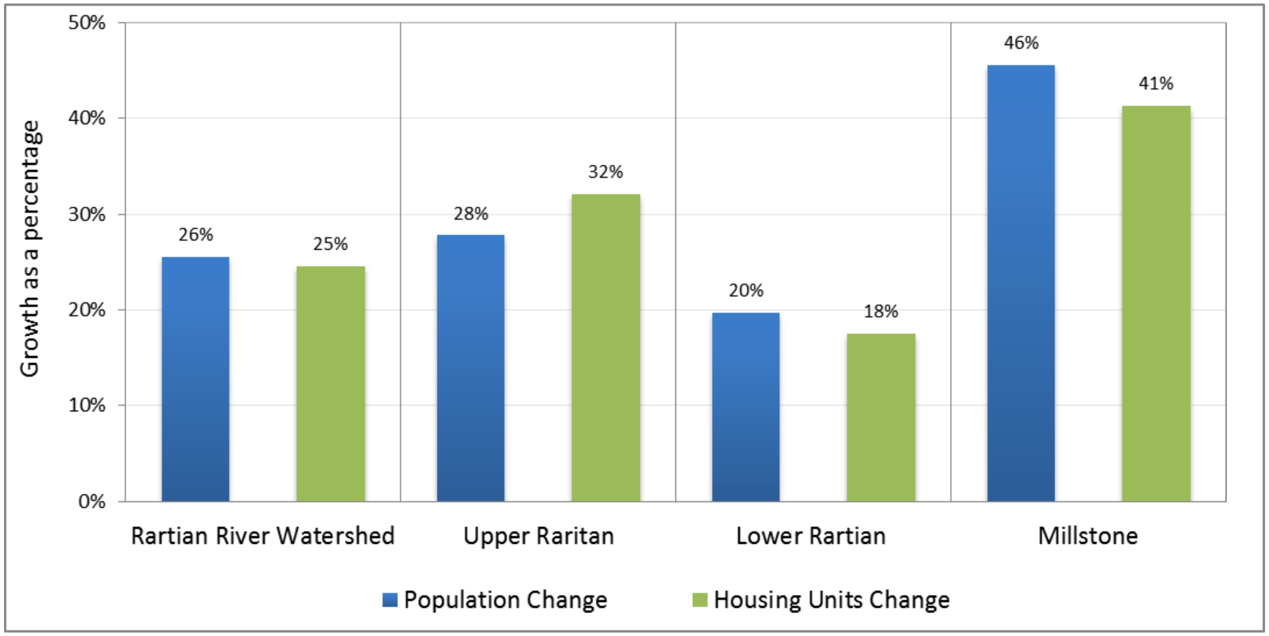


Figure 8. Increase in population and housing units in the Raritan River watershed from 1990 to 2010

Summary—Housing Units

Housing units are associated with an increase in impervious surface that can transport non-point source pollutants into surface waterbodies and degrade water quality. Trends showed an overall increase in housing units, though a slowing of the trends in the more recent time periods may indicate shifts towards higher density housing or that much of the area is already built out. Trends for increasing housing units have negative impacts on water quality in the Raritan basin.

Urban Land Use

Background

Land use is one of the fundamental components that needs to be looked at consistently for maintaining proper water quality in the watershed. Increasing population growth along with growing economic activities creates enormous pressure on land uses resulting in land use changes. Land use change can have positive or negative impacts on water quality depending on the activity. In general, agricultural and urban lands are known as high intensity land uses (unlimited anthropogenic disturbances) and generally have a negative impact on water quality. On the other hand, conversion to forest and wetland uses are considered low intensity land uses (limited anthropogenic disturbances) and are likely to have positive impacts on water quality.

New Jersey, as one of the most densely populated states in the United States, has experienced significant land use change trending towards urban land uses, which are often associated with degradation of water quality. Need for housing and economic activities forces development of new urban land which degrades water quality in the watershed. Degradation of water quality due to land use change poses a threat to both human as well as aquatic ecosystems in the watershed. Analysis of land use change is critical to future management decisions that will improve water quality in the Raritan.

Methodology

Land use/land cover data for the years 1986, 1995, 2002, 2007, and 2012 were obtained from the New Jersey Department of Environmental Protection.

The land use/land cover was classified into six broad Level I categories (urban land, agricultural land, forest, wetlands, water, and barren land) consistent with the Anderson System land use/land cover classification (NJDEP, 2002). We employed a slightly different classification system by incorporating certain Level II classes into Level I classes as follows:

- Urban Land is the sum of Type I Urban land plus Type II Urban Wetlands. Urban lands are characterized by intensive land use altered by humans and also includes recreational or other built up wetlands. Urban land in this report also includes disturbed wetlands.
- Agricultural Land is the combination of NJDEP Type I Agricultural Land plus Type II Agricultural Wetlands. Agricultural land is primarily used in the production of food and fiber. Prime agricultural lands is a subset of this category. This category also includes former wetland areas that were modified under cultivation.

- Forest is the summation of NJDEP Type I Forest and includes any land covered by woody vegetation other than wetlands.
- Wetlands are the combination of Type II Coastal, Forested, and Freshwater Emergent Wetlands. Coastal wetlands include tidal portions of watercourses draining to the Atlantic Ocean with cover type predominately vegetated by herbaceous plants adapted to tidal environments of fluctuating water levels, salinity and sediment deposition and also includes salt marsh transition zones and coastal vegetated dunes. Forested wetlands include non-tidal lowlands associated with primary, secondary and tertiary watercourses, and isolated wetlands, and includes wetlands dominated by deciduous and coniferous trees and non-tidal herbaceous marshes and savannas. Freshwater emergent wetlands include mixed shrub and bog wetlands, herbaceous wetlands, interior phragmites dominated wetlands and un-vegetated flats. The wetlands classification in this report does not include agricultural wetlands or disturbed wetlands.
- Barren Land is the combination of NJDEP Type I Barren Land plus Type II Disturbed Wetlands. This classification includes lands characterized by thin soil, sand or rocks and a lack of vegetative cover in a non-urban setting and can include beaches and rock faces as well as extraction mining operations, landfills, and other disposal sites. Disturbed wetlands include former natural wetlands that have been altered but still exhibit signs of soil saturation.

Since the time frames between mapping dates were not always consistent, an annualized change in land use/cover was also calculated. For convenience, the 1986 to 1995 change is referred to as T1, 1995 to 2002 is T2, 2002 to 2007 as T3, and 2007 to 2012 as T4.

Land Use/Land Cover	Raritan River Watershed (percent)	Upper Raritan (percent)	Lower Raritan (percent)	Millstone (percent)
Urban Land	43.5	32.9	59.5	41.2
Wetlands	11.8	7.2	15.3	15.3
Upland Forest	25.3	35.0	15.3	21.6
Agricultural Land	16.0	22.1	5.5	18.9
Barren Land	1.2	0.4	1.8	1.6
Water	2.2	2.4	2.7	1.4

Table 5. Percent of land use/land cover in the Raritan River watershed as of 2012

Some variances in land use/land cover, especially those related to water, are a result of changes in the resolution of aerial photography that is used to classify land use/ land cover. As resolution increases, individual pixels decrease allowing for greater discernment among features. Smaller streams and lakes that were not visible in older photography became visible as resolution increased. Substantial real change in the area of water was not found.

Status and Trends

In 2012, the Raritan was 43.5 percent urban land, 25.3 percent forest, 16.0 percent agricultural land, 11.8 percent wetlands, 2.2 percent water, and 1.2 percent barren land (Table 5; Figure 9).

Urban land is the dominant land use cover for the Lower Raritan and Millstone (59.5 percent and 41.2 percent respectively), while forest is the dominant land use/land cover in the Upper Raritan at 35 percent.

The largest gain in land use/land cover came

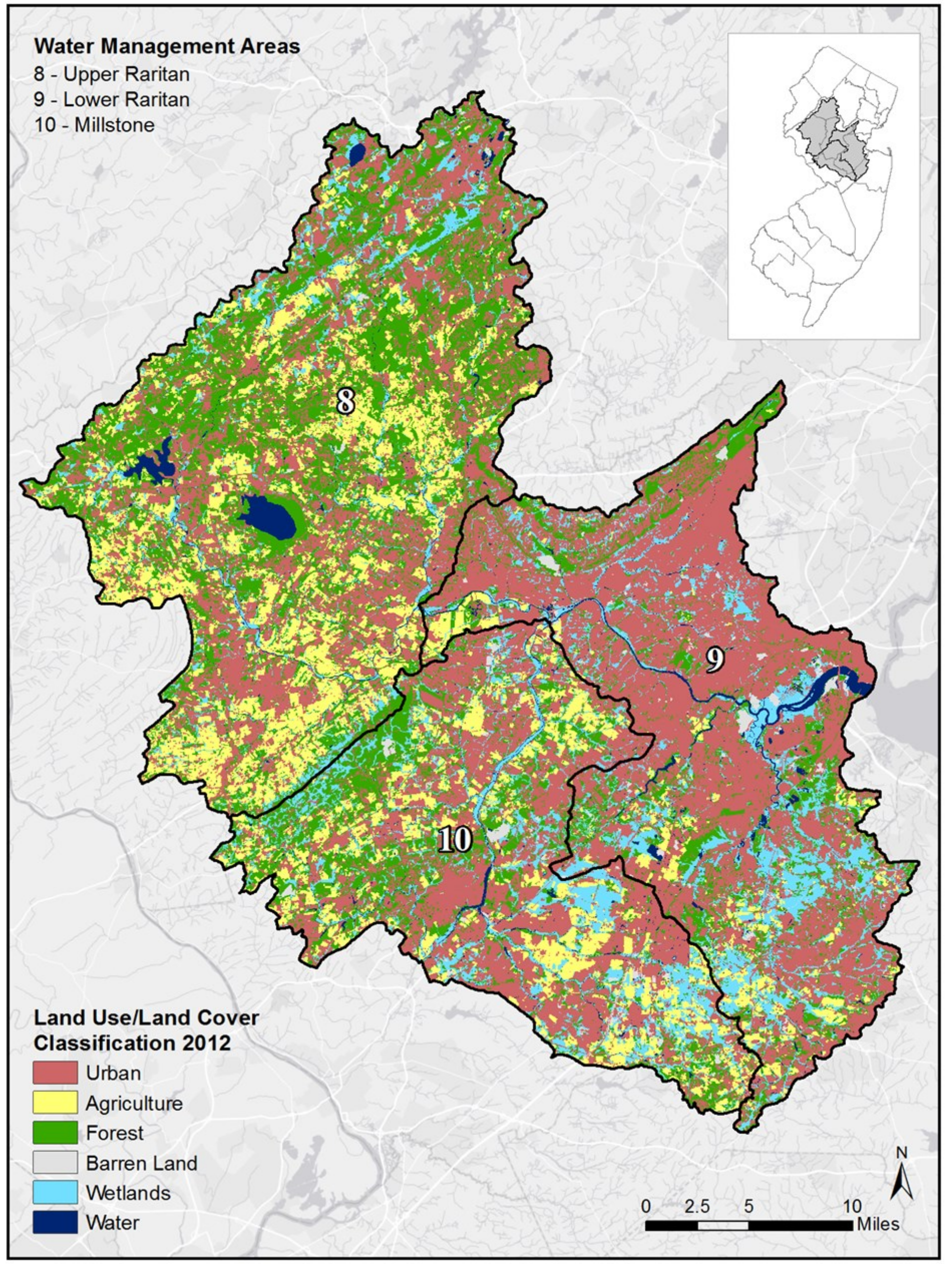


Figure 9. Land use/land cover distribution in the Raritan River watershed as of 2012

Land Use/Land Cover Raritan Watershed	1986 (acres)	1995 (acres)	2002 (acres)	2007 (acres)	2012 (acres)	26 year change	26 year Change (percent)
Urban land	226,508	255,447	282,229	301,796	307,515	81,008	35.8
Upland Forest	186,990	188,025	185,956	177,940	178,678	-8,313	-4.4
Agricultural Land	173,682	148,739	126,451	117,913	112,985	-60,697	-34.9
Wetlands	93,553	87,933	85,954	84,221	83,752	-9,801	-10.5
Water	13,066	13,516	14,588	15,528	15,750	2,685	20.6
Barren Land	12,930	13,241	11,723	9,503	8,220	-4,710	-36.4

Table 6. Change in land use/ land cover acreage in the Raritan River watershed from 1986 to 2012

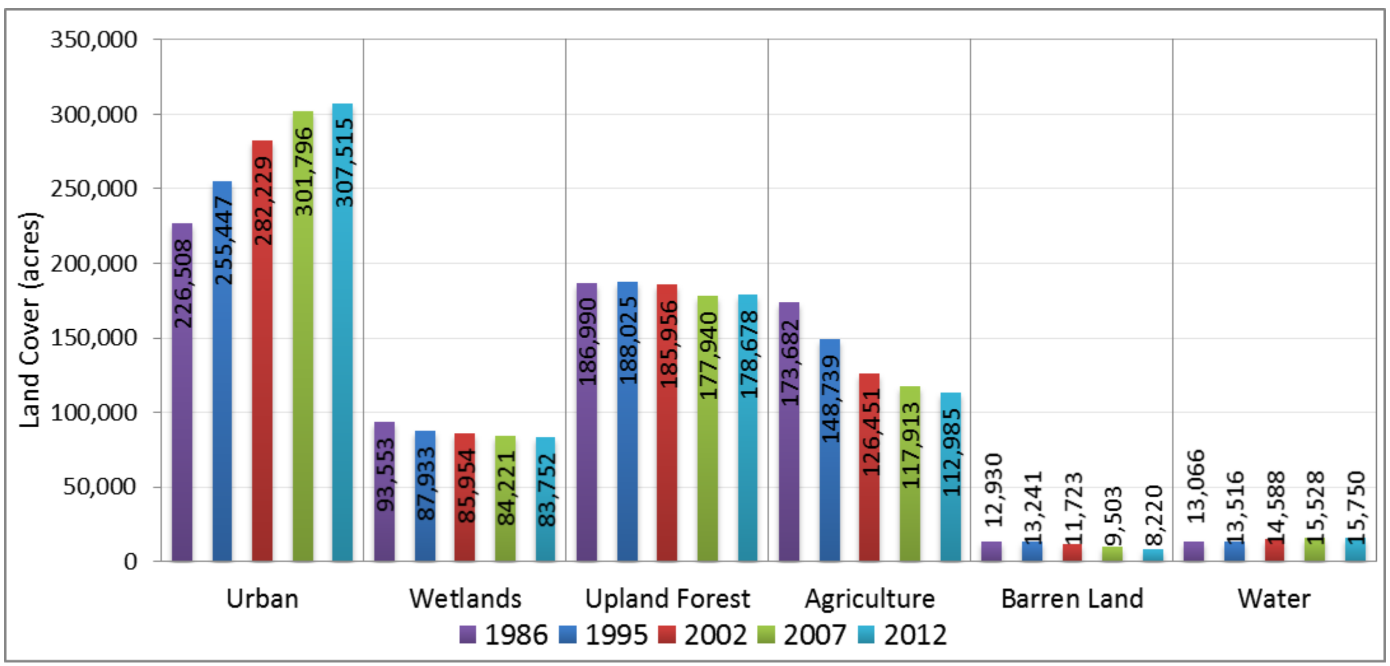


Figure 10. Change in land use/land cover in the Raritan River watershed from 1986 to 2012

in urban land with an increase of 35.8 percent that was nearly evenly spread across the three WMAs with 11.9 percent of the gain in the Upper Raritan, 11.4 percent of the gain in the Lower Raritan and 12.5 percent of the gain in the Millstone (Tables 6 through 9). This new urban land came primarily from the conversion of agriculture land and to a lesser extent upland forest and wetlands. The greatest losses for land use categories were in barren land and agricultural with 36.4 percent and 34.9 percent respectively (Table 6; Figure 10). The Upper Raritan and the Millstone experienced 13.2 percent and 15.4 percent decreases in acres of agricultural land respectively. The change in barren land was primarily in the Lower Raritan with 22.8 percent decline in acres and to a lesser extent in the Upper Raritan with an 11 percent decline. Subsequent sections of this report include more discussion of these changes.

While the annualized pace in growth of urban development was steady from 1986 to 2007, it slowed significantly across the region from 2007 to 2012 (Figure 11). The loss of agricultural land slowed during the T3 (2002 to 2007) time period and was replaced by a jump in the loss of upland forest. Similar trends are found in each of the WMAs (Figures 12 to 14).

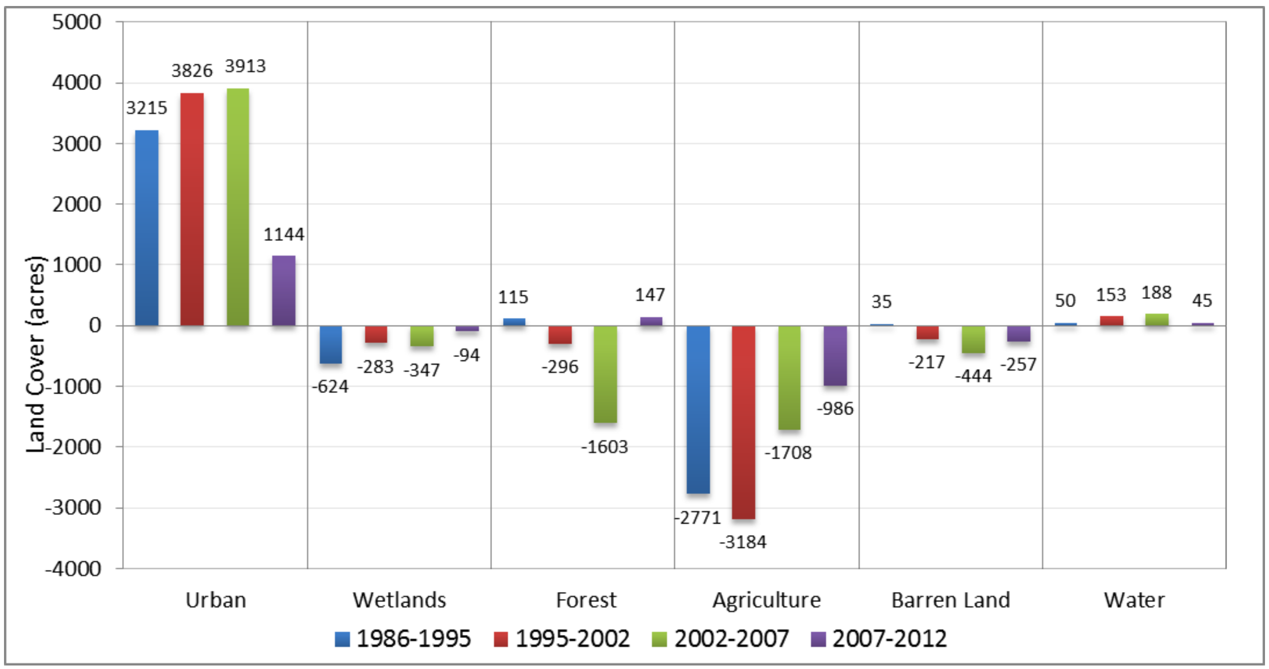


Figure 11. Annualized rate of change of land use/land cover for periods T1, T2, T3, and T4 in the Raritan River watershed

Land Use WMA 08	1986 (acres)	1995 (acres)	2002 (acres)	2007 (acres)	2012 (acres)	26 year change	26 year Change (percent)
Urban land	71,727	80,983	89,921	96,425	98,696	+26,969	+37.6
Upland Forest	107,341	108,553	108,225	104,553	104,734	-2,606	-2.4
Agricultural Land	89,078	79,103	70,603	68,291	66,235	-22,843	-25.6
Wetlands	22,902	22,249	21,943	21,568	21,609	-1,293	-5.6
Water	5,951	6,121	6,699	7,106	7,166	+1,215	+20.4
Barren Land	2,584	2,592	2,320	1,768	1,162	-1,422	-55.0

Table 7. Change in land use/land cover acreage in the Upper Raritan watershed from 1986 to 2012

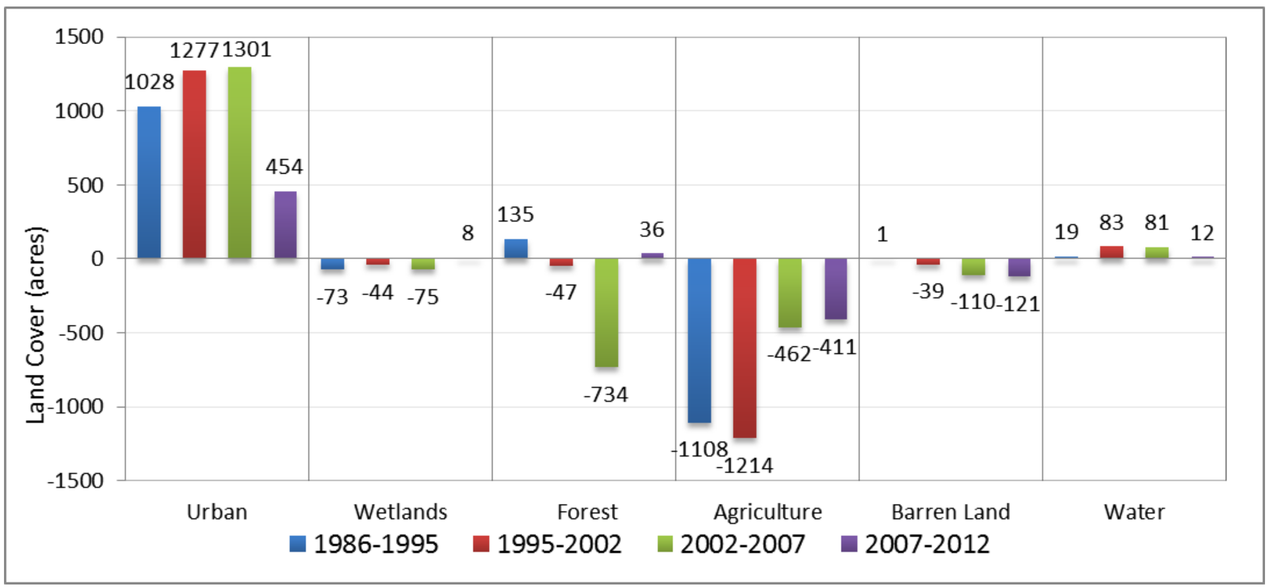


Figure 12. Annualized rate of change of land use/land cover for periods T2, T2, T3, and T4 in the Upper Raritan WMA

Land Use WMA 09	1986 (acres)	1995 (acres)	2002 (acres)	2007 (acres)	2012 (acres)	26 year change	26 year Change (percent)
Urban land	108,088	117,127	124,635	131,808	133,836	+25,748	+23.8
Upland Forest	40,372	39,442	37,912	34,694	34,525	-5,848	-14.5
Agricultural Land	23,446	19,149	15,475	13,023	12,275	-11,171	-47.6
Wetlands	41,009	37,367	35,951	35,006	34,366	-6,643	-16.2
Water	5,141	5,320	5,647	5,939	6,030	+889	+17.3
Barren Land	6,957	6,637	5,424	4,573	4,011	-2,947	-42.4

Table 8. Change in land use/ land cover acreage in the Lower Raritan watershed from 1986 to 2012

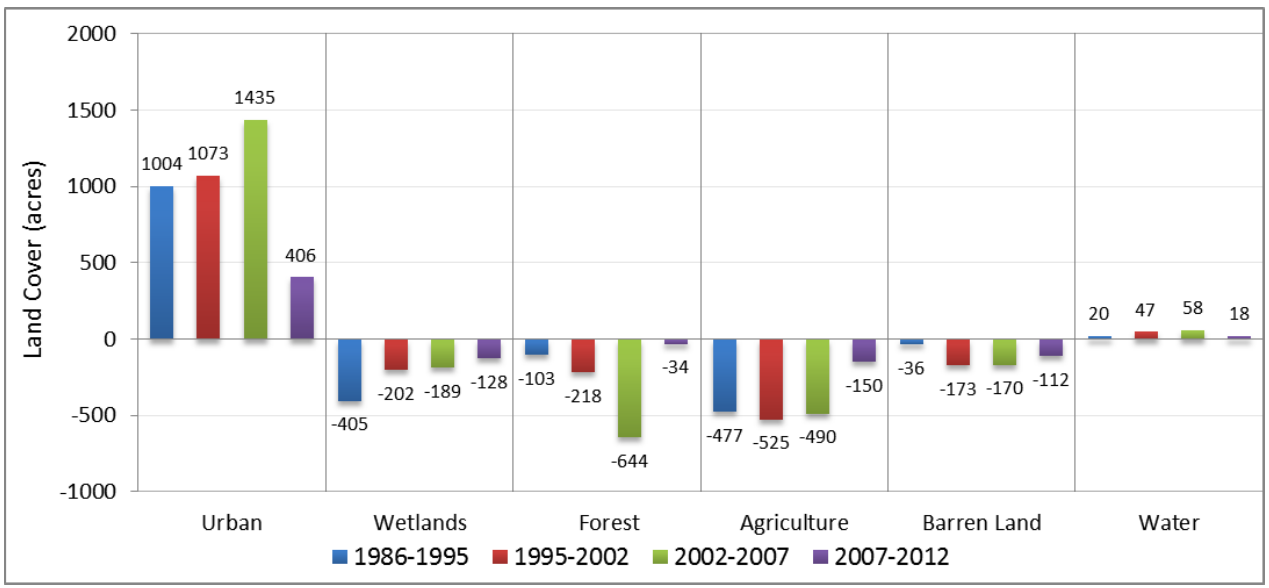


Figure 13. Annualized rate of change of land use/land cover for periods T1, T2, T3, and T4 in the Lower Raritan WMA

Land Use WMA 10	1986 (acres)	1995 (acres)	2002 (acres)	2007 (acres)	2012 (acres)	26 year change	26 year Change (percent)
Urban land	46,692	57,333	67,674	73,563	74,977	+28,285	+60.6
Upland Forest	39,277	40,012	39,818	38,694	39,394	+117	+0.3
Agricultural Land	61,159	50,476	40,373	36,599	34,466	-26,692	-43.6
Wetlands	29,642	28,317	28,060	27,646	27,778	-1,864	-6.3
Water	1,974	2,054	2,242	2,483	2,529	+555	+28.1
Barren Land	3,389	3,954	3,979	3,162	3,001	-387	-11.4

Table 9. Change in land use/land cover acreage in the Millstone watershed from 1986 to 2012

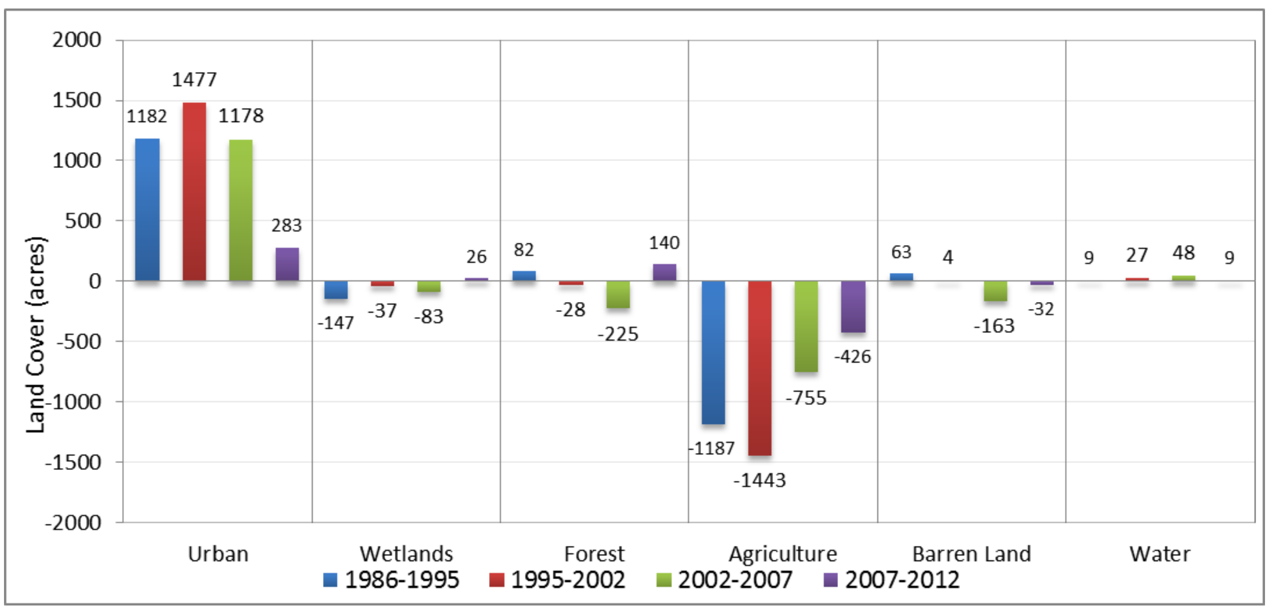


Figure 14. Annualized rate of change of land use/land cover for periods T1, T2, T3, and T4 in the Millstone WMA

Summary—Urban Land Use

The pace of urban development seems to have slowed in recent years. The overall trends were for increase in urban land cover at the expense of agricultural land cover and to a lesser extend of wetlands and forest cover. These changes tend to have a negative impact on water quality as pervious land cover gives way to impervious surfaces. Forest, wetland and a subset of the agricultural land use changes are discussed more fully in subsequent sections.

Key Indicator

Impervious Surface

Background

Impervious surface is also known as impervious cover and has been recognized as a critical driver to degrade water quality in the watershed. Impervious surface is defined as the area that prohibits penetration of water into underlying ground layers, as a result, rain and snow are unable to infiltrate into the ground and runs off. Examples of impervious surface include residential rooftops, public buildings, parking lots, commercial structures, and bedrock close to the soil surface. In general, concrete, asphalt, rooftops, and highly compacted soils that do not absorb water are known as impervious surfaces.

The expansion of impervious surface cover poses a threat to water quality in the watershed. For example, if forest or agricultural land is converted into residential or commercial uses, the impervious surface area increases resulting in a reduction of the amount of infiltration and ultimately leads to lower groundwater recharge. Increases in impervious surface cover also increases the runoff that is likely to carry non-point source pollutants into nearby waterbodies. This leads to deposition of excessive amounts of nutrients such as phosphorus and nitrogen resulting in algal blooms as well as the potential to carry oil, gas and other contaminants from roadways and parking lots into local waterbodies. Increases in impervious surface areas can also add to the volume of runoff and increase the velocity of flows in streams during a precipitation event. The increased volume and velocity of water can erode stream banks increasing sediment loads in streams that further degrades water quality.

Significant research has been conducted on impervious surface cover as it relates to water quality and researchers have found a high correlation between amounts of impervious surface cover and the degree of water quality impairment. When the impervious surface cover is greater than 10 percent of total watershed area, the water quality degrades in the watershed; if it is greater than 25 percent the water quality degrades severely (NJWSA, n.d.). When the impervious surface cover is less than 10 percent of total watershed area, the water quality is considered protected (Arnold and Gibbons, 1996).

Methodology

The impervious surface data for the Raritan were derived from the NJDEP land use/land cover GIS data set. The impervious surface for each land use/land cover polygon was estimated from 0 to 100 percent at five percent increments. Impervious surface data were available for the years of 1995, 2002, 2007, 2012 (Figure 15).

In order to assess the impact of impervious surface on subwatersheds in the Raritan basin, a weighted average of impervious surface within each 14-digit hydrologic unit (HUC-14) was estimated. This was achieved by multiplying the percent impervious cover for each land use within a HUC-14 times its surface area divided by the total area of the HUC-14 to derive the weighted average of impervious surface for that sub-watershed. The resulting percent impervious surface cover was categorized into five classes that correlate to degree of water quality impairment: less than five percent impervious cover (protected); five to 9.9 percent (minimally impacted); 10 to 19.9 percent (moderately impacted); 20 to 24.9 percent (severely impacted); and greater than 25 percent (degraded) (as shown in Figure 16). These same thresholds were employed in the *Portrait of a Watershed* (2002) and generally correspond to those established by Thomas R. Schueler in 1992 and modified by Arnold and Gibbons (1996).

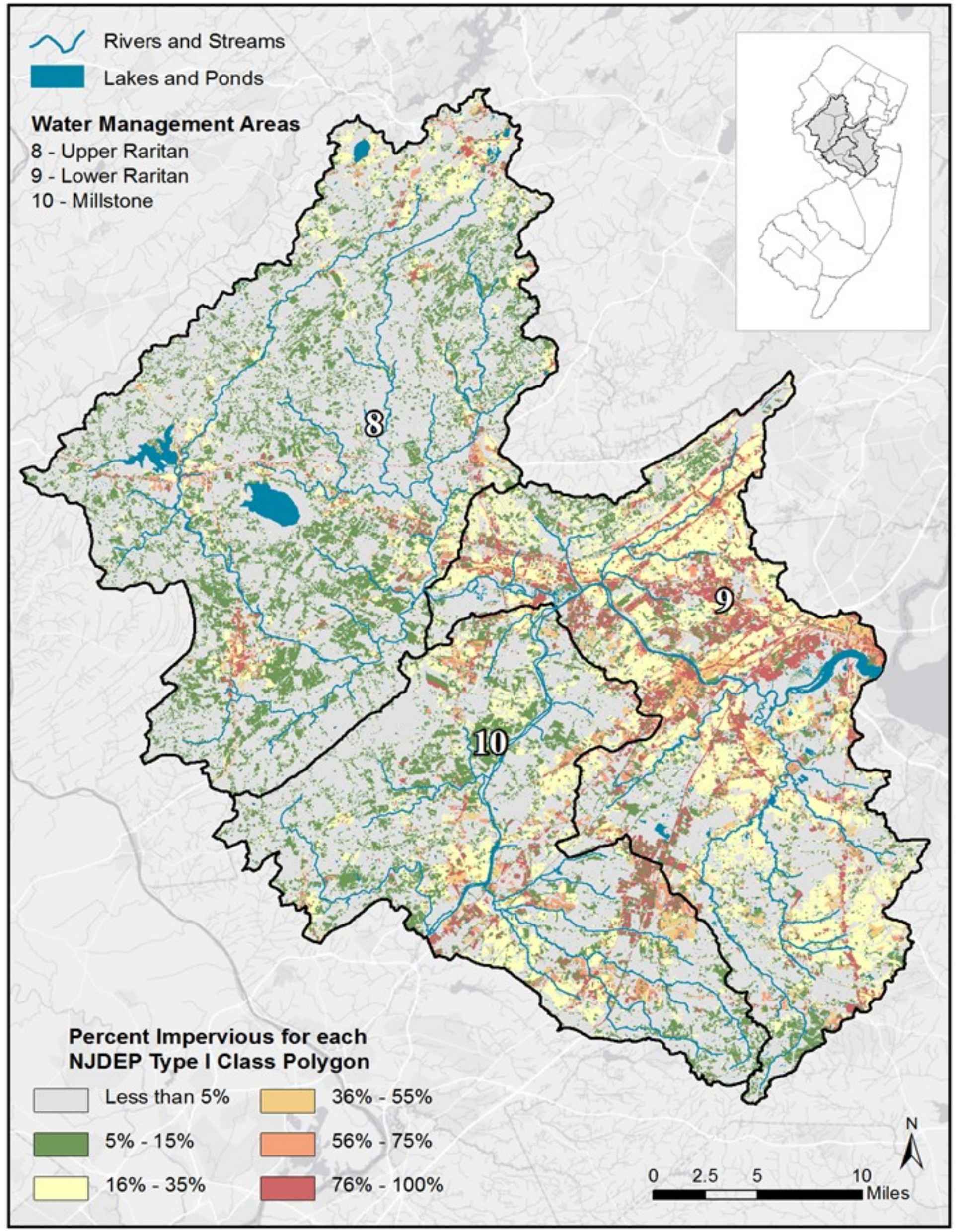


Figure 15. Impervious surface distribution in the Raritan River watershed as of 2012

Status and Trends

The amount of impervious surface cover in the Raritan has been increasing at a steady rate across all WMAs from 1995 to 2012. As expected, the spatial distribution of impervious surface closely parallels the distribution of population and housing unit density (Figure 16). A large percentage of the HUC-14s within the Lower Raritan are classified in the range from moderately impacted to degraded with only three HUC-14s classified in the minimally impacted range and one HUC-14 with weighted average land cover in the protected percent range. Conversely, the HUC-14s within the Upper Raritan are predominantly categorized as protected or minimally impacted with none in the degraded category. The HUC-14s in the Millstone have impervious surface percent cover spanning the entire gradient of classes from protected to degraded. In 2012, 12.9 percent of the Raritan was impervious surface (Table 10) with the highest impervious surface cover in the Lower Raritan (22.4 percent) followed by the Millstone (11.5 percent), and

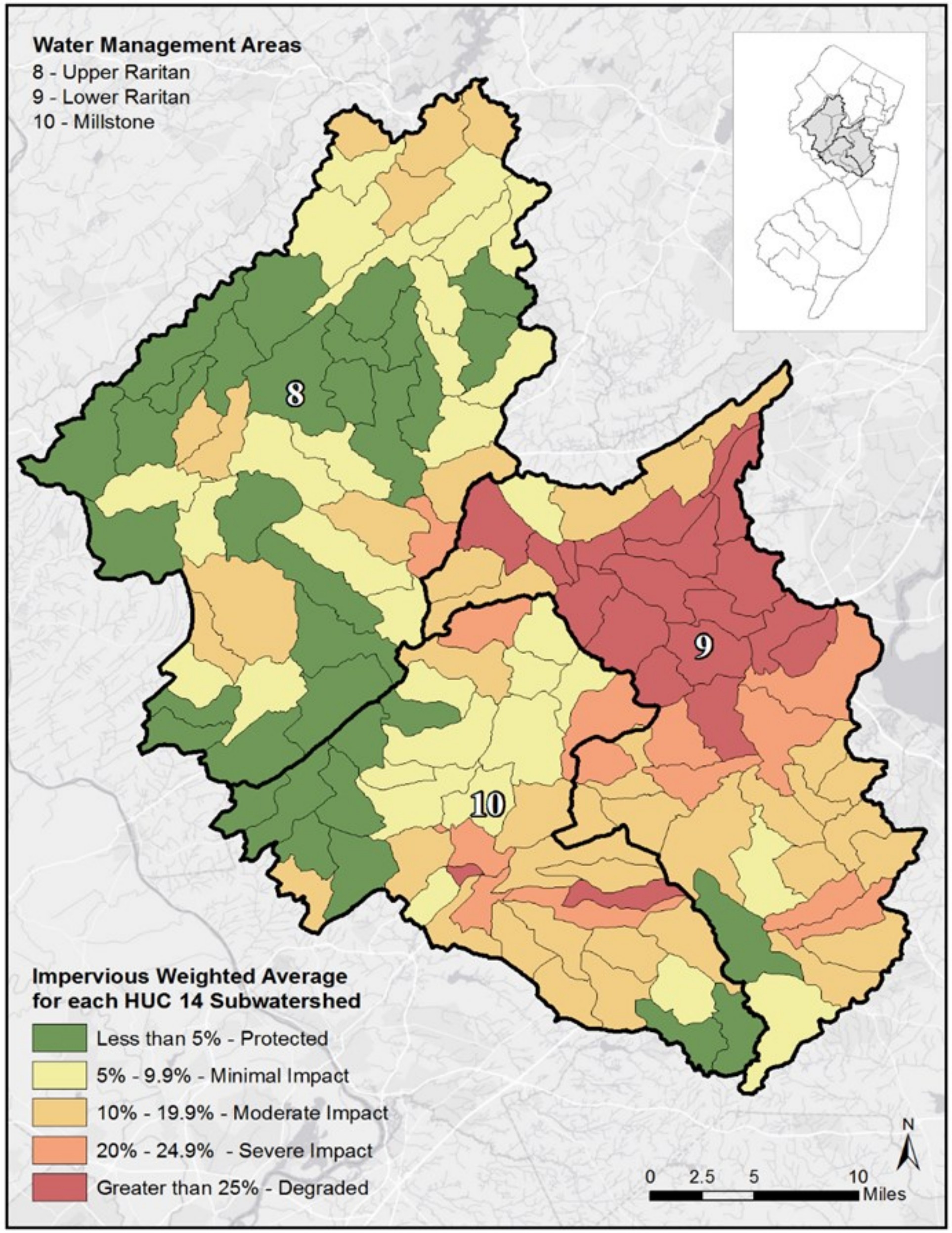


Figure 16. Spatial distribution of weighted average of impervious surface of HUC-14s in the Raritan River watershed as of 2012

Upper Raritan (6.6 percent). Closer examination shows that the Lower Raritan has a much greater area of land with higher-type impervious surface cover categories but in all cases there are extensive areas with low – or less than five percent impervious surface coverage.

Over the 1995 to 2012 time period, the percentage of impervious surface cover increased across all three watershed management areas (Table 10). Looking over the entire 17 year time period, on average the Lower Raritan added approximately 332 acres of new impervious surface per year. The Millstone and Upper Raritan added 225 and 153 acres of impervious surface per year, respectively. Out of 139 HUC-14s, only three showed a slight decrease. Further examination of these watersheds shows areas of redeveloped urban land where commercial land uses were replaced with residential land uses and the overall amount of impervious surface decreased, while 136 HUC-14s depict an increase in impervious surface (Figure 17). Two HUCs experienced an increase of more

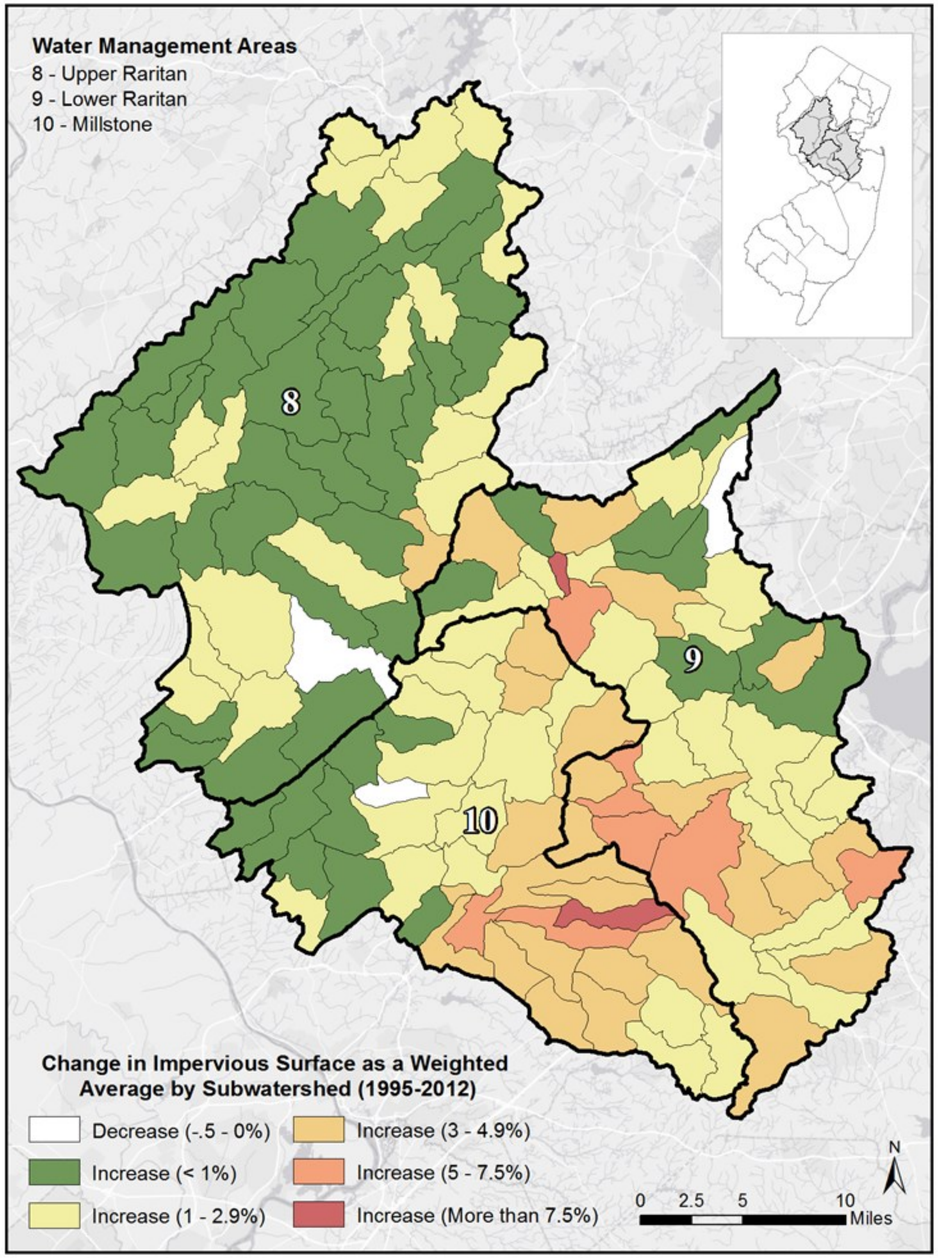


Figure 17. Change in percent of impervious surface cover in the Raritan River watershed from 1995 to 2012

Impervious Surface	1995 Percent IS	2002 Percent IS	2007 Percent IS	2012 Percent IS
Raritan Basin	11.2	12.1	12.7	12.9
Upper Raritan	5.7	6.3	6.6	6.6
Lower Raritan	19.9	21.2	22.1	22.4
Millstone	9.4	10.4	11.1	11.5

Table 10. Weighted average impervious surface cover for all Raritan WMAs from 1995 to 2012

than 7.5 percent impervious surface. The greatest increases in impervious surface cover were recorded in the Lower Raritan and Millstone.

Summary—Impervious Surface

The literature indicates that watersheds with more than 10% impervious cover tend to have impaired water quality, while those with more than 25% impervious cover have degraded water quality. The Raritan had 12.1% impervious cover across the basin in 2012, with the Lower Raritan watershed management area exceeding 22.4% impervious cover. The trend for impervious surfaces is increasing across the Raritan basin with potentially negative impacts on water quality.

Key Indicator

Wetlands

Background

Wetlands are the transitional area or the link between land and water where water covers the soil periodically or throughout the year. The presence of water, nutrients, and sunlight makes wetlands a unique ecosystem in the watershed. The Raritan region includes both inland and coastal wetlands. Examples of coastal wetlands include tidal marshes and mudflats while inland wetlands include swamps, marshes, bogs, depressions, and overflow wetlands along rivers and streams. Wetlands provide a myriad of benefits and services including water filtration, shoreline stabilization, floodwater storage, groundwater recharge, and habitat for fish and wildlife. Most relevant to water quality are wetlands' services for water filtration and stormwater management where wetlands capture and filter materials, sediment and waste from stormwater runoff and floods. Even though wetlands provide a wide range of benefits to society, wetlands loss continues to be prevalent due to infrastructure development, land conversion, water withdrawal, pollution, overexploitation, and introduction of invasive alien species. An assessment of conversion of wetlands is, therefore, important to understanding water quality in the watershed.

Methodology

To more closely examine the changes in wetlands, we considered five classifications of wetlands: forested, emergent, coastal, agricultural, and disturbed. Refer to the Urban Land Use methodology for additional information.

Status and Trends

As of 2012, approximately 13.4 percent of the Raritan basin is made up of wetlands with the majority of wetlands, or ten percent, in forested wetlands (70,402 acres). The remaining acres of wetlands are: 1.6 percent in emergent wetlands (11,156 acres), 1.4 percent in agricultural wetlands (9,875 acres), 0.3 percent in coastal wetlands (2,194 acres), and 0.2 percent in disturbed wetlands (1,220 acres). The Millstone has the highest percentage of forested wetlands with 13.3 percent, followed by the Lower Raritan and Upper Raritan with 12.2 percent and 6.3 percent respectively. Overall, emergent and agricultural wetlands had the largest acreage declines over the 26 years with losses of 5,909 and 3,984 acres respectively across the Raritan basin. The largest acreage change in wetlands within the sub-basins during the 26 year study period was the conversion of 3,461 acres of forested wetlands in the Lower Raritan, which represented an 11.2 percent decrease for the WMA. The Lower Raritan also experienced the largest decline in acres of emergent wetlands with a 38.4 percent

Forested Wetlands	1986 Acres	1995 Acres	2002 Acres	2007 Acres	2012 Acres	26 year change	26 year Change (percent)
Raritan Watershed	74,000	71,096	71,956	70,122	70,402	-3,598	-4.9
Upper Raritan	18,633	18,432	18,881	18,421	18,727	-94	-0.5
Lower Raritan	30,987	28,727	28,567	27,812	27,526	-3,461	-11.2
Millstone	24,380	23,938	24,507	23,888	24,150	-230	-0.9
Emergent Wetlands							
Raritan Watershed	17,065	14,386	11,657	11,890	11,156	-5,909	-34.6
Upper Raritan	4,269	3,818	3,062	3,147	2,881	-1,388	-32.5
Lower Raritan	7,538	6,190	5,042	4,985	4,647	-2,891	-38.4
Millstone	5,258	4,379	3,553	3,758	3,628	-1,630	-31.0
Coastal Wetlands							
Raritan Watershed	2,488	2,450	2,341	2,209	2,194	-294	-11.8
Upper Raritan	0	0	0	0	0	0	0
Lower Raritan	2,485	2,450	2,341	2,209	2,194	-291	-11.7
Millstone	4	0	0	0	0	-4	-100.0
Agricultural Wetlands							
Raritan Watershed	13,859	13,107	11,343	10,370	9,875	-3,984	-28.7
Upper Raritan	4,018	3,934	3,428	3,276	3,151	-867	-21.6
Lower Raritan	3,492	3,286	2,868	2,552	2,406	-1,086	-31.1
Millstone	6,349	5,887	5,047	4,543	4,317	-2,032	-32.0
Disturbed Wetlands							
Raritan Watershed	1,943	3,461	1,887	1,644	1,220	-723	-37.2
Upper Raritan	241	470	145	139	67	-174	-72.2
Lower Raritan	1,243	1,956	1,055	851	650	-593	-47.7
Millstone	459	1,035	687	654	503	+44	+9.6
Total Wetlands							
Raritan Watershed	109,355	104,500	99,184	96,235	94,847	-14,508	-13.3
Upper Raritan	27,161	26,653	25,515	24,984	24,827	-2,334	-8.6
Lower Raritan	45,744	42,608	39,875	38,409	37,423	-8,321	-18.2
Millstone	36,450	35,239	33,794	32,843	32,597	-3,853	-10.6

Table 11. Acres of forested, emergent, coastal, agricultural, and disturbed wetlands in Raritan WMAs from 1986 to 2012

Forested Wetlands Conversion	Raritan River Watershed	Upper Raritan WMA	Lower Raritan WMA	Millstone WMA
Agriculture	-45	-64	-66	84
Barren Land	-2,462	-246	-1,378	-838
Upland Forest	96	38	31	28
Urban	-5,956	-869	-3,774	-1,313
Water	-614	-282	-232	-100
Coastal & Emergent Wetlands	5,383	1,516	1,958	1,908
Net Gain/Loss of Forested Wetlands	-3,598	93	-3,461	-231

Table 12. Conversion of forested wetlands to other land uses in Raritan WMAs from 1986 to 2012

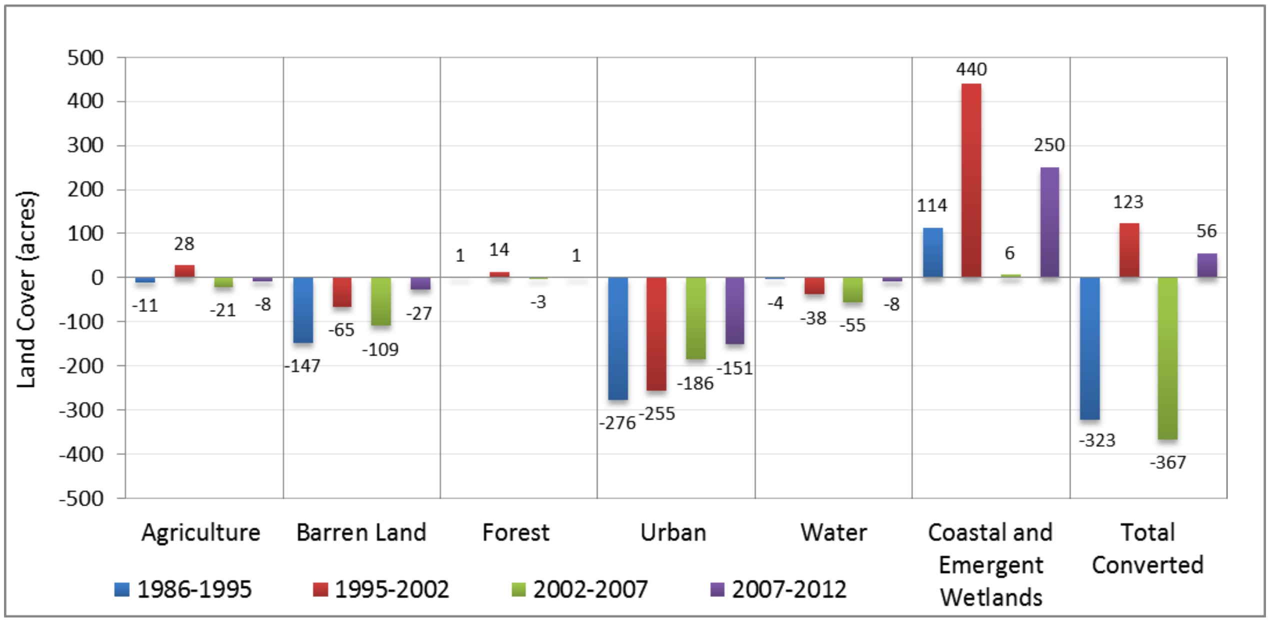


Figure 18. Annualized rate of land use/land cover conversion for forested wetlands in the Raritan River watershed for periods T1, T2, T3, and T4

Coastal and Emergent Wetlands Conversion	Raritan River Watershed	Upper Raritan WMA	Lower Raritan WMA	Millstone WMA
Urban	-1,802	-172	-1,248	-382
Upland Forest	157	48	103	7
Agriculture	1,118	362	272	484
Barren Land	113	42	-144	215
Water	-406	-151	-205	-50
Forested Wetlands	-5,383	-1,517	-1,958	-1,908
Net Gain/Loss of Coastal and Emergent Wetlands	-6,203	-1,388	-3,180	-1,634

Table 13. Conversion of coastal and emergent wetlands to other land uses in Raritan WMAs from 1986 to 2012

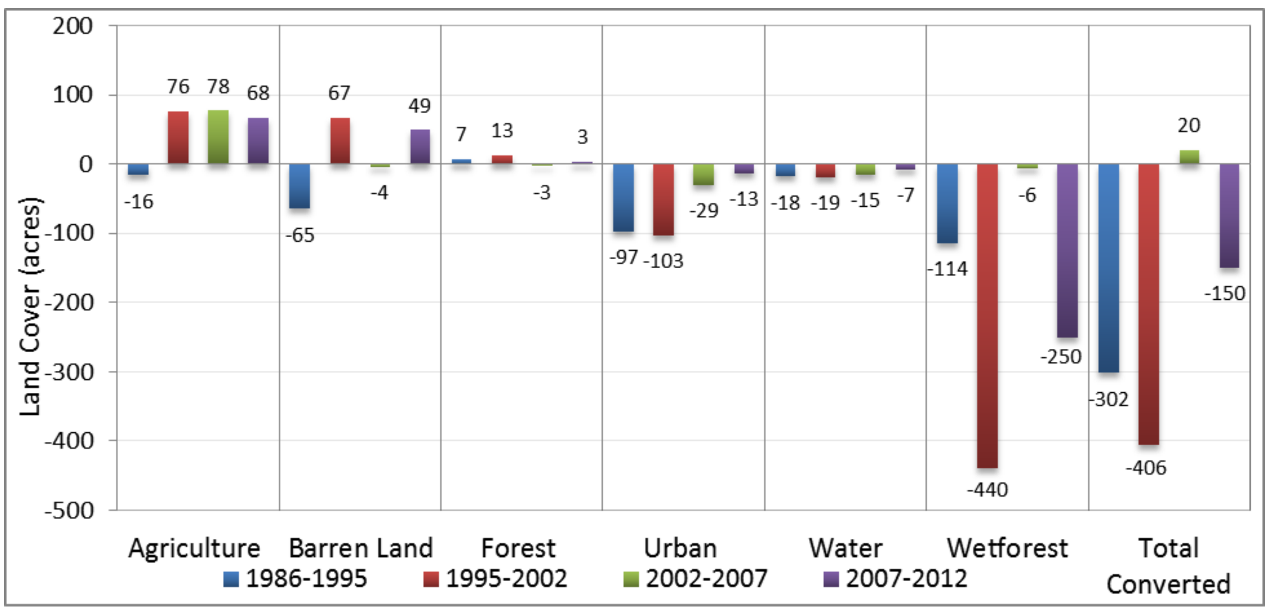


Figure 19. Annualized rate of land use/land cover conversion for coastal and emergent wetlands in the Raritan River watershed for periods T1, T2, T3, and T4

decline or 2,891 acres of emergent wetlands. (Table 11).

Examination across the study period (1986 to 2012) reveals the dynamics of forested wetlands conversion to and from other categories of land use/land cover (Table 11; Figure 18). Over 5,300 acres of emergent wetlands transitioned into forested wetlands presumably through natural succession processes. In contrast, nearly 6,000 acres of forested wetlands were converted into urban land uses followed by nearly 2,500 acres converted to barren (transitional) land cover. The Lower Raritan exhibited both the greatest loss and gain of forested wetlands over the time period with 3,774 acres converted to urban land use and 1,958 converted from coastal and emergent wetlands to forested wetlands.

Conversion of coastal and emergent wetlands to forested wetlands through natural succession represented the largest change for this land cover (Table 13; Figure 19). The next largest conversion of coastal and emergent wetlands was over 1,800 acres converted to urban land uses. The Lower Raritan again exhibited the greatest change in coastal and emergent wetlands with 1,248 acres converted to urban land use and, as indicated above, 1,958 acres converted to forested wetlands.

Gains were more than offset by losses and the overall trends for both forested and coastal/emergent wetlands were downward.

Summary—Wetlands

Wetlands provide a myriad of benefits and services including water filtration, shoreline stabilization, floodwater storage, groundwater recharge and habitat. The wetland type experiencing the highest acreage conversion to other land uses was emergent wetlands, followed closely by agricultural wetlands and forested wetlands. Overall, Raritan wetlands continue to decline in acreage with a loss of over 14,500 acres or more than 13 percent decline in wetlands since 1986. Decline in wetland acres has a negative impact on water quality.

Upland Forest

Background

Upland forest plays an important role in protecting water resources by reducing soil erosion, filtering runoff, and increasing groundwater recharge. Forests, therefore, provide numerous environmental and economic benefits, which elevate water quality and protect water resources. Consequently, an analysis of conversion of upland forest (positive and negative) is required to correlate with water quality in the watershed.

Methodology

See Urban Land Use methodology.

Status and Trends

Just over 25 percent of the Raritan basin is upland forest cover. Of the sub-basins, the Upper Raritan has the highest percentage of upland forest cover with 35 percent, followed by the Millstone and then the Lower Raritan with 21.6 percent and 15.3 percent respectively (Table 4).

The loss of upland forest to urban land uses was significant with a total of 18,810 acres converted to urban land use during the 1986 to 2012 time period (Table 14). This loss of upland forest was partially offset by a gain of 14,491 acres of upland forest from the abandonment of agricultural lands in the Upper Raritan (6,941 acres) and Millstone (5,614 acres) watersheds and to a lesser degree in the Lower Raritan (1,936 acres). The annualized rate of conversion to urban land uses within the four time periods

Upland Forest Conversion	Raritan River Watershed	Upper Raritan WMA	Lower Raritan WMA	Millstone WMA
Agriculture	14,491	6,941	1,936	5,614
Barren Land	-3,180	-1,052	-1,073	-1,054
Urban	-18,810	-8,094	-6,377	-4,338
Water	-617	-337	-207	-73
Wetlands	-253	-86	-133	-34
Net Gain/Loss of Upland Forest	-8,369	-2,628	-5,854	115

Table 14. Conversion of upland forest to other land uses in Raritan WMAs from 1986 to 2012

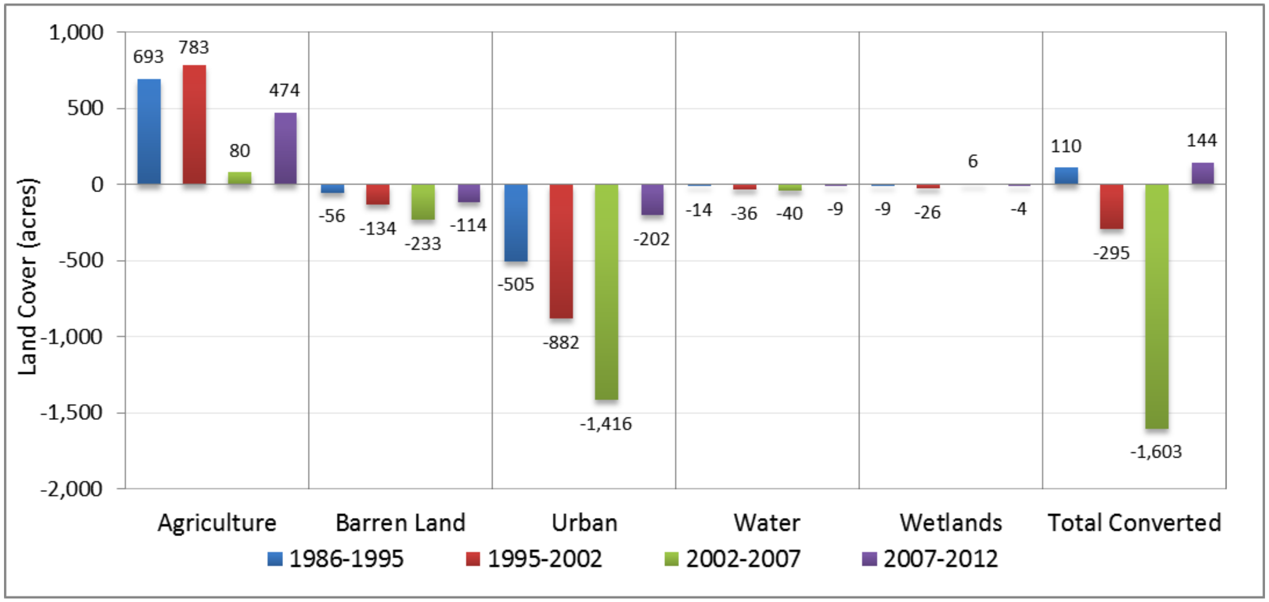


Figure 20. Annualized rate of land use/land cover conversion for upland forests in the Raritan River watershed for periods T1, T2, T3, and T4

reviewed showed a peak loss of 1,416 acres per year in the 2002 to 2007 time period (Figure 20). With the bust in the housing market starting in 2008, the conversion of upland forest to urban land use leveled off to 202 acres per year in the most recent time period. Overall, the amount of upland forest decreased during T2 (1995-2002) and T3 (2002-2007) and increased slightly during T1 (1986-1995) and T4 (2007-2012) with a net result of an overall decline in the amount of upland forest with an associated increase in negative impacts to water quality in the region.

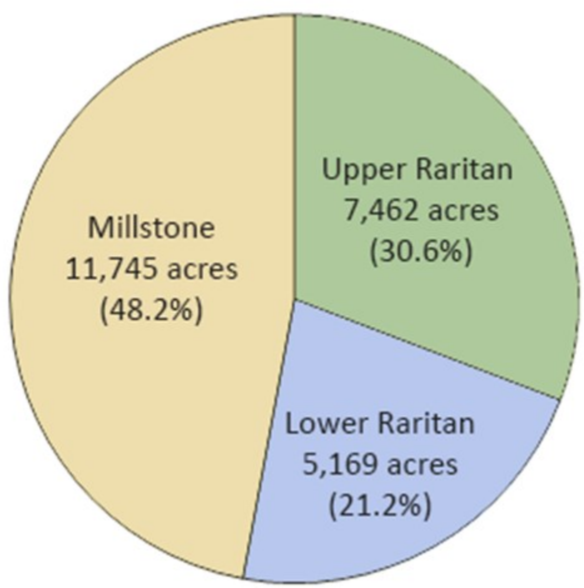
Summary—Upland Forest

Upland forests reduce soil erosion, filter runoff and increase groundwater recharge and therefore elevate and protect water quality. Nearly one-quarter of the Raritan basin land cover is upland forest. The Raritan basin experienced a net loss of upland forest of over 8,300 acres. Loss of upland forest can negatively impact water quality in the region.

Prime Agricultural Land

Background

Urban areas are expanding rapidly in the United States and soil preferable for development is evaluated based on depth to seasonal high groundwater table, slope, and depth to bedrock (NJWSA, 2002). Soil appropriate for agriculture is also suitable for development. Higher population growth combined with economic activities encourages construction of new houses as well as commercial centers. As a result, encroachment of urban areas into prime agricultural land is observed. Prime agricultural land is the portion of agricultural lands that consists of better soil quality, growing season, and soil moisture suitable for production of food, forage, and fiber with a sustainable yield (USDA, 2016). Prime agricultural land generally has greater water permeability and, due to gentler slopes, is less prone to erosion. It provides economically viable options to farmers by producing higher yields with minimal management and proper farming methods (USDA, 2016). Prime agricultural land is a subset of all agricultural lands as recorded in Tables 4 and 5.



Methodology

Prime agricultural lands are Class I and II as extracted from the Soil Survey Geographic database and mapped across the watershed. The status of prime agricultural land conversion was assessed between the 1986 to 2012 time periods while the trends of prime agricultural land conversion were evaluated based on T1 (1986 to 1995), T2 (1995 to 2002), T3 (2002 to 2007), and T4 (2007 to 2012) land use/cover data.

Figure 21. Conversion of prime agricultural land to urban land in Raritan WMAs from 1986 to 2012

Prime Agricultural Land	1986 Acres	1995 Acres	2002 Acres	2007 Acres	2012 Acres
Raritan Watershed	105,369	89,774	75,266	69,333	60,785
Upper Raritan	47,945	42,943	38,154	36,740	33,640
Lower Raritan	15,896	12,882	10,487	8,641	6,951
Millstone	41,528	33,950	26,625	23,952	20,193

Table 15. Prime agricultural lands in Raritan River WMAs from 1986 to 2012

Status and Trends

Approximately twenty three percent of prime agricultural land was converted into urban land between 1986 and 2012. The highest conversion to urban use from prime agricultural land was observed in the Millstone with 11,745 acres or 28.3 percent converted, followed by the Upper Raritan with 7,462 acres (15.6 percent) and the Lower Raritan with 5,169 acres (32.5 percent) converted (Figure 21; Table 15).

The annualized rate of prime agricultural land conversion in the Raritan is shown in Figure 22. Maximum conversion of prime agricultural land into urban land was observed during T2 (1995 to 2002). Among the WMAs, a similar trend was observed for the Upper Raritan and Millstone, while the Lower Raritan had the highest annualized conversion in the T3 (2002 to 2007) period. The highest overall prime agricultural land conversion was observed in the Millstone.

The implications of the conversion of prime agricultural lands to urban land uses is unclear.

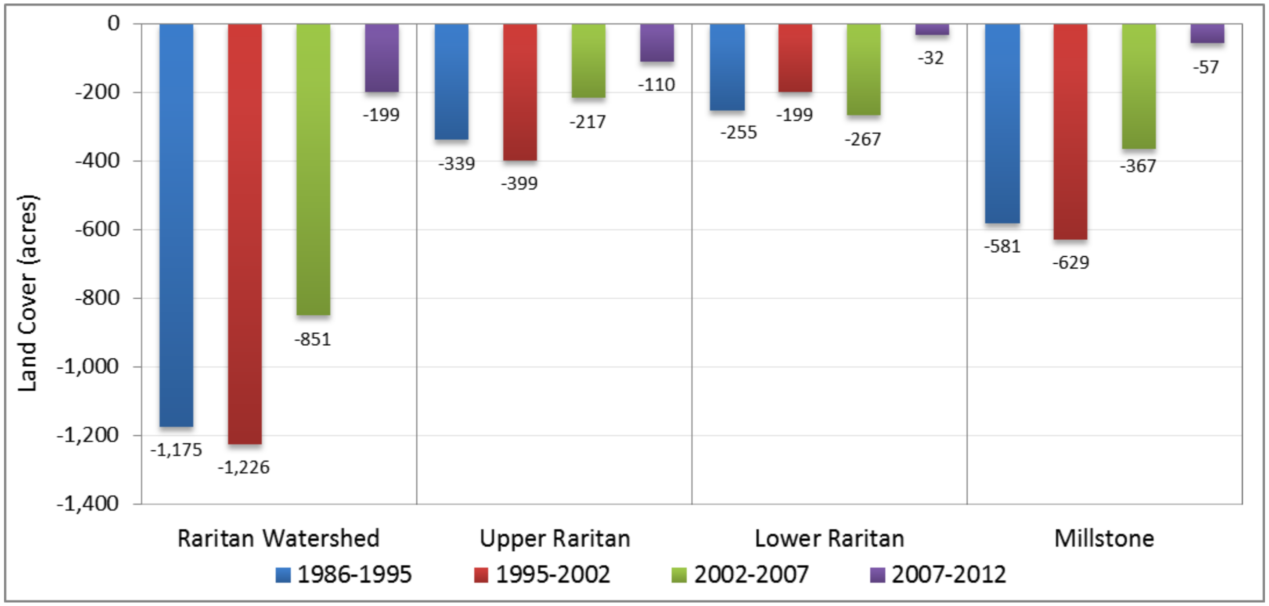


Figure 22. Annualized rate of conversion of prime agricultural land to urban land in Raritan WMAs for periods T1, T2, T3 and T4

Summary—Prime Agricultural Lands

A subset of agricultural land, prime agricultural lands have better soil quality, climate and soil moisture conducive to crop production, have greater water permeability and gentler slopes that are less prone to erosion. These qualities can filter and absorb runoff and increase recharge of groundwater supplies. The Raritan had over 44,500 acres of prime agricultural lands converted to other land uses over the study period, which represents a 42.3 percent change of use for this land cover. While the trend in prime agricultural lands is declining, the implications to water quality are unclear.

Key Indicator

Groundwater Recharge

Background

Groundwater is the water that is present below the earth's surface in the soil pores and rock void spaces. The availability and quality of groundwater is very important as most of the people around the globe depend on groundwater for drinking and for agricultural and industrial purposes. Additionally, groundwater supplies water uniformly to ecologically sensitive areas for survival of plants and animals. Understanding groundwater is vital when considering the overall demand of water in a watershed. Study of groundwater recharge supplements and reinforces analysis of land use/land cover and the resulting impacts on

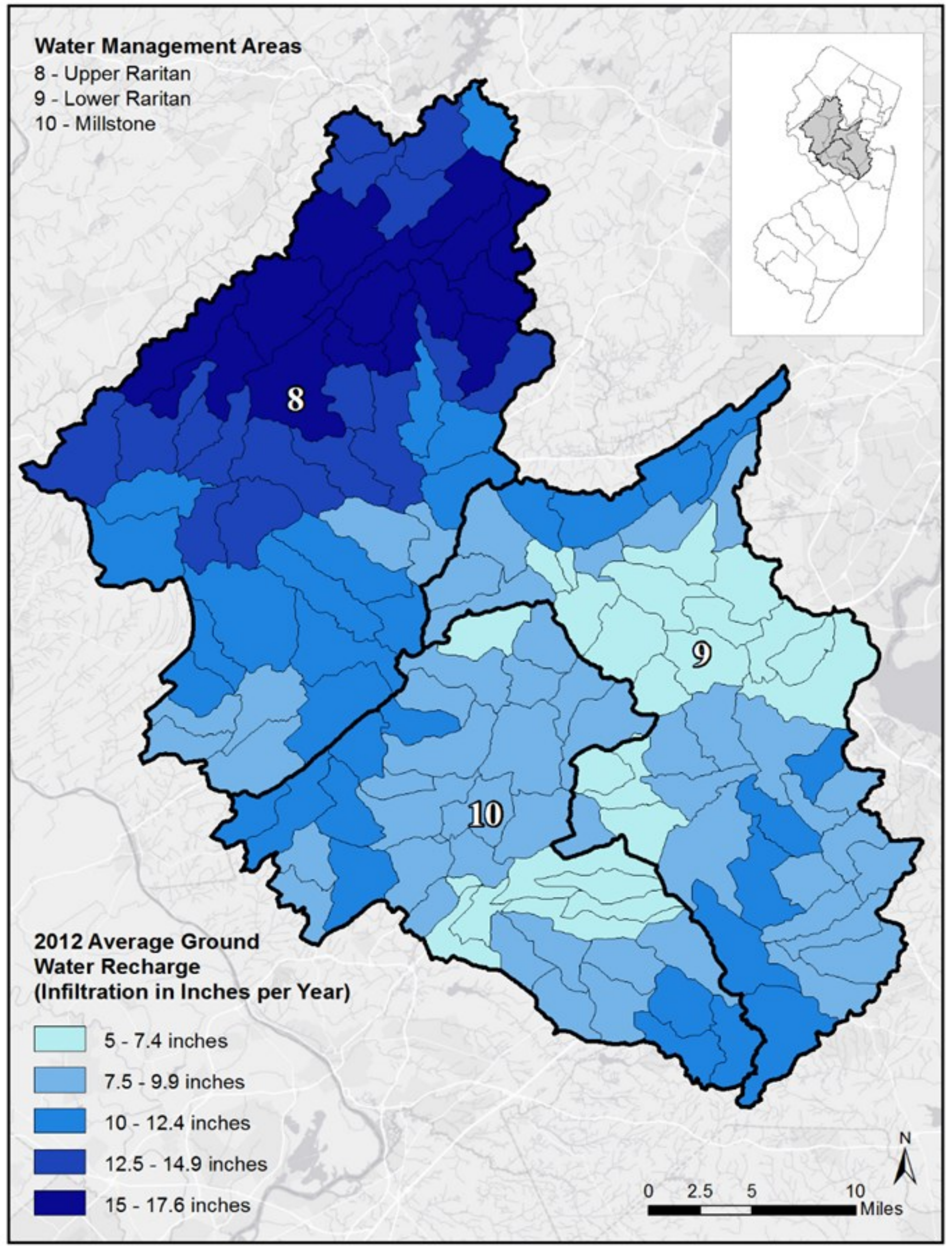


Figure 23. Groundwater recharge in the Raritan River watershed based on HUC-14 as of 2012

water quality as groundwater recharge is closely tied to the infiltration rates exhibited by different land covers. For example, upland forest land cover exhibits the highest recharge rates while high intensity urban land uses with high amounts of impervious surface exhibit the lowest recharge rates.

Methodology

Groundwater recharge in inches per year was estimated on a HUC-14 basis using New Jersey Geological Survey's Groundwater Recharge Methodology Version 6.1 which is based on the equation: *Groundwater recharge (inches/year) = (recharge factor × climate factor × basin factor) - recharge constant.*

The groundwater recharge factor and constant are based on land use and soil type. NJDEP Level III land use GIS data were recoded into 14 categories of land uses. The average revised climate factor of each HUC-14 is provided in the model. The basin factor of one (1) is used for all HUC-14s as recommended in the user guide for the model. The weighted average of groundwater

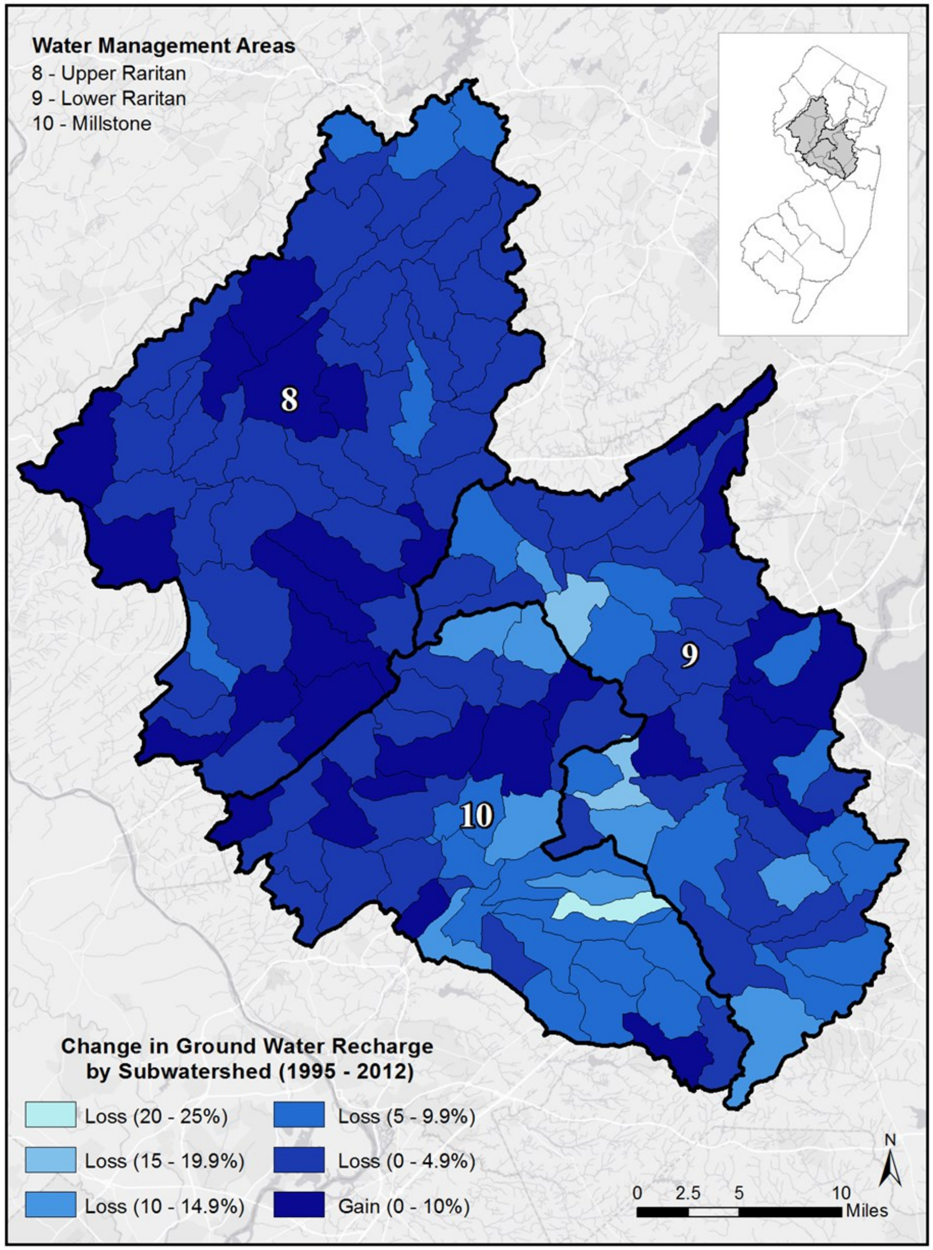


Figure 24. Change of groundwater recharge in the Raritan River watershed based on HUC-14 from 1995 to 2012

recharge of each HUC-14 is the sum of groundwater recharge of each polygon divided by the total area of polygon within each HUC-14. The limitation of this method is that the groundwater recharge of wetlands and waterbodies are not included in the calculation of groundwater recharge.

The trends of groundwater recharge were estimated based on 1995 and 2012 land use/ land cover data.

Status and Trends

The HUC-14 scale groundwater recharge within the Raritan Basin ranges from 5 to 17.6 inches/year (Figure 23). Highest recharge rates were found in the Upper Raritan where upland forest land cover dominates and where there is a minimum of impervious surface. In contrast, the lowest recharge rates were found in the Lower Raritan and are related to extensive impervious surface cover. None of the HUC-14s in either the Lower Raritan or Millstone had recharge rates above 12.4 inches per year.

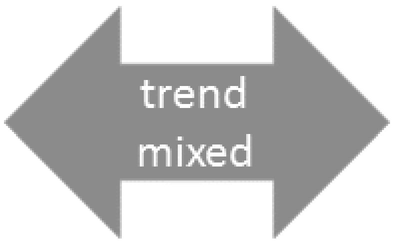
Thirty-nine (out of 52) HUC-14s in the Upper Raritan showed a decline in groundwater recharge rate between 1995 and 2012 with only thirteen HUCs showing gains in recharge (Figure 24). This loss in groundwater recharge rate is closely tied to increasing urban land use with higher impervious surface cover. HUCs showing an increase in recharge are presumably due to increased forest cover. Out of 47 HUC-14s in the Lower Raritan, 40 exhibited a loss of recharge while only seven showed gains. In the Millstone, 32 out of 40 HUC-14s showed a loss with eight showing a gain. Overall, groundwater recharge rates are declining for the Raritan and subwatersheds with associated negative impacts on water quantity and quality. There are a number of other issues related to groundwater such as impacts of septic systems and well water withdrawals that merit further analysis.

Summary—Groundwater Recharge

Groundwater is an important drinking water source in the Raritan and also supplies water uniformly to ecological sensitive areas for survival of plants and animals. Groundwater recharge is intricately tied to infiltration rates of different land covers. Loss of groundwater recharge is tied to increasing urban land use with higher impervious surface covers. The groundwater recharge rates are declining over the study period with associated negative impacts on water quantity and quality.

Key Indicator

Stream Integrity
(Bioassessment)



Background

Bioassessment is the evaluation of stream health using living organisms in natural environmental sites (SCCWRP, 2014). It is the process to quantify living organisms against the localized stressors by counting individual numbers at a particular location in the stream. In comparison to traditional water quality measurements (sediment, total nitrogen (TN), and total phosphorus (TP)), bioassessment measures an integrated stream health as the living organisms are exposed to multiple stressors over time. Bioassessment directly measures the integrity of aquatic life which is based on water quality. Typical assemblages used for bioassessment are algae, amphibians, birds, fish, macroinvertebrates, and vascular plants. In this study, bioassessment is evaluated based on macroinvertebrate and fish sampling.

Methodology

The NJDEP monitors stream biotic condition to develop two indices of stream ecological/ biotic integrity: New Jersey Impairment Score (NJIS) and the Fish Index of Biotic Integrity (FIBI).

Ambient Biomonitoring Network (AMNET) is used to perform a taxonomic analysis of in-stream macroinvertebrates to assess stream health and this analysis is used to calculate a multi-metric index of stream integrity known as the New Jersey Impairment Score (NJIS). The NJIS score is used to categorize the stream into four different assessment categories of poor, fair, good, and excellent. In this study, 1997, 2002, and 2007 AMNET data (available in the public domain) were used.

FIBI measures stream health based on different aspects of the fish assemblage (i.e., ecosystem, population, and community (NJDEP, 2011). A total of 26 fish sampling sites in the Raritan are monitored by NJDEP and these sites are categorized as poor, fair, good, and excellent based on deviation from the reference condition of an unimpaired stream with minimal human disturbance. Three rounds (R1: 2000-2004, R2: 2005-2009, and R3: 2010-2011 for only 12 locations) of FIBI data were available for the Raritan though all sampling sites were not monitored in the same year.

Macroinvertebrate Bioassessment

Status and Trends

As of 2007, 64 out of the 152 AMNET stations (42 percent) across the Raritan basin were characterized as fair; 46 stations (30 percent) were characterized as good; 19 stations (13 percent) were excellent; 19 stations (13 percent) were poor; while four stations had no data (Figure 25). AMNET stations rated as excellent occurred only in the Upper Raritan. In contrast, the Lower Raritan had highest percentage (47 percent) of poor category AMNET stations.

Overall, the trend in the AMNET Impairment Score was deemed mixed. Examination of the change in status between 1997 and 2007 AMNET data showed a majority of stations (86 stations or 56 percent) had no change in status, while 40 stations (26 percent) showed a decline and 26 stations (17 percent) showed

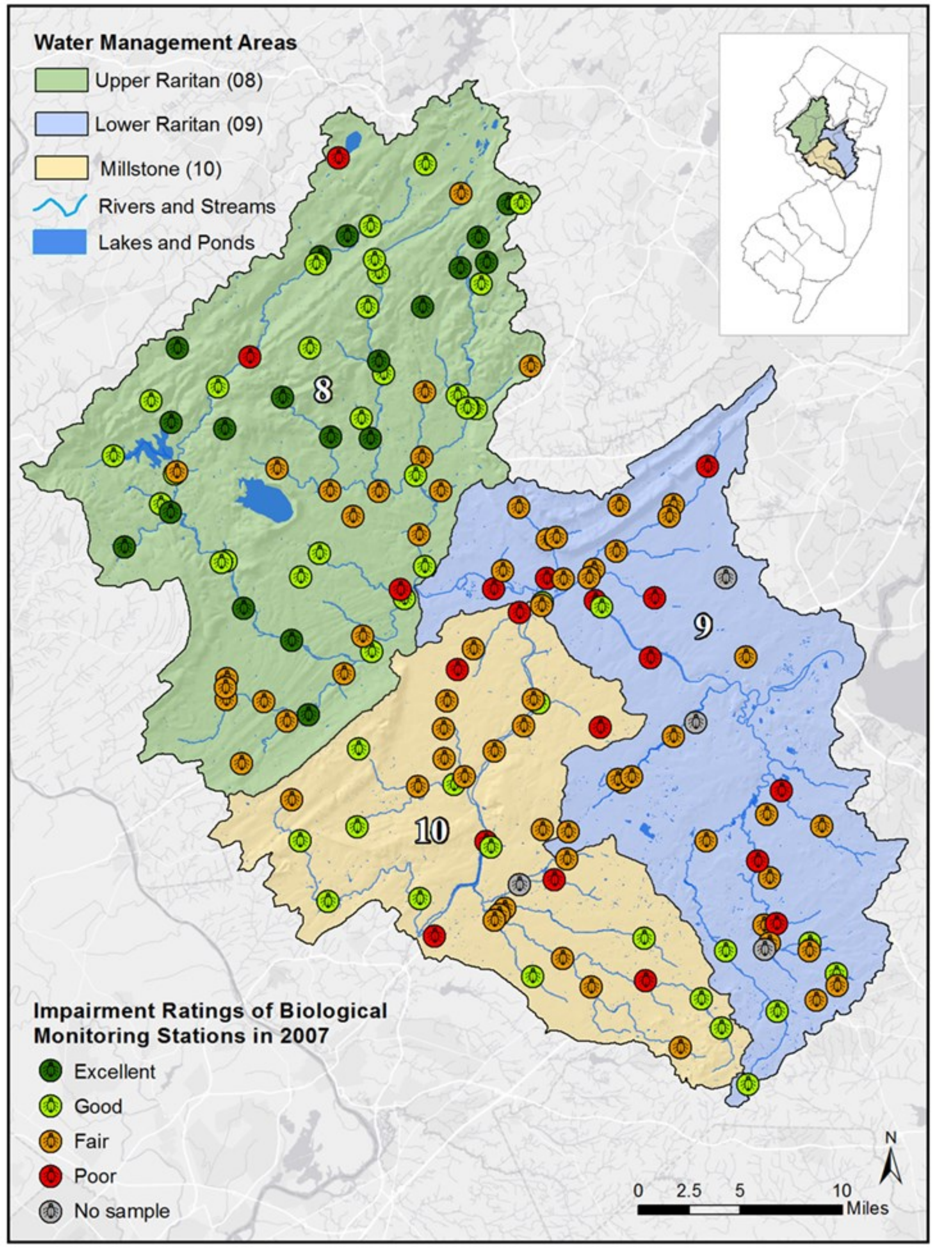


Figure 25. Categorization of stream health based on AMNET data in the Raritan River watershed as of 2007

an increase in stream health (Figure 26). Stream health decreased at 20 locations in the Upper Raritan and ten locations each of the Lower Raritan and Millstone WMAs. In contrast, stream health increased at four locations in the Upper Raritan, nine locations in the Lower Raritan and in thirteen locations in the Millstone. The degree to which changes in land use as compared to point source of pollution and other factors are affecting the AMNET Impairment Score needs further investigation. Future work in this area would be to partner with area stakeholders to update this data.

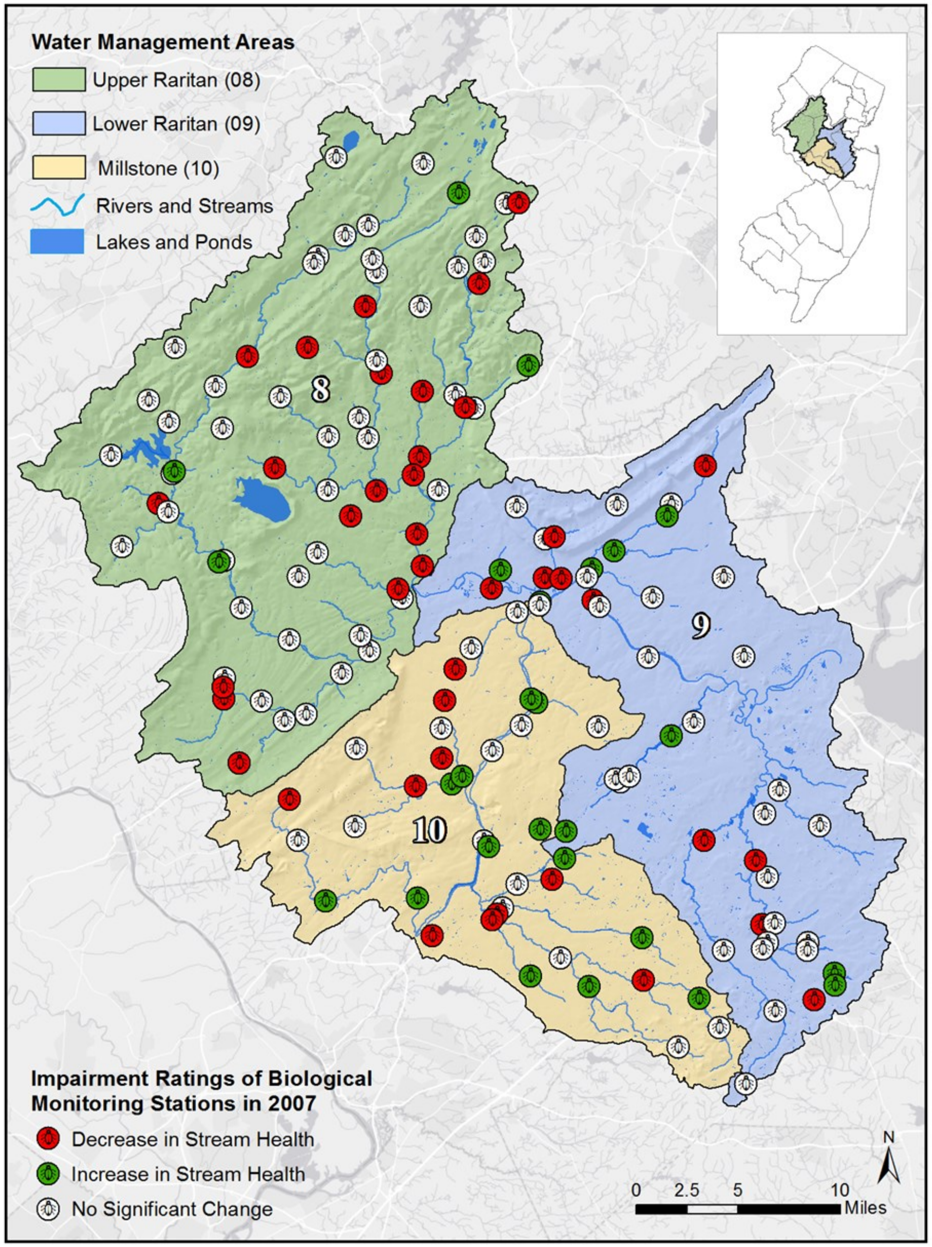


Figure 26. Increase/ decrease in stream health based on AMNET data in the Raritan River watershed as of 2007

Fish Bioassessment

Status and Trends

Out of twelve FIBI stations sampled during Round-3 (2010 and 2011) only one station was categorized as excellent, three stations were categorized as good, six stations as fair, and two stations were categorized as poor category (Figure 27). Excellent category stations were only found in the Upper Raritan and are likely attributed to high forest cover coupled with less development compared to other WMAs.

The trend overall in the FIBI assessment was deemed decreasing. Out of 26 FIBI sampling stations, a decrease in stream health was observed in 15 stations, and no significant change in stream health was observed in nine stations, while an increase was observed in two stations (Figure 28). A decrease in stream health in most of the stations can be

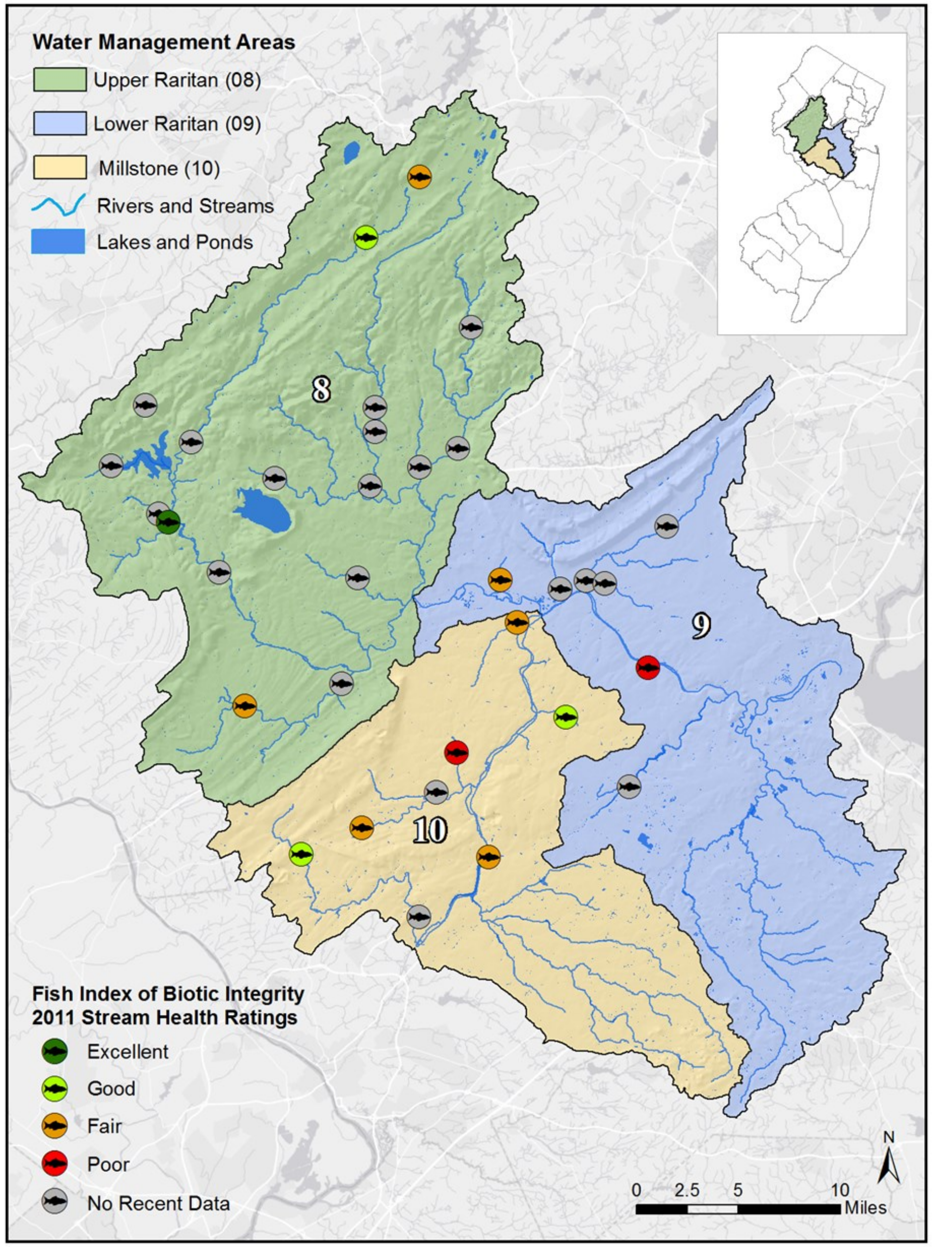


Figure 27. Categorization of stream health based on FIBI data in the Raritan River watershed as of 2011

attributed to an increase in urbanization. Impacts of urbanization change stream hydrology, geomorphology, water temperature, and water chemistry resulting in a decrease in stream health.

Summary—Stream Integrity

The presence or absence of living organisms can be used to measure stream health where the presence of certain macroinvertebrate and fish species indicates good water quality, while the absence of more sensitive and moderately sensitive organisms indicates poor water quality. The trend for macroinvertebrate impairment scores was mixed with some areas improving while others declined. The trend for the index of biotic integrity for fish species was declining, indicating poor water quality.

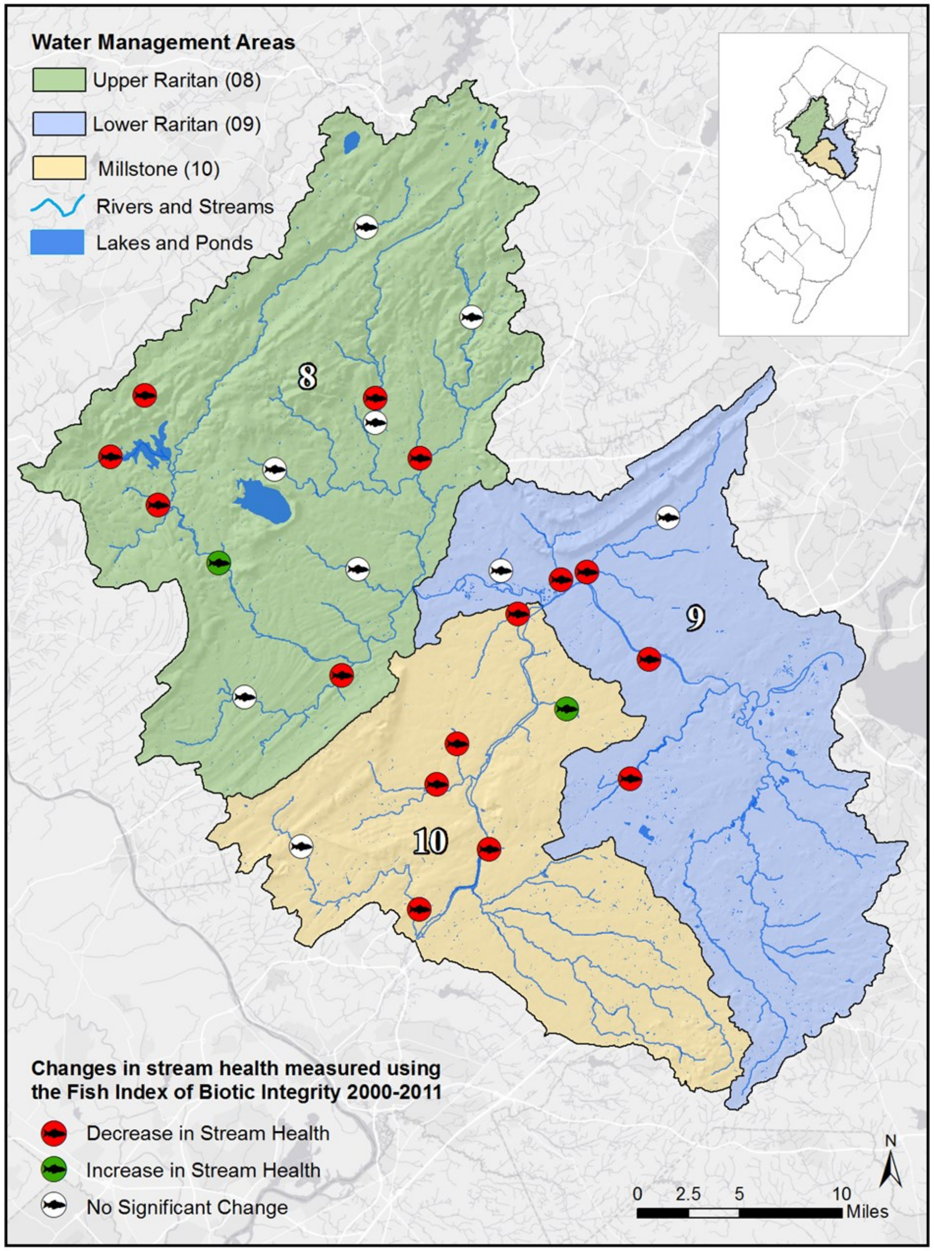


Figure 28. Increase/decrease in stream health based on FIBI data in the Raritan River watershed from 2000 to 2011

Riparian Area Integrity

Background

Riparian areas are transitional areas that lie between terrestrial and aquatic ecosystems (NRCS, 2007). As a result, riparian areas contain both the characteristic of upland as well as aquatic ecosystems. These areas are vital for healthy watersheds as they: protect streambanks and remove sediments and nutrients from runoff; reduce flooding and protect aquatic ecosystems; and provide habitat as well as food to terrestrial and aquatic organisms. Most researchers use the condition of riparian areas as an index to measure stream health.

Even though riparian areas provide a myriad of benefits to our society, these areas have been converted into agricultural land as well as urban land. Agricultural land can generate nonpoint source pollution that degrades water quality; urban land can increase impervious surfaces causing more runoff that can erode stream health. In our investigation of riparian areas, we assumed forest and wetlands to be natural land cover, suitable for habitat and characteristic of supporting good water quality while agricultural land, urban land, and barren land would have negative impacts on stream health. Apart from the above land use parameters, we also investigated the pattern of impervious surface inside riparian areas.

Methodology

Based on NJDEP GIS classification, riparian areas were divided into two separate categories: C1 streams and C2 streams. A stream is designated as C1 when the water has significant importance for ecological, recreational, water supply, and fisheries uses (NJDEP, 2012) and, therefore, should be protected from degradation. Limited pollution to meet the requirement of social and economic development is allowed on C2 streams (NJDEP, 2012). Riparian areas of streams were estimated by buffering 300 feet and 150 feet on both side of C1 and C2 stream, respectively. This methodology varies from that used in the 2002 report and instead follows the "Technical Approach to Landscape Level Inventory and Mapping Memorandum" for the Highlands Council for 300 foot buffers for category one streams and 150 foot buffers for non-category one streams (NRCHC, 2006).

The area of different land uses as well as impervious surface within the buffer were calculated by overlaying land uses of different years (1986, 1995, 2002, 2007, and 2012) onto the buffer layer using the land use classification system. These land uses were further classified into natural land cover (upland forest and wetlands) versus altered land use (urban, agriculture and barren). An increase in altered land cover and an increase in impervious surface implies a decline in riparian buffer integrity.

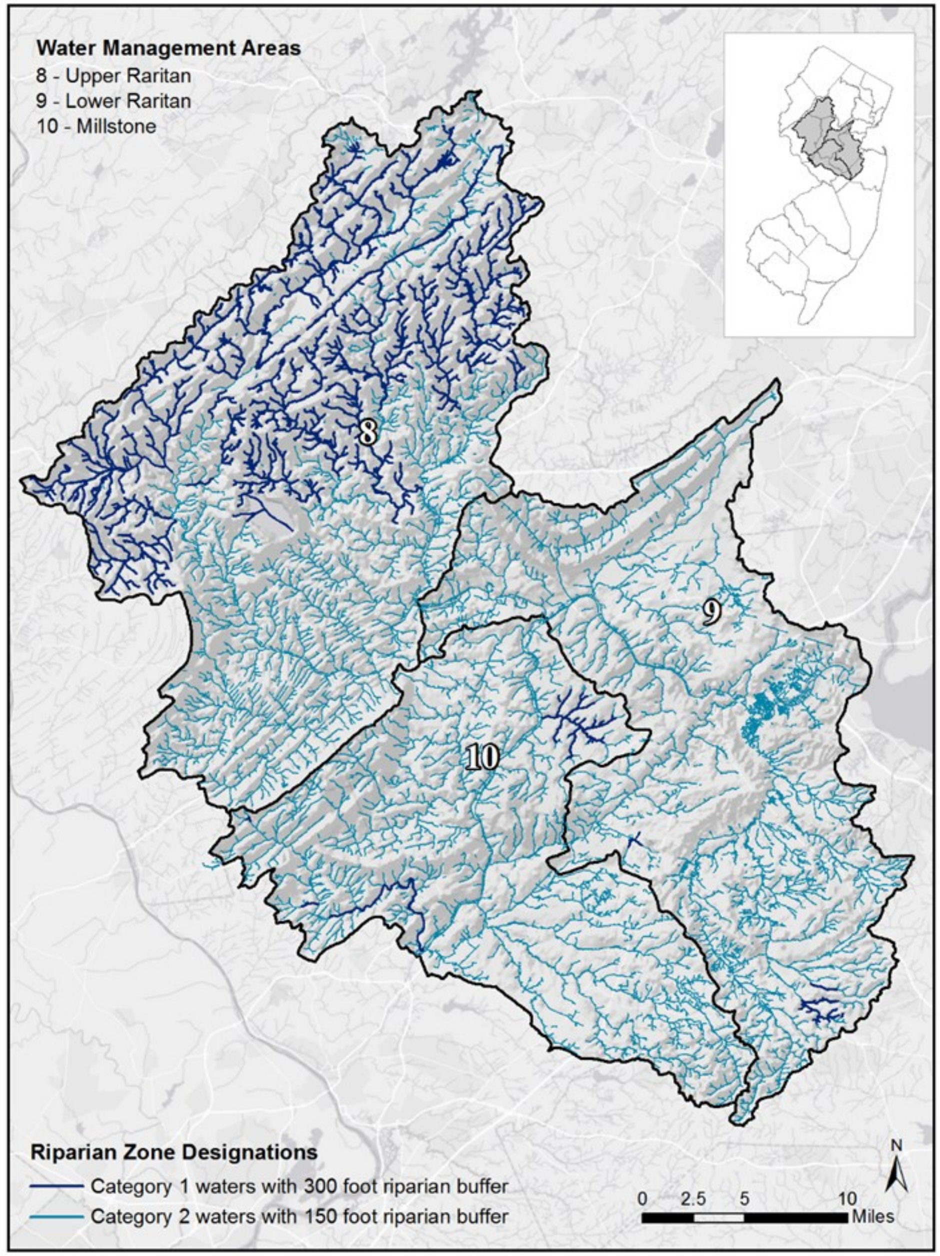


Figure 29. Distribution of C1 and C2 streams in the Raritan River watershed

Category I (C1) Streams

Status and Trends

A total of 37,848 acres of CI riparian buffer were delineated across the Raritan basin (Figure 29, Table 16). The Upper Raritan watershed overwhelming had the highest amount of C1 riparian buffer at over 93 percent, followed by the Millstone with 2.2 percent, and the Lower Raritan with just under five percent. Two-thirds of the C1 riparian buffer areas in the Raritan were in natural land cover.

The amount of altered land cover in the C1 stream riparian buffers decreased slightly in the Lower Raritan, Millstone and the basin as a whole (approximately one percent), while altered land cover in the riparian zones of the Upper Raritan increased slightly (Table 17).

C1 Stream Riparian Buffers	Natural Land Cover (acres)	Altered Land Cover (acres)	Total C1 Riparian Zone (acres)	Impervious Surface Cover (acres)	Impervious Surface Cover (percent)
Raritan Basin	25,393	12,455	37,848	1,291	3.4
Upper Raritan	23,357	11,724	35,081	1,250	3.6
Lower Raritan	639	131	820	12	1.5
Millstone	1,397	600	1,997	29	1.5

Table 16. Natural and altered land cover in C1 Stream riparian zones in 2012

Altered Land Cover in Riparian Buffer for C1 Streams	1986 (acres)	1995 (acres)	2002 (acres)	2007 (acres)	2012 (acres)	26 year change	26 year change (percent)
Raritan Basin	12,545	12,652	12,275	12,543	12,455	-90	-0.7
Upper Raritan	11,678	11,826	11,494	11,796	11,724	+46	+0.4
Lower Raritan	154	140	140	132	131	-23	-14.9
Millstone	713	686	640	614	600	-113	-15.8

Table 17. Altered land cover within riparian buffers of C1 Streams in the Raritan River watershed for the periods 1986 to 2012

Category II (C2) Streams

Status and Trends

A total of 75,549 acres of riparian buffers were delineated around C2 streams in the Raritan (Figure 29, Table 18). The C2 buffer acreage was nearly equally divided among the three sub-watersheds with 36.7 percent in the Lower Raritan, 31.8 percent in the Upper Raritan and 31.5 percent in the Millstone. Approximately 64 percent of the C2 riparian buffer area in the Raritan was composed on natural land cover (Table 17).

The amount of altered land cover in the C2 stream riparian buffers decreased in the Upper Raritan, while altered land cover in the C2 riparian zones of the Lower Raritan, Millstone, and the basin as a whole increased slightly from 1986 to 2012 (approximately two percent) (Table 19).

C2 Stream Riparian Buffers	Natural Land Cover (acres)	Altered Land Cover (acres)	Total C2 Riparian Zone (acres)	Impervious Surface Cover (acres)	Impervious Surface Cover (percent)
Raritan Basin	48,629	26,920	75,549	4,371	5.8
Upper Raritan	14,054	9,942	23,996	949	4.0
Lower Raritan	18,234	9,545	27,779	2,416	8.7
Millstone	16,341	7,433	23,774	1,006	4.2

Table 18. Natural and altered land cover in C2 Stream riparian zones in 2012

Altered Land Cover in Riparian Buffer for	1986 (acres)	1995 (acres)	2002 (acres)	2007 (acres)	2012 (acres)	26 year change	26 year change
Raritan Basin	26,494	27,533	26,589	27,227	26,920	+426	+1.6
Upper Raritan	10,617	10,411	9,973	10,087	9,942	-675	-6.4
Lower Raritan	8,477	9,227	9,076	9,510	9,545	+1,068	+12.6
Millstone	7,400	7,895	7,540	7,630	7,433	+33	+0.4

Table 19. Altered land cover within riparian buffers of C2 Streams in the Raritan River watershed for the periods 1986 to 2012

Summary—Riparian Area Integrity

Riparian areas are transitional areas between terrestrial and aquatic ecosystems that are vital to watershed health. A healthy riparian zone can protect streambanks and remove sediments and nutrients from runoff, reduce flooding, protect aquatic ecosystems and provide habitat for terrestrial and aquatic organisms. We explored land uses in the 300 foot and 150 foot riparian buffer of Class 1 and Class 2 streams respectively. Approximately two-thirds of all riparian buffers in the Raritan basin were in natural cover. Class 1 stream buffers showed an increase in altered land uses in the Upper Raritan and a decrease in altered cover for the Millstone and Lower Raritan. Conversely, Class 2 stream buffers showed a decrease across most of the Raritan basin. Overall, trends were mixed and impacts to water quality are inconclusive.

Known Contaminant Sites & Groundwater Contamination

not sufficient data

Background

Groundwater is one of the most precious sources of drinking and irrigation water around the globe due to its usually good quality and easy accessibility. However, groundwater is susceptible to pollution and frequently, groundwater contamination occurs due to human activity such as intensive interference of natural land use. Groundwater contamination can be from both point and nonpoint sources. Point source pollution includes landfills, illegal dumping, accidental spills, leaks from gasoline storage tanks, and leaks from septic tanks, while nonpoint source pollution includes infiltration from pesticides and fertilizer applications (residential/ commercial and agricultural lands). When groundwater gets contaminated, it is very expensive and difficult to purify, therefore, an analysis was conducted about known contaminated sites as well as known extent of groundwater contamination in the Raritan.

Methodology

As defined by the NJDEP, known contaminated sites (KCS) are non-homeowner sites where soil or groundwater contamination is confirmed to exceed the safe applicable standard. The only available KCS data was for 2014. Additionally, NJDEP has recently changed the site remediation program, which makes it more difficult to compare previous years' data. Therefore, only the status of known contaminated sites is presented in this study and no trend analysis was performed.

Groundwater contamination sites are the locations where the water quality standard exceeds the safe drinking water standards as well as groundwater quality standard due to contamination. The only available data for known extent of groundwater contamination sites was for 2015 from the NJDEP websites. Consequently, trend analysis was not performed for known groundwater contaminated sites.

A well head protection area is an area surrounding a public water supply well and is the area delineated based on the extent of area contributing groundwater to the well. This well head protection area layer was downloaded from NJDEP in order to access the number of contaminated sites inside the well head protection zone. This overlay doesn't imply groundwater contamination, but shows where the probability of contamination of well water is higher.

Similar to KCS, known extent of groundwater contamination sites were downloaded from NJDEP site in the form of a shapefile.

Status and Trends

A total of 1,723 KCS were found in the Raritan (Figure 30), out of which 1,106 contaminated sites were in the Lower Raritan, 327 contaminated sites were in the Upper Raritan, and 290 contaminated sites were in the Millstone.

A total of 358 KCS were observed within well head protection areas with the highest number found in the Lower Raritan (194 KCS) followed by the Upper Raritan (123 KCS) and the Millstone (41 KCS).

A total 5,160 acres of groundwater contamination acres were found in the Raritan. Of these, 1,839 acres were found in the Lower Raritan, 1,668 acres were in the Upper Raritan, and 1,653 acres were in the Millstone (Figure 30).

Further analysis is needed to understand the relationship and impacts of known contaminated sites on water quality in the Raritan region.

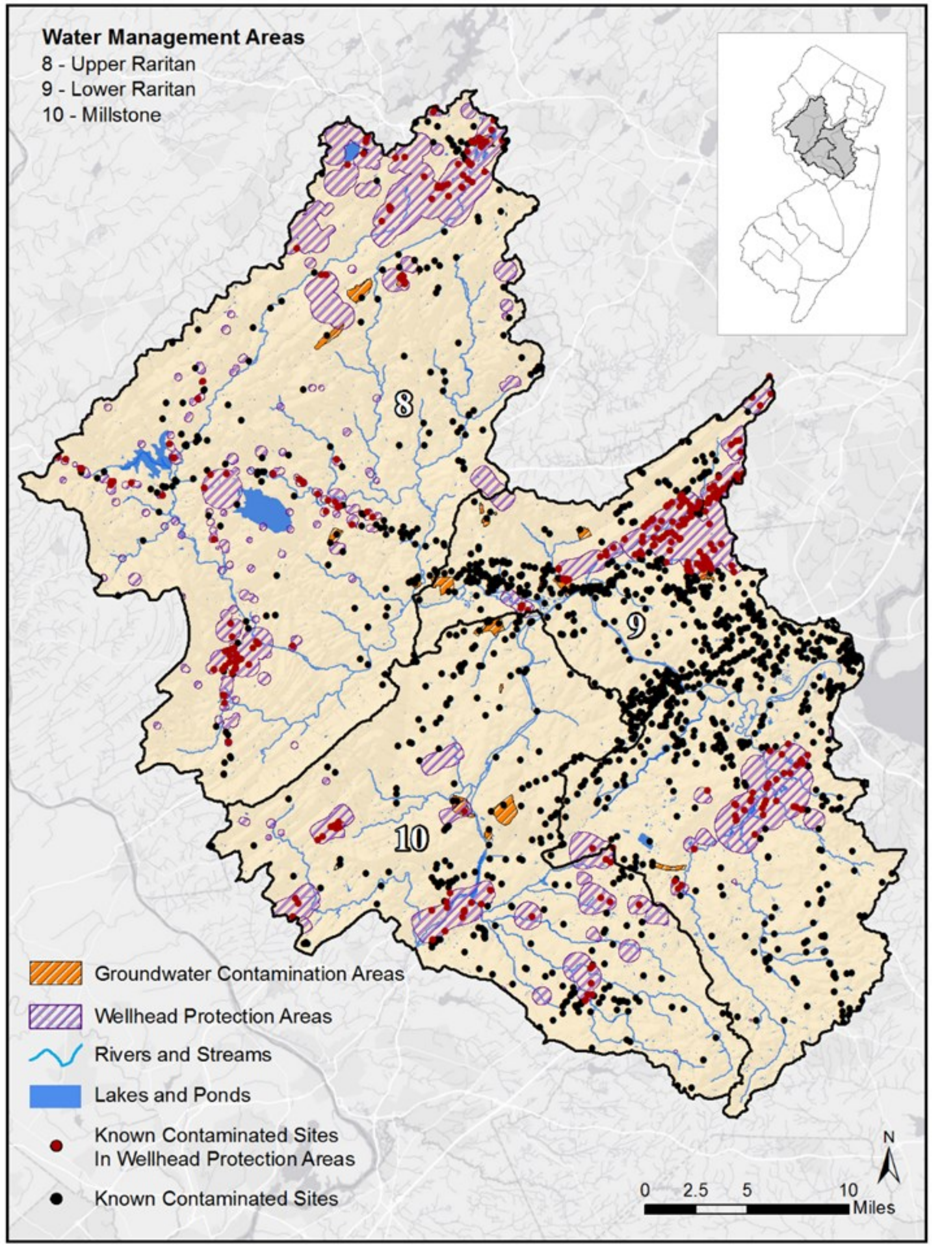


Figure 30. Known contaminated sites, well head protection areas, and groundwater contamination areas in the Raritan River watershed as of 2016

Summary—Known Contaminant Sites & Groundwater Contamination

Groundwater is an important source of drinking water and irrigation water for crops in the Raritan and it also supplies water uniformly to ecologically sensitive areas for survival of plants and animals. Groundwater contamination can occur from point sources of pollution such as landfills, illegal dumping, accidental spills and leaks from gasoline storage tanks or septic systems, while non-point sources come from pesticides and fertilizer applications that infiltrate the groundwater. There are 1,723 known contaminated sites in the Raritan basin with over 20 percent of those in well-head protection areas. Limited data was available to better understand the relationship (if any) between known contaminated sites and groundwater contamination and no trends were determined. Further analysis is needed in this area.

Conclusion

This study presents a updated view of the health of the Raritan River basin and subwatersheds based on eleven indicators including population, housing units, land use, impervious surface, wetland conversion, forest conversion, prime agricultural land conversion, groundwater recharge, bioassessment (stream integrity), riparian areas, known contaminant sites, and groundwater contamination. These indicators were selected based on the previously published *Raritan Basin: Portrait of a Watershed*, prepared by the New Jersey Water Supply Authority in 2002. Most of the indicators were analyzed for the year 1986, 1995, 2002, 2007, and 2012 and their implication to Raritan water quality was evaluated based on both status and trends. Status represents the current condition of an indicator based on the most recent data available in the public domain, which is 2012 in most cases, while trends were determined based on the longest period of data available for each indicator.

Most of the methodology used in this 2016 State of the Raritan report is based on the 2002 report. Relevant data for each indicator was processed using ArcGIS platform. For many of the indicators, the analysis was performed on the Raritan basin as a whole as well as on the three watershed management areas (Upper Raritan, Lower Raritan, and Millstone).

Overall, comparison of this updated analysis with the prior 2002 report (Table 1) shows that trends evident between 1986 and 1995 are continuing in the same general direction though the rate of change in the trends has varied over the longer time period.

Both population and housing units showed similar trends of increasing over time. However, the mean annual growth trend indicated a slowing of the growth rate during the 2000-2010 time period. Population projections indicate the potential for continued growth with basin-wide populations exceeding 1.5 million people by 2034. Based on land use, the Raritan basin contains greater than 40 percent urban land which is higher than the urban land threshold used to identify impaired watersheds. The trend analysis showed the total area of urban land is increasing. The prime contributors to urban land formation were the conversion of agriculture land, forests, and wetlands.

According to impervious surface analysis, 12.9 percent of the total Raritan basin area is impervious surface. Researchers have found that the health of watersheds begins to degrade when impervious surface cover is greater than ten percent of total watershed area. Trend analysis showed that impervious surface in the watershed is increasing.

The Raritan basin continues to see natural areas converted to urban land uses with forested wetlands, coastal and emergent wetlands, and upland forest indicators all trending downwards. Masked in the overall net changes for these indicators are also conversions among and between these land cover types. For example, upland forests increased in some locations due to the abandonment of agricultural lands that was followed by natural succession. However, the net effect was a decline in upland forest area as the gain in new forest land was offset by the conversion of existing forest lands to urban land uses. Elsewhere, abandoned agricultural lands converted to coastal and freshwater emergent wetlands which, in turn, converted to forested wetlands. Prime agricultural land demonstrated a continuous loss to urbanization, however, the rate of conversion decreased sharply during the T4 (2007 to 2012) time period.

According to groundwater recharge, only 28 HUC-14s showed gains in groundwater recharge while 111 HUC-14s showed loss of groundwater recharge. The loss of groundwater recharge in most of the HUC-14s can be attributed to increases in impervious surface cover primarily due to urbanization.

Stream health was based on both AMNET and FIBI, and on the integrity of riparian zones. According to the AMNET and FIBI bioassessment data, the number of locations experiencing a decrease in stream health exceeded those showing an increase in stream health, which indicates increasing impairment in the stream water quality. The riparian areas analysis showed relatively minor land cover changes in the buffer zones adjacent to C1 streams. C2 streams displayed a more significant trend of increasing alteration of riparian buffers and loss of natural land cover in the Lower Raritan and Millstone WMAs.

This report is the first in a series that will eventually assess a broad array of metrics of watershed health for the Raritan Basin. The intent is to inform watershed management planning in concert with remediation, restoration and protection efforts at the state, regional and local levels.

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Figures

Tables

Images

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