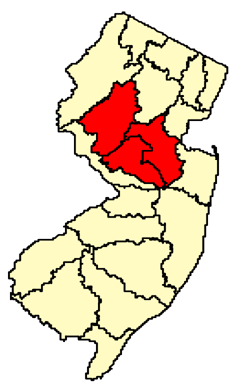
Surface Water Quality and Pollutant Loadings

A Technical Report for the Raritan Basin Watershed Management Project

Raritan Basin



Central to New Jersey

New Jersey Water Supply Authority

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Acknowledgements

Primary Authors:

Amy L. Shallcross, PE, Senior Watershed Protection Specialist
Watershed Protection Programs, NJ Water Supply Authority

Denise M. Zambrowski, former Watershed Protection Specialist
Watershed Protection Programs, NJ Water Supply Authority

Contributing Author:

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

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Summary

The Raritan River Basin is the largest drainage basin entirely within the state of New Jersey and drains an area of approximately 1100 square miles in central and northern New Jersey. The land coverage in most of these watersheds is mixed (urban, agriculture, wetlands, and forest). The most intense urban land use is located along the main stem of the Raritan River, within the Bound Brook watershed, and within the downstream portions of both the Lawrence Brook and South River watersheds. The highest percentage of forested land is found in the upstream/northern portions of the North and South Branch Raritan River watersheds. The highest percentage of agricultural land is found in the South Branch Raritan River and Millstone River watersheds.

The focus of this technical report is the quality of the surface waters in the Raritan River Basin. The concentration, trend, and relationships between flow and season of seventeen water quality constituents, bioassessment ratings, habitat assessment ratings, and concentrations and detection frequencies of pesticides and volatile organic compounds were used to characterize the surface waters of the Basin. The assessment of the quality of surface water in this basin reflects the listing of probable and potential waters that require remedial water pollution controls through total maximum daily load (TMDL) development. This report also discusses the primary water quality indicators of concern and trends of concern for the surface waters of the Raritan River Basin. Finally, the report provides information on the relative pollutant loads from permitted (point) and non-permitted sources for seven water quality constituents.

The characterization of the Raritan Basin indicates that two constituents pose an existing water quality problem and that three constituents have increasing concentration trends that may be a water quality concern. The characterization considers the relationship between the bioassessment and habitat assessment rating and the detection frequency and concentrations of pollutants, including volatile organic compounds (VOCs) and pesticides, in the surface waters. The characterization findings are summarized below.

- The major existing water quality problems through much of the basin are fecal coliform bacteria and total phosphorus concentrations that do not meet the NJ surface water quality standards. Fecal Coliform bacteria indicate the potential presence of disease-causing agents. High phosphorus concentrations indicate the potential for stimulated plant and algal growth, which causes eutrophication problems.
  - The predominant loading of total phosphorus to the surface waters of the Raritan Basin varies from permitted point sources to nonpoint sources depending on the flow regime (low, median, and high), presence of permitted point sources, and the surface water body in question.
  - Fecal coliform bacteria loadings are essentially all from nonpoint sources, such as leaking septic systems, faulty connections to storm sewers, and wildlife (such as geese). As of 1998, the sampling protocol used for fecal coliform has changed and may affect the extent to which the Basin's water bodies are assessed as exceeding the NJ surface water quality standards.
- Almost all of the surface waters sampled in the Basin have increasing trends of chloride, total dissolved solids, and sodium concentrations; although they meet water quality standards,

these trends are a water quality concern in most areas, because higher concentrations of these constituents increases the difficulty and cost of treating the water for drinking.

- The loading of total dissolved solids to the surface waters of the Raritan Basin is predominantly from nonpoint sources during median and high flows. Depending on the surface water the predominant loading is either point or nonpoint source during low flow.
- Chloride loading and yield to the surface waters of the Raritan Basin show an increase from low to high flow regime. No source analysis was conducted for this constituent due to lack of data. However, recent studies strongly indicate that road salt is the primary cause of the increases. An increase in the Basin road lane miles correlates to more salt applied to the road surfaces, which eventually reaches the surface waters.

- The bioassessments of the surface waters in the Raritan Basin reflect a general trend of non-impaired in the western region (mostly the North and South Branch Raritan River watersheds) to moderately impaired in the eastern, downstream portion of the Basin, and severely impaired in the most urban streams.
- The habitat assessment of the surface waters of the Raritan Basin followed a similar trend to the bioassessment ratings, decreasing in score (i.e., decreasing in quality) from west to east, but the scores remained in the optimal/sub-optimal range. Some sites are biologically impaired due to degraded habitats; however, the more likely cause for the biological impairment of surface waters is the water quality within the Raritan Basin.
- Volatile organic compounds (VOCs) are detected in surface waters throughout the Basin, with one VOC in particular – MTBE – detected in every sample analyzed. The concentrations of the VOCs did not violate water quality standards and the number of VOCs detected was larger in the more urban subwatersheds.
- Pesticides were detected in the Basin with the number of different pesticides detected greater in the more urban subwatersheds. The concentrations of some pesticides exceeded water quality standards for human health or aquatic life support in the Neshanic River, main stem Raritan River, Bound Brook, and Stony Brook.

The New Jersey Department of Environmental Protection has listed 131 surface water bodies in the Raritan Basin as having known water quality impairment in Category 5 of their Draft 2002 Integrated Water Quality Report (released on May 20, 2002). Total maximum daily loads (TMDLs) are required for water bodies on the Category 5 List. A TMDL is the amount of constituent load that a water body can receive and still meet water quality standards. TMDL has become the term used for surface water pollution control plans that use TMDL studies to manage waste loadings. Fecal coliform is measured as an indicator of sanitary quality of surface waters. The levels of fecal coliform in the surface waters of the Raritan Basin jeopardize the sanitary quality and impair the use of the waters for primary contact recreation. Total phosphorus, which affects almost all of the surface waters in the Basin, also is frequently listed. Phosphorus is a nutrient necessary for plant growth, which at higher concentrations may cause eutrophication that can impair the aquatic life support capacity of the surface waters.

Gaps in data and information still need to be addressed for this report. Sediment quality data, including heavy metals and chlorinated organic compounds, specific for the Raritan Basin are needed and should be included. Water quality data compiled by USGS and NJDEP for the water years 1998 through 2002 are needed, especially with regard to heavy metals and fecal coliform bacteria. Water quality data from organizations other than the NJDEP or USGS need to be incorporated into the characterization. Recent lake water quality data are needed to address those surface waters, since most of the water quality data reflect the rivers and streams of the Basin. Once information or data become available, the characterization and this technical report may be revised.

Purpose of the Characterization and Assessment for Surface Water Quality and Pollutant Loadings

The Raritan Basin supports a variety of New Jersey ecosystems within the Highlands, Piedmont and Coastal Plain geologic provinces. Many of these ecosystems rely heavily on the close proximity of surface waters, wetlands and high ground water tables. The Raritan Basin is a major source of potable (drinkable) and industrial water supplies in central New Jersey. The surface waters of the Basin are used for recreational and aesthetic purposes. The vitality and health of all these uses depends on the quality of the water. Thus, for watershed management purposes, it is critical to identify water quality constituents that are most important to the water quality and health of streams in the watershed.

The characterization section of this report first identifies the current water quality status of the surface waters of the Raritan Basin. Then, the current water quality is compared to the New Jersey Surface Water Quality Criteria.[1] Where no criterion exists for a specific constituent, federal and New Jersey state primary and secondary drinking water standards are used as an indicator that the water body supports its designated use. These standards are either:

- Maximum contaminant level (MCL) – the highest concentration of a contaminant that is allowed in drinking water.
- Action level (AL) – the concentration of a contaminant that when exceeded triggers remedial action, such as treatment.
- Health advisory level (HAL) – a non-enforceable estimate of acceptable concentrations in drinking water for a contaminant based on health effects information.

The assessment portion of this report summarizes the current water quality relative to the need of establishing a total maximum daily load (TMDL), essentially a surface water pollution control plan, for specific constituents and stream reaches. Both portions of this report are prepared for use in the management planning process for the Raritan River Basin.

Key Issues Regarding Surface Water Quality

Surface waters (streams, rivers, ponds, lakes) are complex ecosystems with chemical, biological, and physical processes that interact with each other. A change of any one of those processes affects the delicate balance with the other processes and ultimately results in changes to the ecosystem. One example of this interaction can be demonstrated by tracking the impacts of a temperature change in the ecosystem. An increase in the temperature of the water (physical) lowers the available amount of dissolved oxygen (chemical) by reducing its solubility in water and stresses the fish (biological) population. The decreased dissolved oxygen concentrations improve the growth conditions for algae and trigger algae blooms (biological). From those processes, chemical, physical, and biological parameters are used as indicators to determine the quality and overall health of the surface water. Additional information derived from the quality of the bottom sediment and point and nonpoint sources of pollution assist in this process. All of these parameters and their sources are used to characterize and assess the surface water quality of the Raritan Basin.

Indicators for Water Quality Status

Indicators of water quality are constituents that are measured through analysis and used to estimate the status of a water body. The State of New Jersey has established surface water quality standards and drinking water quality standards for some of these constituents and the others assist with the assessment of the overall quality of the water.

Dissolved Oxygen

Dissolved oxygen (DO) is the measurement of the amount of oxygen dissolved in water and is considered a direct indicator of water quality. The concentration depends on the physical, chemical and biological characteristics of the water body. Warm temperatures reduce the amount of DO a water body can store. Respiration of aquatic plants and the presence of organic compounds can cause a biological and chemical oxygen demand, lowering the DO concentration. Turbulence, photosynthesis and decreases in temperature increase the concentration of DO in the water. Caution must be exhibited when using grab-sample DO concentration data because the DO concentration exhibits a diurnal fluctuation in response to photosynthesis and respiration of aquatic plants, algae and phytoplankton. The measurement of concentration and flow must be conducted throughout the day to get the average daily load. Through 1997, the USGS/NJDEP monitoring network collected samples only during the day, when oxygen concentrations tend to be greatest. Three surface water quality criteria exist for dissolved oxygen depending on the water body's use designation and are in the units of milligrams per liter (mg/L). The criteria are DO>4 mg/L for non-trout waters, DO>5 mg/L for trout maintenance waters and DO>7 mg/L for trout production waters.

Biochemical Oxygen Demand

Biochemical oxygen demand (BOD) has been used for many years as a measure of the presence of organic materials in water that can support the growth of microorganisms. BOD measures potential oxygen consumption and is a good gauge of stress to the stream ecosystem. BOD_5 measures the residual dissolved oxygen of a sample after a five-day period of incubation at 20° C. BOD is used to quantitatively evaluate the organic load in a water body. Comparison of BOD and DO measurements indicates stresses to the stream. High BOD and low DO indicates a stress from pollutant loads, while low BOD and low DO indicates other stressors. Currently, no water quality criterion exists for BOD.

Total Organic Carbon

Total Organic Carbon (TOC) is a direct measurement of organic compounds in a stream. The analysis for TOC responds to all types of organic substances and does not respond to elements other than carbon. Higher concentrations of TOC indicate a potential for forming disinfection by-products in drinking water and are a concern for water purveyors. Disinfection by-products are formed when disinfectants (such as chlorine) used in water treatment plants react with organic matter (i.e., decaying vegetation) present in the source water and form organic and inorganic byproducts that pose health risks. The disinfection by-products identified in drinking water for which federal regulations have been established are trihalomethanes, halo acetic acids, bromate, and chlorite. Data on concentrations of these disinfection by-products are not routinely collected throughout the basin and when collected are generally found in very low concentrations. No drinking water standard or surface water criterion exists in New Jersey for TOC.

Ammonia plus Organic Nitrogen

Ammonia plus organic nitrogen, also called Total Kjeldahl Nitrogen or TKN, represents the reduced portion of total nitrogen in a stream. When a compound is reduced it gains an electron by bonding with hydrogen. Ammonia in natural waters results from either direct discharge, such as wastewater discharges and animal wastes, or the decomposition of nitrogenous organic matter, such as detritus (dead plant matter). Ammonia is highly soluble in water and high concentrations are a concern for water purveyors because of increased treatment costs. Ammonia and organic nitrogen are both oxygen consumers and indicators of ecosystem health. No water quality criterion exists for ammonia plus organic nitrogen.

Un-ionized Ammonia

Un-ionized ammonia is the portion of ammonia in water that is not reduced to ammonium ions. Un-ionized ammonia is toxic to fish and other aquatic animals. Because un-ionized ammonia cannot be measured directly, the total ammonia concentration, pH and water temperature are used to calculate the concentration. Un-ionized ammonia has a surface water quality criterion of 0.05 milligrams per liter (mg/L) in non-trout streams and 0.02 mg/L in trout streams.

Note: The NJ DEP has proposed an amendment to the NJ surface water criterion for un-ionized ammonia, to a set of formulas based on temperature and pH.

Nitrate plus Nitrite

Nitrate plus nitrite represents the oxidized form of nitrogen in the stream. When a compound is oxidized it loses an electron (by adding oxygen in this case). They are found in surface waters as a result from wastewater discharge, runoff from land application of fertilizers, and ground water polluted by fertilizers. Nitrate concentrations in surface waters tend to be higher than nitrite because nitrite rapidly oxidizes to nitrate. They are a primary nutrient for rooted aquatic plants and algae and are a concern for water users. The drinking water standard for nitrate is 10 mg/L and nitrite is 1 mg/L. The surface water criterion for nitrate is the same as the drinking water standard and there is no criterion for nitrite. Nitrate is less toxic than either ammonia or nitrite, but can cause methemoglobinemia (“blue baby” syndrome) in small children and fish.

Total Phosphorus

Total phosphorus in surface water is a key nutrient for stimulating excessive growth of aquatic plants and algae, resulting in the eutrophication of water bodies. Phosphorus is a common element in igneous minerals and sediments and is found both in solution and adsorbed to particulates. Orthophosphate is the soluble form of phosphorous and is readily available for uptake by aquatic plants and algae. Although phosphorus occurs in surface waters naturally through weathering of minerals and sediment, human influence has increased its presence. The use of orthophosphorus on lawns, gardens, and agricultural lands leads to its presence in runoff. Phosphorus also enters streams from wastewater treatment plant effluent. The surface water quality criterion for phosphorus is 0.1 mg/L, and this criterion shall not be exceeded in any stream unless it can be demonstrated that total phosphorus is not a limiting nutrient and will not render the waters unsuitable for the designated uses. A second surface water quality criterion of 0.05 mg/L exists for lakes, reservoirs, and streams at the point of entry to these water bodies. The NJ DEP recently adopted an amendment to the NJ surface water criterion for total phosphorus to allow watershed-based criteria in addition to site-specific criteria.

Total Dissolved Solids

Total dissolved solids (TDS) in water consist of dissolved mineral salts that change the physical and chemical properties of the water. A high concentration of TDS in water is a concern for water purveyors because it alters the taste. High TDS concentrations also exert osmotic pressure in water purification systems in hospitals and industries and exert osmotic pressure on the stream ecosystem. Although fish can acclimate slowly to higher TDS concentrations than they are accustomed, they cannot survive a sudden exposure to a high TDS concentration. The New Jersey Drinking Water Standard for TDS is 500 mg/L. The surface water quality criteria are:

- No increase in background levels that may adversely affect the survival, growth or propagation of the aquatic biota (increases up to 133% of background are deemed to be in compliance), and
- No increase in background levels that would interfere with the designated or existing use or 500 mg/L, which ever is more stringent.

Note: The NJ DEP has proposed an amendment to the NJ surface water criterion for total dissolved solids to replace the language regarding the 133% threshold with a new threshold that directly measures toxicity to aquatic life.

Hardness

Hardness in water is mostly caused by calcium and magnesium ions, with all other divalent cations also contributing to the concentration. The geology surrounding the water body is largely the source of hardness, although some industrial wastes and irrigation drainage contribute. The measurement of hardness represents the soap-neutralizing capacity of water and is expressed in terms of an equivalent concentration of calcium carbonate. The drinking water standard for hardness is >50 mg/L and <250 mg/L. Excessive hardness in water is considered undesirable to consumers because higher soap consumption and scale formation in pipes, hot-water heaters, et cetera, result. Therefore, this constituent is a concern for water purveyors. Another water quality concern is the inverse relationship of hardness and the solubility of heavy metals. As the hardness increases the solubility of the heavy metal decreases. Therefore, in waters with low hardness, also described as “soft” water, fish and other aquatic organisms become more sensitive to heavy metal uptake because the metals are more water-soluble. This is one process by which heavy metals become incorporated into the food chain.

Dissolved Chloride

Dissolved chloride in surface waters occurs naturally from the geology but high concentrations typically result from runoff of deicing salts applied to road surfaces. Dissolved chloride is a good conservative element to use for quality assurance in a mass balance model because no natural biological or chemical processes remove or add chloride to the surface water. Therefore, the mass of dissolved chloride remains constant in the surface water unless there is a discharge to or withdrawal from the water body. The conservative characteristic of chloride can be a problem for water purveyors and their customers.[2] Spikes in chloride concentrations that occur from storm runoff may interfere with the chemical processes used in treating drinking water. Hospitals and industries, such as pharmaceutical manufacturers, have water purification systems (for de-ionized water) that rely on fairly constant chloride concentrations. The drinking water standard and surface water criterion for dissolved chloride in New Jersey is 250 mg/L.

Dissolved Sodium

Dissolved sodium from weathering of rocks and other sources of sodium salts are very soluble in water and any sodium that is dissolved in surface waters tends to remain in solution. One of the sources of sodium in surface waters is from runoff of sodium salts used for deicing roads. The federal drinking water standard for dissolved sodium is 50 mg/L.[3]

Sulfate

Sulfate occurs naturally in surface water as a result of the weathering of both igneous and sedimentary rocks. Metallic sulfides, produced from weathering, oxidize to yield sulfate ions. Other contributions of sulfates in surface water are leachate from abandoned mines, air deposition from the combustion of fuels, and industrial wastewater. The surface water criterion and drinking water standard for sulfate are 250 mg/L. Sulfates affect the taste of drinking water and are therefore a concern for water purveyors.

Total Suspended Solids

Total suspended solids (TSS) in surface waters occur primarily from storm water runoff, stream bank and channel erosion, dead plant matter, plankton, and re-suspension of sediment into the water column. A high concentration of TSS negatively affects the surface water's ecosystem and aesthetics. Fish and shellfish can be injured or killed from the TSS by abrasive injuries, clogging gills and respiratory passages, and by blanketing the bottom, killing eggs, young, and destroying spawning beds. The waters become cloudy and the system can develop noxious conditions, reducing the aesthetic value of the waters. Other pollutants, such as phosphorus and petroleum hydrocarbons, adsorb or bond to the particles therefore magnifying the impact the solids have on the surface water quality. TSS also interferes with the treatment processes for water purveyors. The surface water criterion is 25 mg/L in trout waters and 40 mg/L in non-trout waters.

pH

The measurement of pH in water is the measurement of the negative logarithm of the hydrogen ion concentration. The pH scale ranges from 1 to 14 and a value of 7 is neutral. Acidic conditions have a pH value less than 7 and basic conditions have a value greater than 7. The measurement of the pH of surface waters is important because many pollutants increase in toxicity with changes in pH. Examples of this phenomenon are the dissolution of metal ions in acidic (low pH) waters and the shift of ammonium ions to un-ionized ammonia in basic (high pH) waters. The pH of water is important to water purveyors because taste, corrosiveness, and the effectiveness of chlorination and coagulation in treatment processes are affected. Aquatic ecosystems also are influenced by pH. In general, pH alone is not a problem, but the combination of pH with temperature, dissolved oxygen, prior acclimatization, and the presence of various ions. Some compounds are more toxic to the aquatic organisms at different pH values. For example, the toxicity of nickel cyanide increases as the pH value decreases. The New Jersey surface water criterion for pH is > 6.5 and < 8.5.

Alkalinity

Alkalinity is not a specific polluting substance, but represents the buffering capacity of the water. Alkalinity is a measure of the ability of the water to neutralize hydrogen ions and is expressed in terms of an equivalent amount of calcium carbonate.[4] The presence of carbonates, bicarbonates, and hydroxides, for the most part, causes alkalinity in water. The natural alkalinity of surface water is frequently increased by the addition of municipal and industrial wastewater effluent. The affect that alkalinity has on aquatic organisms depends on the pH of the water. Abnormal development and other damage to fish occur in waters with high alkalinity and low pH values. An indirect effect of decreased alkalinity levels on aquatic organisms is the increase of the toxicity of heavy metals. Presently, no water quality criterion exists for alkalinity.

Fecal Coliform

An indication of the sanitary quality of a water body is determined from fecal coliform bacteria counts. Fecal coliform bacteria are used as an indicator of fecal contamination and of the possible existence of waterborne enteric pathogens. This is because coliform bacteria are derived from the digestive tract of mammals. Sources for fecal coliform in surface water are untreated wastewater, failing septic systems, and animal waste. High fecal coliform counts can render the effected water body unsuitable for swimming. Two surface water quality criteria have been established that concentrations should not exceed: 1) a geometric mean of 200 colonies per 100 milliliters and 2) 400 colonies per 100 milliliter in more than 10 percent of total samples collected in a 30 day period.

Recently, non-point sources have surpassed point sources as the major source of fecal contamination to surface waters. This creates a need to identify the source of fecal contamination from non-point pollution. Fecal coliform measurements do not provide information on the specific source of pollution, such as animal versus human. To address this need the USGS and NJDEP have begun monitoring for other indicator organisms such as Enterococcus bacteria, *Escherichia coli* (E. coli), and bacteriophages (viruses that infect bacteria) specific to humans or using DNA testing to determine species.

Volatile Organic Compounds

Volatile organic compounds (VOCs) are a class of organic compounds found in almost all natural and synthetic materials and are commonly used in fuels, fuel additives, solvents, perfumes, flavor additives, and deodorants.[5] Potential health hazards and environmental degradation resulting from the widespread use of VOCs has prompted concern among scientists, industry, and the general public.[6] Sources of VOCs in surface waters include industrial and municipal wastewater discharges, urban runoff, precipitation, and accidental spills of crude petroleum and fuel products.[7] Surface water quality standards and drinking water standards exist for some individual compounds but not all of the VOCs found in surface waters. Criteria apply to a single VOC even though typically more than one compound is present in samples. This raises concern for long-term cumulative and synergistic effects on human and aquatic health.

The concentration and number of VOCs detected in surface waters has been associated with the land use within the drainage basin. In a study of streams in New Jersey and Long Island, New York, the concentrations were higher and more VOCs were detected in streams with a high percentage of urban land use in their drainage basin.[8]

Some of the most common VOCs detected in surface waters in New Jersey are Methyl tert-butyl ether (MTBE), Chloroform, 1,1,1-Trichloroethane (TCA), Trichloroethylene (TCE), and Tetrachloroethylene (PCE). Table 1 lists these VOCs and the corresponding standards or criteria.

MTBE is a fuel oxygenate added to gasoline to enhance combustion and reduce carbon monoxide emissions and ozone in the atmosphere. Chloroform is a byproduct from the chlorination of water and also is produced in New Jersey for use as an industrial solvent, an extracting agent, and in the production of fluorocarbons, dyes, and pharmaceuticals. Another commonly used solvent is TCA, which is used in drain cleaners, shoe polish, spot removers, insecticides, and printing ink. TCE is used as a metal degreaser and is found in many products such as dyes, printing inks, and rug cleaners. Finally, PCE is used for dry cleaning, in the production of chlorofluorocarbons, and in rug cleaners, degreasers, paint strippers, and spot removers.[9]

Table 1. Five most frequently detected VOCs in New Jersey and corresponding standards or criteria.

Volatile Organic Compound	Federal & N.J. Drinking Water Standards: Maximum Contaminant Level (MCL)	N.J. Surface Water Quality Criteria: Human Health Criteria (HHC) for freshwaters
MTBE	70 µg/L (MCL)* +°	--
Chloroform	80 µg/L (MCL)**°	5.67 µg/L (HHC)
TCA	30 µg/L (MCL)*°	127 µg/L (HHC)
TCE	5 µg/L (MCL)*	1.09 µg/L (HHC)
PCE	5 µg/L (MCL)*	.388 µg/L (HHC)

* N.J. MCL as of November 1996[10]; +EPA recommends MTBE concentrations not exceed 20 – 40 µg/l in drinking water to avoid taste problems. ** Federal MCL as of January 1, 2002 for total trihalomethanes (dichlorobromomethane, chlorodibromomethane, bromoform, & chloroform) – current MCL is 100 µg/L. ° These standards have been reduced since the completion of the water quality status analyses; thus, reported exceedences may be understated.
Source: Reiser and O'Brien, 1998; NJDEP, 1998d; NJDEP, 2000a.

Pesticides

Pesticides are synthetic compounds widely used in New Jersey to control insects (insecticides), unwanted plants (herbicides), and fungi (fungicides). Surveys conducted by the New Jersey Pesticide Control Program determine the amount of pesticides used by licensed applicators for agriculture, lawn care, golf-course maintenance, and mosquito control. These amounts do not include the amount and type of pesticides used by homeowners within the Raritan Basin. Table 2 lists the eight highest used pesticides in New Jersey and percent of total pesticide use for agriculture, golf courses, and lawn care services.

Though pesticides have increased productivity of agriculture and eased the burden of lawn maintenance, bioaccumulation in the food chain and potential adverse effects on non-target organisms and the environment in general have become a matter of concern. For this reason more persistent pesticides have been replaced with less persistent and more water-soluble pesticides. This exchange reduces the risk of accumulation in sediments and the food chain, but increases the risk of widespread low levels of dissolved pesticides entering surface water systems, some of which are used for drinking water supplies.

Table 2. Pesticides Most Commonly Used by Licensed Applicators in New Jersey

Agriculture (1997 Survey)		Golf Courses (1999 Survey)		Lawn Care Service (1998 Survey)	
Pesticide	**Percent of Total Use**	**Pesticide**	**Percent of Total Use**	**Pesticide**	**Percent of Total Use**
Sulfur (fungicide)	16.4%	Chlorothalonil (fungicide)	41.4%	2,4-D (herbicide)	18.0%
Metam-sodium (fumigant)	15.4%	Mancozeb (fungicide)	6.6%	Pendimethalin (herbicide)	13.7%
Metolachlor (herbicide)	8.1%	Propamocarb (fungicide)	6.6%	Mecoprop (herbicide)	8.2%
Chlorothalonil (fungicide)	5.7%	Dithiopyr (herbicide)	6.4%	Glyphosate (herbicide)	5.4%
Captan (fungicide)	5.2%	Iprodione (fungicide)	5.8%	Trichlorfon (insecticide)	4.4%

Agriculture (1997 Survey)		Golf Courses (1999 Survey)		Lawn Care Service (1998 Survey)	
Pesticide	Percent of Total Use	Pesticide	Percent of Total Use	Pesticide	Percent of Total Use
Mancozeb (fungicide)	3.6%	Fosetyl-al (fungicide)	5.0%	Chlorpyrifos (insecticide)	3.9%
Oil (insecticide)	3.2%	Thiophanate/T-methyl (fungicide)	4.5%	Imidacloprid (insecticide)	3.8%
Acetochlor (herbicide)	3.2%	Quintozene (fungicide)	3.4%	Triclopyr (herbicide)	3.8%
Source: NJDEP Pesticide Control Program Surveys, 1997; 1998; 1999.					

The total concentration of pesticides and number of pesticides detected in a surface water decreases with increasing forested land use in the drainage basin.[11] The highest concentrations of a pesticide are typically found in streams where the land use in its drainage basin is generally associated with applications of that pesticide.[12] The five most frequently detected pesticides in ground water in New Jersey are the same five most frequently detected pesticides in surface water.[13] Eight of the more frequently detected pesticides in surface water from seven sites sampled year round from 1996 through 1998 are listed in Table 3. Only three have drinking water standards and none of those pesticides have surface water quality criteria.

Table 3. Eight more frequently detected pesticides and corresponding drinking water standard

Pesticide	Federal & N.J. Drinking Water Standards: Maximum Contaminant Level (MCL)
Alachlor (herbicide)	2 µg/L
Atrazine (herbicide)	3 µg/L *
Carbaryl (insecticide)	--
Desethyl-Atrazine (degradation by-product of Atrazine)	--
Diazinon (insecticide)	--
Metalochlor (herbicide)	--
Prometon (herbicide)	-- *
Simazine (herbicide)	4 µg/L
* Under federal review as of summer 2000.[14] – No established standard. Sources: Reiser, 1999; Reiser and O'Brien, 1999; NJDEP, 2000a.	

Heavy Metals

Heavy metals include arsenic, cadmium, chromium, copper, iron, lead, manganese, mercury, nickel, and zinc. The persistence and concentrations of these trace elements in the water column and bottom sediment may reflect the concentrations found in resident aquatic organisms (through bioaccumulation), such as fish. This presents a human health concern if contaminated aquatic organisms, like fish and shellfish, are consumed. Bottom sediment can be a source or sink of heavy metals depending on the physiochemical conditions in the water column.[15] Natural presence in surface water occurs from the weathering of rocks and soil. Anthropogenic sources include atmospheric deposition from combustion processes, fertilizers, inorganic pesticides, and industrial solvents.[16] Trace elements in bed sediments in New Jersey streams are more closely related to land use or population density in proximity to the sampling site than point sources in the basin.[17] Heavy metals and the corresponding drinking water standard and surface water quality criteria are listed in Table 4.

Table 4. Heavy Metal Drinking Water Standards and Surface Water Criteria.

Heavy Metal	N.J. Drinking Water Standards: Maximum Contaminant Level (MCL) (as of December 2000)	N.J. Surface Water Quality Criteria: Human Health Criteria (HHC) for freshwaters
Arsenic	50 µg/L	0.0170 µg/L
Cadmium	5 µg/L	10 µg/L
Chromium (total)	100 µg/L	160 µg/L
Copper	1300 µg/L *	--
Iron	300 µg/L **	--
Lead✧	15 µg/L*	5 µg/L
Manganese	50 µg/L**	100 µg/L
Mercury	2 µg/L	0.144 µg/L
Nickel	--	516 µg/L
Zinc	5000 µg/L**	--

*Action Level not MCL. Water company must take action if 10% of tap water samples exceed standard; **Secondary Standards; ✧NJ DEP proposed amendment to NJ surface water criterion for lead. – No established standard or criteria. Sources: NJDEP, 1998d; NJDEP, 2000a.

Past water quality samples (pre-1998) were tested for Total Recoverable Metals. However, water quality criteria were expressed as dissolved metals concentrations. Methods are becoming available to determine dissolved metals concentrations from total recoverable metals concentrations so that water quality status and trends can be determined for metals using data sets from the past and newly collected data. The NJDEP and the USGS are determining the methodology for using such translators for water quality data comparisons.

Currently, NJDEP's Division of Science, Research and Technology is reviewing data from the 303(d) Reconnaissance Monitoring Program. This water quality sampling program used NJDEP "clean methods" and collected data during 1999 and 2000. Both dissolved and total recoverable metals were sampled during low flow periods. Samples at higher flows will be collected in the future. Data from this sampling period were not yet available to the public prior to the release of this report but will be incorporated as soon as possible.

Physical Indicators of Water Quality Status

Temperature

The temperature of water influences the chemical and biological processes and the aquatic life present in water bodies. The amount of sunlight, rainfall, air temperature, ground water discharge, and thermal point sources all influence the surface water temperature. Increased water temperature lowers the amount of dissolved oxygen available for the aquatic life present and promotes excessive growth of aquatic plants and algae. Also, the toxicity of pollutants tends to intensify with an increase in temperature. The N.J. Surface Water Quality Criteria for temperature and heat dissipation areas are dependant on the freshwater classification of the surface water (Table 5).

Table 5. Surface water criteria for temperature and heat dissipation areas.

Freshwater Classification	N.J. Surface Water Quality Criteria
FW2-TP (fresh water trout production streams)	"No thermal alterations which would cause changes in ambient temperatures except where properly treated wastewater effluents are discharged. Where such discharges occur, temperatures shall not deviate more than 0.6° Celsius (C) (1° Fahrenheit) from ambient temperature."
FW2-TM (fresh water trout maintenance)	"No thermal alterations that would cause temperatures to exceed ambient by more than 1.1°C (2°F) or cause the water to exceed 20°C (68°F)."
FW2-NT (fresh water non-trout)	"No thermal deviations that would cause temperatures to deviate more than 2.8°C (5°F) at any time from ambient temperatures. No heat may be added which would cause temperatures to exceed 27.8°C (82°F) for small mouth bass or yellow perch waters, or 30°C (86°F) for other non-trout waters."
Source: NJ Surface Water Quality Standards N.J.A.C. 7:9B, 1998.	

Turbidity

The turbidity of water is a measure of the extent to which the intensity of light passing through is reduced by suspended or colloidal matter.[18] Although total suspended solids affects turbidity, the degree of turbidity in water is not equal to the concentration of suspended solids. Turbidity is a measure of only one effect of suspended solids on the quality of water. Other sources of turbidity are microorganisms, algae, dead plant matter, silica or other mineral substances, clay, silt, and fibers. Excessive turbidity affects the aquatic ecosystem in many ways. The penetration of light is reduced therefore reducing photosynthesis and the productivity of aquatic plants. This in turn reduces the amount of food available to the fisheries. The low visibility can make food difficult for the fish to find. A high degree of turbidity can be lethal to fish from the layers of particulate matter lining the gills and inhibits feeding and restricts the growth of shellfish. Turbidity also affects the temperature of surface waters, where the bottom temperatures are lower in turbid waters than in clear waters.

Physical Characteristics

The physical characteristics of a stream channel are important for habitat assessments and affect water quality. The streambed substrate, channel morphology, bank structure, and riparian vegetation are used to evaluate the physical attributes of a stream habitat. According to the U.S. Environmental Protection Agency Rapid Bioassessment Protocol, four condition categories are used to rate the physical habitat parameters as either optimal, sub-optimal, marginal, or poor. This assessment is used as supplementary information for assessments of ecological indicators, such as benthic macroinvertebrates. The N.J. DEP used the abovementioned protocol to assess the habitats of N.J. waters as part of the Ambient Biomonitoring Network.[19] The habitat assessment was conducted independently of the macroinvertebrate analysis and does not factor into the final impairment score. The data are used primarily as supplemental information, since habitat degradation alone can account for the biological impairment of a stream.

Ecological Indicators of Water Quality Status

Ecological indicators of water quality focus on the species richness and density of algae, aquatic plants, benthic macroinvertebrates, and fish. These indicators reflect the overall ecological integrity of the system and directly assess the status of the surface water in question. They are capable of detecting impairments to the aquatic life and the relative severity of the impairment, integrating stresses of the ecosystem over time, and providing an ecological measure of fluctuating environmental conditions. Though they do not assess human health issues regarding water quality, they can serve as a preliminary assessment to prioritize water quality problems within a watershed and can document recovery of a surface water system following a restoration project. Typically the species density of algae and aquatic plants and the species richness and density of macroinvertebrates and fish are used for indicators of water quality in surface waters.

Algae

Algae are the dominant primary producers in most aquatic ecosystems and are directly affected by physical and chemical factors. The rapid reproduction rates and very short life cycles make algae valuable indicators of short-term impacts.[20] These plants are a diversified group that may be unicellular or multi-cellular, motile or immobile, of which practically all have photosynthetic pigments.[21] Algae are found in many types of aquatic habitats ranging from shallow areas of clear water lakes and streams to large lakes and the slowest reaches of rivers. Benefits of algae to the ecosystem are reoxygenation, mineralization of nutrients, and food source. The growth rates are influenced by amounts of pH, turbidity, sunlight, temperature, water velocity, and nutrients.[22] The amounts of these criteria are influenced by the surface water quality and may increase the growth rate and create algal blooms. Problems associated with algal blooms are shading of other algal species and aquatic plants, eutrophication of water body, water supply taste and odor production, interference with water supply treatment processes, destruction of recreational and aesthetic values, and large fluctuations in dissolved oxygen and pH levels. Fluctuations in dissolved oxygen and pH are due to the diurnal process of photosynthesis. The large fluctuations in concentrations of dissolved oxygen can cause fish kills. Also, some algae release high concentrations of toxins that can lead to fish kills.

Aquatic Plants

Aquatic plants grow in wetlands, shallow lakes, and streams. They are either free-floating or attached/rooted and are either submerged or emergent. The normal growth of aquatic plants is a part of a complex ecosystem in a state of dynamic balance. When the balance is affected by pollution, heavy growths of aquatic plants or “weeds” occur. In polluted waters, a lower number of specific species of plants tend to occur in dense populations. The dense growth creates breeding areas for unwanted insects such as mosquitoes, restricts movement of water and creates stagnant pools, exhausts nutrient supply, exerts a large dissolved oxygen fluctuation, and shades out sunlight. Flooding and silting of water bodies occurs from the restricted movement of water resulting in physical change of the channel or lake bottom. The detritus produced from the death of the abundant vegetation releases a major loading of organic matter and nutrients. The recreation and aesthetic value of the water body is ruined and the production of detritus, odors and bad tastes limit the use for water supplies.

Benthic Macroinvertebrates

Benthic macroinvertebrates (primarily insects) dominate the trophic level between the primary producers (algae and aquatic plants) and fish. The benthic macroinvertebrates are used as an indicator because, in flowing waters, they maintain their position in the stream either by living in or on the streambed (benthos) or attached to fixed objects. Therefore, they are good indicators of localized conditions and are well suited for assessing site-specific impacts. The U.S. Environmental Protection Agency Rapid Biological Assessment Protocol assesses benthic macroinvertebrates to identify the general ecological integrity of the surface water and fluctuating environmental conditions that can be monitored over time. The impacts are easily measured and ecological changes can be observed quickly due to the relatively short life cycles of the macroinvertebrates. The biological impairment of surface water is reflected by the:

- Absence of pollution sensitive macroinvertebrates;
- Excessive dominance by certain macroinvertebrates;
- Low overall macroinvertebrate richness; and
- Perceptible shifts in community structure.

Using these characteristics the bioassessed surface water fits into one of the following three categories of water quality: non-impaired, moderately impaired, and severely impaired. The N.J. DEP uses modified Rapid Bioassessment Protocol II (RBP II) methods that provide an expedient tool for site ranking, screening and trend monitoring for assessment of N.J. waters.[23]

Fish

Fish have been used for centuries as important indicators of water quality. Long-term effects and broad habitat conditions are reflected due to the relatively long life cycle and mobility. Fisheries range in species and trophic levels providing an integrated assessment of environmental health.[24] Assessment of the contamination of fisheries, especially the bioaccumulation of toxins in fish tissue, is very important because they are at the top of the aquatic food web and are consumed by humans.

Sediment Indicators of Water Quality Status

Surface water quality is affected by the quality of the sediment it flows over. The bottom sediment of surface water exerts a sediment oxygen demand on the dissolved oxygen present in the water column, acts as a sink for pollutants, and re-suspends during high flows.

Sediment Oxygen Demand

Organic matter present in the sediment exerts a demand on oxygen resources of the surface water. Sources of this organic matter are detritus from aquatic or surrounding vegetation or effluent from treatment operations containing sludge. Oxidation of the organic matter in the sediment occurs only at the sediment-water interface.

Sink for Pollutants

Particulates settle out of the water column along with pollutants adsorbed to them, such as phosphorus, petroleum hydrocarbons, and trace elements. Precipitates from chemical reactions in the water column also settle to the bottom sediments.

Re-suspension of Sediment

Transportation of sediment and associated pollutants downstream occurs when velocities increase and scour the bottom thereby re-suspending sediments. The re-suspension affects the turbidity of the surface water and concentrations of total suspended solids and total dissolved solids.

Trends and Relationships

A trend in water quality is an inclination or tendency towards a concentration level. Water quality trends are defined through the statistical analysis of the concentration of a single constituent at the same station over a period of time to determine if the concentration has decreased or increased at that station (i.e. the concentration is predicted to most likely be higher or lower when next sampled or at different levels for different seasons). When applied to the water quality sampling stations throughout the Raritan River Basin, such analyses can determine if a constituent's concentration has increased or decreased. This also assists in predicting future concentrations and linking these results to changes in the land use of the basin. The trends discussed in this report were summarized from three studies by the USGS[25] covering the periods of 1976-1993 (concentrations and flow), 1986-1995, and 1991-1997.

Relationships between water quality constituents and flow or season assists in determining possible sources of those constituents. For example, if a constituent concentration is higher during low flow than during high flow, the source of the constituent could be from the ground water that provides the base flow or from a point source, such as a wastewater treatment plant. Increases of the constituent concentration during high flows implicate nonpoint sources in stormwater runoff. If a relationship exists between the growing season and high constituent concentration in the water, the source may be from nonpoint sources, such as runoff from turf or crop areas.

Point and Nonpoint Source Pollutant Loading

Point source pollution is the discharge of effluent to surface water from a discrete conveyance, such as pipes or man-made ditches. Nonpoint source pollution is from any other source, such as precipitation and the resulting water that runs over land or through the ground accumulating and carrying pollutants to a near by body of water. Previous efforts of the Clean Water Act of 1972 focused on improving water quality in surface waters using Best Available Technology to improve the quality of point source effluent. This succeeded in reducing the amount of nutrients, total suspended solids, biochemical oxygen demand, heavy metals, and other pollutants discharged into streams. For many streams, including those of the Raritan Basin, improving the quality of the point source effluent was not enough to attain fishable and swimmable status. Both point and nonpoint contributions of pollution need to be considered and characterized on a watershed basis.

This report gives an estimate of the percent of constituent loading from point and nonpoint sources for 7 water quality constituents (ammonia plus organic nitrogen (TKN), BOD, TDS, nitrate plus nitrite, TOC, total phosphorus, and TSS) that are important for characterizing the water quality and health of the streams in the Raritan Basin. The point source discharges to the streams of the Raritan Basin are regulated and monitored by the New Jersey Pollutant Discharge Elimination System (NJPDES). They are categorized as minor or major, and as municipal, industrial, non-contact cooling water, or petroleum cleanup. The last two categories were not included in the analysis. During 1991-1997, the study period for the analysis, 73 facilities discharged treated effluent to streams in the portion of the Basin covered by the study. Constituent loads were determined in pounds per day and are calculated for low, median, and high flows. Yields were also determined for the watersheds of the sampling sites, and often are more useful than total load in understanding nonpoint source pollutant loadings. To calculate yield, the instream load is divided by the drainage area resulting in pounds per day per square mile (also known as a unit load). Estimated contributions of loads from baseflow also are included. The estimated point and nonpoint source loading results will be used for to develop of strategies for the TMDLs and Watershed Management Plan for the basin.

Characterization of Surface Water Quality

Characterization of surface water quality in the Raritan River Basin determines the current water quality and trends. The surrounding land use, ecology, and human systems within the Raritan Basin watersheds influence the water quality of all water bodies within the Basin. A trend in water quality is defined as a discernable (statistically significant) increase or decrease in the level of a water quality indicator over a specific period of time. Trends in water quality are influenced by changes in the characteristics of the drainage basin, including pollutant discharges. Surface water quality and respective trends over a period of time can be used as a tool to evaluate the improvement or degradation of a water body. Trends result from changes in the amount and type of effluent discharged by point sources, land use, amount and quality of runoff reaching surface waters (alteration of hydrology).

Methodology and Information Sources

The primary resources used in this study include:

Evaluation of Water Quality Status in the Raritan River Basin, Water Years 1991-1997

This resource provided most of the technical analysis of surface water quality for the Raritan River Basin. Over 800 samples were taken throughout the Basin at 21 sites during water years 1991-1997. Samples were analyzed for a variety of water quality constituents; however, only 17 constituents were chosen for analysis by this project. The 17 chosen included the 8 selected for the loading analysis and 9 with either a surface water or drinking water quality standard. The U.S. Geological Survey provided data for this report. Analyses performed included investigating trends and evaluating relationships of concentration and load with flow and season.

Evaluation of Permitted and Nonpermitted Loads in the Raritan River Basin, Water Years 1991-1997

All of the technical analysis for the point and nonpoint source loading into the surface waters of the Raritan River Basin were provided by this report. This report documents the results of the analysis of loads of 8 water quality constituents among the most important for characterizing the water quality for the Raritan Basin. Water quality and stream flow data collected from over 800 samples at 21 sites with in the Raritan Basin during water years 1991-1997 are used for computation of instream loads and yields. Sources of instream loads were investigated by estimating contributions of point and nonpoint source loads to total instream loads. The U.S. Geological Survey and TRC-Omni Environmental Corporation provided data for this report.

USGS Water Resources Data-New Jersey, Water Years 1998 and 1999, Water-Quality Data

These two volumes of water quality data provide the most recent information collected in this basin by the USGS. Additional data were collected that are not part of the systematic data collection program and are the National Water Quality Assessment Program (NAWQA) and the USGS/NJDEP cooperative Ambient Stream Monitoring Program. The NAWQA program is a long-term program conducted by the USGS with goals to provide the status and trends of water quality conditions. The USGS/NJDEP cooperative Ambient Stream Monitoring Program is designed to meet the expanding need for surface water quality data in the State of New Jersey. Recently, the cooperative program added more surface water quality sampling stations in response to the watershed management plan initiative by the State and the data gathered from those stations, as of now, are not used in this report.

NJDEP Ambient Biomonitoring Network, 1994 and 1999 Benthic Macroinvertebrate Data for the Raritan Region

Most of the information regarding the biological monitoring of benthic macroinvertebrates in streams of the Raritan River Basin was provided by this resource. A study of the Ambient Biomonitoring Network (AMNET) for the Raritan Basin occurred during 1993-1994 and encompassed 146 stations. The current study occurred during 1998-1999 and encompassed 164 stations. The two studies allow comparison of the bioassessment ratings for the Raritan Basin between 1993-1994 and 1998-1999. Supplemental evaluations were also conducted on the physical attributes of stream habitat and morphological abnormalities of individual macroinvertebrates.

New Jersey’s Draft 2002 Integrated List of Water Bodies and Their Support of Designated Uses And Compliance with Water Quality Standards (May 20, 2002)

This report assigns water bodies to one of five categories based on the most recent monitoring data evaluated by NJDEP. Categories 1 through 4 contain water bodies that meet all designated uses to those that do not, where enforceable management strategies are in place to address the impairments. Water bodies listed in Category 5 are those impaired water bodies will most likely require the development of a TMDL.

New Jersey 1996 State Water Quality Inventory Report

This resource provided the NJDEP watershed management area specific surface water quality assessments, including individual assessments of each watershed that lie within the Watershed Management Areas and its description, water quality assessment in detail and summary, description of point and nonpoint source pollution, and designated uses.

Final Comprehensive Conservation and Management Plan for the New York – New Jersey Harbor Estuary Program, March 1996.

This document supplied most of the information for the New York-New Jersey Harbor Estuary Program section. The plan provides a description of the Harbor Estuary and Bight and identification of the problems for this area. Objectives and action items are included that addresses each problem.

Note: N.J. DEP data from water quality monitoring in the Raritan Basin during 1999, 2000, and 2001 were not available for this report.

North and South Branch Raritan Watershed Management Area (WMA 8)

The North and South Branch Raritan Watershed Management Area (WMA) encompasses approximately 43% of the Raritan Basin and drains portions of the Highlands physiographic province (also know as the New England Province), which reaches elevations of approximately 1,400 feet in some areas (see Figure 5 – Topography and Major Landforms within the Raritan Basin – of the technical report "Setting of the Raritan River Basin"). The North and South Branch Raritan WMA includes portions of Morris, Hunterdon, and Somerset counties and is comprised of the South Branch Raritan River and North Branch Raritan River watersheds (see Figure 2 – Political Geography of the Raritan Basin – of the technical report "Setting of the Raritan River Basin").

The South Branch of the Raritan River drains an area of 279 square miles and flows from western Morris County through central Hunterdon County and into western Somerset County before joining the North Branch Raritan River (see Figure 10 – Surface Water Hydrology within the Raritan Basin – of the technical report "Setting of the Raritan River Basin"). The South Branch is 51 miles long; the Spruce Run, Mulhockaway Creek, and Neshanic River are three tributaries within the South Branch Watershed that have chemical water quality monitoring stations that are part of the USGS/NJDEP cooperative Ambient Stream Monitoring Program's network of sampling stations (Figure 1). Major impoundments located in this watershed are the Spruce Run Reservoir and Round Valley Reservoir. Budd Lake is a large natural lake in the headwaters area. The land use, according to the 1995/1997 land use data from NJDEP, in this watershed is mostly agriculture (28%) and forest (32.6%) with urbanized areas following (25.7%). The streams in this watershed are classified as FW-2 Trout Production, FW-2 Trout Maintenance, and FW-2 Non-Trout.

The North Branch of the Raritan River drains an area of 190 square miles and is 23 miles long, flowing from northwestern Morris County through Somerset County to the confluence with the South Branch Raritan River (see Figure 10 – Surface Water Hydrology within the Raritan Basin – of the technical report "Setting of the Raritan River Basin"). Rockaway Creek and Lamington River are tributaries that have chemical water quality monitoring stations that are part of the USGS/NJDEP cooperative network. Lake Cushetunk and Ravine Lake are the only significant impoundments in this watershed. The three major land uses in this watershed as of 1995-1997 are forest (41.5%), agriculture (20.8%), and urban (28.4%). The streams in this watershed are classified as FW-2 Trout Production, FW-2 Trout Maintenance, and FW-2 Non-Trout.

Surface Water Quality Trends and Relationships

Water quality of the North and South Branch Raritan Watershed Management Area was evaluated over a period of seven years (1991-1997) and data on 17 water quality constituents were assessed for trends. As seen in Figures 2 and 3, quality trends exist for some of the constituents. For the South Branch and North Branch Raritan watersheds these figures show that some nutrients have decreased over nine years. They are total ammonia, organic nitrogen, and total phosphorus. No significant trend for nitrate plus nitrite concentrations existed. Increasing trends in the North and South Branch Raritan include the following constituents: chloride, total dissolved solids, hardness, pH, and sodium.

Relationships within the North and South Branch Raritan WMA are apparent when comparing the concentration of the constituents with flow conditions and season of the year. As seen in Figure 4 for the South Branch and Figure 5 for the North Branch subwatersheds, the two flow conditions, high and low, have relationships with some of the constituents. Alkalinity, un-ionized ammonia, total dissolved solids, hardness, pH, sulfate, and water temperature decrease with increasing flow. An explanation for this relationship is that the higher flow means an increase in volume of water that in turn dilutes the concentration of alkalinity, un-ionized ammonia, total dissolved solids, hardness, and sulfate and decreases the temperature. The decrease in pH levels, causing the water to become more acidic, is from the acidic precipitation. The opposite occurred for dissolved oxygen and total suspended solids, increasing concentration with increasing flow. A possible explanation for the increase of dissolved oxygen is that the high flow aerates the water column. Total Suspended Solids likely increases with higher flows due to erosion materials contained in runoff and scour in the stream channel causing the bottom sediment to become re-suspended in the water column. In the South Branch Raritan River, three of the four USGS/NJDEP sampling sites show a slight relationship of nitrate plus nitrite concentration decreasing with increasing flow.

The growing season occurs from April to October and the rest of the year is the non-growing season (November to March). For all 12 USGS/NJDEP sampling sites in the North and South Branch Raritan WMA relationships exist between water quality and temperature, DO, and season, as would be expected. During the growing season, the water temperature in the WMA is higher than during the non-growing season. The dissolved oxygen is the opposite, with higher concentrations during the non-growing season than the growing season. The solubility of oxygen in water is inversely related to the temperature of the water, which is why the dissolved oxygen concentrations are higher during the colder non-growing season. Other relationships in this WMA are an increase in alkalinity and un-ionized ammonia concentration, and fecal coliform levels during the growing season. Figures 6 and 7 show the relationships between season and constituent concentrations for the South Branch and North Branch Raritan watersheds, respectively.

The North Branch Raritan Watershed has increased hardness and total phosphorus concentrations during the growing season. Another relationship is also identified between higher nitrate/nitrite concentrations and non-growing season in two tributaries, the Neshanic and Lamington Rivers, within the North and South Branch Raritan Watershed. The higher nitrate/nitrite concentrations may be due to more oxidation when the weather is cooler and the dissolved oxygen concentrations are higher in the non-growing season.

Comparison to Surface Water Quality Standards and Criteria

The three best overall water quality streams of the Basin are in the North and South Branch Raritan WMA as well as one of the worst overall water quality streams. The Spruce Run, Mulhockaway Creek, and Lamington River either had the lowest concentrations of constituents not meeting water quality standards or the highest frequency of meeting water quality standards for 14 of the 17 constituents. The Neshanic River had either the highest concentrations of constituents or the highest frequency of NOT meeting water quality standards for 13 of the 17 constituents.

The South Branch of the Raritan River shows overall good water quality with some evidence of problems. Warm summertime temperatures and low flow conditions, especially in the trout production and maintenance sections of the river, threaten aquatic life. Though nutrient concentrations over the water years 1986-1995 have decreased (nitrogen and phosphorus), elevated levels of phosphorus still are observed during the growing season (April – October) and low flow conditions. The upstream section of the South Branch has lower percentages of phosphorus concentrations exceeding the surface water quality criterion than downstream. At the downstream sampling site, Three Bridges, approximately 60% of the samples taken exceeded the 0.1 mg/L criterion for total phosphorus and of the samples taken during low flow conditions 75% exceeded the criterion. The sanitary quality of the South Branch of the Raritan River is marginally acceptable; fecal coliform levels tend to increase during the growing season.

The Spruce Run and the Mulhockaway Creek both flow into the Spruce Run Reservoir, from which Spruce Run flows into the South Branch Raritan River. Both are trout streams, have over 40% of forested land in their drainage area, and exhibit similar water quality. Although both of these streams exhibit the best water quality of the Raritan Basin, they still have some problems. During the growing season and low flow conditions, both streams exceeded the temperature criterion for trout streams. Approximately 24% of the samples taken in the growing season during low flow conditions for both streams exceeded the criterion. Phosphorus levels were elevated and 32% and 18% of samples from Spruce Run and Mulhockaway Creek, respectively, exceeded the 0.05 mg/L criterion for streams entering lakes as applied to the Spruce Run Reservoir. The sanitary quality is marginal for both, with 29% of samples exceeding 400 colonies per 100 milliliter. The established surface water standard is 400 colonies per 100 milliliter in 10 percent of total samples collected in a 30-day period[26].

The Neshanic River is a tributary to the South Branch of the Raritan River. This non-trout river has over 40% of its drainage area in agricultural land use as of 1995, which is the highest percentage in the entire Raritan River Basin. No permitted point sources discharge to the Neshanic River. The overall water quality is one of the worst in the Basin. The Neshanic portion of the Basin has the highest alkalinity concentrations and highest frequency of exceeding the upper limit of the pH criteria. The sanitary quality of the water is poor, with 69% of the total samples taken exceeding the fecal coliform criterion (400 colonies/100mL), and during the growing season the fecal coliform numbers increase. The phosphorus levels show an increase with high flow conditions and 20% of samples collected during high flow exceeded the total phosphorus criterion.

The overall water quality issues for the North Branch Raritan River are elevated total phosphorus and fecal coliform levels. In the portion of the North Branch designated as trout production or trout maintenance, approximately 40% of samples taken during low flow conditions exceeded the criterion for total phosphorus but only 9% exceeded the criterion during high flow conditions. Elevated temperatures that exceed the criterion for trout waters are also a problem in the upper reaches of the river, especially during the growing season and low flow conditions. Proceeding down the North Branch to the non-trout section, fecal coliform levels create a poor sanitary condition. For all samples, 46% exceeded the criterion (400 colonies/100mL), with 70% of those samples taken during low flow conditions exceeding the water quality standard.

The Lamington River, a tributary to the North Branch Raritan River, shows good water quality. Summer time low flow and high temperatures affect the trout production section of the river. A tributary to the Lamington River, Rockaway Creek, shows poor sanitary quality and elevated phosphorus levels. This is especially true during low flow conditions with 54% of samples exceeding the fecal coliform criterion (400 colonies/100mL) and 70% exceeding the total phosphorus criterion.

Comparison to Other Indicators of Chemical Quality

The occurrence of volatile organic compounds (VOCs) in the North and South Branch Raritan Watershed Management Area was studied by the U.S. Geological Survey's (USGS) National Water Quality Assessment (NAWQA) program. All of the samples taken from locations within this watershed had at least one VOC detected, Methyl tert-butyl ether (MTBE). The concentrations from all samples did not exceed the health advisory level (HAL) and the median concentration was greater in the cooler months than in the warmer months.[27] The Neshanic River had four VOCs detected in samples, other than MTBE. They were chloroform, trichloroethene (TCE), toluene, and carbon disulfide. The chloroform and carbon disulfide median concentrations were greater during the warmer months than in the cooler months possibly from inputs from chlorinated water sources (chlorinated ground water, swimming pools) that are less diluted due to the decreased flows during the warmer months. The dominant land use in the Neshanic River watershed is agriculture and could be the reason for the low number of VOCs detected, as compared to the urban watersheds of the Raritan Basin.

Pesticide application in the North and South Branch Raritan Watershed Management Area is estimated by surveys conducted by the NJDEP Pesticide Control Program for the following categories: agriculture, golf courses, lawn care services, and mosquito control.

- **Agriculture** – According to the 1997 survey[28] for agriculture, which targets agricultural, nursery, and greenhouse use, application amounts range from 1,000 to 10,000 pounds (lbs) per year per subwatershed (HUC-11) of pesticide (active ingredient) over most of the watershed management area. Two subwatersheds, the Lamington River and the South Branch Raritan River from the confluence with Spruce Run to the village of Three Bridges, have higher application amounts ranging from 10,000 to 50,000 lbs. Comparing the 1994 survey for agriculture pesticide use to the 1997 survey, as seen in Figure 8, the South Branch Raritan River from Spruce Run to Three Bridges subwatershed reflected an increase in pesticide use.
- **Golf Courses –** The 1999 survey[29] for golf course pesticide use shows application amounts over 10,000 lbs in the Lamington River subwatershed and 5,000 to 10,000 lbs in the South Branch Raritan River subwatershed. The other areas of the North and South Branch Raritan Watershed Management Area have application amounts in the range from 1 lb to 5,000 lbs. Most of the total pesticides used on golf courses were applied to the greens and tee boxes. The application amounts in this management area have not dramatically changed from the 1996 survey as seen in Figure 9.
- **Commercial Lawn Care –** The amount of pesticide used for lawn care by registered pesticide businesses in the North and South Branch Raritan WMA during 1998[30] ranged from 20,000 to 30,000 lbs, a decrease from 1995 where over 30,000 lbs were applied (Figure 10).

The detection of pesticides in the waters of the North and South Branch Raritan WMA most likely occurs for all surface waters due to the widespread use of pesticides and the many types applied in the basin. Pesticides have been detected in the Spruce Run, Neshanic River, South Branch Raritan River, Dawson's Brook, and Lamington River. The presence of specific pesticides in surface waters is related to the land use of the basin and studies have shown that the total pesticide concentration and number of pesticide compounds increase with increasing percentage of agricultural land use.[31] Specifically, the concentrations of four of the most frequently detected pesticides increase significantly as the percentage of agricultural land increased.[32] All of the drainage basins for these surface waters have similar land use, predominantly forest, except for the Neshanic River. The dominant land use in the Neshanic watershed is agriculture. Fifteen pesticides were detected during the growing season of 1996, including all 8 of the most frequently detected pesticides.[33] Most of the pesticides detected are exclusively used in agriculture and concentrations were significantly higher than those drainage areas with less agricultural land use.[34] The number and concentration of detected pesticides were higher during the growing season and during runoff events.

The following pesticide, sampled from the Neshanic River at Reaville, N.J., had a concentration that exceeded established water quality criteria [35]:

- Atrazine exceeded the USEPA drinking water maximum contaminant level of 3.0 μg/L in a sample collected during runoff in the growing season.

The South Branch Raritan River and the Lamington River have the next highest numbers of pesticides detected, with 9 (during 1998) and 10 (during 1999) total pesticides respectively.[36, 37] Both had seven of the eight more frequently detected pesticides present. The other two streams had less than 5 pesticides detected during 1998.[38] None exceeded regulatory thresholds.

Most pesticides are applied during the spring and summer months - the growing season - and the detection frequency, concentration, and number of pesticides is higher during this time of year. The behavior of the detection frequency, concentration, and number of pesticides to the flow conditions present in the stream at time of sampling have shown that they increase during runoff conditions. This is more pronounced when the runoff condition occurs during the growing season, for most pesticides. The presence of pesticides in the surface waters of the North and South Branch Raritan Watershed Management area is a potential threat to the public water supply in the basin.

Ecological Indicators of Water Quality

Assessment of benthic macroinvertebrates and their habitats in the North and South Branch Raritan Watershed Management Area were conducted as part of the NJDEP Ambient Biomonitoring Network. As of 1999, most of the management area has a non-impaired bioassessment rating. Approximately one quarter of the 67 AMNET sites located in the WMA are moderately impaired and one site is severely impaired. A cluster of seven moderately impaired AMNET sites occur in the Neshanic River watershed. The severely impaired sampling site is located on the Mine Brook, near Bernardsville. The habitat assessment for this site is sub-optimal; therefore the biological impairment can be associated primarily with water quality rather than poor physical habitat conditions. The current bioassessment ratings compared to the 1994 data remains fairly constant, with one exception; there were no severely impaired sites in 1994 (Figure 11). The physical habitat assessment of the streams in the North and South Branch Raritan Watershed Management Area is fairly constant, at near optimum levels, throughout. Though some localized degradation from land use sources exists, the stream biotic integrity in this management area is generally quite favorable.[39] The existing biotic integrity can be a result of an association between land use characteristics and benthic macroinvertebrate community composition. Generally, a severely impaired rating is most significantly and positively related to the area of urban land, and most significantly and negatively related to the area of forested land.[40] The North and South Branch Raritan Watershed Management Area, as of 1995, has many subwatersheds that have the highest percentage of forested land in the entire basin, most over 40% with the exception of the Neshanic, which has approximately 22% forested land. The higher percentage of forested land use in this management area reflects the non-impaired bioassessment rating given to most of the sampling sites.

Sediment Quality

For the NAWQA program, bed sediment was sampled from the Neshanic River at Reaville and analyzed for trace elements and chlorinated organic compounds: Antimony (Sb), arsenic (As), cadmium (Cd), copper (Cu), chromium (Cr), lead (Pb), manganese (Mn), mercury (Hg), nickel (Ni), Selenium (Se), zinc (Zn), dichlorodiphenyl-trichloroethane (DDT), polychlorinated biphenyls (PCBs), and chlordane. All of the compounds were detected. Trace element concentrations were generally within the concentration range where adverse biological effects are expected to occur on occasion[41]. For all but lead and mercury, the trace element concentrations also exceeded the estimated baseline concentrations. Chlorinated organic compound concentrations were below detection limits for samples from the Neshanic River at Reaville.

Analysis of Point and Nonpoint Source Pollutant Loading

The North and South Branch Raritan WMA has 36 permitted discharges into its surface waters and the Neshanic River is the only sampling site in a subwatershed that has no permitted discharges. The effluent discharges range from 0.0003 to 3.9 cubic feet per second (cfs). Most of the seven constituents – ammonia plus organic nitrogen, BOD, TDS, nitrate plus nitrite, TOC, TP, TSS - analyzed for source loading were attributed to non-permitted sources. However, especially during low flows, permitted sources accounted for more than 50% of the load at some of the water quality sampling sites for ammonia plus organic nitrogen, nitrate plus nitrite, and total phosphorus, as shown in Table 6.

Table 6. Permitted Sources Accounting For Over 50% of Total Instream Load – North and South Branch Raritan WMA

	North Branch Raritan		Lamington River		Rockaway Creek	South Branch Raritan		
	Chester	Burnt Mills	Pottersville	Burnt Mills		Middle Valley	Stanton	Three Bridges
Base Flow	• Ammonia + organic nitrogen* • BOD • TDS • Nitrate + nitrite* • TP*	• Ammonia + organic nitrogen* • Nitrate + nitrite* • TP	• TDS* • Nitrate + nitrite* • TP*	• TP*	• Ammonia + organic nitrogen* • TP*	• TP*	• TP	• TP
Median Flow	• Ammonia + organic nitrogen • Nitrate + nitrite* • TP*	• Ammonia +organic nitrogen	• Nitrate + nitrite* • TP*	• TP	• Ammonia + organic nitrogen • TP*	• TP*	• TP	• TP
High Flow	• Nitrate + nitrite • TP		• Nitrate + nitrite • TP*		• TP*		• TP	
* Permitted sources make up over 75% of total load.								

Possible Causes of Water Quality Concerns

The point and non-point sources of pollutants in this WMA were assessed in the 1996 New Jersey State Water Quality Inventory Report. This report provides guidance in determining the possible causes of the water quality concerns described in the above sections. Facilities that discharge effluent into the surface waters of this WMA have the potential to be a significant point source because of their contribution of flow compared to base flow. According to the 1996 report there were no active enforcement cases against any of those facilities. Past enforcement actions have been reconciled due to the facility upgrading or ceasing their discharge and the facilities are no longer considered to be impairing the water quality.

The surface waters of the North and South Branch Raritan Watershed Management Area have pollutant loadings from non-point sources. For the South Branch Raritan watershed, according to the 1996 NJ State Water Quality Inventory Report, there is a "gradual" decline in agricultural non-point source pollution and a "rapid" increase in suburban non-point source pollution. Agricultural non-point source pollutants are suspected of contributing nutrient and sediment loads. The construction of housing and roads, known sources of sediment loading, along with runoff from the suburban landscape and storm drains, known sources of nutrient and sediment loading, all contribute to the suburban non-point source pollution. The primary source of non-point pollutants for the North Branch Raritan watershed is from suburban landscape runoff and development.[42] Non-point source pollutants from agriculture are a suspected but unconfirmed problem for this watershed.

Lower Raritan Watershed Management Area (WMA 9)

The Lower Raritan Watershed Management Area (WMA) encompasses approximately 33% of the Raritan Basin and contains the lowest elevations of the Basin, particularly in the area surrounding Raritan Bay. This watershed management area lies in Middlesex, Monmouth, Somerset and Union counties and includes the following watersheds: Main Stem Raritan River, Bound Brook, Green Brook, Lawrence Brook, South River, Manalapan River, and Matchaponix Brook. The Raritan River Main Stem begins at the confluence of the North and South Branches of the Raritan River and flows for 31 miles to empty into the Raritan Bay. Two low dams, the Calco and Fieldsville dams, are located on the river. Tides affect this waterway to the Fieldsville Dam upstream of the city of New Brunswick. For this report the tidal section of the Raritan River will be covered in the New York-New Jersey Harbor Estuary Program section. The Delaware and Raritan Canal flows alongside the Raritan River from the confluence with the Millstone River to New Brunswick. Many small recreational lakes and ponds are located within this WMA and include Watchung Lake, Surprise Lake, Spring Lake, and Green Brook Pond. Dams on the Lawrence Brook are associated with the Lawrence Chain of Lakes, including Davidson's Mill Pond, Dean's Mill Pond, Farrington Lake, Mill Pond, Weston Mill Pond, and the Weston Arch Dam – where the City of New Brunswick draws its water supply. The land use in this watershed management area, as of 1995, is mostly urban/suburban (51%) with industrial and commercial centers throughout. The streams in this watershed are classified as FW-2 Trout Maintenance, FW-2 Non-Trout and SE-1.

The South River, a major tributary to the main stem of the Raritan River, has a watershed that drains an area of 133 square miles. Formed from the confluence of the Manalapan and Matchaponix Brooks, the South River originates from Durhernal Lake in Spotswood Borough. The river flows for 10 miles through Middlesex County to the Raritan River at Sayreville Borough and is affected by the tides. The South River watershed has 4 impoundments (Durhernal Lake, Lake Manalapan, Lake Topanemus, and DeVoe Lake) and two other tributaries (Deep River and Tennants Brook). This sub-basin has over 30% urban land use and the waters within this watershed are classified as FW-2 Non-Trout and SE-1.

Surface Water Quality and Trends

Water quality of the Lower Raritan Watershed Management Area was evaluated over a period of nine years (1986-1995) and data on 17 water quality constituents were assessed for trends (Figure 12). Four monitoring stations are located in the Lower Raritan WMA. The Bound Brook and Lawrence Brook watersheds had no monitoring stations before 1998. Total ammonia plus organic nitrogen concentrations decrease over time for the entire watershed management area. The South River watershed has more trends, as shown in the Manalapan and Matchaponix Brooks. The Matchaponix Brook shows a decreasing trend of total ammonia and total phosphorus. Other than the decrease in total ammonia plus organic nitrogen, the Manalapan Brook shows increasing trends associated with BOD, TDS, chloride and sodium.

Flow conditions have been associated with relationships in parameter concentrations for the Lower Raritan WMA and are shown in Figure 13. The alkalinity, un-ionized ammonia, total dissolved solids, hardness, pH, sulfate, and chloride concentrations decrease with increasing flow; they are diluted by the increase in volume of water. The total suspended solids concentration shows an increase with increasing flow, possibly due to scouring of the bottom sediment and stream banks, causing solids to become suspended in the water column. All of these parameters, with the exception of chloride, have the same relationships as in the North and South Branch Raritan WMA. Additional relationships with flow occur within the Raritan River Main Stem subwatershed and Matchaponix Brook subwatershed. Total phosphorus decreases with increasing flow in the Raritan River Main Stem. Both Nitrate/Nitrite and sodium decrease and organic nitrogen increases with increasing flow in the Matchaponix Brook.

Relationships also exist with the growing (April to October) and non-growing (November to March) seasons in this watershed management area, as shown in Figure 14. All four of the USGS/NJDEP sampling sites for water quality in the Lower Raritan show relationships with temperature, DO, and season. To summarize this relationship, the solubility of the oxygen is inversely related to the water temperature and the water temperature is related to the season of the year; therefore, the dissolved oxygen concentration is dependent on the season. The DO concentration is higher during the colder non-growing season because of the temperature-dependent solubility. Other relationships in this WMA are an increase in fecal coliform, total organic carbon, and total phosphorus levels during the growing season. Additional relationships with season occur in the Manalapan Brook, showing an increase in levels of un-ionized ammonia during the growing season; total dissolved solids (TDS) and nitrate/nitrite increase during the non-growing season. The increases in TDS concentrations are most likely attributable to the application of road salt for deicing. The higher nitrate/nitrite concentrations may be due to more oxidation when the weather is cooler and the dissolved oxygen concentrations are higher as in the non-growing season.

Comparison to Surface Water Quality Criteria

The Main Stem of the Raritan River is one of the three streams ranked worst for overall water quality in the entire Raritan Basin. The Main Stem of the Raritan River has the highest concentrations or highest frequency of NOT meeting the standards/criteria for 14 of the 17 constituents. The elevated total phosphorus and fecal coliform levels increase from Manville downstream to Bound Brook. These levels are exacerbated during low flow conditions, where over 60% and 100% of the samples taken at Bound Brook, during low flow exceeded the criteria for fecal coliform (a geometric mean of 200 colonies/100 mL) and total phosphorus, respectively. Over 80% of all water quality samples at Bound Brook exceeded the total phosphorus criterion.

The Matchaponix and Manalapan subwatersheds reflect the water quality in the South River watershed. Both brooks have very good sanitary quality based upon fecal coliform levels. In the Manalapan Brook, 31% of the samples tested for total phosphorus exceeded the water quality criterion. The Matchaponix has the highest total dissolved solids concentration (though no sample exceeded the drinking water standard) and the highest frequency of not meeting the lower limit of the criterion for pH for the Lower Raritan WMA. The pH condition may be natural, related to acid-producing soils in the subwatershed, though this impact can be exacerbated by soil erosion and land disturbances.

Comparison to Other Indicators of Chemical Quality

Volatile organic compounds detected in the Lower Raritan Watershed Management Area occurred in the main stem Raritan River, Green Brook, and Bound Brook. Again, MTBE was detected in all samples from the locations within this watershed but the concentrations did not exceed USEPA MCLs or human health advisory levels. This highest concentration of MTBE was measured at the sampling site most upstream in the Bound Brook watershed. The Bound Brook had the maximum concentration for 28 of the 47 VOCs detected and highest detection frequencies and median concentrations of MTBE, TCE, and PCE for samples collected by the USGS during April 1996 through April 1997.[43] The watershed for the Bound Brook is dominated by urban land use that are most likely the reason for the number of VOCs detected in the samples. The large drainage area of the main stem of the Raritan River, near Bound Brook, integrates the effects of many different land uses, physiographic settings, and point-source discharges. The sampling station on the Raritan River at Bound Brook had the maximum concentration for 8 of the 47 detected VOCs.[44] However, no concentrations of VOCs measured in samples exceeded criteria, standards or advisory levels in the watershed management area.

Pesticide application in the Lower Raritan Watershed Management Area is estimated by surveys conducted by the NJDEP Pesticide Control Program for the following categories: agriculture, golf courses, lawn care services, and mosquito control.

- **Agriculture** – According to the 1997 survey[45] for agriculture application, amounts range from 1,000 to 10,000 lbs of pesticide (active ingredient) over the entire watershed except for the subwatershed of the Raritan River, from the confluence of the North and South Branch of the Raritan River to the confluence of the Millstone, that ranges from zero to 1,000 lbs. Comparing the 1994 survey for agriculture pesticide use to the 1997 survey, the Lower Raritan River Watershed experienced a decrease in pesticide use in the Manalapan Brook subwatershed and the Raritan River from the North and South Branch confluence to the confluence with the Millstone River (Figure 8).

- **Golf Courses –** The 1999 survey[46] for golf course pesticide use shows that application amounts increased from 1 lb to 5,000 lbs in 1996 to between 5,000 to 10,000 lbs in the subwatersheds of the Manalapan River and the Raritan River, from the confluence with the Millstone River to the confluence with the Lawrence River (Figure 9). The rest of the Lower Raritan Watershed Management Area has remained constant with application amounts in the range of 1 lb to 5,000 lbs. Most of the total pesticides used on golf courses were applied to the greens and tee boxes.
- **Commercial Lawn Care –** Over 30,000 lbs of pesticide was used for lawn care by registered pesticide businesses in the Lower Raritan WMA during 1998[47] and 1995 (Figure 10). The application rate remained the same.

The detection of pesticides in the Lower Raritan WMA most likely occurs for all surface waters due to the wide spread use of pesticides in the basin. Pesticides have been detected in the following surface waters in this management area: Raritan River (near Bound Brook, N.J.), Bound Brook, Green Brook, Peters Brook, Ireland Brook, and Matchaponix Brook. The eight most frequently detected pesticides were detected at every site sampled. The Raritan River and Bound Brook had 23 and 20 different pesticides detected, respectively, according to the USGS Water Data Report for New Jersey for water year 1998. There was only one site, Green Brook, which had less than 10 pesticides detected.[48] The land use in the watersheds of these basins is predominantly urban, except for the Raritan River that has a drainage basin that results in an integration of multiple land uses. The detection frequency, concentration, and number of pesticides reflect the land use, season, and flow. For example, most of the pesticides present in maximum concentrations from samples from the Bound Brook are associated primarily with lawn care, rights of way maintenance, and mosquito control.[49] Most pesticides are applied during the spring and summer months and the detection frequency, concentration, and number of pesticides is higher during this time of year. The correlation of the detection frequency, concentration, and number of pesticides to the flow conditions present in the stream at time of sampling have shown that they increase during runoff conditions. The phenomenon is more pronounced when the runoff condition occurs during the growing season, for most pesticides.

The following pesticides, sampled from the Raritan River at Bound Brook, N.J., had concentrations that exceeded established water quality criteria:[50]

- Atrazine exceeded the USEPA drinking water maximum contaminant level of 3.0 µg/L in two samples collected during runoff in the growing season.
- Cyanazine exceeded the USEPA human health advisory level of 1.0 µg/L in one sample collected during runoff in the growing season.
- DDE exceeded the NJ human health criterion of 0.0000588 µg/L in one sample collected during runoff in the growing season.

The following pesticides, sampled from the Bound Brook at Middlesex, N.J., had concentrations that exceeded established water quality criteria:[51]

- Chlorpyrifos exceeded the USEPA aquatic life criterion of 0.041 µg/L in one sample collected during runoff in the growing season.
- Ethyl-parathion exceeded the USEPA chronic aquatic life criterion of 0.013 µg/L in one base-flow sample collected in growing season.

Two other pesticides exceeded other water quality criteria that do not apply legally in New Jersey but can be used as indicators, as follows:

- Chlortholonil, a fungicide, exceeded the Canadian Standard of 0.018 µg/L in two samples collected from the Bound Brook at Middlesex, NJ.

- Diazinon exceeded the Great Lakes Water Quality Objective of 0.08 µg/L in two samples from the Raritan River at Bound Brook, NJ and in 10 samples from the Bound Brook at Middlesex, NJ.

The presence of pesticides in the surface waters of the Lower Raritan Watershed Management Area represents a potential threat to the public water supply in the basin.

Ecological Indicators of Water Quality

The 1999 assessment of benthic macroinvertebrates and their habitat in the Lower Raritan Watershed Management Area involved a total of 46 AMNET sampling sites. Most of this watershed area has a moderately impaired rating, with only five sites rated as non-impaired. Of the six severely impaired sites, four are located in the South River Watershed, one on Bound Brook, and one on Mile Run. Compared to the 1994 AMNET study, a significant improvement was seen at seven sites and a significant decline at three sites (Figure 15). The overall habitat assessment is sub-optimal with a few marginal sites and the overall stream biotic integrity of this watershed management area is impaired. Comparing the habitat assessment and the biotic assessment, water quality is the primary impairment rather than physical habitat degradation. This is a reflection of the higher percentage of urban land use as compared to forested. For example, over 40% of the Matchaponix Brook watershed is in urban land use and all of the AMNET sampling sites are rated as moderately impaired.

Sediment Quality

For the NAWQA program, bed sediment was sampled from two sites in the Lower Raritan WMA and analyzed for trace elements and chlorinated organic compounds: Antimony (Sb), arsenic (As), cadmium (Cd), copper (Cu), chromium (Cr), lead (Pb), manganese (Mn), mercury (Hg), nickel (Ni), Selenium (Se), zinc (Zn), dichlorodiphenyl-trichloroethane (DDT), polychlorinated biphenyls (PCBs), and chlordane. Samples were collected from the Raritan River at Queens Bridge and from Bound Brook at Middlesex. All of the compounds were detected at both locations. For seven of the trace elements, concentrations exceeded baseline estimates for the Bound Brook at Middlesex and were generally within the concentration range where adverse biological effects are expected to occur either occasionally or frequently[52]. For all but lead and mercury, the trace element concentrations also exceeded the estimated baseline concentrations for the Raritan River at Queens Bridge. Chlorinated organic compound concentrations were detected at both locations in the Lower Raritan WMA. Total chlordane concentrations in samples from Bound Brook at Middlesex were above concentrations expected to frequently cause adverse biological effects[53].

Analysis of Point and Nonpoint Source Pollutant Loading

The Lower Raritan WMA has six major permitted discharges into its surface waters, ranging from 0.0005 to 25.6 cfs (excluding the Middlesex County Utilities Authority discharge, which is downstream of the USGS/NJDEP monitoring network and nearly out of the Basin). Other industrial permitted facilities are located along Bound Brook, Lawrence Brook, and along the Main stem of the Raritan downstream of Bound Brook. Permitted point source flows exceed 25% of baseflow at the Matchaponix Brook and Raritan River at Bound Brook sites. The sampling site on Manalapan Brook is the only site in the WMA that has no permitted discharges upstream. The majority of the seven constituents – ammonia plus organic nitrogen, BOD, TDS, nitrate plus nitrite, TOC, TP, TSS - analyzed for source loading were attributed to non-permitted sources. However, especially during low flows, permitted sources accounted for more than 50% of the load at some of the water quality sampling sites for nitrate plus nitrite, TDS and total phosphorus, as shown in Table 7. Permitted loads were less than 50% of the total load for all constituents at the Raritan River at Manville at all flows studied.

Table 7. Permitted Sources Accounting For Over 50% of Total Instream Load – Lower Raritan WMA

	Raritan River – Bound Brook	Matchaponix Brook
Base Flow	• Ammonia + organic nitrogen* • TDS • Nitrate + nitrite* • TP*	•BOD •TDS* •Nitrate + nitrite* •TP*
Median Flow	• Nitrate + nitrite*	•TDS •Nitrate + nitrite •TP*
High Flow		•Nitrate + nitrite •TP*
* Permitted sources make up over 75% of total load.		

Possible Causes of Water Quality Concerns

The Lower Raritan Watershed Management Area is "believed to be heavily influenced by both point and non-point sources" of pollution according to the 1996 New Jersey State Water Quality Inventory Report. Some point sources in this WMA have been eliminated or upgraded. The major sources of non-point pollutants in this WMA are from urban and suburban development and land uses. Additional sources of pollutants are suspected to originate from land disposal of wastewater and local chemical spills. Also, a number of hazardous waste sites are located in this WMA, some of which are on the National Priorities List, that have been reported as impairing surface waters.[54]

The New York-New Jersey Harbor Estuary Program

The information for this section was drawn from the New York – New Jersey Harbor Estuary Program's Final Comprehensive Conservation and Management Plan.

The National Estuary Program was established as part of the 1987 amendments to the Clean Water Act because Congress recognized the significance of preserving and enhancing coastal environments. The purpose of the National Estuary Program is to promote the development of comprehensive management plans for estuaries of national significance threatened by pollution, development, or overuse.[55] The New York-New Jersey Harbor Estuary was designated an "Estuary of National Significance" in 1988 and accepted into the National Estuary Program. Congress also required the preparation of a restoration plan for the New York Bight, and efforts for both plans were joined because the Harbor and Bight are linked in so many ways. The New York-New Jersey Harbor Estuary Program (NY-NJ HEP) was convened and created the Management Conference, which is a partnership of federal, state, and local governments; scientists; civic and environmental advocates; the fishing community; business and labor leaders; and educators. The mission of the Management Conference was to develop a plan to protect and restore the Estuary and began with this goal, "to establish and maintain a healthy and productive ecosystem with full beneficial uses".[56]

The New York-New Jersey Harbor Estuary encompasses the waters of the New York Harbor and tidally influenced portions of all rivers and streams that empty into the Harbor including the Raritan River. The Harbor Transect is an imaginary line between Sandy Hook, New Jersey and Rockaway Point, New York that creates the lower boundary of this core area. The watershed of this Estuary encompasses about 16,300 square miles, including much of eastern New York, northern New Jersey, and small parts of Connecticut, Massachusetts, and Vermont. The water quality of the Estuary is affected not only by the activities occurring directly within, but also by activities occurring within the entire watershed. As rainwater moves over the land in the watershed and enters the rivers, it carries many potential pollutants that flow downstream and eventually end up in the Estuary.

The New York Bight is the ocean area extending approximately 100 miles off shore from the Harbor Transect to the outer limits of the Continental Shelf. The landward border of the Bight includes 240 miles of shoreline, extending from Cape May, New Jersey to Montauk Point, Long Island.

Characterization of Surface Water Quality for the Harbor Estuary

Historically, the water quality of the Harbor Estuary has been poor since the early 1900's. Since the passage of the Clean Water Act, in 1972, investments in water pollution control programs have significantly improved the water quality. Despite these improvements, many problems remain and many uses or values are still impaired from current or old abuses. These impairments include human use such as fish consumption advisories and intermittent closures of bathing beaches, and ecosystem health and productivity such as declines in fish and shellfish populations. The NY-NJ HEP identified and decided to focus on five primary causes to these impairments:

- Habitat Loss and Degradation
- Toxic Contamination
- Pathogen Contamination
- Floatable Debris
- Nutrient and Organic Enrichment

Habitat Loss and Degradation:

The NY-NJ Harbor Estuary and Bight is located at the confluence of several major river systems and sustains diverse habitats and species. This area lies on the Atlantic Flyway, which is a major pathway for migratory birds, and the various habitats provides these birds with food and rest. The Harbor Estuary/Bight has exceptionally diverse plant life and concentration of marine, estuarine, and diadromous fish. Recreation is a dominant component of the tourist economies of New York and New Jersey and the recent water quality improvements have reawakened the recreational and scenic potential of the shorelines.

The following impairments have been identified as part of the habitat loss and degradation of the Harbor Estuary/Bight:

- Habitat Loss, Fragmentation, and Degradation
- Impaired Commercial and Recreation Fisheries
- Impaired Coastal and Terrestrial Living Resources
- Limited Public Access

The factors contributing to these impairments are pollutant loadings, coastal development, shoreline and aquatic habitat modification, alteration of freshwater inputs, human disturbance of natural habitats, over-harvesting, and insufficient/inadequate sites for public access.

Toxic Contamination:

Toxic contaminants are man-made and naturally occurring substances that can cause adverse ecosystem or human health effects when exceeding certain concentrations (NYNJHEP plan). The pollution of the Harbor Estuary/Bight was worse in past decades than today, largely due to the uncontrolled release of toxic substances to the environment prior to the Clean Water Act. Since then improvements have been made to public and industrial wastewater treatment and certain toxic substances have been banned or reduced. Still, a toxic contamination problem exists in the Harbor Estuary/Bight and has been characterized in two ways, ecosystem and chemical-specific.

For the ecosystem approach direct evidence from field and laboratory studies is used to characterize the adverse effects of toxic contamination on the Harbor Estuary/Bight ecosystem. Evidence of current and past problems of the Harbor Estuary/Bight is listed:

- Sediments from most of the Harbor and some areas of the Bight are toxic to a variety of organisms in laboratory tests.
- Ambient waters of the Harbor are sometimes toxic to sensitive organisms in laboratory tests.
- Reproductive impairment in fish-eating birds, historically caused by DDT.
- Decreased reproductive success of nesting birds and in some fish species: fin rot, development of certain types of tumors, developmental abnormalities, behavioral impairments, and altered life histories; are believed to be consistent with toxic contamination.
- The degradation of the bottom-dwelling organisms community possibly caused by toxic contamination and/or other stressor such as hypoxia.

The chemical-specific approach identifies concentrations of a number of chemicals in the water, sediments, and tissues of edible fish, crustaceans, and shellfish in the Harbor Estuary/Bight that exceed the criteria and standards developed by government agencies to protect marine life, wildlife, and human health. A result of this approach is that some fish, crustaceans, and shellfish caught in these waters are considered unsafe for human consumption. The NY-NJ HEP has identified specific chemicals of concern, listed in Table 8.

Sources that contribute to the problem are municipal discharges, direct/indirect industrial discharges, combined sewer overflows, storm water, contaminated sediments, atmospheric deposition, chemical/oil spills, tributary inputs, solid/hazardous waste sites, and other non-point sources.

Table 8. Chemicals of concern in the NY-NJ Harbor Estuary and Bight

Chemical Name	Medium:		
	Water	Biota	Sediments
Metals:			
Arsenic		○	
Cadmium		○	
Copper	■		
Mercury	●	●	○
PCBs	●	●	○
Dioxin			○
PAHs	●	○	○
Pesticides:			
DDT & metabolites		○	
chlordane		●	
dieldrin		○	
heptachlor		○	
heptachlor epoxide		○	
hexachlorobenzene		○	
gamma-BHC		○	
VOCs:			
tetrachloroethylene	●		

○ = exceedances of unenforceable criteria; ● = exceedances of enforceable standards;
■ = predicted by mathematical modeling to sometimes exceed enforceable standards
Source: NY-NJ Harbor Estuary Plan, 1996.

Pathogenic Contamination:

Pathogens are present in untreated or inadequately treated human sewage and animal wastes. Human sewage and related discharges have impaired the water quality of the Harbor Estuary/Bight for a long time. Problems associated with this impairment are:

- Closure of recreational beaches
- Degradation of the water for recreational boaters
- Closure or restriction of shellfish beds
- Risks to living marine resources

No portion of the Harbor is approved for the direct harvesting of shellfish but all public bathing beaches, located in the outer reaches of the Harbor, are approved for recreational bathing. The waters located in the Bight are approved for shell fishing, except for a Federal Shellfish Closure Area around the former municipal sewage sludge disposal site, and all ocean beaches are approved for bathing. Sources of pathogenic contamination of the Harbor Estuary/Bight are municipal discharges, combined sewer overflows, storm water, vessel discharges, and other non-point sources.

Floatable Debris:

Floatable debris is waste material that is buoyant, such as wood, beach litter, aquatic vegetation, street litter, sewage related wastes, fishing gear, and medical wastes. The

Hudson-Raritan Plume carries Harbor discharges into the Bight and ocean waters. Problems caused by floatable debris in the Harbor Estuary/Bight are:

- Bathing beach closures caused by wash-up of floatable debris.
- Hazards to shipping and recreational boating caused by drift materials, such as timbers, pilings, plastics, etc.
- Hazards to coastal species by entrapment and entanglement in plastic wastes (six pack rings, fishing line and nets, shopping bags), ingestion of plastic items that are mistaken for food, and accumulation of debris in coastal habitats can smother vegetative areas.

Sources of floatable debris in the Harbor Estuary/Bight are combined sewer overflows, storm water, non-point sources (litter, landfill practices, & marine transfer operations), decaying shoreline structures, sunken vessels, and vessel discharges.

Nutrients and Organic Enrichment:

The excessive enrichment by nutrients and organic materials, or eutrophication, is a problem for the waters of the Harbor/Bight. Problems associated with eutrophication in the waters of this area are:

- Low dissolved oxygen, or hypoxia, that has the potential to damage living marine organisms especially in the bottom waters.
- Noxious water quality conditions such as odors and localized fish kills.
- Novel algal blooms either from the type of phytoplankton present, persistence of the bloom, or the high concentration of algal cells.

The general trend over the past 15 years regarding dissolved oxygen is improvement in the highly polluted waterways and inner Harbor areas and declines in the relatively cleaner bays and outer reaches of the Harbor. Though causes of low dissolved oxygen in the Harbor are not apparent, there is some evidence that both nitrogen and organic materials are a dominant factor. Nitrogen has been identified by the NY-NJ HEP as the limiting nutrient in the Harbor/Bight for phytoplankton growth. Significant sources of nitrogen to the Harbor/Bight are municipal discharges, tributary inputs, sediment flux, and atmospheric deposition. Other sources that contribute to the nutrient and organic enrichment problems are combined sewer overflows, storm water, and other non-point sources.

Millstone Watershed Management Area (WMA 10)

The Millstone Watershed Management Area (WMA) drains an area of 271 square miles, including parts of Hunterdon, Somerset, Mercer, Middlesex, and Monmouth Counties, and encompasses approximately 25% of the Raritan Basin. This river is 38 miles long and flows from Millstone Township in Monmouth County to the Raritan River in Manville Borough, Somerset County, by way of Carnegie Lake. Most of the lower half of the Millstone River flows adjacent to the Delaware and Raritan Canal. Major tributaries to the Millstone River are Stony Brook, Beden Brook, Cranbury Brook, Bear Brook, Rock Brook, Rocky Brook, Royce Brook, Ten Mile Run, and Six Mile Run. The largest impoundment in this watershed management area is Carnegie Lake in Princeton Township, but a large number of smaller lakes also are present. The three major land uses in this watershed are urban (31%), agriculture (24.5%), and forest (22%) as of 1995/97. All surface waters within the Millstone Watershed Management Area are classified as FW-2 Non-trout.

Surface Water Quality and Trends

Water quality in the Millstone Watershed Management Area was evaluated over a period of time (with flow for trends 1976-93; trends 1986-95; status and trends 1991-97)[57] with data for 17 water quality constituents (Figure 16). Total ammonia plus organic nitrogen concentration has decreased, but nitrate/nitrite concentrations have remained similar over time; both trends are likely due to improved sewage treatment facilities that convert ammonia to nitrates. Also, chloride, sodium, and total dissolved solids levels have increased over time.

Water quality relationships associated with flow conditions are observed in this watershed management area and are listed in Figure 17. For the Millstone WMA, the total suspended solids and dissolved oxygen levels increase with increasing flow. This relationship can be explained with the increase of flow aerating the water and scouring the channel sediment and stream banks and suspending sediments in the water column. Constituents that decrease with increasing flow are alkalinity, total dissolved solids, hardness, nitrate/nitrite, pH, sodium, sulfate, and temperature. Most likely, these constituents have consistent sources (point sources and ground water) at low flows. The pH decreases with increased flow because precipitation generally has a pH less than 5.0 units. The Millstone shares similarities in constituent/flow relationships with the other two watershed management areas; TSS, alkalinity, TDS, hardness, pH, sulfate, temperature, and DO. Other constituent/flow relationships exist in the Stony Brook subwatershed, such as ammonia plus organic nitrogen, total organic carbon, biochemical oxygen demand, and total phosphorus that increase with increasing flow. The opposite with regard to ammonia plus organic nitrogen and total phosphorus occurs in the Beden Brook subwatershed; they decrease with increasing flow.

Growing (April to October) and non-growing (November to March) seasons also are related to constituent concentrations in the Millstone Watershed, as seen in Figure 18. All five USGS/NJDEP sampling sites for water quality in the Millstone WMA have relationships for temperature, DO, and season. This reflects the relationships of water temperature to oxygen solubility and season and explains the higher DO concentrations during the colder non-growing season. Other constituents in this WMA have seasonal relationships, such as ammonia plus organic nitrogen, total phosphorus, total organic carbon, total suspended solids, and fecal coliform with concentrations increasing during the growing season. Additional relationships with season occur in the upper reaches of the Millstone River with chloride having a tendency to increase during the non-growing season, most likely due to road salt application for deicing. Also, in the Stony Brook subwatershed, increasing nitrate/nitrite levels are shown to occur during the non-growing season.

Comparison to Surface Water Quality Criteria

The Millstone River is one of the three rivers ranked worst for overall water quality in the entire Raritan Basin. This WMA has monitoring stations with the highest concentrations or highest frequency of NOT meeting the standards/criteria for 14 of the 17 constituents. The phosphorus concentrations in 31% of the samples exceeded the criterion at the upper reaches near Manalapan. As the Millstone flows downstream to Grovers Mills and Blackwells Mills the phosphorus levels exceeded the criterion in 70% and 97% of samples, respectively. The Millstone at Grovers Mills is the only station in the Raritan Basin that did not always meet the criterion for dissolved oxygen of non-trout waters, the designation that applies to all waters in the Millstone Watershed Management Area. Both Stony Brook and Beden Brook have elevated total phosphorus levels, with samples exceeding the criterion at 38% and 47% respectively, and with Beden Brook having 67% of samples taken during low flow conditions exceed the criterion. Fecal coliform levels are elevated in both brooks, with 26% of Stony Brook samples not meeting the criterion (400 colonies/100mL) and 40% for Beden Brook. TSS exceeded the standard in 15% of samples at Stony Brook. Only the Grover's Mill site had no samples that exceeded the standard for TSS.

Comparison to Other Indicators of Physical and Chemical Quality

Two tributaries within the Millstone River Watershed Management Area, Stony Brook and Beden Brook, were sampled for VOCs. All of the samples taken from the two brooks had MTBE present. The samples from the Stony Brook, taken by the USGS during April 1996 through April 1997, had other VOCs detected, some of which were: Chloroform, Carbon disulfide, and Acetone.[58] The land use within the drainage area of the Stony Brook is in transition from predominantly forested and agricultural to suburban. No samples exceeded relevant criteria or standards.

Pesticide application in the Millstone River Watershed Management Area is estimated by surveys conducted by the NJDEP Pesticide Control Program for the following categories: agriculture, golf courses, lawn care services, and mosquito control.

- **Agriculture** – According to the 1997 survey[59] for agriculture application, amounts range from 1,000 to 10,000 lbs of pesticide (active ingredient) over the entire watershed except for the subwatershed of the Millstone River above Carnegie Lake, in which 10,000 to 50,000 lbs were applied. Comparing the 1994 survey for agriculture pesticide use to the 1997 survey, the Millstone River Watershed experienced a decrease in pesticide use in the subwatershed of the Millstone River below Carnegie Lake (Figure 8).
- **Golf Courses –** The 1999 survey[60] for golf course pesticide use shows that application amounts increased from 1 lb to 5,000 lbs in 1996 to between 5,000 to 10,000 lbs in the subwatershed of the Millstone River below Carnegie Lake (Figure 9). The rest of the Millstone Watershed Management Area has remained constant with application amounts in the range of 1 lb to 5,000 lbs. Most of the total pesticides used on golf courses were applied to the greens and tee boxes.
- **Commercial Lawn Care –** Over 30,000 lbs of pesticide was used for lawn care by registered pesticide businesses in this WMA during 1998[61], an increase from 10,000 to 20,000 in 1995 (Figure 10).

Pesticides have been detected in the Millstone Watershed Management Area and most likely are present in the remaining surface waters due to the widespread use of pesticides in the basin. The following surface waters have had pesticides detected in the water: Stony Brook, Millstone River, Rocky Brook, Cranbury Brook, Heathcote Brook, and Pike Run. Only Stony Brook samples had concentrations that exceeded established water quality criteria. The land use in this Watershed Management Area is in transition, from predominantly forest and agriculture to more urban. The presence of pesticides follows the same patterns as the previous watershed management areas. The Stony Brook, sampled at Princeton, N.J., has the most pesticides detected and 8 of the 20 are the most frequently detected pesticides.[62] The concentration and number of most of these pesticides increase during the growing season and during runoff conditions.

The following pesticides, sampled from the Stony Brook at Princeton, N.J., had concentrations that exceeded established water quality criteria:[63]

- Atrazine exceeded the USEPA drinking water maximum contaminant level of 3.0 µg/L in one sample collected during runoff in the growing season.
- Alachlor exceeded the USEPA drinking water maximum contaminant level of 2.0 µg/L in one sample collected during runoff in the growing season.
- Cyanazine exceeded the USEPA human health advisory level of 1.0 µg/L in one sample collected during runoff in the growing season.
- Dieldrin exceeded the NJ human health criterion of 0.000135 µg/L and the NJ aquatic life criterion of 0.0019 µg/L in one base flow sample collected during the growing season.

Two other surface waters, Heathcote Brook and Pike Run had the next highest number of pesticides, 13 and 12 respectively.[64,65] The others had 9 or less pesticides detected.

Ecological Indicators of Water Quality

The Millstone Watershed Management Area currently has 37 AMNET sampling sites for assessing benthic macroinvertebrates and their habitat. Thirty of the sites (about 80%) are rated as moderately impaired, the highest percentage of the three areas. Two of the sites are rated non-impaired and five sites are rated severely impaired. Compared to the prior study from 1994, this management area had a decrease in percent of non-impaired sites and moderately impaired sites with an increase in percent of severely impaired sites (Figure 19). The habitat and benthic macroinvertebrate assessments for this management area are at sub-optimal and moderately impaired levels, respectively. An upward trend of both scores is observed from upstream to downstream, indicating that stream biotic quality is significantly dependent on habitat quality. Land use in this watershed is similar to the South River subwatershed, in that the Millstone has a higher percentage of urban land use as compared to the forested land use and that the stream biotic integrity is impaired.

Sediment Quality

For the NAWQA program, bed sediment was sampled from one site in the Millstone WMA, the Stony Brook at Princeton. Samples were analyzed for trace elements and chlorinated organic compounds: Antimony (Sb), arsenic (As), cadmium (Cd), copper (Cu), chromium (Cr), lead (Pb), manganese (Mn), mercury (Hg), nickel (Ni), Selenium (Se), zinc (Zn), dichlorodiphenyl-trichloroethane (DDT), polychlorinated biphenyls (PCBs), and chlordane. All of the compounds were detected at this location. Trace element concentrations exceeded baseline estimates for all but lead and mercury. Concentrations for all but Chromium were in the range at which adverse biological effects are rarely expected to occur. Chlorinated organic compound concentrations were detected. Total DDT was detected at a concentration above the detection limit and within the range expected to rarely cause adverse biological impacts.[66]

Analysis of Point and Nonpoint Source Pollutant Loading

The Millstone WMA has 31 permitted discharges into its surface waters, ranging from 0.0002 to 12.1 cfs. Permitted point source flows exceed 25% of baseflow at the Beden Brook and Millstone River at Blackwells Mill and Grovers Mill sites. The sampling site on the Millstone River near Manalapan is the only site that has no permitted discharges upstream. The majority of the seven constituents – ammonia plus organic nitrogen, BOD, TDS, nitrate plus nitrite, TOC, TP, TSS - analyzed for source loading were attributed to non-permitted sources. However, especially during low flows, permitted sources accounted for more than 50% of the load at some of the water quality sampling sites for nitrate plus nitrite, TP, and TDS, as shown in Table 9. The total phosphorus load is more than 75% attributable to point sources during low flow conditions in the Millstone River at Grovers Mill, the Stony Brook at Princeton, and Beden Brook near Rocky Hill.

Table 9. Permitted Sources Accounting For Over 50% of Total Instream Load – Millstone WMA

	Millstone River		Stony Brook at Princeton	Beden Brook near Rocky Hill
	Grovers Mill	Blackwells Mill		
Base Flow	• TDS • Nitrate + nitrite* • TP*	• TDS* • Nitrate + nitrite*	• TDS • TP*	• TDS* • Nitrate + nitrite* • TP*
Median Flow	• Nitrate + nitrite	• Nitrate + nitrite	• TP	• TP
High Flow	None	None	None	None
* Permitted sources make up over 75% of total load.				

Possible Causes of Water Quality Concerns

The wastewater facilities that discharge effluent into the surface waters of the Millstone WMA can be a potentially significant point source. According to the 1996 New Jersey State Water Quality Inventory Report, some of those treatment plants have either ceased discharging or have been upgraded. The non-point sources of pollution in this WMA are predominantly associated with suburban development, such as construction sites, storm sewers, and runoff from suburban surfaces. The agricultural non-point source pollutants are predominant in specific regions of this WMA. Leachate from landfills also is recognized as a surface water impairment problem.

Assessment of Surface Water Quality

Assessment of surface water quality in the Raritan River Basin compares the “current” water quality and trends to surface water quality standards, including water quality criteria (numeric and narrative), designated uses of water bodies and antidegradation policies. The characterization of the surface waters of the Basin allows for the assessment of impairments to water body uses.

Methodology and Information Sources

In May of 2002, the NJDEP released the Integrated List, a draft inventory and listing of the status of water bodies in the State. The draft Integrated List is a combination of the requirements of sections 305b and 303d of the Clean Water Act. Section 305b requires States to inventory their water bodies and define their uses, while Section 303d requires States to list water bodies defined as impaired. In New Jersey’s List, Categories 1 and 2 contain water bodies without impairments. Category 3 contains water bodies where impairments are known but causal agents are not, and generally are near AMNET stations indicating impairments. Category 4 contains water bodies where remedial work is being performed to alleviate the impairment. Category 5 contains impaired water bodies where remedial work, including the development of TMDLs, is needed but not yet planned. Along with the Integrated List, NJDEP released their schedule of “TMDL responses to be completed by 2004.” The Raritan Basin is listed for preparation of Fecal Coliform TMDLs at seven locations by 2004. In addition, thirteen sites in the Raritan Basin are listed for additional monitoring for various metals, including arsenic, cadmium, chromium, copper, lead, mercury, nickel, selenium, and zinc.

North and South Branch Raritan Watershed Management Area (WMA 8)

Impaired Water Bodies and Scheduled TMDLs

Thirty-six surface water bodies (streams, reservoirs, etc.) in the North and South Branch Raritan Watershed Management Area are listed in Category 5 of NJDEP’s Draft 2002 Integrated List. These water bodies are identified as having known water quality impairment and where TMDLs are most likely necessary. Table 10 lists the impaired surface waters for the North and South Branch

Raritan Watershed Management Area. According to the Draft 2002 Integrated List, these water bodies were listed for either water quality impairments indicated by poor bioassessment ratings (macroinvertebrates), eutrophic conditions, or not meeting surface water quality standards for one or more of the following: temperature, pH, fecal coliform, total phosphorus, dissolved oxygen, total suspended solids, arsenic, cadmium, copper, lead, and mercury. Fourteen of the water bodies were listed for biological impairment (macroinvertebrates). On NJDEP's schedule of TMDLs or other responses to be completed by 2004, three water bodies are listed for fecal Coliform TMDLs and five water bodies are listed for additional metals monitoring to confirm impairment. Table 11 lists the water bodies in the North and South Branch Raritan WMA that are scheduled for work by 2004. As the 2002 Integrated List and the schedule for TMDL development have only been issued in draft, please refer to NJDEP's web site for the most recent or final version of the 2002 Integrated list and TMDL schedule at www.state.nj.us.dep/dsr/watershed/integratedlist.

Table 10. Impaired Water Bodies in the North and South Branch Raritan Watershed Management Area (WMA 8)

WMA	Station Name	Site ID	Parameters Not Attaining	Data Source	Basin ID
N&S	Back Brook at Rt. 609 in East Amwell Twp	AN0335	Macroinvertebrates	AMNET	1
N&S	Beaver Brook at Lehigh St. in Clinton Town	AN0324	Macroinvertebrates	AMNET	2
N&S	Chambers Brook at North Branch Depot	01399900	Fecal Coliform	NJDEP/USGS	3
N&S	Drakes Brook at Emans Rd in Roxbury Twp	AN0311	Macroinvertebrates	AMNET	4
N&S	Holland Brook at S Br Rd in Branchburg Twp	AN0343	Macroinvertebrates	AMNET	5
N&S	Lamington (Black) R Near Pottersville	01399500	Phosphorus, Fecal Coliform	NJDEP/USGS	6
N&S	Lamington River at Ironia Rd. in Chester Twp	AN0356	Macroinvertebrates	AMNET	7
N&S	Lamington River at Burnt Mills	01399780	Phosphorus, Fecal Coliform	NJDEP/USGS	8
N&S	Lamington River Near Ironia	01399200	Phosphorus, Fecal Coliform, Dissolved Oxygen	NJDEP/USGS	9
N&S	Mine Brook at Bernardsville Rd. In Bernardsville Boro	AN0352	Macroinvertebrates	AMNET	10
N&S	Mine Brook at Far Hills Rd (Rt. 512) in Far Hills Boro	AN0353	Macroinvertebrates	AMNET	11
N&S	Mulhockaway Creek at Van Syckel	01396660	Fecal Coliform	NJDEP/USGS, Metal Recon.	12
N&S	Neshanic River at Reaville – Everitt Rd. in Raritan Twp	AN0333	Macroinvertebrates	AMNET	13
N&S	Neshanic River at Rt 514 in Hillsborough Twp	AN0337	Macroinvertebrates	AMNET	14

WMA	Station Name	Site ID	Parameters Not Attaining	Data Source	Basin ID
N&S	Neshanic River at Reaville	01398000	Phosphorus, Fecal Coliform, Dissolved Oxygen, pH, TSS Copper, Lead	NJDEP/USGS, Metal Recon.	15
N&S	North Branch Raritan River Near Raritan	01400000	Phosphorus, Fecal Coliform	NJDEP/USGS	16
N&S	Pleasant Run at S Br Rd in Branchburg Twp	AN0340	Macroinvertebrates	AMNET	17
N&S	Rockaway Creek at Whitehouse	01399700	Phosphorus, Fecal Coliform, pH, Lead, Mercury	NJDEP/USGS, Metal Recon.	18
N&S	Rockaway Creek S Br at Rt 22 in Readington Twp	AN0368	Macroinvertebrates	AMNET	19
N&S	Round Valley Recreation Area	Not Listed	Eutrophic	NJDEP Clean Lakes Prog.	20
N&S	North Branch Raritan River at Burnt Mills	01399120	Fecal Coliform, Copper	NJDEP/USGS, Metal Recon.	21
N&S	North Branch Raritan River near Chester	01398260	Fecal Coliform	NJDEP/USGS	22
N&S	South Branch Raritan River at Station Rd in Raritan Twp	AN0326	Macroinvertebrates	AMNET	23
N&S	South Branch Raritan River at Arch St at High Bridge	01396535	Fecal Coliform, Temperature	NJDEP/USGS, Metal Recon.	24
N&S	South Branch Raritan River at Middle Valley	01396280	Phosphorus, Fecal Coliform, Temperature	NJDEP/USGS, Metal Recon.	25
N&S	South Branch Raritan River at Stanton Station	01397000	Fecal Coliform, pH, Temperature, Arsenic	NJDEP/USGS, Metal Recon.	26
N&S	South Branch Raritan River at Three Bridges	01397400	Phosphorus, Fecal Coliform	NJDEP/USGS, Metal Recon.	27
N&S	South Branch Raritan River at South Branch	01398102	Phosphorus, Fecal Coliform, pH	NJDEP/USGS, Metal Recon.	28
N&S	Raritan River at Raritan	01400120	Phosphorus, Fecal Coliform, pH	NJDEP/USGS	29
N&S	Second Neshanic River at Rt 31 in Raritan Twp	AN0331	Macroinvertebrates	AMNET	30
N&S	Spruce Run at Newport	01396550	Fecal Coliform, Temperature	NJDEP/USGS, Metal Recon.	31
N&S	Spruce Run in Spruce Run Reservoir at Spruce Run	8-SP-1	Cadmium	NJDEP/USGS, Metal Recon.	32
N&S	Spruce Run near Glen Gardener	01396588	Fecal Coliform, Temperature	NJDEP/USGS, Metal Recon.	33
N&S	Spruce Run at Clinton	01396800	Phosphorus, pH, Temperature	NJDEP/USGS	34
N&S	Stony Brook at Fairview Avenue at Naughright	01396219	Fecal Coliform	NJDEP/USGS	35
N&S	Third Neshanic River at Rt 31 in Raritan Twp	AN0332	Macroinvertebrates	AMNET	36
Source: New Jersey's 2002 Integrated List of Water bodies, released in Draft on May 21, 2002 by NJDEP					

TABLE 11. North and South Branch Raritan WMA

Water Bodies Scheduled for TMDL or Other Response to be Completed by 2004.

Site ID	Station Name	Non-Attainment Parameter(s)	Response
01398300 *	Dawson's Brook near Ironia	Fecal Coliform	FC TMDL
01399100 *	Middle Brook near Burnt Mills	Fecal Coliform	FC TMDL
01399900	Chambers Brook at North Branch Depot	Fecal Coliform	FC TMDL
01399120	North Branch Raritan River on Burnt Mills Road in Burnt Mill	Copper, Lead+	Monitor to Confirm Impairment
01398000	Neshanic River on Reaville-Everitt Road near Reaville	Copper, Lead+	Monitor to Confirm Impairment
01399700	Rockaway Creek on Lamington Road near Whitehouse	Lead, Mercury	Monitor to Confirm Impairment
01389102	South Branch Raritan River on Studdiford Drive – South Branch**	Arsenic, Chromium, Copper, Lead	Monitor to Confirm Impairment
01396800	Spruce Run in Spruce Run Reservoir at Spruce Run	Cadmium	Monitor to Confirm Impairment
* Not listed in Category 5 on the Draft Integrated List; + Not noted on Schedule, but noted on Category 5 List; **Metals not listed on Category 5 List.			

Other Waters of Concern

Other waters of concern in the North and South Branch Raritan Watershed Management Area are Budd Lake located in Mount Olive Township. Budd Lake is at the source of the South Branch Raritan River and exerts a strong influence upon water quality. At the most upstream AMNET sampling site, the South Branch Raritan River is moderately impaired. Budd Lake is subject to algal blooms with several genera of blue-green algae. Over 60 percent of total phosphorus loadings to the lake are derived from surface water runoff from surrounding land areas, according to a 1998 Phase 1 Diagnostic Study.[67] The Neshanic River, although not listed for pesticide contamination, had violations of water quality standards for toxic substances (specific criteria for pesticides are not listed in the water quality standards) as indicated by the NAWQA sampling program.

Primary Indicators of Concern

Fecal Coliform and Total Phosphorus are indicators of concern for the North and South Branch Raritan Watershed Management Area that are pervasive throughout the basin. For specific bodies of water, pH is an indicator of concern. Fecal coliform is an indicator of concern for the entire area. The sanitary quality of the waters within this watershed is in jeopardy. Total phosphorus affects almost every water body sampled in this watershed, except for the Mulhockaway Creek, but fortunately the latest trend data show these concentrations decreasing. The pH levels are a concern for the surface waters in the South Branch Raritan River watershed, except for the Spruce Run and Mulhockaway Creek, and the non-trout waters of the North Branch Raritan River watershed. These waters have exceeded the upper limit of the N.J. Surface Water Quality Criterion for pH and the increasing trend suggests a potential problem.

Trends of Concern

The three trends of concern for the North and South Branch Raritan Watershed Management Area are sodium, total dissolved solids, and chloride. These constituents have shown an increase over the past 20 years. The presence of these constituents in the surface waters is from the salting of roads during icy or snowy road conditions. The increase can be associated with the construction and widening of roads throughout this watershed management area. More roads relates to more salt and grits applied to the surfaces and eventually reaching the surface waters. Although the concentrations of chloride and total dissolved solids have not exceeded surface water quality criteria, sodium concentrations have exceeded the drinking water standard in a few instances. Almost all of the exceedances have occurred during high flow conditions.

Point and Nonpoint Source Contributions

Total phosphorus exceeded the 0.1 mg/l standard in every water body sampled in this watershed, except for the Mulhockaway Creek; therefore, understanding the sources of this constituent is important. The point and nonpoint source contributions to the total loading for total phosphorus are estimated for the surface waters of this WMA. The Neshanic River, with no permitted point sources, and Mulhockaway Creek, with only one minor permitted point source, have essentially 100% of the phosphorus load attributable to nonpoint sources. The Spruce Run is the only other surface water that is affected predominantly by nonpoint sources; 90% of the total load is nonpoint source. During low flow regimes, permitted point sources contribute over 80% of the total load in the Rockaway Creek, Lamington River, and the upstream portion of both the South Branch Raritan River and North Branch Raritan River. The remaining surface waters in this watershed management area have a mix of point and nonpoint sources for total phosphorus loading.

One of the increasing trends of concern in this watershed management area is for total dissolved solids (TDS). The surface waters of the South Branch Raritan receive TDS loading predominantly from nonpoint sources, even during low flow. The TDS loading to the surface waters of the North Branch Raritan is predominantly from nonpoint sources during median and high flows. During low flows, the point source loading is over 60% of the total load for the upstream portions of the North Branch Raritan and Lamington Rivers.

Chloride, a constituent demonstrating an increasing trend, was not analyzed for point and nonpoint source contribution because no data exist for permitted sources in the study area. The total load and yield were determined for the surface waters of the North and South Branch Raritan WMA. The Lamington River water quality sampling site near Pottersville had the highest yield for chloride, out of all surface waters in this WMA and for all flow regimes. The yield of chloride, from low to high flow, for this station is 101, 265, and 422 (lbs/day)/mi^2. For all of the surface waters in this WMA, the load and yield of chloride increases from low to high flow, indicative of nonpoint source behavior. Peak yields are related to high flow during the winter months and maximum yields occurred during the non-growing season.

Lower Raritan Watershed Management Area (WMA 9)

Impaired Water Bodies

Forty-eight surface water bodies (streams, reservoirs, etc.) in the Lower Raritan Watershed Management Area are listed in Category 5 of NJDEP's Draft 2002 Integrated List. These water bodies are identified as having known water quality impairment and where TMDLs are most likely necessary. Table 12 lists those surface water bodies for the Lower Raritan Watershed Management Area. According to the Draft 2002 Integrated List, these water bodies were listed for either water quality impairments indicated by poor bioassessment ratings (macroinvertebrates), eutrophic conditions, or not meeting surface water quality standards for one or more of the following: pH, fecal coliform, total phosphorus, total suspended solids, arsenic, cadmium, chromium, copper, lead, mercury and zinc. On NJDEP's schedule of TMDLs or other responses to be completed by 2004, two water bodies are listed for fecal Coliform TMDLs and one water body is listed for additional metals monitoring to confirm impairment. Table 13 lists the water bodies in the Lower Raritan WMA that are scheduled for work by 2004. As the 2002 Integrated List and the schedule for TMDL development have only been issued in draft, please refer to NJDEP's web site for the most recent or final version of the 2002 Integrated list and TMDL schedule at www.state.nj.us.dep/dsr/watershed/integratedlist.

Table 12. Impaired Water Bodies in the Lower Raritan Watershed Management Area (WMA 9)

WMA	Station Name	Site ID	Parameters Not Attaining	Data Source	Basin ID
LR	Ambrose Brook at Raritan Avenue in Middlesex Boro	AN0425	Macroinvertebrates	AMNET	37
LR	Barclay Brook Near Englishtown	01405285	pH	NJDEP/USGS	38
LR	Bound Brook at Bound Bk Rd in Middlesex Boro	AN0424	Macroinvertebrates	AMNET	39
LR	Bound Brook at Middlesex	01403900	Phosphorus, Fecal Coliform, TSS	NJDEP/USGS	40
LR	Bound Brook at Woodbrook Rd in South Plainfield Boro	AN0424B	Macroinvertebrates	AMNET	41
LR	Bound Brook at Route 28 at Middlesex	01403385	Phosphorus, Fecal Coliform	NJDEP/USGS	42
LR	Davidson’s Mill Lake	Davidson’s Mill Lake	Eutrophic	NJDEP Clean Lakes Prog.	43
LR	Deep Run at Route 516 in Old Bridge Twp	AN0454	Macroinvertebrates	AMNET	44
LR	Deep Run at Route 9 in Old bridge Twp	AN0453	Macroinvertebrates	AMNET	45
LR	Devoe Lake	Devoe Lake	Eutrophic	NJDEP Clean Lakes Prog.	46
LR	Green Brook at Clinton Ave in North Plainfield Boro	AN0423	Macroinvertebrates	AMNET	47
LR	Green Brook at Main St. in Bound Brook Boro	AN0426	Macroinvertebrates	AMNET	48
LR	Green Brook at Raymond Ave in Plainfield City	AN0421	Macroinvertebrates	AMNET	49
LR	Green Brook at North Plainfield	01403470	Fecal Coliform	NJDEP/USGS	50
LR	Ireland Brook at Riva Road in South Brunswick Twp	AN0433	Macroinvertebrates	AMNET	51
LR	Ireland Brook at Patrick’s Corners	01404470	pH	NJDEP/USGS	52
LR	Lake Topanemus at Pond Road in Freehold	61	Phosphorus, Fecal Coliform	Monmouth County	53
LR	Lawrence Brook at Davidson’s Mill Rd in South Brunswick Twp	AN0431	Macroinvertebrates	AMNET	54
LR	Lawrence Brook at Ridge Rd in South Brunswick Twp.	AN0430	Macroinvertebrates	AMNET	55
LR	Lawrence Brook at Riva Rd in Milltown Boro	AN0434	Macroinvertebrates	AMENT	56
LR	Lawrence Brook on Davidson’s Mill Rd, Black Horse	9-LAW-1	Arsenic, Cadmium, Chromium, Copper, Lead, Mercury, Zinc	NJDEP/USGS, Metal Recon.	57
LR	Manalapan Lake	Manalapan Lake	Eutrophic	NJDEP Clean Lakes Prog.	58
LR	Manalapan Brook at Federal Rd in Monroe Twp	AN0439	Macroinvertebrates	AMNET	59
LR	Manalapan Brook at Old Forge Road in Monroe Twp	AN0440	Macroinvertebrates	AMNET	60

WMA	Station Name	Site ID	Parameters Not Attaining	Data Source	Basin ID
LR	Manalapan Brook at Federal Road Near Manalapan	01405340	Phosphorus, Fecal Coliform, pH	NJDEP/USGS	61
LR	Manalapan Brook at Spotswood	9-MAN-2	Arsenic, Lead, Mercury, Zinc	NJDEP/USGS, Metal Recon.	62
LR	Manalapan Brook near Spotswood *(possible duplicate entry)*	01405340	Phosphorus, Fecal Coliform, pH	NJDEP/USGS	63
LR	Matchaponix Brook at Rt. 527 in Manalapan Twp	AN0448	Macroinvertebrates	AMNET	64
LR	Matchaponix Brook at Spotswood	01405302	pH	NJDEP/USGS	65
LR	Matchaponix Brook at Texas Rd in Monroe Twp	AN0451	Macroinvertebrates	AMNET	66
LR	Matchaponix Brook at Englishtown	01405195	Fecal Coliform	NJDEP/USGS	67
LR	Matchaponix Brook at Englishtown Boro	AN0447	Macroinvertebrates	AMNET	68
LR	Mile Run at Rt. 527 in Englishtown Boro	AN0429	Macroinvertebrates	AMNET	69
LR	Peters Brook at Rt. 28 at Somerville Boro	AN0376	Macroinvertebrates	AMNET	70
LR	Peters Brook at Rt. 28 at Somerville	01400395	Fecal Coliform	NJDEP/USGS	71
LR	Pine Brook at Pension Rd in Manalapan Twp	AN0449	Macroinvertebrates	AMNET	72
LR	Raritan River above Millstone River confluence in Bridgewater Twp	AN0377	Macroinvertebrates	AMNET	73
LR	Raritan River at Manville	01400500	Phosphorus, Fecal Coliform, pH	NJDEP/USGS	74
LR	Raritan River at Queens Bridge	01403300	Phosphorus, Fecal Coliform, TSS	NJDEP/USGS	75
LR	Raritan River	Not Listed	Lead	NJDEP/USGS, Metal Recon.	76
LR	Stony Brook at Westend Ave in North Plainfield Boro	AN0422	Macroinvertebrates	AMNET	78
LR	Tennent Brook at Old Bridge South Amboy Road in Old Bridge Twp	AN0455	Macroinvertebrates	AMNET	79
LR	Topanemus Lake	Topanemus Lake	Eutrophic	NJDEP Clean Lakes Prog.	80
LR	Weamaconk Lake	Weamaconk Lake	Eutrophic	NJDEP Clean Lakes Prog.	81
LR	Weamaconk Creek at Rt. 522 in Englishtown Boro	AN0443	Macroinvertebrates	AMNET	82
LR	Weamaconk Creek at main St (Tennent Rd) in Manalapan	81	Macroinvertebrates	Monmouth County	83
LR	Wemrock Brook at Route 9 (after 1st Pipe) in Freehold	69	Phosphorus, Fecal Coliform	Monmouth County	84
LR	Wemrock Brook at Route 9 (before Pipes) in Freehold	68	Phosphorus, Fecal Coliform	Monmouth County	85

TABLE 13. Lower Raritan WMA Water Bodies
Scheduled for TMDL or Other Response to be Completed by 2004.

Site ID	Station Name	Non-Attainment Parameter(s)	Response
01403470	Green Brook at North Plainfield	Fecal Coliform	FC TMDL
01400395	Peters Brook at Route 28 at Somerville	Fecal Coliform	FC TMDL
01405440	Manalapan Brook at Spotswood	Lead, Zinc	Monitor to Confirm Impairment

Other Waters of Concern

Most of the surface waters of the Lower Raritan Watershed Management Area are biologically impaired. The constituents that impaired these surface waters threaten those reaches of surface waters that are non-impaired. Therefore, other waters of concern for this management area are the headwaters of the Manalapan Brook and those reaches of the Middle Brook and Raritan River that are considered biologically non-impaired. The NAWQA sampling program indicated that the Raritan River at Bound Brook and Bound Brook at Middlesex had exceedances of water quality standards for toxic substances (pesticides); however, these water bodies are not listed for toxic substances or pesticides.

Primary Indicators of Concern

Two indicators of concern for the entire Lower Raritan Watershed Management Area are fecal coliform and total phosphorus. For the Matchaponix and Manalapan Brooks, pH is an indicator of concern. About 35% of field samples from Matchaponix Brook had pH measurements less than 6.5 units. For the Manalapan Brook, 37% of samples had pH measurements less than 6.5 units, below the lower limit of the NJ Surface Water Quality Criteria.

Trends of Concern

The increasing trend of chloride over the past 20 years is a concern in this WMA. The increasing trend of chloride, sodium, and total dissolved solids is a concern for the Manalapan Brook. These constituents are present in the surface waters from the salting of roads during icy or snowy road conditions. The increase can be associated with the construction and widening of roads within this watershed. Although the concentrations of chloride and total dissolved solids have not exceeded surface water quality criteria, the continuing increase of these constituents should be addressed.

Point and Nonpoint Source Contributions

Total phosphorus affects every water body sampled in this watershed. The point and nonpoint source contributions to the loading for total phosphorus are estimated for the surface waters of the Lower Raritan WMA. The Manalapan Brook, with no permitted point sources upstream of the sampling site, has 100% of the phosphorus load coming from nonpoint sources. Conversely, the Matchaponix Brook has essentially 100% of the total phosphorus load originating from permitted point sources at the monitoring site. During low flow regimes, 78% of the total phosphorus load is from permitted point sources for the water quality site on the Raritan River near Bound Brook. During median and high flows, the loadings are a more equal mix of point and nonpoint sources. Further upstream on the Raritan River-near Manville, the total phosphorus load is predominantly nonpoint sources – over 70%.

One of the increasing trends of concern in this watershed management area is for total dissolved solids (TDS). The Manalapan Brook receives 100% of the TDS loading from nonpoint sources for all flows. At the sampling site on the Raritan River near Manville the total instream load is predominantly from nonpoint sources. During low flow, the TDS loading for the Matchaponix Brook is approximately 90% from point sources. As the flow increases the loading becomes more of an equal mix of point and nonpoint source contribution. The Raritan River near Bound Brook has a TDS load that is approximately an equal mix of both sources, with increasing flow tilting the ratio towards predominantly nonpoint sources.

Chloride, another increasing trend of concern, was not analyzed for point and nonpoint source contribution because no data exist for permitted sources in the study area. The total load and yield were determined for these surface waters. The Matchaponix Brook had the highest yield for chloride, out of all surface waters in this WMA for low and median flows – 95 and 170 (lbs/day)/mi^2. The sampling site on the Raritan River at Manville had the highest yield, 259 (lbs/day)/mi^2, during high flows, but the site on the Matchaponix Brook came a close second with 251 (lbs/day)/mi^2. For all of the surface waters in this WMA, the load and yield of chloride increases from low to high flow, indicative of nonpoint source behavior. Peak yields are related to high flow during the winter months and maximum yields occurred during the non-growing season.

The New York-New Jersey Harbor Estuary Program

The NY-NJ HEP has adopted a Comprehensive Conservation and Management Plan to focus on:

- Protecting, restoring, and enhancing habitat;
- Developing management strategies;
  - To prevent pollution;
  - To reduce contaminants at the source;
  - To favor non-structural solutions and the use of natural systems; and
  - To integrate plans across land, water, and air; and
- Forming public/private partnerships in the region and coordinating with other geographic plans to protect and restore the environment.

This plan includes over 300 actions to address identified problems and an implementation structure to monitor and report on the success in meeting the NY-NJ HEP vision. The plan also addresses the water bodies of the Harbor Estuary that need TMDLs, including the Raritan River and Bay. Currently, the Raritan River Estuary is listed for Lead in Category 5 of the Draft 2002 Integrated List (Table 14) although others pollutants of concern have been noted in the Comprehensive Conservation and Management Plan including: fecal coliform, dissolved oxygen, arsenic, cadmium, copper, mercury, nickel, zinc, and PCB-1254. USEPA is coordinating the development of TMDLs for the Harbor Estuary. By June 30, 2007, USEPA has agreed to develop TMDLs for dissolved oxygen, fecal Coliform, mercury, PCBs, Dioxins, PAHs, and Pesticides[68]. As the 2002 Integrated List and the schedule for TMDL development have only been issued in draft, please refer to NJDEP's web site for the most recent or final version of the 2002 Integrated list and TMDL schedule at www.state.nj.us.dep/dsr/watershed/integratedlist.

Table 14. Impaired Water Bodies in NY-NJ Harbor Estuary

WMA	Station Name	Site ID	Parameters Not Attaining	Data Source	Basin ID
LR	Raritan River Estuary	Not Listed	Lead	NJDEP/USGS, Metal Recon.	77

Millstone Watershed Management Area (WMA 10)

Impaired Water Bodies and Scheduled TMDLs

The Millstone Watershed Management Area has forty-four water bodies in Category 5 on NJDEP's Draft 2002 Integrated List (four are repeated). Table 15 contains the impaired water bodies in the Millstone WMA. Etra Lake, the only lake on the list, is listed for depressed dissolved oxygen, total phosphorus, sedimentation, and excessive aquatic macrophyte growth. The other water bodies are listed for either water quality impairments indicated by poor bioassessment ratings (macroinvertebrates), eutrophic conditions, or not meeting surface water quality standards for one or more of the following: temperature, pH, fecal coliform, total phosphorus, total suspended solids, arsenic, cadmium, chromium, copper, lead, mercury, nickel, selenium and zinc. On NJDEP's schedule of TMDLs or other responses to be completed by 2004, two water bodies are listed for fecal Coliform TMDLs and six water bodies are listed for additional metals monitoring to confirm impairment. Table 16 lists the water bodies in the Millstone WMA that are scheduled for TMDL development by 2004. As the 2002 Integrated List and the schedule for TMDL development have only been issued in draft, please refer to NJDEP's web site for the most recent or final version of the 2002 Integrated list and TMDL schedule at www.state.nj.us.dep/dsr/watershed/integratedlist.

Table 15. Impaired Water Bodies of the Millstone Watershed Management Area (WMA 10)

WMA	Station Name	Site ID	Parameters Not Attaining	Data Source	Basin ID
M	Bedens Brook at Aunt Molly Rd (above STP) in Hopewell Twp	AN0398	Macroinvertebrates	AMNET	86
M	Bedens Brook at Rt 206 in Montgomery Twp	AN0401	Macroinvertebrates	AMNET	87
M	Bedens Brook near Rocky Hill	01401600	Phosphorus, Fecal Coliform, Lead	NJDEP/USGS, Metal Recon	88
M	Big Bear Brook at Old Trenton Rd (Rt 535) in West Windsor Twp	AN0383	Macroinvertebrates	AMNET	89
M	Cranbury Brook at Applegarth Rd in Monroe Twp	AN0385	Macroinvertebrates	AMNET	90
M	Cranbury Brook at Edgemere Ave In Plainsboro Twp	AN0386	Macroinvertebrates	AMNET	91
M	Cranbury Brook Near Prospect Plains	01400690	Fecal Coliform, pH	NJDEP/USGS	92
M	Devils Brook at New Rd in South Brunswick Twp	AN0387	Macroinvertebrates	AMNET	93
M	Devils Brook at Schalk's Road in Plainsboro Twp	AN0389	Macroinvertebrates	AMNET	94
M	Duck Pond Run at Clarksville	01401200	Fecal Coliform	NJDEP/USGS	95
M	Etra Lake	Etra Lake	Eutrophic	NJDEP Clean Lakes Program	96
M	Heathcote Brook at Kingston	01401400	Fecal Coliform	NJDEP/USGS	97
M	Millstone River above Raritan River confluence in Franklin Twp	AN0414	Macroinvertebrates	AMNET	98
M	Millstone River at Applegarth Road in Monroe Twp	AN0382D	Macroinvertebrates	AMNET	99
M	Millstone River at Blackwells Mills Rd in Hillsborough Twp	AN0410	Macroinvertebrates	AMNET	100
M	Millstone River at Grovers Mill Road in Plainsboro Twp	AN0382	Macroinvertebrates	AMNET	101
M	Millstone River at Rt 33 in Millstone Twp	AN0379	Macroinvertebrates	AMNET	102
M	Millstone River at Rt 535 in East Windsor Twp	AN0382B	Macroinvertebrates	AMNET	103

WMA	Station Name	Site ID	Parameters Not Attaining	Data Source	Basin ID
M	Millstone River near Manalapan	01400450	Phosphorus, Fecal Coliform, pH, TSS, Arsenic, Lead	NJDEP/USGS, Metal Recon	104
M	Millstone River above Raritan River Confluence in Manville	10-MIL-3	Arsenic	NJDEP/USGS, Metal Recon	105
M	Millstone River at Blackwells Mills	01402000	Phosphorus, Fecal Coliform, Arsenic	NJDEP/USGS, Metal Recon	106
M	Millstone River at Grovers Mill	01400650	Phosphorus, Fecal Coliform	NJDEP/USGS	107
M	Millstone River near Grovers Mill	01400640	Phosphorus	NJDEP/USGS	108
M	Millstone River on Wihousky St., Manville	10-MIL-6	Arsenic	NJDEP/USGS, Metal Recon	109
M	Millstone River at Kingston	01401440	Phosphorus, Fecal Coliform, pH, Temperature	NJDEP/USGS	110
M	Millstone River at Weston	01402540	Phosphorus, Fecal Coliform, pH	NJDEP/USGS	111
M	Millstone River at Route 33 in Millstone	5	Phosphorus, Fecal Coliform	Monmouth County	112
M	Millstone River off Rt 1, Plainsboro	10-MIL-7	Arsenic, Cadmium, Chromium, Copper, Nickel, Selenium, Zinc	NJDEP/USGS, Metal Recon	113
M	Millstone River off Rt 1, Plainsboro *(duplicate entry)*	10-MIL-7	Arsenic, Cadmium, Chromium, Copper, Nickel, Selenium, Zinc	NJDEP/USGS, Metal Recon	114
M	Millstone River off Rt 27 in Kingston	10-MIL-2	Arsenic, Cadmium, Chromium, Lead, Mercury, Zinc	NJDEP/USGS, Metal Recon	115
M	Millstone River off Rt 27 in Kingston *(duplicate entry)*	10-MIL-2	Arsenic, Cadmium, Chromium, Lead, Mercury, Zinc	NJDEP/USGS, Metal Recon	116
M	Pike Run at Rt 533 in Montgomery Twp	AN0405	Macroinvertebrates	AMNET	117
M	Pike Run Near Rocky Hill	01401700	Phosphorus, Fecal Coliform	NJDEP/USGS	118
M	Rock Brook at Burnt Hill Rd in Montgomery Twp	AN0400	Macroinvertebrates	AMNET	119
M	Rocky Brook at Rt 33 in Hightstown Boro	AN0381	Macroinvertebrates	AMNET	120
M	Rocky Brook on Rt 33 in Hightstown	10-ROC-1	Arsenic, Chromium, Lead, Zinc	NJDEP/USGS, Metal Recon	121
M	Rocky Brook on Rt 33 in Hightstown *(duplicate entry)*	10-ROC-1	Arsenic, Chromium, Lead, Zinc	NJDEP/USGS, Metal Recon	122
M	Rocky Brook, Rt 130, Hightstown	10-ROC-2	Chromium, Lead, Zinc	NJDEP/USGS, Metal Recon	123
M	Rocky Brook, Rt 130, Hightstown *(duplicate entry)*	10-ROC-2	Chromium, Lead, Zinc	NJDEP/USGS, Metal Recon	124
M	Royce Brook at Rt 533 in Manville Boro	AN0413	Macroinvertebrates	AMNET	125

WMA	Station Name	Site ID	Parameters Not Attaining	Data Source	Basin ID
M	Six Mile Run at Canal Rd in Franklin Twp	AN0409	Macroinvertebrates	AMNET	126
M	Stony Brook at Mine Rd in Hopewell Twp	AN0391	Macroinvertebrates	AMNET	127
M	Stony Brook at Old Mill Rd in Hopewell Twp	AN0392	Macroinvertebrates	AMNET	128
M	Stony Brook at Rt 206 in Princeton Twp	AN0393	Macroinvertebrates	AMNET	129
M	Stony Brook at Princeton	01401000	Phosphorus, Fecal Coliform, pH, TSS, Copper, Lead	NJDEP/USGS, Metal Recon.	130
M	Stony Brook on Mine Rd in Hopewell Twp.	10-STO-3	Arsenic, Cadmium, Chromium, Lead, Mercury, Zinc	NJDEP/USGS, Metal Recon.	131

TABLE 16. Millstone WMA Water Bodies
Scheduled for TMDL or Other Response to be Completed by 2004.

Site ID	Station Name	Non-Attainment Parameter(s)	Response
01401200	Duck Pond Run at Clarksville	Fecal Coliform	FC TMDL
01401400	Heathcote Brook at Kingston	Fecal Coliform	FC TMDL
10-MIL-7	Millstone River off Route 1, Plainsboro	Cadmium, Chromium, Nickel, Selenium, Zinc	Monitor to confirm impairment
10-MIL-2	Millstone River off Route 27 in Kingston	Arsenic, Cadmium, Chromium, Lead, Mercury, Zinc	Monitor to confirm impairment
10-ROC-1	Rocky Brook on Route 33 in Hightstown	Chromium, Lead, Zinc	Monitor to confirm impairment
10-ROC-2	Rocky Brook, Route 130, Hightstown	Chromium, Lead, Zinc	Monitor to confirm impairment
10-STO-3	Stony Brook on Mine Road in Hopewell	Arsenic, Cadmium, Lead, Chromium, Mercury, Zinc	Monitor to confirm impairment
01401000	Stony Brook on Route 206, Princeton	Copper, Lead	Monitor to confirm impairment

Other Waters of Concern

Peddie Lake, located in the Borough of Hightstown, is a water of concern in the Millstone Watershed Management Area. This lake is affected by non-point source pollution associated with agriculture, such as sediments, nutrients, and pesticides.[69] Carnegie Lake, an inline impoundment located on the Millstone River in Princeton has previously been noted for mercury in fish tissue and has had sedimentation problems in the past. In addition, the Delaware and Raritan Canal, a water supply source from the Delaware River that runs through the WMA along the Millstone River, has had sedimentation problems. Stony Brook at Princeton has exceeded water quality standards for toxic substances (pesticides) in the NAWQA sampling program, but is not listed as impaired by toxic substances on the integrated list.

Primary Indicators of Concern

Some indicators of concern are pervasive through the entire Millstone Watershed Management Area and others are for specific surface waters. Two indicators of concern for the surface waters of the Millstone Watershed Management Area are fecal coliform and total phosphorous. The pH levels are a concern for the Stony Brook (>8.5 units) and certain reaches of the Millstone River (Manalapan <6.5 units). Temperature and dissolved oxygen are a concern for two specific reaches of the Millstone River. Sodium exceeded drinking water standards at Stony Brook. TSS is a constituent of concern at all sites except Grover's Mill.

Trends of Concern

Two trends of concern for this WMA are chloride and total dissolved solids. These constituents have shown an increase over the past 20 years. The presence of these constituents in the surface waters is from the salting of roads during icy or snowy road conditions. The increase can be associated with the construction and widening of roads within this watershed. Although the concentrations of chloride and total dissolved solids have not exceeded surface water quality criteria, the continuing increase of these constituents should be addressed.

Point and Nonpoint Source Contributions

Every water body sampled in the Millstone WMA is affected by total phosphorus. The point and nonpoint source contributions to the total loading for total phosphorus are estimated for these surface waters. The Millstone River near Manalapan, with no permitted point sources upstream, has 100% of the phosphorus load from nonpoint sources. During low flow, the sampling site at the Millstone River at Grovers Mill is affected by permitted point sources that contribute over 80% of the total instream load. Stony Brook and Beden Brook instream loads are predominantly from point sources during periods of low and median flows. For the high flows the total instream load is predominantly from nonpoint sources. The Millstone River near Blackwells Mills has total instream phosphorus loads that are predominantly from nonpoint sources.

One of the increasing trends of concern in this watershed management area is for total dissolved solids. The upstream section of the Millstone at Manalapan has 100% of the total instream load for TDS from nonpoint sources. The Stony Brook, Beden Brook, and Millstone River at Grovers Mill and Blackwells Mills at median and high flows have total instream loads that are predominantly from nonpoint sources. During low flows, the Stony Brook and Millstone River at Grovers Mill have total instream loads consisting of an approximate even mix from point and nonpoint source. The Beden Brook and Millstone at Blackwells Mills, during low flow, have total instream loads consisting predominantly from point sources.

The total load and yield for chloride, another increasing trend of concern for the Millstone WMA, were determined. This constituent not analyzed for point and nonpoint source contribution because no data exist for permitted sources in the study area. The Millstone River water quality sampling site at Grovers Mills had the highest yield for chloride for all flow regimes, out of all surface waters in this WMA. The yield of chloride for this station is 55, 153, and 292 (lbs/day)/mi^2, from low to high flow, respectively. For all of the surface waters in this WMA, the load and yield of chloride increases from low to high flow, indicative of nonpoint source behavior. Peak yields are related to high flow during the winter months and maximum yields occurred during the non-growing season.

Legal Implications of Surface Water Quality in the Raritan Basin

TMDL Process and Requirements

The Clean Water Act requires states to identify and designate beneficial uses for each body of water in the state and adopt water quality standards that will protect those designated uses. For many years water quality improvement focused on point sources and technological controls on those sources. Although water quality has improved, the waters are far from clean and the focus of water quality improvement has widened to include non-point sources of pollution.[70]

Under section 303(d) of the Clean Water Act, states are required to develop lists of impaired waters (those waters that do not support their designated uses or meet water quality standards set forth by the state) and establish a priority ranking and develop Total Maximum Daily Loads (TMDLs) for those waters. A TMDL is essentially a surface water pollution control plan, and by legal definition is the maximum amount of a pollutant that a body of water can receive and still meet water quality criteria. To calculate a TMDL for a single pollutant, the allowable loads from all point and non-point sources are added. This calculation must include a margin of safety to ensure that the receiving water can meet its designated use, set by the State, and account for seasonal variation in water quality. The TMDL program has been identified to resolve water quality problems because both point and non-point source pollution will be addressed.

The Clean Water Act provides special authority for restoring polluted waters under section 303(d). The U.S. Environmental Protection Agency issued regulations in 1985 and 1992 that implement section 303(d) – the TMDL provisions. In July 2000, the EPA published the most recent TMDL Rule that was scheduled to become effective October 1, 2001. EPA has pushed the effective date back to allow for changes, while implementing the pre-existing rule. NJDEP adopted TMDL rules on May 7, 1977 and proposed new TMDL rules in July 2000. However, NJDEP has announced that the July 2000 proposal will not be adopted, and that the current rules (including the TMDL provisions) will remain in effect for the time being.

Overview of Current TMDL Regulations and Program

USEPA's 1992 TMDL Regulations, under which the current program operates, mandates that states, territories, and authorized tribes list impaired and threatened waters and develop TMDLs. The following is an overview of the regulations:

- States must submit a list of waters that are impaired or threatened by pollutants and that require TMDLs every two years to the EPA. (The EPA decided not to require a year 2000 list; the 2002 list was proposed by NJDEP in June 2002).
- The methodology for listing waters must consider all existing and readily available water quality related information and be submitted to the EPA. Also, a "good cause" must be provided, when requested, for those waters that are not listed or removed from the list.
- The priority ranking of the listed waters must take into account the severity of impairment and the designated use.
- The pollutant(s) causing the impairment must be identified.
- States must identify those waters targeted for TMDL development within the next two years.
- A TMDL must include waste load allocations from point sources, load allocations from non-point sources and natural background conditions, a margin of safety, and a consideration for seasonal variations.
- The calculations used to establish TMDLs are subject to public review.

- The EPA has 30 days to approve the list and associated TMDLs. If the list or individual TMDL is disapproved the EPA has 30 days to establish the list or individual TMDL and must seek public comment.

Overview of the New TMDL Regulations and Program

In 1996, the EPA convened a Federal Advisory Committee to evaluate the EPA's and states' implementation of section 303(d) of the Clean Water Act and improving the TMDL program. The committee's recommendations, issued in 1998, were used to guide the development of proposed changes to the current TMDL regulations. The EPA issued a draft in August 1999 for public comment and published the final rule in July 2000, however the EPA is prohibited from spending fiscal year 2000 and 2001 money to implement this new rule. The new rule was to become effective on 1 October 2001 but has been delayed by additional EPA rulemaking efforts.

The following is an overview of the final TMDL rule[71]:

- States must submit a more comprehensive list of impaired water bodies every four years to the EPA. Threatened waters may be included at the discretion of the State.
- States must establish a schedule for clean-up plans of listed waters within 10 years, with an option for a 5-year extension. EPA prefers that higher priority be given to impaired waters that are drinking water sources or support endangered species.
- The elements of a TMDL:
  - Identification of water body, location, pollutant, and water quality criterion.
  - Amount of pollutant allowable and load reduction needed to meet criteria.
  - Identification of pollutant sources, creation of load allocations for point and non-point sources, and development of an implementation plan.
  - Include a margin of safety, consideration for seasonal variation, and allowances for reasonable increases of pollutant loads in the future.
  - A transition period to phase in new TMDL elements.
  - Public comment on methodology, lists, prioritization schedules, and TMDLs prior to the State's submission to EPA.
  - "EPA will back-stop State efforts to develop TMDLs"
- The States will have the flexibility to:
  - Decide which sources of pollution to clean up and how.
  - Produce implementation plans to address local conditions.

Impact on Pollutant Discharges

The new USEPA TMDL regulations require that the implementation plan for the TMDL provide reasonable assurances that implementation will occur. For the State of New Jersey, the DEP proposes these technical and regulatory options for TMDL and waste load allocation (WLA) development in the proposed Water Quality and Watershed Management Rule, N.J.A.C. 7:15 (as proposed in the NJ Register on July 3, 2000):

- The ability to use a model that will match the water quality issue and goal for the watershed for the TMDL/WLA analysis.
- The assignment of the margin of safety and reserve capacity will depend on the segment of the water body.
- A variety of management options and tradeoffs will be developed along with the TMDL/WLA analysis to encourage coordination and cooperation in the management of pollutant sources and the development of cost effective mechanisms to attain water quality goals.

Data, Information and Assessment Needs

The needs for surface water quality data are:

- Recent sediment quality data;
- Results of the heavy metals monitoring from 1999-2000 forward;
- Results of the Cooperative Monitoring Network from 1998 to the present, especially with regard to the new fecal coliform monitoring protocol; and
- Recent lake water quality data.

Conclusions

The Raritan River Basin

The surface water quality in the Raritan Basin has been studied for many decades, but recent data (1991-1999) were used to characterize and assess the quality of these waters. The analysis of some of this data resulted in water quality constituent trends, relationships to flow and season, and point and nonpoint source contributions. Surface waters of the Raritan Basin have been identified by the NJDEP as having water quality impairments and were included on the 303(d) List. Among the streams listed by the NJDEP for the Basin for specific pollutants, there are two common impairments:

- Total phosphorus
- Fecal coliform bacteria

Trends of constituent concentrations over a period of 9 years have been identified, but there is no trend that applies to all of streams sampled in the Basin. Relationships between constituent concentration and either flow or season have been identified in the Raritan Basin. Two constituent/flow relationships apply to all of the streams sampled:

- Increasing flow and decreasing alkalinity concentration
- Increasing flow and decreasing hardness concentration

These relationships reflect the effect of dilution by the increased volume of water associated with the increased flow in the stream.

Two relationships were found between constituent concentration and season that apply to all streams sampled in the Basin:

- Growing season and increasing temperature
- Non-growing season and increasing dissolved oxygen

These two relationships are also dependant on each other. The solubility of oxygen in water depends on the temperature of the water. As temperature increases the concentration of dissolved oxygen decreases. During the non-growing season the water temperature decreases, thus increasing the dissolved oxygen concentration.

The analysis of point and nonpoint source contributions to the total instream load of 7 water quality constituents was beneficial for identifying starting points for strategy development for the TMDL process. Another constituent, chloride, was not analyzed for source analysis, but the load and resulting yield for the surface waters of the Raritan Basin consistently increased from low to high flow, indicating a significant impact of nonpoint sources. The focus was primarily on the impairment caused by total phosphorus and two constituents – TDS and chloride, which have shown an increasing trend of concern.

Volatile Organic Chemicals (VOCs) were detected in the surface waters of the Raritan Basin, but in concentrations that have not exceeded any criteria or standard. The higher number and concentrations of VOCs detected occurred in the eastern – more urban – area of the Basin. Methyl tert-butyl ether (MTBE) is the one VOC that was consistently detected in all of the surface waters sampled in the Basin.

Pesticides have been detected in most of the surface waters of this Basin, with some of concentrations that violated drinking water standards and/or surface water quality standards. The specific pesticides detected in the surface water were dependent on the surrounding land use; the total concentration and number of compounds increased with increasing percent agricultural land use.

Generally, the trends for the bioassessment ratings of the Raritan Basin decreased from non-impaired in the western region to moderately impaired in the eastern, urbanized region. The habitat assessment for the Basin followed a similar trend, decreasing from west to east, but remained in the optimal/sub-optimal range. The decline in bioassessment rating relative to the habitat assessment for the Raritan Basin signifies that the biological impairment is primarily due to water quality rather than degraded habitat.

The characterization and assessment of the Raritan Basin indicates a relationship between surface water quality and land use. The three major land uses in the Raritan Basin, as of 1995, are urban (36%), forested (27%), and agriculture (19%). Of those major land uses, the amount of forested land correlated best with the quality of the water. The higher the percentage of forested land, the lower the number and severity of surface water impairments. This relationship is more apparent when the surface water quality of each watershed management area is discussed.

North and South Branch Raritan Watershed Management Area

The North and South Branch Raritan Watershed Management Area, as compared to the other WMAs in the Raritan Basin, has the best water quality. All but one of the surface waters in this management area, as of 1995, have between 40% and 53% forested land. The Neshanic River is the exception with 22% forested land. Approximately 73% of the sampling stations on these streams have a non-impaired bioassessment rating. Again, the Neshanic River is the primary exception. No volatile organic compounds were measured at concentrations of concern and the number of compounds detected was small. MTBE was the only VOC with a 100% detection frequency in all samples taken from this WMA.

The North and South Branch Raritan WMA does have water quality concerns that include total phosphorus concentrations and fecal coliform counts not meeting standards and an increasing trend of chloride, total dissolved solids, and sodium concentrations. These concerns, although at a lower level, also affect the three best water quality streams in the entire Raritan Basin: the Spruce Run, Mulhockaway Creek, and Lamington River. These streams exhibit problems meeting standards for phosphorus, fecal coliform, and temperature during low flow conditions and during the growing season. Most of the constituents analyzed for the three streams had low concentrations and met water quality standards. Also, the bioassessment ratings of those streams were non-impaired (except for one moderately impaired station on the upper reaches of the Lamington River). As of 1995, these streams have over 40% forested land. In contrast, the Neshanic River is one of the worst surface waters for water quality in this WMA and the Raritan Basin and, as of 1995, has 22% forested land. The Neshanic River sampling station has either the highest concentration or the most samples not meeting standards of most of the constituents analyzed. All of the Neshanic River macroinvertebrate sampling stations are rated as moderately impaired. Pesticides were detected in the surface waters of the North and South Branch Raritan WMA, most likely from the widespread use of pesticides in the basin for many purposes, including agriculture, lawn maintenance including golf courses, and mosquito control. The Neshanic River is the only surface water in this WMA to have concentrations that violated surface water quality standards and had the highest number of pesticides detected.

Thirty-six water bodies within the North and South Branch Raritan WMA are listed on the draft 2002 Integrated List in Category 5 by the NJDEP. These water bodies have a known water quality impairment and TMDLs will most likely be developed for temperature, pH, fecal coliform, total phosphorus and mercury. The use impairment of these waters includes primary contact, aquatic life support, and fish consumption.

The most common source of the water quality concerns in this WMA is from non-point source pollution. However, point sources are significant in some waters. The point and nonpoint source analysis for the North and South Branch Raritan WMA differed between the North Branch and South Branch subwatersheds for some constituents. The instream load of total phosphorus for the majority of impaired waters of the North and South Branch Raritan WMA are predominantly from permitted point sources during low flows. The North Branch Raritan River total phosphorus load continues to be mostly from point sources during the median and high flows, which is not true of the South Branch Raritan. The instream load of total dissolved solids is predominantly from nonpoint sources at all flows with a few locations influenced by point sources during low flow.

Lower Raritan Watershed Management Area

The Lower Raritan Watershed Management Area has water quality concerns, especially the Main Stem of the Raritan River, which is ranked as one of the worst for water quality in the Raritan Basin. The Main Stem of the Raritan River either has the highest concentration or the most samples not meeting criteria/standards of most of the constituents analyzed. The percentage of forested land upstream of monitoring stations in this WMA (which includes land upstream of the WMA itself), as of 1995, ranges from 16% to 35%. The higher percentage of forested land occurs at the upstream portion of the main-stem Raritan where the forested land percentages of the North and South Branch Raritan WMA are integrated.

The water quality concerns for this management area include total phosphorus and fecal coliform levels not meeting standards and an increasing trend of chloride and sodium concentrations. The bioassessment ratings of approximately 76% of the sampling stations on these streams are moderately impaired. Many volatile organic compounds were detected in this watershed management area; for example, 28 VOCs were detected in the highly urban Bound Brook subwatershed, but the concentrations did not exceed standards. MTBE was the only VOC that was detected in all samples taken from this WMA. Pesticides also were detected in the surface waters of the Lower Raritan WMA, most likely from the widespread use of pesticides in the basin for many purposes. The Main Stem Raritan River and the Bound Brook had the highest numbers of pesticides detected and had concentrations that violated water quality criteria.

Forty-eight water bodies within the Lower Raritan WMA are listed by the NJDEP as having known water quality impairments that most likely will require the development of TMDLs for pH, fecal coliform, total phosphorus, sedimentation, and excessive macrophyte growth. The use impairment of these waters includes primary contact, aquatic life support, and boating.

The water quality concerns of Lower Raritan Watershed Management Area are from both point and non-point source pollution. The point and nonpoint source analysis for the Lower Raritan WMA varied depending on the location of the surface water quality sampling site. The Manalapan Brook has no permitted point sources; therefore, all constituent loading is from nonpoint sources, including total phosphorus, TDS, and chloride. Nearly all the loading for total phosphorus for the Matchaponix Brook is from permitted point sources at all flow regimes. The TDS loading for this brook swings from predominantly point source during low flow, to nonpoint source during high flow. The total phosphorus and TDS loading to the Raritan River Main Stem upstream at Manville is predominantly from nonpoint sources. Further downstream at the Raritan River at Bound Brook, the loading for total phosphorus and TDS is predominantly from point sources during low flow and becomes predominantly nonpoint sources during high flow.

Millstone Watershed Management Area

The Millstone Watershed Management Area has water quality concerns, especially the Millstone River, which is ranked as one of the three worst water quality in the Raritan Basin. The Millstone River either has the highest concentration or the most samples not meeting standards of most of the constituents analyzed. The percentage of forested land upstream of monitoring stations in this WMA, as of 1995, ranges from 16% to 39%. The Stony and Beden Brooks have the highest percentages of forested land in the WMA.

The water quality concerns for this management area include total phosphorus and fecal coliform levels not meeting standards and increasing trends of chloride and total dissolved solids concentrations. The bioassessment rating of approximately 81% of the sampling stations on these streams are moderately impaired. A few volatile organic compounds were detected in this watershed management area, but the concentrations did not exceed criteria/standards. MTBE was the only VOC that was detected in all samples taken from this WMA. Pesticides also were detected in the surface waters of the Millstone WMA. The Stony Brook had the highest numbers of pesticides detected and had concentrations that violated water quality criteria.

Forty-four waters within this WMA are on the draft 2002 Integrated List, Category 5 as having known water quality impairment where TMDLs are most likely to be developed for pH, fecal coliform, total phosphorus, temperature, dissolved oxygen, sedimentation, excessive macrophyte growth. The use impairment of these waters includes primary contact, aquatic life support, boating, and fish consumption. Three surface water bodies have known use impairment but unknown violations of surface water quality criteria.

The water quality concerns of Millstone Watershed Management Area are from both point and non-point source pollution. The point and nonpoint source analysis for the Millstone WMA varied depending on the location of the surface water quality sampling site during low flows. The total phosphorus loading is predominantly from point sources during low and median flows except for the Millstone River near Manalapan, where no point sources are located upstream of the sampling site. The TDS loading for this WMA varies from point source to equal mix to nonpoint source predominance during low flow. Then, the predominance switches to mostly nonpoint source loading as the flow regime increases.

Glossary of Terms for Surface Water Quality and Pollutant Loadings

“Action level” is the level at which, if the concentration of a contaminant exceeds the water quality standard, triggers remedial action, such as treatment.

“Anthropogenic” is man-made, not natural.

“Aquatic macroinvertebrate” is an aquatic insect, worm, or crustacean.

“Aquatic macrophyte” is an aquatic plant.

“Bioaccumulation” is the net uptake of a material by an organism from food, water, and (or) respiration that results in elevated internal concentrations.

“Designated use” is the use specified in water quality standards for each water body or segment, whether or not they are being attained.

“Diadromous fish” means fish that spend most of their life in one type of water, either fresh or saline, and migrate to the other type to spawn.

“Ecological indicators” are plant or animal species, communities, or special habitats with a narrow range of ecological tolerance.

“Eutrophication” is the process of enrichment of a water body due to an increase in nutrient loading.

“Health advisory level” is a non-enforceable estimate of acceptable drinking water levels for a contaminant based on health effects information.

“Impairment” is a detrimental effect of the biological integrity of a water body caused by a change in the chemical, physical, or biological quality or condition that prevents attainment of the designated use.

“Maximum contaminant level” is the highest level of a contaminant that is allowed in drinking water.

“Non-point source pollution” is pollution that results from storm water runoff over different land uses to receiving waters.

“Point source pollution” is pollution that is derived from a localized, single source and is discharged from a pipe or other distinct source.

“Storm water runoff” is the flow of water on the surface of the ground, resulting from precipitation.

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

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

“Trend in a water quality” is defined as the statistical analysis of the concentration of a constituent at the same station over a period of time.

“Total maximum daily load” (TMDL) is the amount of constituent load that a receiving water body can receive and still meet water quality standards. Essentially, a TMDL and the process of determining the TMDL become a surface water pollution control plan, for specific constituents and stream reaches.

“Water quality criteria” is a scientifically derived ambient concentration of a contaminant that protects human health and aquatic life.

“Water quality standard” is an allowable contaminant concentration in a water supply that is enforceable by law.

“Watershed” is the land area that drains into a body of water.

“Watershed Management Area” is 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 for Surface Water Quality and Pollutant Loadings

AL – action level
AMNET – Ambient Biomonitoring Network
BOD – biochemical oxygen demand
DO – dissolved oxygen
FW2-TP – fresh water trout production stream
FW2-TM – fresh water trout maintenance stream
FW2-NT – fresh water non-trout stream
HAL – health advisory level
HHC – human health criteria
MCL – maximum contaminant level
MTBE – methyl tert-butyl ether
NAWQA – national water quality assessment program
NJDEP – New Jersey Department of Environmental Protection
NY-NJ HEP – New York – New Jersey Harbor Estuary Program

PCE - tetrachloroethylene
TCA – 1,1,1-trichloroethane
TCE - trichloroethylene
TDS – total dissolved solids
TMDL – total maximum daily load
TOC – total organic carbon
TSS –total suspended solids
USEPA – United States Environmental Protection Agency
USGS – United States Geological Survey
VOC – volatile organic compound
WMA – watershed management area

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