EVALUATION OF PERMITTED AND NONPERMITTED LOADS IN THE RARITAN RIVER BASIN, WATER YEARS 1991-97

A Technical Report for the Raritan Basin Watershed Management Project

Final Report: August 2001
Data provided by the US Geological Survey

Table of Contents

List of Figures

Figure

List of Tables

Table

List of Tables From “Preliminary Evaluation of Water Quality Status in the Raritan River Basin, Water Years 1991-1997 (not included)

List of Appendices

Appendix

Acknowledgements

Primary Author:

Robert G. Reiser
United States Geological Survey

The NJ Water Supply Authority acknowledges its heavy debt to Robert Reiser of the United States Geological Survey who developed the data and other extensive information for this report for the Raritan Basin Watershed Management Project. TRC-Omni Environmental Corporation also provided information for this report, as did the NJ Department of Environmental Protection-Division of Water Quality. Thanks go also to the Characterization Committee and Project Team of the Raritan Basin Watershed Management Project for all of their comments, hard work and suggestions. Project Team members include:

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

Evaluation of Permitted and Nonpermitted Loads in the Raritan River Basin, Water Years 1991-97

Abstract

Eight water quality constituents were studied at 21 surface water-quality sites in the Raritan River basin from 1991-97. Loads in pounds per day (lbs/day) and yields in pounds per day per square mile (lbs/day/mi^2) were computed for total ammonia plus organic nitrogen (TKN), biochemical oxygen demand (BOD), chloride, total dissolved solids (TDS), nitrate plus nitrite (NO3+NO2), total organic carbon (TOC), total phosphorus (TP), and total suspended solids (TSS). Permitted and nonpermitted loads were computed for all constituents except chloride.

Regression analysis was used to develop a relation between total instream load and stream flow. The regression equation was used to predict total instream loads at 3 different flow conditions. Instream loads were studied at low, median, and high flow, as defined by the 90th, 50th and 25th percentile flows. The portions of total instream load originating from permitted point sources and from non- permitted sources was computed from (1) effluent-quality and -quantity data reported for permitted point sources and (2) water-quality and streamflow data from water quality sites in the basin.

The Raritan River sampling site at Bound Brook represents a composite of water draining nearly three quarters of the Raritan River basin including effluent from 70 permitted point sources. The percent of total instream load at median flow consisting of permitted sources at the Bound Brook sampling site at average flow ranges from 4 to 56 percent depending on the constituent. Permitted sources comprise, 4 percent of TSS; 10 percent of TOC, 14 percent of BOD, 22 percent of TDS, 35 percent of TKN, 45 percent of TP, and 56 percent of NO3+NO2.

Permitted sources of TKN comprise more than a third of the load at low flow at the majority of sites. Loads from permitted sources comprise more than a third of TDS load at low flow at nearly half the sites. TDS load at median and high flow is primarily from nonpermitted sources. Loads from permitted sources comprise less than a third of the load at all except one site at low flow. Loads from permitted sources comprise more than a third of TP and NO3+NO2 load at low and median flow conditions at more than a third of the sites. Permitted sources comprise more than a third of the BOD load at low flow at a few sites. TOC, and TSS loads are mainly from nonpermitted sources.

Nonpermitted TKN yields at high flow are highest at the Millstone and Raritan River, Stony Brook and Matchaponix Brook sites. Nonpermitted yields of BOD are highest at South Branch Raritan River sites, Millstone River at Grovers Mill and Stony Brook. Nonpermitted yields of TDS are highest at sites on the South Branch Raritan River, North Branch Raritan River and Lamington River in the New England province. Nonpermitted yields of NO3+NO2 are highest at the 2 most upstream sites in the Millstone and South Branch Raritan River basins and Neshanic River. Nonpermitted yields of TOC are highest in the Lamington and Millstone Rivers, South Branch Raritan River at High Bridge and Stony Brook. Nonpermitted yields of TP are highest at the Millstone and Raritan River, South Branch Raritan River at Three Bridges, and Beden Brook sites.

Nonpermitted yields of TSS are highest at the Millstone River sites, Raritan River at Bound Brook and Stony Brook.

Nonpermitted yields were related to environmental factors such as land use, soils, lithology, basin shape, and hydrology. Increases in TP and TSS yields were most strongly correlated with increases in soils, lithology and slope associated with the Coastal Plain. Increases in BOD correlate most strongly with increases in flow-per-unit area and factors describing urban areas at low flow and with a decrease in soils and lithology associated with the Coastal Plain and an increase in septic system density at median and high flow. Increases in TKN yields are most strongly correlated to decreases in slope and forested land at high flow and increases in flow-per-unit area and basin shape associated with the New England province at low flow.

Increases in nonpermitted TDS yields are most strongly correlated to increases in septic system density, flow-per-unit area, and soils and lithology associated with the New England province. Increases in nonpermitted NO3+NO2 yields are most significantly correlated to increases in flow-per-unit area, septic system density and soil permeability at low flow. No significant correlations exist at high flow, except flow-per-unit area. Increases in nonpermitted TOC yield are correlated most significantly to increases in factors describing urban land uses, flow-per-unit area, and permeability.

Introduction

The Clean Water Act (CWA) of 1972 was enacted to address the issue of water quality in our nation's waterways. One of the Act's goals is to improve water quality in streams to a fishable and swimmable status. Initial efforts for improving stream water quality focused on implementing Best-Available-Technology for treating effluent from municipal wastewater treatment plants. Efforts focused on improving the quality of these point source discharges by requiring secondary and advanced treatment. This technology reduced the amount of nutrients, TSS BOD, heavy metals and other pollutants discharged to streams.

The effort to clean up point source discharges has lead to substantial improvements in water quality of many streams during the first 20 years of the CWA. This method for improving water quality has focused on providing sufficient instream dilution of point source effluent at low flow conditions to achieve water quality goals. On many streams improving the quality of point source effluent without addressing non-point sources of pollution was not enough to attain fishable and swimmable status. During the first 20 years of the CWA nonpoint sources of pollution were rarely evaluated (Jarrell, 1999). Law suits, beginning in the late 1980's, pushed the U.S. Environmental Protection Agency (USEPA) and state agencies to consider both point and nonpoint sources of pollution on a watershed basis (Jarrell, 1999).

The New Jersey Department of Environmental Protection (NJDEP) has implemented a watershed management approach for characterizing water quality in New Jersey. Three unique watershed management areas—Upper Raritan, Lower Raritan and Millstone--comprise the Raritan River Basin. Both point and nonpoint source contributions to pollution need to be characterized in these areas. The watershed approach considers the concerns of many stakeholders including municipal and industrial dischargers, water purveyors, municipal officials, environmental groups, agriculture, and development interests in working toward best management practices for cleaner water in the Raritan River Basin.

NJDEP, as required by section 303d of the CWA, has identified a number of stream reaches in the Raritan basin that exhibit current or historical exceedances of surface water quality standards (NJDEP, 1998). The water quality parameters with exceedances of standards include: pH, temperature, fecal coliform, dissolved oxygen, ammonia, and TP. Biological impairment based on results from macroinvertebrate studies, occurs along many stream reaches in the basin (NJDEP, 1997). The most frequently occurring exceedances of standards were for biological impairment followed by fecal coliform and TP. Exceedances occurred on Beden Brook, Etra Lake, Lamington River, Millstone River, Manalapan Brook, Matchaponix Brook, Mulhockaway Creek, Neshanic River, North Branch Raritan River, Raritan River (main stem), Rockaway Creek, South Branch Raritan River, Spruce Run, and Stony Brook (NJDEP, 1997).

This report is one part of a series of technical reports written for the Raritan Basin watershed management project implemented by the NJDEP and coordinated by the New Jersey Water Supply Authority (NJWSA). This report provides technical analysis of pollutant loads in the basin by the U.S. Geological Survey (USGS). Point source data from permitted facilities and Omni Environmental Corporation provided instream attenuation rates to the USGS. Information from this report will contribute to a more detailed characterization and assessment study and be incorporated into a large report integrating other reports on basin setting, basin water budget, water supply, biology, and studies of riparian areas.

Purpose and Scope

This report documents the results of the analysis of loads of 8 water quality constituents among the most important for characterizing the water quality and health of streams in the Raritan River basin. Water quality and streamflow data collected from 801 samples at 21 sites during the 1991 through 1997 water years are used for computation of instream loads and yields (load per unit area). Sources of instream loads were investigated by estimating contributions of point source and nonpoint source loads to total instream loads along stream reaches throughout the basin. This study is a precursor to determining which constituents and which stream reaches need total maximum daily loads (TMDLs) established. Results from this study will be used to assess a modeling strategy for (TMDL) implementation in another study.

This evaluation of water quality loads and yields includes a summary of loads and yields at each site, comparisons between sites, a comparison of ground water quality to stream quality at low flow, estimates of mean annual loads contributed by ground water, relations of nonpermitted yields to basin characteristics, and analysis of the influence of changes in loading from permitted facilities on trends in total instream load.

Description of Study Area

The Raritan River Basin comprises an area of 1,105 square miles in central and northern New Jersey and is the largest drainage basin entirely within the State. The major subbasins are the South and North Branch Raritan Rivers, Millstone River, South River, Bound Brook and Lawrence Brook. The major impoundments in the basin include Spruce Run Reservoir, Round Valley Reservoir and Budd Lake. The basin drains all or portions of 100 municipalities in Hunterdon, Mercer, Middlesex, Monmouth, Morris, Somerset and Union counties.

The Raritan River basin drains an area encompassing three physiographic provinces. Northern portions of the North and South Branch Raritan Rivers are located in the Highlands province. This area is underlain by predominately granite, gneiss, and small amounts of marble of Precambrian age. These rocks are resistant to erosion and create a hilly upland dissected by deep steep-sided valleys of major streams. The entire Bound Brook subbasin and a large portion of the North and South Branch Raritan River subbasins are located in the Piedmont physiographic province. The Piedmont province is a broad lowland containing ridges underlain by interbedded sandstone, shale, conglomerate, basalt, and diabase. The South River, Lawrence Brook and much of the Millstone

River subbasins are within the Coastal Plain physiographic province. The Coastal Plain is mainly flat and underlain by unconsolidated layers of sand, silt and clay (NJDEP, 1992).

Twenty-one water-quality stations sampled by the NJDEP/USGS cooperative network from 1991-97 are located throughout the basin (**fig**. **1**). Twelve sites drain basins located entirely in one province; five in the Highlands, four in the Coastal Plain, and three in the Piedmont province. Eight sites drain basins located in two provinces. The Raritan River at Bound Brook subbasin includes stream flows originating in all three provinces (**fig. 1a**).

Mixed land uses are predominant in most of the basins draining to these sites in 1995 (**fig. 1a**). The land use types considered were urban, agriculture, forest, wetland, water and barren land. Only Spruce Run at Glen Gardner has a single land use type representing more than 50 percent of the basin. Spruce Run is 52.8 percent forested (**table 1**). The most intense urban land use is located along the main stem of the Raritan River, the Bound Brook subbasin, and the lower portions of the Lawrence Brook and South River subbasins. The highest percentages of forested land use are found in the upper portions of the North and South Branch Raritan River subbasins. The highest percentages of agricultural land uses are found in the South Branch Raritan River and Millstone River subbasins. The highest percentages of wetlands are in the Millstone and South River subbasins.

Municipal and industrial point source discharges exist in all the major subbasins (**table 1**). The Neshanic River, Manalapan Brook, and Millstone River near Manalapan are the only sites without any point source loads from permitted facilities discharged to the stream upstream from the site. Raritan River at Queens Bridge at Bound Brook integrates the South Branch Raritan, North Branch Raritan and Millstone River subbasins and has 73 industrial and municipal point sources upstream.

Previous Studies

Water quality, streamflow, and time-of-travel data were characterized in the basin for the period 1955-72 (Anderson, and Faust, 1974). Streamflows decreased during the period. In general, water quality was categorized as good for most industrial, domestic and recreational uses except along the main stem Raritan River downstream from Manville. Maximum observed concentrations of ortho-phosphates, phenolic materials, and coliform bacteria increased during the study period. Dissolved oxygen decreased and BOD increased on the Raritan River downstream of Manville. Comparisons with water quality data from the late 1920's to 1955-72, indicated concentrations of sulfate, chloride, nitrate, and dissolved solids increased significantly during the period.

Relations of water quality to streamflow were determined for 18 water quality constituents at 21 surface-water stations within the Raritan River basin for the years 1976-93 (Buxton and others, 1999). Storm water runoff was found to be the most likely contributor of instream loads for TOC, suspended sediment, chloride, TKN, and total ammonia. Trends were evaluated for both high and low flow periods for both concentrations and loads. Median concentrations for 1989-93 were compared to the median values from 1976-93.

Trend tests on values of 24 water-quality characteristics at 83 surface-water quality stations in New Jersey, including 21 stations in the Raritan River Basin, were conducted on data from 1986-95 (Hickman and Barringer, 1999). More sites showed decreases in phosphorus and TKN than increases. More sites showed increases rather than decreases in NO3+NO2, TDS, and chloride.

The presence of trends in the concentrations of constituents at stream sites was analyzed for statistical association with drainage basin characteristics (Robinson and others, 1996). Urbanized basins were associated with increasing concentrations of sodium, chloride, magnesium and pH. Trends in dissolved solids, especially sodium and chloride, were strongly associated with application rates of road deicing salts. Trends in BOD and nutrients showed little association with the amount of effluent discharged to streams. Trends in total ammonia and trends with agricultural land use seem to indicate that nonpoint sources may be more of an influence than effluent discharge.

The relative contribution of point source loads to total instream loads was analyzed at seven sites in the Musconetcong, Rockaway, and Whippany River basins (Price and Schaefer, 1995). Data for BOD (BOD), total nitrogen, TP, and TOC (TOC) from 1985-90 were studied in each basin. Differences between sites were attributed to the presence or absence of major point sources and reservoir effects.

Methods of Study

The methods used to select stream sampling sites, and water quality constituents to be studied are described in this section. Also methods for data review, analysis, computation of total instream loads and yields and presentation of the results are documented.

Water-Quality Data

Water quality and streamflow data used in this study are primarily from the cooperative network of the USGS and NJDEP (Reed and others, 1998). Twenty-one sites in the Raritan River basin have a continuous record of data collected routinely five times per year from 1991-97 (**table 1**). A fewer number of samples were collected at sites 01397000, 01400650 and 01402000 and a fewer number of constituents were sampled during part of the study period at site 01403300. Only one sample was collected at sites 01397000 and 01402000 in 1991. No samples were collected at site 01400650 in 1995. At site 01403300, a few constituents were not sampled during significant portions of study period: BOD from 1992-94 and TOC from 1991-94.

The period 1991-97 was chosen to allow for an adequate amount of data for statistical analysis. Beginning in 1998, the network of cooperative sites changed and many of the sites included in this study were no longer sampled. The data collected at these sites during the study period include field parameters; pH, dissolved oxygen, specific conductance, water temperature, and alkalinity; nitrogen species, phosphorus, 8 major ions, hardness, fecal coliform, TSS, TDS, dissolved organic carbon and suspended organic carbon. Additional samples were collected at sites 01398000, 01401000, and 01403300 in 1996-97 for the USGS Long Island/New Jersey National Water Quality Assessment (LINJ NAWQA) project.

Point source effluent-quality and -quantity were derived primarily from the NJDEP discharge monitoring report (DMR) database. Some facilities do not report data for several of the constituents to the NJDEP database. Additional data were requested from these facilities by Omni Environmental Corporation (Omni). Some facilities do not sample for all of the constituents studied. Concentrations of these constituents were estimated by Omni from data collected at facilities with similar operations and effluent treatment or from scientific literature.

Selection of Constituents

Eight constituents considered to be important indicators of the water quality in the Raritan River Basin were chosen for analysis. Sufficient amounts of data are available for the chosen constituents during the period 1991-97 to complete a statistical analysis. The constituents chosen for analysis include TKN, BOD, chloride, NO3+NO2, TOC, TP, TDS, and TSS. Five of these constituents have existing quality criteria. BOD, TKN and TOC do not have water quality standards.

TKN represents the reduced portion of total nitrogen in a stream. High ammonia concentration is a concern of water purveyors because of increased treatment costs. Organic nitrogen and ammonia are both oxygen consumers and an indicator of ecosystem health. No water quality standards exist for TKN.

BOD quantifies the potential oxygen consumption and is an indicator of stress to the stream ecosystem. Rather than an actual compound or element, BOD is a measure of residual dissolved oxygen after a 5-day period of incubation at 20 ^{o} C. Oxygenated water is added to the sample enhancing the ability of microorganisms to decompose organic matter in the water and consume oxygen in the process. BOD can be used to evaluate the organic load in a quantitative way (Hem, 1985). No water quality standard exists for BOD.

NO3+NO2 represents the oxidized form of nitrogen in the stream. NO3+NO2 has a combined drinking water standard of 10 mg/L (USEPA, 1996). Nitrite is found in very small concentrations in surface waters because nitrite is rapidly oxidized to nitrate. Nitrate enters surface water from wastewater treatment plants, failing septic systems, and nonpoint sources such as agricultural activities. Rooted aquatic plants and algae use Nitrate as a primary nutrient. Nitrate is found in surface water in much higher levels than nitrite. Nitrate is considerably less toxic to aquatic organisms than are ammonia and nitrite; however in excess amounts (>10 mg/L), nitrate contributes to methemoglobinemia, “blue baby” syndrome, in small children and fish (Buxton and others, 1999).

TOC is a direct measure of organic compounds in a stream. Increased levels may indicate a potential for forming disinfection by-products in drinking water. Data on concentrations of specific forms of organic carbon such as chloroform and other disinfection by-products and other VOCs are not routinely collected throughout the basin and generally are found in very low concentrations. A fraction of TOC is assimilateable carbon used as a nutrient by microorganisms and contributing toward BOD. In combination with TKN, TOC is an indicator of ecosystem health. TOC can be an indicator of nonpoint source pollution or a poorly controlled process in a sewage treatment plant. No drinking water or surface water standard exists in New Jersey for TOC.

TP concentrations are important because of the affects on stream health. TP can stimulate excessive growth because algae and aquatic plants use TP as a primary nutrient. Exceedances of the 0.1 mg/L surface water standard are common throughout the Raritan River Basin. This standard shall not be exceeded in any stream unless it can be demonstrated that TP is not a limiting nutrient and will not render the waters unsuitable for the designated uses (NJDEP, 1998). For the purposes of this study, 0.1 mg/L is used as a reference point in all streams studied. A second surface- water standard of 0.05 mg/L exists for lakes and reservoirs and for streams at the point of entry to these water bodies (NJDEP, 1998). Phosphates are found in solution and attached to particulates. Phosphorus is a common element in igneous rock and is fairly abundant in sediments (Buxton and others, 1999). Orthophosphorus applied to agricultural land, lawns, and gardens can be washed into streams in runoff. Phosphorus also enters streams from wastewater treatment plants.

TDS is an important constituent for purveyors and water users. A high concentration of TDS can have impacts on the taste of water and could impact hospitals, industrial facilities and the stream ecosystems. TDS concentrations are increasing over time at some locations in the basin. The concurrent drinking water and instream standard is 500 mg/L (USEPA, 1996).

TSS is regulated and may be one of the more important indicators of non-point source pollution. The health of stream ecosystems is affected by concentrations of TSS. The primary sources of TSS in streams are from storm runoff, instream erosion, and resuspension. A poorly controlled process from an STP and algae blooms may also cause an increase in TSS concentrations. The surface water standard is 40 mg/L in nontrout waters and 25 mg/L in trout waters (NJDEP, 1998).

Dissolved chloride has a drinking water and surface water standard of 250 mg/L in New Jersey (NJDEP, 1998). Most of the highest concentrations in surface waters are caused by runoff from deicing salts applied to roads. Dissolved chloride is a conservative element that can be used to quality assure a mass balance model. Conservative elements such as chloride are not removed or added to the stream by biological or chemical processes. The chloride load will stay the same or increase as water moves downstream in gaining streams. Changes in load are caused by discharges or withdrawals from the stream or stream reaches that loose flow to ground water.

Data Review

All instream water quality data were reviewed extensively for quality assurance purposes and moved to a SAS database (SAS Institute, Inc., 1995) for data manipulation and statistical analysis. Data for all 8 constituents were plotted versus streamflow, plotted to observe seasonal differences and compared with measured levels of other constituents. The review resulted in less than 0.1 percent of the values being changed or removed from the database. The majority of the corrections were to field readings or data entered into the database manually from paper copies.

Missing values of total NO3+NO2 were replaced with values of dissolved NO3+NO2. Little difference is observed when both values are present for a sample. NO3+NO2 is present in water almost exclusively as dissolved species (Hem, 1985). TOC was calculated by adding suspended organic carbon to dissolved organic carbon. Missing values of TSS were substituted with values of total suspended sediment.

Instantaneous flow data associated with each sample were checked by plotting the flows versus gage height, plotting flows versus mean daily flow when available and by using regression procedures to identify data outliers. Large residuals from the regressions were evaluated for possible errors. Thirty-one out of 801 flows associated with the samples from 1991 through 1997 were revised.

Statistical Methods

Data from all 801 samples collected during the study period were used in this analysis. The flow and concentration data from each sample were used to compute instantaneous loads for the 8 constituents. A relation was developed between load and flow at each site. Median concentrations of 17 constituents were computed and related to land use. Detection frequencies were computed for each constituent in Table 2 of the technical report “Preliminary Evaluation of Water Quality Status in the Raritan River Basin, Water Years 1991-1997.” Water quality data that contain concentrations of constituents reported as less than or in some cases greater than an analytical detection limit set by the laboratory are considered censored data or non-detects. Four of the seven constituents contain censored data. Nonparametric methods of statistical analysis are used on these censored data sets.

Regression techniques were used to evaluate concentration and load. Relations between instantaneous streamflow and concentration, and instantaneous flow and load were analyzed at each of the sites. Tobit regression is a procedure that uses censored data to develop the relation. Constituents detected in more than 50 percent of the samples from a site were analyzed by using Tobit regression (Cohn, 1988). BOD data were censored in 53 - 56% of samples at 3 sites. Tobit results at these sites are considered to be less reliable. The relation was considered to be significant if the slope of the regression line was different from zero at the 0.05 level of significance. A base-10 logarithm transformation of streamflow and concentration was used to normalize the data before using Tobit regression. Median concentrations of the 17 compounds were evaluated with respect to land use at the 21 sites by using least squares linear regression (Ott, 1988).

Multivariate regression techniques were used to estimate velocities and nonpermitted yields by developing linear relations with basin characteristics, such as velocity related to slope, drainage area and streamflow events. Data for each variable were normalized in order to obtain the best linear relation. The Shapiro-Wilk statistic (SAS Institute, Inc., 1995) was used to test for normality in the dataset of each variable. Data were normalized using various transformations to make the data more symmetric and linear. In some cases the raw data were normally distributed and therefore no transformation was needed. Variables that could not be normalized were dropped from the analysis. Multi-colinearity between variables was examined by using the variance inflation factor test (VIF). Pearson correlation analyses were also performed to determine interaction between the basin characteristics, such as urban land use related to septic system density.

Pearson correlation analysis was used to identify pairs of variables with high correlation coefficients and a low probability level of significance. This indicates a strong linear relation between these independent variables. This indicates the possibility that correlated variables measure the same effect on nonpermitted yield and if used together in a model, may increase instability in coefficient estimates (SAS, System for regression, 1995). This is referred to as multi-colinearity and is measured by computing the variance inflation factor (VIF). Variables with low VIF do not show multi-colinearity.

The variance inflation factor is defined as $1/(1-R^2)$. Any variables associated with a VIF exceeding the definition, are more closely related to other independent variables than they are to the dependant variable (SAS, System for regression, 1995). Only models with a VIF less than $1/(1-R^2)$ were considered in this analysis.

A procedure in SAS called the R-square selection method was used to summarize information on the estimated coefficients from many different models. The method was used to assist in selecting a suitable subset of variables for a final model (SAS, System for regression, 1995). The models were evaluated by looking at statistics describing the model's prediction quality and multi-colinearity: R-squared value, Mallow's CP, Press statistic and VIF. The best models showed the best combination of low Mallow's CP, press, standard error as measured by the coefficient of variation and VIF and a high r-square. A low mallows CP and low VIF were the statistics most influential in choosing a model. Mallow's CP is a measure of the total squared error of a model (SAS, System for regression, 1995).

A stepwise regression procedure was another approach used to choose the best model (SAS Institute Incorporated, 1995). This method starts with the best univariate model and adds variables one by one that result in the largest increase in R-square. Variables with a greater than 5 percent probability level of significance were removed from the model. The models chosen by this method were not necessarily the best as defined by the statistics that describe the model's prediction quality and multi-colinearity. Models were selected based on the summary from the R-square selection method, analysis of multi-colinearity, and the stepwise procedure.

Trend tests by Hickman and Barringer, 1999 were conducted on data from 1986-95 by using the Seasonal Kendall test on uncensored data sets (Helsel and Hirsch, 1992) and Tobit regression on censored data sets. Results from Hickman and Barringer, 1999 are presented in this report for all constituents except TSS. The seasonal Kendall test was performed on TSS data for this analysis. All censored values were given a value of 0.50 mg/L or one half the censored value.

Trend tests were conducted on concentration data from 1991 through 1997 by using the Seasonal Kendall test (Helsel and Hirsch, 1992). This is a nonparametric test designed for water quality data that are not normally distributed. The test also accounts for seasonal variability in the data by only comparing data collected in the same season. **Table 2** lists the results of the test performed on 2 sets of data; 1) all data and 2) data collected at low flow conditions. The test was performed on all constituents, those with and without censored data. All censored values in the dataset were used in the analysis by substituting a value of one half the censored value. A significant trend exists if the test statistic, Tau, was significantly different from zero at the 0.05 level.

Computation of Instream Loads and Yields

Instream loads were computed for each sample by multiplying the instantaneous streamflow by the concentration and applying unit conversions to give a value of load in pounds per day. The formula used is as follows:

$$\text{Load (lb/d)} = \text{concentration (mg/L)} \times \text{streamflow (ft}^3\text{/s)} \times 2.20462 \times 10^{-6}\ \text{lb/mg} \times 86{,}400\ \text{s/d} \times 28.316\ \text{L/ft}^3.$$

Instantaneous yields (loads per unit area) were computed by dividing load by drainage area. This area-normalized load is used to eliminate some of the bias associated with increases in loads caused by increases in flow associated with increases in drainage area. This method does not eliminate all the bias in flow between sites caused by changes in drainage area because the flow per square mile varies across the study area. Flows per square mile are highest in the New England province and lowest in the Piedmont Province.

Loads and yields computed from concentrations which are reported as less than the laboratory detection limit are also reported as a “less than” value. The probability plotting procedure, described in the Statistical Methods section, was used to report estimated percentiles for censored constituents. Summary tables of instantaneous yields (**tables 6, 8, 10, 12, 14, 16, 18, 20**) from sample data report estimated percentiles and the actual minimum “less than” value computed from censored concentrations.

Presentation of Tables, Figures, and Appendixes

Figures 2 and **3** present a comparison of land use percentages in the 21 basins with median concentrations of selected constituents. Median concentrations at each site are ordered by percent land use. The median concentrations of the selected constituents were found to be significantly related to the land uses presented in the figures. Boxplots presented in **figures 5-10** show the distribution of constituent concentrations in stream baseflow and shallow ground water in 3 subbasins. The pie charts presented in **figure 12** show estimates of the percentage of total instream load at average flow that originates from ground water, runoff and permitted point sources.

The stacked bar charts in **figures 15-21** present the instream load for each of the 7 constituents studied. The portion of permitted and nonpermitted load comprising the total instream load is presented at each site at 3 flow conditions. The stacked bar charts are clustered in groups of 3 for each site. The bar on the left represents the load present in the stream at low flow. The bar in the middle of the cluster represents the instream load at median flow conditions and the bar on the right represents high flow conditions.

The maps in **figures 22-28** allow for comparison of nonpermitted yields along stream reaches and between drainage basins. Symbols are color coded according to the amount of nonpermitted yield at the site. A plus sign in the circle represents more than 75% of the instream load originating from nonpermitted sources. A minus sign in the circle represents less than 25 percent of the instream load originating from nonpermitted sources. These figures summarize the results listed in odd numbered **tables 7-21**. The tables are referenced in the text, however, not all of the figures are referenced in the text.

Appendixes A-H contain figures that present plots of concentration versus flow, load versus flow and concentration versus time for each constituent at each site. The graph at the top of the figure presents a plot of concentration versus flow. The middle plot shows the relation of load versus flow, the regression line for total instream load, and the estimated line for permitted load. The bottom plot of concentrations sampled over the study period includes a trend line whenever a significant trend exists. Each appendix contains the figures at each site for one of the 8 constituents studied. A separate figure exists for each constituent at each site, for a total of 21 figures in each appendix.

Table 2 is a summary of results from trend tests on 8 constituents and on streamflow from 1991-97. The results are from tests on all the sampled data and on data sampled only at low flow conditions. The numbers in the table represent the slope of the trend line when a significant trend exists. The trend slope is an estimate of the change in concentration in units per year.

Tables 3 and **4** are a summary of ordinary least squares regression results of land uses versus median concentration and yield. Red plus signs indicate a significant increase in load or yield with an increase in the percentage of land use. Blue minus signs indicate a significant decrease in load or yield with an increase in the percentage of land use. **Table 5** lists median concentrations of 7 constituents at 3 sites. The table lists medians from all samples and from baseflow samples. The median concentrations from selected shallow ground water wells are listed for comparison to surface water concentrations.

Tables 6-21 present statistical summaries of yields from samples and estimated loads and yields, including permitted and nonpermitted yields, at 3 flow conditions. The even numbered **tables 6-20** present the number of samples collected, the number of censored values, the maximum and minimum values sampled and percentiles of the sampled values. The odd numbered **tables 7-21** present estimates of loads and yields at each site at 3 flow conditions. The portion of instream load and yield originating from permitted and nonpermitted sources are also presented. **Table 26** presents the results of correlation analysis between nonpermitted yield and basin characteristics.

Streamflow

Streamflow is measured at each of the 21 water quality sites studied in the Raritan River Basin. Instantaneous streamflow is determined for the mean time of each sample from ratings that relate water level elevation recorded during the sample to streamflow. Seven of the 21 sites have a continuous 15-minute record of streamflow. The other 14 sites have instantaneous streamflow measurements that are correlated to mean daily streamflows at nearby continuous-record gauging stations to estimate flow at the time of the sample. Streamflow at the time of sampling is needed for computation of loads.

Streamflow data can be used to develop a flow-duration curve summarizing magnitude and frequency of flow at each site. Flow and water quality at a particular flow duration can be compared between sites. Flow duration curves showing the percentage of time that a particular flow is equaled or exceeded at a site were developed at each of the sampling sites (Searcy, 1959). Flow durations at the sites with continuous streamflow records were computed from the Daily Value Statistics (DVSTAT) computer program associated with the USGS database (WATSTORE). The seven-day ten-year low-flow statistic (MA7CD10) was also computed at each site with a continuous record of streamflow. The MA7CD10 flow was computed from the entire period of streamflow record at all sites except for the South Branch Raritan River sites at Stanton, and Three Bridges, and the Raritan River sites at Manville and Bound Brook. Streamflow records after streamflow regulation began in September 1963 at Spruce Run and Round Valley Reservoirs were used for computing MA7CD10 flow at these sites.

Correlation procedures were used to estimate flow duration and MA7CD10 flow at the 14 sites without a continuous record of streamflow from streamflow records at nearby gauging stations. A streamflow record extension technique, maintenance of variance extension (MOVE1), was used to develop a correlation between instantaneous flow at the sampling site and mean daily flow at a nearby continuous-record gauging station (Hirsch, 1982). The log of flow is used to normalize the data before the relation is developed. This technique is best for estimating low to median flow conditions. The accuracy of the MOVE1 method was tested at the 7 gauging stations at various flow durations. Estimates of flows at the 25th percentile were found to be within 10 percent of the values computed from the daily flow record. The prediction of flows higher than the 25 percentile was found to have a larger standard error. A test for baseflow conditions excludes high flow measurements from the correlation. The flow duration values for Raritan River at Bound Brook and for Millstone River at Grovers Mill were estimated using drainage area adjustments from nearby gauging stations.

Samples at all sites cover the range of approximately 10 to 90 percent flow duration with some sites having high-flow samples that exceed the 1 percent duration and others with samples at flows as low as approximately the 98 percent duration. The majority of the samples collected at high flows are during a receding hydrograph. These samples are not representative of water quality conditions throughout the entire hydrograph. Samples are random and no sampling has been conducted throughout a storm hydrograph. No samples were collected at any site at flows as low as the MA7CD10 flow.

Streamflow Characteristics

Streamflows throughout the study area vary according to the physiographic province, soils, bedrock, topography, reservoirs, impervious surfaces and other characteristics of the basin. Streamflows in the piedmont portion of the study area are the most variable. Streams in this area yield the lowest flows at baseflow conditions. The yield at the 90th percent flow duration is less than 0.10 cubic feet per second per square mile (cfsm) in the Neshanic River, Stony Brook and Beden Brook basins. The yield in the upper portion of the South Branch Raritan River basin is 0.60 cfsm. The highest yield at 90th percent flow duration is 0.71 cfsm at South Branch Raritan River at Stanton. Flow at this site is augmented by releases from Spruce Run reservoir during low flow conditions. Yields at the 25th percent flow duration vary from 1.2 cfsm at Manalapan Brook to 2.5 cfsm at South Branch Raritan River at High Bridge. Yields are highest at sites on the South Branch Raritan and Lamington Rivers.

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

Comparison to Historical Data

The statistics of mean daily stream flow at the 7 sites with continuous streamflow records for 1991-97 were compared to the long-term flow statistics at those sites in Table 3 of the technical report "Preliminary Evaluation of Water Quality Status of the Raritan Basin, Water Years 1991-1997." The long-term statistics for South Branch Raritan River at Stanton and for Raritan River at Manville were based on the period 1964 through 1998. Earlier records of flow at these sites do not reflect the Spruce Run reservoir releases beginning in September 1963.

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

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

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

Monthly precipitation records from the National Oceanic and Atmospheric Administration’s National Climatic Data Center were used to compare precipitation from 1991-97 to long-term periods of record (NOAA, 2000). The average annual precipitation in northern New Jersey climate division 1, covering the Piedmont, New England and Valley & Ridge physiographic provinces during 1991-97 is equal to long term averages. Precipitation averaged 47.1 inches per year in New Jersey climate division 1 from 1991-97. The precipitation from 1960-99 averaged 47.4 inches and the average from 1895-1999 was 46.0 inches. The average annual precipitation in southern New Jersey climate division 2, covering most of the New Jersey coastal plain province averaged 45.9 inches from 1991-97. Averages for this climatic division for 1960-99 and 1895- 1999 were 44.6 and 44.3 inches respectively.

Summary of Water Quality Status

This section gives a general summary of the results from the previous report on the water quality status of the Raritan River basin presented to the NJWSA in January 2000. Seventeen water quality constituents were studied at the 21 surface water-quality sites during the first phase of the project. Results from recent studies of volatile organic compounds, pesticides, and trace elements and organics in streambed sediments were also summarized. This summary focuses on the water quality status of the 8 constituents studied during the load analysis phase of the project.

The water quality status at the sampling sites was summarized by comparing the values of constituents to standards and by comparing values between sites. The sites with the best and worst water quality were summarized. The most desirable rating for each constituent is given to the three sites with the most samples meeting the standard or having the most desirable median values. The least desirable rating was given to the three sites with the most samples not meeting the standard or with the most undesirable median value. The sites with the most desirable rating for the most constituents are Mulhockaway Creek, Spruce Run, Millstone River at Manalapan, Manalapan Brook, and Lamington River at Pottersville. The sites with the least desirable rating for the most constituents are Millstone River at Black Wells Mills, Matchaponix Brook, Raritan River at Bound Brook, Neshanic River, and Millstone River at Grovers Mill.

Water quality standards establish the water quality goals and policies underlying the management of New Jersey's waters (NJDEP, 1997). The criteria are set by the NJDEP to protect public health and welfare and to enhance the quality of water. The Federal Clean Water Act requires wherever attainable that surface-water quality standards should provide for protection and propagation of fish, shellfish and wildlife and to provide for recreation in and on the water (NJDEP, 1997). Drinking water standards are set by USEPA and NJDEP. These standards, known as maximum contaminant levels (MCLs) are the maximum permissible levels allowed in public drinking water (USEPA, 1996). The standard is set for water being delivered to public water supply users after treatment. Both standards are used as references to instream measurements.

Surface water and/or drinking water standards exist for 5 of the 8 constituents studied. Two of the 5 constituents did not meet standards at one or more sites in the basin. The most commonly occurring constituent measured above standards from all samples was phosphorus, > 0.1 mg/L in 32 percent of samples. Total suspended solids concentrations exceeded the standard of 40 mg/L in 7.6 percent of the samples collected at nontrout sites. Concentrations exceeded the standard of 25 mg/L in 1.7 percent of the samples collected at trout sites. Chloride, TDS, and NO3+NO2 did not exceed the standard in any samples. Phosphorus was above 0.1 mg/L in all samples except one at Millstone River at Blackwells Mills and in more than half the samples at Raritan River at Bound Brook, Millstone River at Grovers Mills and South Branch Raritan River at Three Bridges.

Concentrations of all constituents change significantly as streamflow changes at one or more sites. TDS decreased significantly with an increase in streamflow at all sites. All significant relations between BOD, TOC and TSS were increasing with increasing streamflow. TKN, chloride, NO3+NO2, and TP concentrations were found to increase with flow at one or more sites and decrease with flow at one or more sites. Increases in TSS concentrations were significantly related to increases in TP, TKN, and TOC at approximately half of the sites studied. Chloride concentrations at some sites, increased significantly as flow increased in the nongrowing season and decreased as flow increased in the growing season.

Data were grouped by the flow condition in which samples were collected. All constituents except BOD were found to change significantly between the groups of samples collected at flows less than the median and those collected at flows greater than the median at one or more sites. The following constituents were significantly higher in low flow samples at one or more sites; TDS, and TP. TSS were significantly higher in high flow samples at one or more sites. Ammonia plus organic nitrogen, chloride, NO3+NO2, and TOC were significantly higher at some sites at low flow and significantly higher at other sites at high flow.

All constituents were found to change significantly between seasons at one or more sites. The following constituents were significantly higher in the growing season at one or more sites: TKN, BOD, and TP. The following constituents were significantly higher in the nongrowing season at one or more sites: chloride, TDS, and NO3+NO2. TSS was significantly higher in the growing season at 5 sites and in the nongrowing season at one site.

Trends in data over time exist for all constituents except TSS at one or more sites in the basin. All trends for TOC, and TP were decreasing over time. All observed trends for chloride, TDS, and NO3+NO2 were increasing over time. BOD decreased at 2 sites and increased at one site.

Trends in data collected at high flow conditions exist for 6 of the 8 constituents analyzed and at low flow conditions for 5 of 8 constituents at one or more sites. All trends observed for TKN, and TOC concentrations decrease at one or more sites during either high flow and/or low flow. All trends observed for chloride, TDS, NO3+NO2, and TP increase at one or more sites during either high flow or low flow.

Relation of Constituents to Total Suspended Solids

TSS significantly increase with flow at most sites. Most suspended solids in surface water are found in stormwater runoff caused by erosion. Algae, however, also contributes to TSS concentrations in streams and is typically found in highest levels at low flow in the summer months. Algae may contribute to the lack of significant increases in concentration of TSS concentration with flow at some sites.

Suspended sediments can transport nutrients, organic carbons, and trace elements associated with sediment. TKN, TP, and TOC are constituents associated with sediment and also dissolved in water. The magnitude of these constituents can be a measure of the amount of these concentrations associated with sediment. Concentrations of TKN, TP, and TOC were found to significantly increase as concentrations of TSS increased at 10, 11 and 13 sites respectively. Concentrations of NO3+NO2 are inversely related to suspended sediment concentration at 5 sites and increased with sediment concentrations at one site. Most NO3+NO2 is dissolved in the water column and not associated with sediment transported in storm runoff. NO3+NO2 is mainly transported to streams in point source and ground water discharge.

Relation of Constituents to Land Use

Mixed land uses predominate most areas of the Raritan River basin. The sites studied have drainage basins that reflect this mix of land uses. Only one site has a single land use category -- urban, agriculture, forest, or wetland -- representing 50 percent or more of the basin. Spruce Run is 52.8 percent forested **(table 1**).

The land uses are derived from a 1995/97 GIS coverage (New Jersey Department of Environmental Protection, 2000). The percentage of forested land in the basins studied varies from 16.1 percent at Millstone River at Grovers Mill to 52.8 percent at Spruce Run. The percentage of land consisting of urban land uses varies from 16.0 percent in the Millstone River near Manalapan basin to 43.2 in the Matchaponix Brook subbasin. Agricultural land use varies from 5.3 percent at North Branch Raritan River near Chester to 41.5 percent in the Neshanic River. The percentage of wetlands varies from 4.7 percent in the Rockaway Creek subbasin to 30 percent in the Manalapan Brook subbasin.

Total developed land use was computed by adding urban and agricultural land uses in the drainage basins upstream of each site. Total undeveloped land use was computed by adding forest, water, wetland and barren land use categories. The percentage of total developed land use varied from 37 percent at Spruce Run to 65 percent at Neshanic River. Population density computed as people per square mile is derived from the 1990 census data. Population densities vary from 127 in the Millstone River near Manalapan subbasin to 1,220 in the Matchaponix Creek basin.

This initial analysis is performed on concentrations and total loads computed from samples. This data include nonpermitted and permitted source loads. Ordinary least squares regression found significant relations between median concentrations and median total yields to land use. These relations were found to exist in the basin despite the lack of sites representing drainage areas with a single predominant land use (**figs. 2 and 3**)(**tables 3 and 4**).

These results may indicate that nonpoint sources may be related to particular land uses, however the volume of permitted point source effluent was not considered in this preliminary analysis. In this analysis it was not determined whether the differences in concentrations between developed and undeveloped areas are from land use or from point source influences. Analysis of nonpermitted loads will be discussed later in this report. Land use and other basin characteristics were found to be related to nonpermitted loads.

Concentration

Median concentrations, water temperatures and pH were compared to percentages of urban, urban residential, agriculture, forest, water, wetland, population density, total developed and total undeveloped land uses. Median values of 15 of the 17 constituents, studied in the preliminary evaluation of water quality in the basin, were found to be significantly related to at least one land use category (**table 3**). Median un-ionized ammonia and BOD concentrations were not related to any land use category.

Eleven constituents were found to be significantly related to the percentage of forested land use in the drainage basin, more than to any other category. Median concentrations of alkalinity, dissolved oxygen, hardness, and median measurements of pH increased with an increase in forested land in a basin. Concentrations of TKN, NO3+NO2, TP, sulfate, TOC, TSS and measurements of water temperature decreased as forested land increased. Five of the 8 constituents studied for load analysis were significantly related forested land use; all showed a significant decrease as forested land use increased (**fig. 2**)

Nine constituents were related to the percentage of developed and undeveloped land use. Concentrations of TKN, NO3+NO2, TP, sulfate, TOC, TSS and measurements of water temperature and fecal coliform counts increased and pH decreased with increasing percentage of total developed land use. Five of the 8 constituents studied for load analysis were significantly related to total developed land use; all showed a significant decrease as forested land use increased (**fig. 3**). The same constituents showed significant opposite relations to undeveloped land use.

The median concentration of nine constituents was related to the percentage of wetlands, however only alkalinity was related to the percentage of lakes and ponds. Alkalinity, dissolved oxygen, fecal coliform count, hardness nitrate + nitrite, and pH decreased with an increase in wetlands. Sulfate, TSS and TKN increased as the percentage of wetlands in the basin increased. Only three constituents were related to agricultural land use. Median chloride concentrations decreased and TSS and fecal coliform counts increased with the percentage of agricultural land use.

Population density was found to be related to more constituents than the percentage of urban land use. High-density urban land use appears to influence more water quality constituents than low-density urban land use. Median concentrations of seven constituents were related to population density. Chloride, TKN, sodium, sulfate, and TDS increased and dissolved oxygen and nitrate + nitrite decreased with increasing population density. Chloride, sodium, sulfate, and TDS also increased with urban land use.

Total Yield

The median of sampled yields of the 8 constituents were also compared to land use percentages and population density. Fewer significant relations between yields and land use were apparent than between median concentration and land use. This may be related to changes in streamflow across the study area. More constituent yields were related to population density in the basin than any other category (**table 4**). Total yields of chloride, TKN, NO3+NO2, and TDS increased with increases in population density in the basin.

Yields of chloride, TDS and NO3+NO2 also increased significantly as urban land use increased. Yields of chloride, TOC, and TDS decreased as agricultural land use increased.

TDS was the only constituent in which median yields were related to the percentage of forested land use. Yields increased as both the percentage of forested land and total undeveloped land increased. TDS also decreased as the percentage of total developed land increased. This appears to be more a function of physiographic province than of land use. Forested land is more prevalent in the New England province and agricultural land is more prevalent in the piedmont province. Both areas have higher TDS yields than the coastal plain because of lithology.

Relation of Selected Constituents to Ground Water Quality

Water quality data from shallow ground water wells (**fig. 4**) located in three subbasins were compared to surface water quality data collected at one sampling site in each of the three subbasins. Ground water data collected from 1985 through 1994 from wells less than 120 feet in depth in unconfined aquifers upstream of three stream sites were used for comparison. Twenty-three of the fifty-two wells located in the South Branch Raritan River at Middle Valley drainage area, six of the twenty-six wells in the Lamington River at Pottersville drainage basin, and seven of sixteen wells in the Millstone River at Grovers Mill drainage area contain water quality data for the six constituents studied.

The South Branch Raritan River at Middle Valley and Lamington River at Pottersville sites were chosen because water quality data were available from a number of shallow wells sampled during 1988-90 as part of a study of ground water flow and quality in the valley-fill and carbonate-rock aquifer system in the highlands province of New Jersey (Nicholson and others, 1993). The Millstone River at Grovers Mill site in the coastal plain was also chosen because of elevated concentrations of some constituents in the stream and the availability of some shallow ground water-quality data. These three sites are also favorable because of a lack of surface water diversions and reservoirs in the basins. However, each basin has point sources contributing to streamflow. Effluent flow and effluent load contributing to instream load at the three sites was subtracted from estimated baseflow load originating from ground water.

Chloride (**fig. 5**), TDS (**fig. 6**), NO3+NO2 (**fig. 7**), ammonia plus organic nitrogen (**fig. 8**), dissolved organic carbon (**fig. 9**) and total phosphorus (**fig. 10**) data from ground water were chosen for comparison with data from streams. Ortho-phosphorus data were not analyzed in surface water samples during the period 1991-97 and TP data are not available in ground water. Ortho-phosphorus in ground water however is essentially equal to TP in surface water. Therefore, ortho-phosphorus in ground water was compared to TP in surface water (**fig. 10** and **table 5**). Suspended organic carbon is added to dissolved organic carbon to compute TOC. Suspended organic carbon is only sampled in surface water, therefore dissolved organic carbon was chosen for comparative purposes. TSS and BOD data are only available in surface water.

The wells are randomly distributed across the three basins. A single concentration representing each constituent was chosen for each well. The majority of the wells have only one sample. Two wells located in the South Branch Raritan River at Middle Valley Basin have two samples and two wells in the Millstone River at Grovers Mill basin have five samples. At the wells with more than one sample, a median concentration was computed for each constituent and used to represent the well.

Median concentrations in shallow ground water were computed for each basin from the single concentration representing each well (**table 5**).

In general the ground water data are more variable than the stream data. This is probably because the stream data were collected at a single location and the ground water concentrations representing the basin were collected from wells at different locations. Concentrations of chloride, TDS, NO3+NO2, and DOC are more variable in ground water in each of the three subbasins. TKN concentrations are more variable in ground water in 2 of the 3 subbasins. Variability in phosphorus concentrations could not be compared because of a large percentage of ground water samples below the laboratory detection limit. In general, median concentrations of all constituents studied except for nitrate plus nitrite are typically lower in ground water than in surface water. The distribution of concentrations at the wells and the stream sites is presented by boxplots. Distributions of constituents and variability in concentrations observed are similar for each of the constituents.

Concentration in Ground Water and Streams

The distribution of concentrations at the wells and the stream sites are presented in boxplots (**figs. 5-10**). The boxplots show the distribution of concentrations in each basin from all stream samples, baseflow samples only, and ground water samples. Stream samples collected at flows less than or equal to the 75th percentile were considered to be baseflow. In general the ground water data are more variable than the stream data. This is probably because the stream data were collected at a single location and the ground water concentrations were collected from wells at different locations throughout the basin. In general, median concentrations of all constituents studied except for NO3+NO2 are typically lower in ground water than in surface water.

Median chloride concentrations in ground water are an order of magnitude lower than in surface water at baseflow conditions in the Lamington River subbasin, half the concentration of surface water in the South Branch Raritan River subbasin and equal in the Millstone River subbasin. Median concentrations in surface water are similar in each basin. Median chloride concentrations are 2.0 mg/L, 12 mg/L and 24 mg/L in ground water in the Lamington, South Branch Raritan, and Millstone Rivers respectively. The ground water data are more variable than surface water data in each basin (**fig. 5**).

Median TDS concentrations are slightly lower in ground water than at baseflow conditions in surface water in all three subbasins. Median ground water concentrations are slightly lower in the Lamington River subbasin (112 mg/L) than the median concentrations of 126 and 129 mg/L in the other two basins. Variability as measured by IQR is greater in ground water than in surface water in each subbasin (**fig. 6**).

Median NO3+NO2 concentrations in ground water are more than 75 percent greater than in surface water at baseflow conditions in the Lamington River and Millstone River subbasins. The median ground water concentration in the South Branch Raritan River subbasin was less than the median concentration from the surface water data. Concentrations in ground water were more variable than concentrations in surface water at each site (**fig. 7**). The median concentration in ground water in the Millstone River subbasin (9.0 mg/L) was more than 7 times greater than the median concentrations of 1.2 and 1.5 mg/L in the other 2 subbasins (**table 5**).

Median ammonia plus organic nitrogen concentrations from ground water data in the Lamington River and South Branch Raritan River subbasins were essentially equal to the median concentration in surface water (**fig. 8**). The median ground water concentration in the Millstone River basin was half that found in surface water. Median ground water concentrations were similar in each basin: ranging from 0.25 mg/L to 0.30 mg/L.

Median dissolved organic carbon concentrations in ground water are more than 3 times lower than the median concentrations observed in surface water in each subbasin (**fig. 9**). The median ground water concentration in the Lamington River subbasin is twice that found in the Millstone River and South Branch Raritan River subbasins.

Concentrations of TP at baseflow conditions are greater than concentrations of orthophosphorus in ground water in each subbasin (**fig. 10**). Median ortho-phosphorus concentrations in ground water are less than the 0.01 mg/L detection limit in the Millstone and South Branch Raritan River subbasins and 0.01 mg/L in the Lamington River subbasin. Median TP concentrations are 0.15 mg/L, 0.12 mg/L and 0.06 mg/L during baseflow conditions in the Millstone, South Branch Raritan, and Lamington River basins respectively.

Constituent Loads and Yields

Total instream loads were computed from water-quality and streamflow data at sampling sites. Methods were used to differentiate between the portion of total instream load originating from permitted point sources and from non- permitted sources. The portions from both sources were computed from 1) effluent-quality and -quantity data reported for permitted point sources and 2) water-quality and streamflow data from USGS and NJDEP water quality sites in the basin. Travel time and attenuation rates (see page 36) were used to estimate the amount of permitted point source loads contributing to total instream load at stream sites at low, median and high flow conditions.

Attenuation rates for both growing and nongrowing seasons were analyzed in this study. A growing season rate at 20 degrees Celsius was used for the primary calculation and analysis of permitted load. The results of the load analysis published in this report are for the growing season unless stated otherwise. A nongrowing season rate calculated at 5 degrees Celsius was also applied to the permitted loads for comparative purposes.

Non-permitted load is the remaining portion of total instream load not accounted for by permitted point sources. Estimates of non-permitted yields were computed from nonpermitted loads. Non-permitted yields were used to compare stream quality between sites and to investigate the relation of basin characteristics to stream quality. Nonpermitted chloride load could not be estimated because chloride data from permitted sources was not available and could not be accurately estimated (Written communication, James Cosgrove, Omni Environmental Corp., 2001).

Both loads and yields are used to summarize water quality in this study. Instantaneous loads and yields of the 7 selected constituents are computed from concentration and flow from each sample and are presented in statistical summaries. Total instream load and yield is estimated at three flow conditions and the portion of total load originating from permitted and nonpermitted sources is summarized and presented in tables and figures. The percentage of instream load contributed from baseflow was estimated at three sampling sites at average flow conditions. Loads are presented in units of pounds per day (lb/day). The yields presented are in units of pounds per day per square mile (lb/day)/mi^2.

The largest loads at a site are found at the highest flows sampled. The largest yields recorded at most sites are also typically found during the highest flow event sampled. The largest loads recorded for all constituents except BOD were at the site the largest drainage basin, Raritan River at Bound Brook. The maximum BOD load occurred at Lamington River at Burnt Mills. Many of the larger yields recorded in the basin, occurred at sites with smaller drainage areas. The majority of the samples collected at high flows are during a receding hydrograph. These samples are not representative of water quality conditions throughout the entire hydrograph. Highest loads typically occur on the rising limb of the hydrograph. Therefore, average total instream loads calculated from this data will typically be lower than the true long-term average load.

Relation to Streamflow

Tobit regression was used to define the relationship between load and streamflow at each sampling site. Instantaneous loads were correlated to instantaneous stream flow at the 0.05 significance level for all constituents except phosphorus. P values are generally less than 0.001 for all constituents except for phosphorus, which ranges from 0.005 to 0.06 at 5 sites. The only site with a relation exceeding a p-value of 0.05 was North Branch Raritan River at Burnt Mills. The Tobit regression equation was used to estimate total instream load at various flow conditions.

Appendixes A-H illustrate the relation of load to streamflow, the Tobit regression line, and the permitted load line in graphs. **Figure 11** is an example from **appendix F** of TP at Raritan River at Manville. The graph at the top of the figure presents a plot of concentration versus flow. The middle plot shows the relation of load versus flow and the bottom plot shows concentration versus time. The plot of load versus flow shows the regression line for total instream load, and the estimated line for permitted load. The plot of concentrations sampled over the study period includes a trend line whenever a significant trend exists

The slope in the Tobit regression equation is used as an indicator of the increase in load occurring in the stream between baseflow and high flow conditions. The larger the slope, the greater the contribution to instream loads from runoff at high flows. The smaller the slope, the larger the contribution from ground water and point sources, because the instream load will be constant with increasing flow (Buxton and others, 1999). The results from analysis of load slopes are consistent with results from the previous studies of Tobit regression of concentration to flow and with results of ANOVA between samples grouped by those above and those below median flow.

The largest slopes occurred when relating TSS to flow. TSS was found to significantly increase as flow increases at the majority of sites (see January 2000 report). On average, the smallest slopes occurred when relating TDS to flow. TDS was found to significantly decrease as flow increases at all sites. TDS was the only constituent with slopes less than 0.98 at all sites. The smallest slope was 0.68 at Matchaponix Brook, a site with the highest percentage of total instream TDS load originating from permitted sources.

The largest variability in slopes between sites was observed for NO3 + NO2 and TP. The smallest slopes recorded for any constituents were for NO3+NO2 at Matchaponix Brook and North Branch Raritan River near Chester: 0.35 and 0.37 respectively. A large percentage of NO3+NO2 load at both of these sites is from point sources. The largest slope recorded for NO3+NO2 was 1.44 at Neshanic River at Reaville, a stream with highly variable streamflow and no permitted sources. The smallest slopes recorded for TP ranged from 0.52 to 0.58 at the North Branch Raritan River sites and Lamington River at Pottersville. These three sites have a large percentage of TP yield from permitted sources. The largest slopes were 1.44 and 1.39 at the Millstone River near Manalapan and Mulhockaway River sites. The Millstone River site has no phosphorus yield from permitted sources and the Mulhockaway River site has a very small yield from permitted sources.

Summary of total load and yield by constituent

Summaries of total loads and yields for each of the 8 constituents are included in this section. A statistical summary of instantaneous total yields from samples is compared between sites. Loads at low, median, and high flow conditions are discussed from the results of Tobit regression analysis. The slopes from the relation of load to streamflow are compared between sites. The 7 sites with the highest total yields are summarized.

Ammonia Plus Organic Nitrogen, Total

Instantaneous total yields of total ammonia plus organic nitrogen computed from samples (**table 6**) and yields estimated from regression analysis at low, median and high flows are summarized in this section. The median of the yields sampled ranges from a low of 0.78 (lb/day)/ mi^2 at Beden Brook and Matchaponix Brook to a high of 3.82 (lb/day)/mi^2 at Millstone River at Grovers Mill. The smallest yields sampled were less than 0.10 (lb/day)/mi^2 at Matchaponix Brook, Spruce Run, Mulhockaway Creek and Neshanic River, at low flow conditions in the summer months. The largest yields sampled were 1,400 (lb/day)/mi^2 at Stony Brook during a 10 year flood event in January 1996, and 630 (lb/day)/mi^2 at Neshanic River during a runoff event in July 1996. Yields at North Branch Raritan River at Burnt Mills never exceeded 7.7 (lb/day)/mi^2. Yields at South Branch Raritan River at Three Bridges never dropped below 0.64 (lb/day)/mi^2.

The total yield at median flow conditions ranged from lows of 0.8 –0.9 (lb/day)/mi^2 at Mulhockaway River and Spruce Run to highs of 2.3 –3.8 (lb/day)/mi^2 at the Millstone River sites at Grovers Mill and Blackwells Mill. TKN yield at high flow (25th percentile flow) ranged from a high of 7.0 (lb/day)/mi^2 at Millstone River at Grovers Mill to a low of 1.4 (lb/day)/mi^2 at Mulhockaway Creek (**table 7**). Yields at baseflow (90th percentile flow) were lowest 0.1 - 0.3 (lb/day)/mi^2 in the Mulhockaway Creek, Spruce Run, Stony Brook, Beden Brook and Neshanic River. Yields were highest 1.0 - 1.4 (lb/day)/mi^2 at Millstone River at Grovers Mill and South Branch Raritan River sites at Stanton and Three Bridges (**table 7**).

Median daily instream TKN load for 1991-97 ranges from at low of 9.5 lbs/day at Mulhockaway Creek to a high of 1,640 lbs/day at Raritan River at Bound Brook (**table 7**). The largest TKN load observed was 80,634 lbs/day at Raritan River at Bound Brook during the highest flow sampled, in March 1995.

The slopes from the relation of load to stream flow range from a high of 1.4 at Matchaponix Brook to a low of 0.79 at Rockaway Creek. The other sites with small slopes, less than 0.90, are Beden Brook, North Branch Raritan River at Burnt Mills, and Raritan River at Manville. This may indicate that constant sources from ground water and/or point sources have a greater influence on instream load at these sites than at others. Slopes are also highest, greater than 1.2 at Millstone River at Manalapan, and South Branch Raritan River at Stanton and Middle Valley indicating a greater influence from intermittent nonpoint sources at higher flows at these sites than at other sites.

Biochemical Oxygen Demand

A statistical summary of BOD yields computed from samples is presented in **table 8**. The median of sampled yields ranges from lows of 2.22 (lb/day)/mi^2 at Neshanic River and 2.30 at Beden Brook to highs of 11.9 at South Branch Raritan River at Three Bridges and 8.98 (lb/day)/mi^2 at South Branch Raritan River at Stanton. The smallest yields were less than 0.23 (lb/day)/mi^2 at Stony Brook, and Beden Brook at extreme low flow conditions, at the 95 % flow duration in August 1993. The largest yields were 589 (lb/day)/mi^2 at Lamington River at Burnt Mills during a runoff event in July 1997, and 573 (lb/day)/mi^2 at Stony Brook during a runoff event in March 1997. Yields at North Branch Raritan River at Burnt Mills never exceeded 31.9 (lb/day)/mi^2. Yields from samples at South Branch Raritan River at Stanton are higher at the 10th percentile flow, 3.9 (lb/day)/mi^{2,} than at any other site.

Estimates of load and yield from the Tobit regression analysis of load versus flow are presented in **table 9** for three flow conditions. The yield at median flow conditions ranged from a low of 0.96 lb/day/mi^2 at Millstone River near Manalapan to a high of 9.6 (lb/day)/mi^2 at South Branch Raritan River at High Bridge. BOD yield at high flow (25th percentile flow) ranged from a high of 18.0 lb/day/mi^2 at South Branch Raritan River at High Bridge to a low of 1.5 lb/day/mi^2 at Millstone River at Manalapan (**table 9**). Yields at baseflow (90th percentile flow) were lowest 0.4 - 0.6 lb/day/mi^2 in the Stony Brook, Beden Brook and Neshanic River tributaries to the South Branch Raritan River and Millstone River at Manalapan and highest 5.4 - 5.6 lb/day/mi^2 at South Branch Raritan River sites at Stanton and Three Bridges (**table 9**).

Median daily instream BOD load for 1991-97 ranges from at low of 7.1 lbs/day at Millstone River near Manalapan to a high of 4,360 lbs/day at Raritan River at Bound Brook. The largest load observed was 58,898 lbs/day at North Branch Raritan River at Burnt Mills during the highest flow sampled at the site in July 1997. This is the only constituent in which the largest load was not measured at Raritan River at Bound Brook.

The slopes from the relation of load to stream flow range from 1.2 at South Branch Raritan River at Middle Valley to 0.78 at Rockaway Creek. Slopes are also smallest, less than 0.90, at North Branch Raritan River at Burnt Mills, Neshanic River, and Millstone River at Manalapan. This may indicate that constant sources from ground water and/or point sources have a greater influence on instream load at these sites than at others. Slopes are also highest, greater than 1.1 at Manalapan Brook, and South Branch Raritan River at High Bridge indicating a greater influence from intermittent nonpoint sources than at other sites.

Chloride

A statistical summary of chloride yields computed from samples is presented in **table 10**. Median yields from samples range from lows of 57.8 (lb/day)/mi^2 at Stony Brook and 66.4 (lb/day)/mi^2 at Beden Brook to highs of 253 (lb/day)/mi^2 at Lamington River at Pottersville and 232 (lb/day)/mi^2 at North Branch Raritan River near Chester. The smallest yields were 1.99 (lb/day)/mi^2 at Neshanic River and 7.56 (lb/day)/mi^2 at Stony Brook at low flow conditions in July and August 1995. The largest yields were 3.636 (lb/day)/mi^2 at Stony Brook during a 5 year flood event in October 1996, and 3,533 (lb/day)/mi^2 at Neshanic River during a runoff event in February 1994. Yields at Manalapan Brook never exceeded 232 (lb/ day)/mi^2. Yields at Lamington River at Pottersville never dropped below 70 (lb/ day)/mi^2.

Peak yields are related more to high flow in the winter months than to high flow regardless of the season. The maximum yields occurred from January to April at all sites except Stony Brook. Maximum yields at 10 sites were measured during the second, third and 15th highest flows sampled and not during the highest flow, which is typically the case for the other constituents. Yields at Manalapan Brook never exceeded 232 (lb/day)/mi^2. Yields at Lamington River at Pottersville never dropped below 70.2 (lb/day)/mi^2.

The median daily yields, during 1991-97, ranged from a low of 71 (lb/day)/mi^2 at Stony Brook to a high of 265 (lb/day)/mi^2 at Lamington River at Pottersville. Chloride yields at high flow (25th percentile flow) ranged from a high of 421 (lb/day)/mi^2 at South Branch Raritan River at High Bridge to a low of 117 lb/day)/mi^2 at Manalapan Brook (**table 11**). Yields at baseflow (90th percentile flow) were lowest 7.8 - 12 (lb/day)/mi^2 at the Stony Brook, Beden Brook and Neshanic River sites and highest 66 - 95 (lb/day)/mi^2 at Matchaponix Brook and the main stem South Branch Raritan River sites (**table 11**).

The median daily instream chloride load for 1991-97 ranges from a low of 568 lbs/day at Millstone River near Manalapan to a high of 90,340 lbs/day at Raritan River at Bound Brook. The largest load observed was 1.1 million lbs/day at Raritan River at Bound Brook during the second highest flow sampled in February 1993. The load during the highest flow sampled at Raritan River at Bound Brook in July 1997, was 663,000 lbs/day. The higher load in February is probably caused by an increase in chloride in runoff from application of road salt.

The slopes from the relation of load to stream flow range from 1.2 at Mulhockaway Creek to 0.69 at Matchaponix Brook. Slopes are also smallest, less than 0.90, at Raritan River at Bound Brook, Stony Brook, and Manalapan Brook. This may indicate that constant sources from ground water and/or point sources have a greater influence on instream load at these sites than at others. Even though the low slope at Raritan River at Bound Brook indicates a greater influence from a constant source, data show higher loads from isolated samples collected during runoff events in the winter months. Slopes are also highest, greater than 1.1 at South Branch Raritan River at Stanton and South Branch Raritan River at High Bridge, indicating a greater influence from intermittent nonpoint sources than at other sites.

Dissolved Solids, Total

A statistical summary of TDS yields computed from samples is presented in **table 12**. Median yields range from lows of 323 (lb/day)/mi^2 at Stony Brook and 357 (lb/day)/mi^2 at Manalapan Brook to highs of 999.8 (lb/day)/mi^2 at Lamington River at Pottersville and 994 (lb/day)/mi^2 at South Branch Raritan River at High Bridge. The maximum yields were 27,150 (lb/day)/mi^2 at Stony Brook at Princeton during a runoff event in October 1996, and 12,341 (lb/day)/mi^2 at Lamington River at Burnt Mills during a runoff event in July 1997. The smallest yields were less than 19 (lb/day)/ mi^2 at Neshanic River and 32 (lb/day)/mi^2 at Stony Brook at low flow conditions, between 90- 95% flow duration in July and August 1993. Yields at Manalapan Brook never exceeded 1,038 (lb/ day)/mi^2. Yields at South Branch Raritan River at Three Bridges never dropped below 477 lb/day/mi^2.

Median daily yields, during 1991-97, ranged from a low of 330 (lb/day)/mi^2 at Manalapan Brook to a high of 1,030 (lb/day)/mi^2 at the South Branch Raritan River sites at High Bridge and Middle Valley. Yields at high flow (25th percentile flow) ranged from a high of 1,562 (lb/day)/mi^2 at North Branch Raritan River at Burnt Mills to a low of 508 (lb/day)/mi^2 at Manalapan Brook (**table 13**). Yields at baseflow (90th percentile flow) were lowest 57-82 (lb/day)/mi^2 in the Stony Brook, Beden Brook and Neshanic River tributaries to the South Branch Raritan River and highest 488 - 552 (lb/day)/mi^2 at the main stem South Branch Raritan River sites and Matchaponix Brook (**table 13**).

Median daily instream TDS load for 1991-97 ranges from a low of 2,650 lbs/day at Millstone River near Manalapan to a high of 480,000 lbs/day at Raritan River at Bound Brook. The largest load observed was 5.02 million lbs/day at Raritan River at Bound Brook during the second highest flow sampled in March 1995. A slightly lower load (5.01 million lbs/day) was observed during the highest flow sampled in July 1997.

The slopes from the relation of load to stream flow range from 0.98 at Mulhockaway Creek to 0.68 at Matchaponix Brook. Slopes are also smallest, less than 0.80, at South Branch Raritan River at Middle Valley and Raritan River at Bound Brook. This may indicate that constant sources from ground water and/or point sources have a greater influence on instream load at these sites than at others. Slopes are also highest, greater than 0.91 at Raritan River at Manville, Spruce Run, and South Branch Raritan River at Stanton, indicating a greater influence from intermittent nonpoint sources at these sites than at others.

NO3+NO2

A statistical summary of NO3+NO2 yields computed from samples is presented in **table 14**. Median yields range from lows of 2.3 (lb/day)/mi^2 at Stony Brook and 4.4 (lb/day)/mi^2 at Manalapan Brook to highs of 24.2 at Matchaponix Brook and 20.6 (lb/day)/mi^2 at Millstone River at Grovers Mill. The maximum yields were 261 (lb/day)/mi^2 at Stony Brook at Princeton during a runoff event in January 1996, and 163 (lb/day)/mi^2 at Raritan River at Bound Brook during a runoff event in July 1997. The smallest yields sampled were less than 0.004 (lb/day)/mi^2 at Neshanic River and 0.04 (lb/day)/mi^2 at Stony Brook at extreme low flow conditions, at the 95% flow duration in July and

August 1995. Yields at Manalapan Brook never exceeded 16.7 (lb/day)/mi^2. Yields at Matchaponix Brook never dropped below 13.2 lb/day)/mi^2.

Median daily yields, during 1991-97, ranged from a low of 1.6 (lb/day)/mi^2 at Stony Brook to a high of 23.7 (lb/day)/mi^2 at Matchaponix Brook. Yields at high flow (25th percentile flow) were lowest 4.7 - 8.5 (lb/day)/mi^2 at Stony Brook, Millstone River at Blackwells Mill, Manalapan Brook and Mulhockaway Creek and highest 17.7 - 30.6 (lb/day)/mi^2 at Millstone River at Grovers Mill, Matchaponix Brook, and South Branch Raritan River at High Bridge (**table 15**). Yields at baseflow (90th percentile flow) were lowest 0.1 - 0.8 (lb/day)/mi^2 in the Neshanic River, Stony Brook, and Beden Brook and highest 8.1 - 17.6 (lb/day)/mi^2 at the Matchaponix Brook, Millstone River at Grovers Mill and North Branch Raritan River at Chester (**table 15**).

Median daily instream NO3+NO2 load for 1991-97 ranges from a low of 51.6 lbs/day at Millstone River near Manalapan to a high of 6,260 lbs/day at Raritan River at Bound Brook. The largest load observed was 131,100 lbs/day at Raritan River at Bound Brook during the highest flow sampled in July 1997.

The slopes from the relation of load to stream flow range from 1.44 at Neshanic River to 0.35 at Matchaponix Brook. Slopes are also smallest, less than 0.70, at North Branch Raritan River near Chester, Millstone River at Grovers Mill and South Branch Raritan River at Middle Valley. This may indicate that constant sources from ground water and/or point sources have a greater influence on instream load at these sites than at others. Slopes are also highest, greater than 1.09 at Raritan River at Manville, Manalapan Brook and Stony Brook, indicating a greater influence from intermittent nonpoint sources at these sites than at others.

Organic Carbon, Total

A statistical summary of TOC yields computed from samples is presented in **table 16**. Median yields range from lows of 7.6 (lb/day)/mi^2 at Beden Brook and 8.3 (lb/day)/mi^2 at Neshanic River to highs of 31.1 (lb/day)/mi^2 at Lamington River and 23.8 (lb/day)/mi^2 at South Branch Raritan River at Three Bridges. The maximum yields were 8,145 (lb/day)/mi^2 at Stony Brook at Princeton during the highest flow sampled in October 1996, and 1,472 (lb/day)/mi^2 at Lamington River at Burnt Mills during the highest flow sampled in July 1997. The smallest yields measured were 0.26 (lb/day)/mi^2 at Stony Brook and 0.66 (lb/day)/mi^2 at Neshanic River at extreme low flow conditions, at approximately the 95% flow duration in July 1995 and August 1993. Yields at North Branch Raritan River at Burnt Mills never exceeded 77.4 lb/day/mi^2. Yields at Raritan River at Manville never dropped below 9.2 lb/day/mi^2.

Median daily yields, during 1991-97, ranged from a low of 10.0 (lb/day)/mi^2 at Neshanic River to a high of 32.3 (lb/day)/mi^2 at Lamington River near Pottersville (**table 17**). Yields at high flow (25th percentile flow) were lowest, 21.1 – 23.3 (lb/day)/mi^2, at Manalapan Brook, Mulhockaway Creek and Rockaway Creek. Yields were highest, 40.6 - 52.6 (lb/day)/mi^2, at the Lamington River sites at Pottersville and Burnt Mills, and Millstone River at Grovers Mill, (**table 17**). Yields at baseflow (90th percentile flow) were lowest, 1.1 –1.6 (lb/day)/mi^2, at Neshanic River, Stony Brook, and Beden Brook. Highest yields at baseflow ranged from 10.7 - 11.8 (lb/day)/mi^2 at the South Branch Raritan River sites at Three Bridges, and Stanton, and at Lamington River at Pottersville (**table 17**).

Median daily instream TOC load for 1991-97 ranges from at low of 101 lbs/day at Millstone River near Manalapan to a high of 12,500 lbs/day at Raritan River at Bound Brook. The largest load was 647,879 lbs/day at Raritan River at Bound Brook during the highest flow sampled in July 1997.

The slopes from the relation of load to stream flow range from 1.27 at South Branch Raritan River at Middle Valley to 0.88 at North Branch Raritan River at Chester. Slopes are also smallest, less than 0.90, at Raritan River at Manville. This may indicate that constant sources from ground water and/or point sources have a greater influence on instream load at these sites than at others. Slopes are also highest, greater than 1.2 at Millstone River at Manalapan, and Mulhockaway Creek, indicating a greater influence from intermittent nonpoint sources at these sites than at others.

Phosphorus, Total

A statistical summary of TP yields computed from all samples is presented in **table 18**. Median yields range from lows of 0.09 (lb/day)/mi^2 at Mulhockaway River and Neshanic River to highs of 0.98 (lb/day)/mi^2 at Millstone River at Blackwells Mill and 0.93 (lb/day)/mi^2 at South Branch Raritan River at Three Bridges. The maximum yields were 394 (lb/day)/mi^2 at Stony Brook during the highest flow sampled in January 1996, and 214 (lb/day)/mi^2 at Neshanic River during the highest flow sampled in July 1996. The smallest yields were less than 0.01 (lb/day)/mi^2 at Mulhockaway Creek and Neshanic River at low flow conditions. The Mulhockaway Creek sample was at approximately the 95% flow duration in August 1995 and the Neshanic River sample was collected at a flow between the median and 75% flow duration in October 1996. Yields at Spruce Run never exceeded 1.04 (lb/day)/mi^2. Yields at Millstone River at Blackwells Mill never dropped below 0.55 (lb/day)/mi^2.

Median daily yields, during 1991-97, ranged from a low of 0.10 (lb/day)/mi^2 at Mulhockaway Creek and Neshanic River to a high of 1.0 (lb/day)/mi^2 at Millstone River at Blackwells Mills. Yields at high flow (25th percentile flow) were lowest 0.2 (lb/day)/mi^2 at Spruce Run, Mulhockaway Creek, North Branch Raritan River at Burnt Mills, and South Branch Raritan River at Stanton (**table 19**). Highest yields at high flow were 1.1 - 1.6 (lb/day)/mi^2 on the Millstone River at Blackwells Mill and Grovers Mill, Raritan River at Bound Brook and South Branch Raritan River at Three Bridges (**table 19**). Yields at baseflow (90th percentile flow) were lowest 0.01 - 0.05 (lb/day)/mi^2 at Neshanic River, Stony Brook, Mulhockaway Creek, and Matchaponix Brook. Highest yields at baseflow ranged from 0.3 - 0.6 (lb/day)/mi^2 at the Millstone River sites at Grovers Mill and Black Wells Mill, Raritan River at Bound Brook and South Branch Raritan River at Three Bridges (**table 19**).

Median daily instream TP load for 1991-97 ranges from at low of 1.1 lbs/day at North Branch Raritan River near Chester to a high of 673 lbs/day at Raritan River at Bound Brook. The largest load was 29,772 lbs/day at Raritan River at Bound Brook during the second highest flow sampled in March 1995.

The slopes from the relation of load to stream flow range from 1.44 at Millstone River at Manalapan to 0.52 at North Branch Raritan River at Burnt Mills. Slopes are also smallest, less than 0.60, at North Branch Raritan River near Chester, and Millstone River at Blackwells Mill. This may indicate that constant sources from ground water and/or point sources have a greater influence on instream load at these sites than at others. Slopes are also highest, greater than 1.3 at Matchaponix Brook, and Mulhockaway Creek, indicating a greater influence from intermittent nonpoint sources at these sites than at others.

TSS

A statistical summary of TSS yields computed from samples is presented in **table 20**. Median yields range from lows of 10.2 (lb/day)/mi^2 at Stony Brook and 10.7 (lb/day)/ mi^2 at Neshanic River and Beden Brook, to highs of 50.4 (lb/day)/mi^2 at Millstone River at Manalapan and 37.8 (lb/day)/mi^2 at Millstone River at Grovers Mill. The maximum yields were 247,000 (lb/day)/mi^2 at Stony Brook during the highest flow sampled in October 1996, and 158,000 (lb/day)/mi^2 at Neshanic River during the highest flow sampled in July 1996. The smallest yield was 0.10 (lb/day)/mi^2 at Neshanic River at the lowest flow sampled in July 1995. Yields at North Branch

Raritan River at Chester never exceeded 120 (lb/day)/mi^2. Yields at Millstone River near Manalapan never dropped below 12.6 (lb/day)/mi$^{2.}$

Median daily yields, during 1991-97, ranged from a low of 9.6 (lb/day)/mi^2 at North Branch Raritan River near Chester to a high of 62 (lb/day)/mi^2 at Millstone River at Grover Mill. Total yields at high flow (25th percentile flow) were lowest 23.5 - 29.2 (lb/day)/mi^2 at North Branch Raritan River near Chester, Mulhockaway Creek, and Spruce Run (**table 21**). Highest yields at high flow ranged from 118 - 131 (lb/day)/mi^2 on the Millstone River at Blackwells Mill and Grovers Mill, and Raritan River at Bound Brook (**table 21**). Yields at baseflow (90th percentile flow) were lowest 0.4 - 1.8 (lb/day)/mi^2 at Neshanic River, Stony Brook, and Beden Brook. Highest yields at baseflow ranged from 10.0 - 19.1 (lb/day)/mi^2 at the Millstone River sites at Grovers Mill and Black Wells Mill, and the South Branch Raritan River sites at High Bridge and Three Bridges (**table 21**).

Median daily instream TSS load for 1991-97 ranges from at low of 130 lbs/day at North Branch Raritan River near Chester to a high of 95,000 lbs/day at Raritan River at Bound Brook (**table 21**). The largest load was 26 million lbs/day at Raritan River at Bound Brook during the second highest flow sampled at the site in March 1995.

The slopes from the relation of load to stream flow range from 1.89 at Raritan River at Bound Brook to 0.96 at Beden Brook. Slopes are smallest, less than 1.2, at Lamington River at Pottersville, Millstone River at Grovers Mill and Rockaway Creek. This may indicate that constant sources from ground water and/or point sources have a greater influence on instream load at these sites than at others. Slopes are also highest, greater than 1.7 at Millstone River near Manalapan and South Branch Raritan River at Middle Valley, indicating a greater influence from intermittent nonpoint sources at these sites than at others.

Sources

Ground Water

Ground water discharge (baseflow) provides a significant portion of total stream flow in the basin. Baseflow provides between 38 and 75 percent of mean annual stream flow at gauging stations in the study area (CH2M Hill and others, 1992). Baseflow comprises an average of 70 percent of mean annual flow at 5 gages in the highlands physiographic province; 42 percent of mean annual flow at 6 gages in the piedmont province; and 62 percent of mean annual flow at 3 gages in the inner coastal plain portion of the Raritan basin. Runoff is a higher percentage of total streamflow in the piedmont province because of the presence of shallow soils with low permeability.

The ground water contribution to load in streams was estimated at the South Branch Raritan River at Middle Valley, Lamington River at Pottersville, and Millstone River at Grovers Mill sites for the period 1991-97 (**fig. 4**). Baseflow was computed by separating streamflow into baseflow and runoff using hydrograph separation techniques. The sliding interval method (Pettyjohn and Henning, 1979) has been used by the USGS and others to estimate the baseflow component of streamflow in New Jersey. The method is designed to estimate baseflow from mean daily streamflow. The calculation of baseflow at a site provides an estimate of ground water discharge to the stream. Baseflow is approximately 71 percent of mean daily streamflow at South Branch Raritan River at Middle Valley, 78 percent at Lamington River at Pottersville, and 66 percent at Millstone River at Grovers Mill.

Hydrograph separation was performed on mean daily streamflows at the Lamington River site for 1922-89 as part of a study to develop the New Jersey water supply master plan (CH2M Hill and others, 1992). The percentage of streamflow consisting of baseflow from this study at the

Lamington River site was also used in this analysis. Average streamflow for the 1991-97 period was only 6 percent higher than the 1922-89 period. Mean daily streamflows are not available for the South Branch Raritan River and Millstone River at Grovers Mill sites. Average flow at these sites was estimated from average flow at nearby gauging stations by using the MOVE1 correlation procedure (see Statistical Methods section). The percentage of streamflow consisting of baseflow at the nearby gauging stations was transferred to the sampling sites. Average flow for South Branch Raritan River at Middle Valley was derived from a correlation with South Branch Raritan River at High Bridge. Results from hydrograph separation for the High Bridge site for 1919-89 were derived from CH2MHill and others, 1992. Average flow for Millstone River at Grovers Mill was estimated from correlation with the Crosswicks Creek at Extonville gage. Results from hydrograph separation for the Extonville gage from 1991-96 were received by written communication from Martha Watt at USGS in Trenton.

Total instream loads at the South Branch Raritan River at Middle Valley, Lamington River at Pottersville, and Millstone River at Grovers Mill sites were estimated from the Tobit regression equation relating load to stream flow. The regression equations are used to estimate the constituent load at various streamflows. Constituent loads calculated at the average flow condition for the period 1991-97, were used for estimating the portion of instream load originating from ground water because results from the hydrograph separation program are for average flow conditions. The percentage of instream load contributed by ground water discharge was estimated at three sampling sites at average streamflow conditions during 1991-97. Median concentration of each constituent from wells in the basin (**table 5**) was used to represent the quality of ground water entering the stream in the basin. These estimates of ground water quality are based on a limited amount of data and indicate the relative proportion of ground water contributions to baseflow. The baseflow load in each of the three subbasins is contributed by permitted point sources and ground water discharge to the stream. The baseflow load was calculated by using the following equation:

> Baseflow load (lb/d) = (median ground water concentration (mg/L) x ground water component of mean daily flow (ft^3/s) x 2.20462×10^{-6} lb/mg x 86,400 s/d x 28.316 L/ft^3)+ point source load

The percentage of instream load contributed by baseflow at average flow conditions was estimated for each site for chloride, TDS, NO3+NO2, ammonia plus organic nitrogen, total nitrogen, ortho-phosphorus and dissolved organic carbon (**fig. 12**). Baseflow loads include estimated load from permitted point sources and load from ground water. Load from point sources was subtracted from estimated baseflow load to estimate the percentage of load from ground water. Point source data are not available however for chloride and dissolved organic carbon. For these constituents the percentage of baseflow load originating from point sources is not known.

The estimate indicates that ground water contributes a majority of the mean annual instream load of TDS, and TKN at each site while contributing a small percentage of the TP, and DOC load. Chloride load from ground water is small at the Lamington and South Branch Raritan River sites and large at Millstone River. NO3+NO2 load from ground water is slightly less than half the instream load at South Branch Raritan and Lamington Rivers and almost three quarters of the total load at the Millstone River site.

The percentage of TDS load contributed to the three streams during baseflow conditions is fairly consistent between sites (63 - 68%)(**fig 12**). TKN load from ground water was estimated to be 58, 71, and 79 percent of total instream load at Millstone River, South Branch Raritan River and Lamington River respectively. TP loads contributed to streams from ground water were estimated to be very low. Median ortho-phosphorus concentrations were 0.01 mg/L in the Lamington River subbasin and less than 0.01 mg/L in the South Branch Raritan River and Millstone River subbasins. The percentage of instream phosphorus load contributed by baseflow is less than or equal to 0.03 percent at each site. Dissolved organic carbon load in baseflow was estimated to be from 15 to 20 percent of total instream load at the three sites. Chloride load from baseflow varies from 6 percent of total load at Lamington River to 68 percent at the Millstone River site.

Initial estimates of NO3+NO2 load from ground water were higher than total instream load at the Lamington River and Millstone River sites. NO3+NO2 load from baseflow was estimated to be 75, 121, and 208 percent of total instream load at South Branch Raritan River, Millstone River, and Lamington River, respectively. The median concentration of NO3+NO2 in ground water is nearly twice as high as in stream baseflow (**table 5**). Other studies have reported similar conclusions. Denitrification in the near-stream subsurface environment (hyporheic zone) has been shown to substantially reduce the nitrate load in ground water discharge to streams (Robertson and others, 1991).

The USGS Long Island/New Jersey National Water Quality assessment (NAWQA) program used a ground water flow model along with a particle-tracking program to simulate transport of nitrate from the water table to streams and water supply wells (Kauffman, 1999). Concentrations of nitrate in three streams at baseflow conditions were compared to concentrations simulated from the model. Nitrate concentrations measured in the streams were consistently about 40 percent less than the simulated concentration, however, concentrations at wells were similar to the simulated concentration. The apparent nonconservative behavior in streams is most likely from denitrification in the aquifer near the streams and (or) by instream processes.

Initial estimates of NO3+NO2 load from baseflow were adjusted by subtracting the permitted point load and 40 percent of the ground water load estimate to get the estimated load from ground water. NO3+NO2 load from ground water was estimated to be 72, 45 and 44 percent of total instream load at Millstone River, Lamington River, and South Branch Raritan River respectively. Total nitrogen load was computed by adding NO3+NO2 and TKN loads. Estimates of total nitrogen load from ground water were 72, 52, and 49 percent of total instream load at Millstone River, Lamington River, and South Branch Raritan River respectively.

Permitted Sources

All point source discharges to New Jersey streams are controlled and monitored by The New Jersey Pollutant Discharge Elimination System (NJPDES), a program implemented by NJDEP (NJDEP, 1997). NJPDES was promulgated in 1981 and NJDEP implements the permitting program through the authority of the New Jersey Water Pollution Control Act, the Federal Clean Water Act, and USEPA’s National Pollutant Discharge Elimination System. Permitted point sources in New Jersey are categorized as minor or major, and as municipal, industrial, non-contact cooling-water, or petroleum cleanup. Discharges of non-contact cooling water and those from temporary cleanup sites were excluded from this study. The permitted data used in this analysis is the actual data reported by the facilities, not the data at full design flow.

Discharge

A total of 73 facilities --49 municipal and 24 industrial-- discharged effluent to streams in the study area during the period 1991-97 (**fig. 13**). The average total permitted effluent discharged in the study area from 1991-97 was 72 cfs. An average of 64.7 cfs from 70 facilities is discharged upstream from the Raritan River at Queens Bridge sampling site. Total effluent discharged to the three major subbasins of the study area are 23 cfs from 32 facilities in the Millstone River, 8.2 cfs from 19 facilities in the South Branch Raritan River, and 8.0 cfs from 17 facilities in the North Branch Raritan River. Permitted discharges averaged 25.6 cfs from 2 facilities to the main stem of the Raritan River and 7.3 cfs from 3 facilities to the Matchaponix Brook upstream of the sampling site at Spotswood.

The Delaware and Raritan Canal runs through the study area but was not considered a part of the study area for this project. Princeton Plasma Physics Lab (NJ0023922) discharged 0.01 cfs to the canal from 1994-97. American Cyanamid Corporation (NJ0005541) discharged 0.10 cfs to Duck Pond Run that empties into the canal from 1991-97. The mean daily flow coming into the Raritan River basin from the Delaware River basin at the basin divide in the Delaware & Raritan Canal at Port Mercer gauging station was 134 cfs from 1990-97. Water is diverted from the canal at Ten Mile Lock into the Millstone River near the confluence with the Raritan River. The mean daily flow diverted from the canal to the Millstone River for 1991-97 was 18.9 cfs. The mean daily flow diverted from the canal to the river in the growing season months is 11.4 cfs. The permitted loads from the 2 permitted facilities are a minor portion of the total loads in the canal. The portion of the permitted loads in the canal being discharged to the Millstone River is considered to be negligible. The remaining flow in the Delaware and Raritan Canal empties into the Raritan River downstream of the Raritan River at Bound Brook site (01403300) – a portion of the basin outside of the study area.

At least one permitted source of wastewater exists upstream from 18 of the 21 instream water quality sampling sites studied. The Neshanic River, Manalapan Brook and Millstone River near Manalapan are the only sites without permitted sources discharging upstream. The Millstone River, South Branch Raritan River, North Branch Raritan River, Matchaponix Brook and main stem of the Raritan River receive direct discharges from 31, 19, 17, 3 and 3 facilities respectively.

Total permitted point-source discharge was compared to stream flow statistics upstream of sampling sites. The most significant impact of permitted point sources on a stream will occur at baseflow conditions when the percentage of streamflow consisting of effluent is highest. Average flow from point sources above the sampling site ranged from zero to 45 percent of baseflow, as defined by the 90th percentile flow duration at the sampling sites. Five sites-- Beden Brook, Matchaponix Brook, Millstone River at Blackwells Mills, Millstone River at Grovers Mill, and Raritan River at Bound Brook-- had permitted point source flows exceeding 25 percent of baseflow; 45, 40, 32, 28, and 27 percent respectively. Approximately 170 cfs is withdrawn from the Raritan River for water supply, 2 miles upstream from the sampling site at Raritan River at Bound Brook (01403300). If the 170 cfs were not withdrawn from the river, 24 percent of baseflow would consist of permitted effluent at the Raritan River at Bound Brook.

Streams in the piedmont portion of the study area yield the lowest flows at baseflow conditions (page 14). The stream reach upstream from the Beden Brook site has one of the lowest yields of flow at baseflow conditions, leading to point sources constituting a relatively high percentage of stream flow.

Three small facilities discharge to streams that drain into large impoundments. The Hagedorn Center for Geriatrics (NJ0022144) discharged 0.04 cfs to Spruce Run and Union Township Elementary School (NJ0024091) discharged 0.004 cfs to Mulhockaway Creek during the study period. Both of these streams drain into Spruce Run Reservoir. Time-of-travel (TOT) through Spruce Run Reservoir is slow enough that the load entering the reservoir from the two point sources, discharging a total of 0.044 cfs will be insignificant by the time the discharge reaches the reservoir outlet. A combination of the capacity of the reservoir and TOT from point of entry to the outlet of the reservoir makes the point source loads insignificant to the total load leaving the reservoir. The same assumption is made for the 0.0003 cfs discharged by Goldmine Estates Water System (NJ0063002) and its small load to Budd Lake.

During the study period 3 municipal facilities, 4 industrial facilities, and 2 water treatment plants stopped reporting discharges (**table 24**). Discharge from Peapack & Gladstone STP (NJ0021881) and Bedminster STP (NJ0028495) was transferred to Environmental Disposal Corporation (NJ0033995). All three of these facilities are located in the North Branch Raritan River basin upstream of the Burnt Mills sampling site and continued to discharge to North Branch Raritan River upstream of the sampling site. Gold Mine Estates Water System (NJ0063002) stopped discharging 0.0003 cfs to Budd Lake in 1997. Three industrial facilities did not report any discharges after 1994. Carter Wallace (NJ0002666), and Johnson & Johnson (NJ0026140) are upstream from the Millstone River at Blackwells Mills site, and Gibson Tube Co (NJ0064700) is upstream from Raritan River at Bound Brook. The average discharges were 0.17, 0.10, and 0.05 cfs at the three facilities respectively. The Raritan -Millstone (NJ0000965) and Hightstown (NJ0003832) water treatment plants stopped reporting discharges of 0.06 cfs in 1994 and 1995 respectively.

During the study period, 4 municipal and 3 industrial facilities began discharging (**table 24**). Sarnoff Corporation (NJ0000272) began reporting 0.10 cfs discharge to the Millstone River upstream of the Blackwells Mills sampling site in 1995. Fina Oil and Chemical Co. (NJ0089168) did not report any discharge until reporting 0.001 cfs in 1997. Hi-Speed Checkweigher Co. Inc. (NJ0105279) began discharging an average of 0.1 cfs to Drakes Brook, upstream of South Branch Raritan River at Middle Valley, in 1994. Freehold Water Treatment Plant (NJ0029190) began reporting an average of 0.0005 cfs discharged upstream from the Matchaponix Brook sampling site in 1993. Oxbridge Treatment Plant (NJ0067733) began discharging an average of 0.03 cfs to Pike Run upstream from Millstone River at Grovers Mill. Cherry Valley Sewage Treatment Plant (NJ0069523) began discharging 0.09 cfs to Beden Brook, upstream from the sampling site, in 1993. Glen Meadows/Twin Oaks Sewage Treatment Plant (NJ0100528) began discharging 0.01 cfs to South Branch Raritan River.

Average annual discharges at some facilities varied from year to year. The water treatment plants were the most variable as a group. Two facilities varied from 0 to 0.2 cfs in any given year. Average annual discharge at another 3 water treatment plants varied by orders of magnitude from less than 0.001 cfs to 0.1 cfs during the study period. Average annual discharge from the Raritan Township MUA-Flemington peak flow facility (NJ0028436) varied from 0.0005 to 1.4 cfs. Wilson Color Inc. (NJ0003051) did not report any discharge in 1997. Bristol Meyers Squibb (NJ0000795) discharged 0.08 cfs from 1991 to 1993 and did not report discharge again until 1997. FMC Corporation (NJ0027731) did not report any discharges in 1993 or 1994. Also, Firmenich Inc. (NJ0031445) did not report discharge in 1991 or 1995.

The largest discharge from point sources from within the Raritan Basin comes from the two outfalls of the Middlesex County Utilities Authority. One outfall discharges to the North Channel of the Raritan River and the other discharges directly to the Raritan Bay. The total discharge from these two outfalls was about 200 cfs. Since the discharges are downstream of all the sampling locations in the NJDEP/USGS Cooperative Network, the discharge is not considered in this report.

Load

The point source load from permitted facilities was computed primarily from discharge quantity and quality data obtained from the NJDEP Discharge Monitoring Report database. The database, however, does not contain data for all constituents at all the facilities. Some facilities collect additional data, which are not included in the NJDEP database. Omni obtained additional data from these facilities. When no data were available, constituent concentrations were estimated from data at similar facilities or from scientific literature. Monthly data were used to compute an average annual load at each facility for each year and for the 1991-97 period (**table 24)**.

The effluent loads remained fairly constant from 1991-97 at most of the permitted facilities. Changes occurred at the 17 facilities listed in the previous section that did not discharge each year and at 6 other facilities believed to have upgraded treatment of effluent based on substantial changes in reported concentrations. The effluent from two facilities in the North Branch Raritan River basin was transferred to a third facility resulting in improved treatment and a decrease in loading to the stream. Some facilities also showed an increase in load over the study period caused by an increase in flow. Some of these changes in effluent quality resulted in changes in the instream component of total load at some sampling sites (**table 23**).

Effluent loads at six facilities changed as a result of upgrades in treatment. Effluents loads of BOD, TKN, TOC, TP, and TSS decreased. Loads of NO2+NO3 increased while TDS load generally remained unchanged. The six facilities with upgraded treatment include Town of Clinton WWTP (NJ0020389), Hagedorn Center for Geriatrics (NJ0022144) and East Windsor Water Pollution (NJ0023787) in 1993, North Princeton Developmental Center (NJ0022390) in 1994, Bernardsville STP (NJ0026387) in 1992, and Mountainview Correctional Institution (NJ0028479) in 1992 and again in 1997. Facility NJ0022144 discharges to Rocky Run upstream from the Spruce Run sampling site. Facilities NJ0020389 and NJ0028479 discharge to South Branch Raritan River and Beaver Brook upstream from the South Branch Raritan River sampling sites at Stanton and Three Bridges. Facility NJ0026387 discharges to Mine Brook upstream from the North Branch Raritan River at Burnt Mills sampling site. Facility NJ0022390 discharges to Rock Brook upstream from the Beden Brook sampling site. Facility NJ0023787 discharges to Millstone River upstream from the Grovers Mill sampling site. Effluent loads from Bernardsville STP (NJ0028495) and Peapack/Gladstone STP (NJ0021881) were transferred to Environmental Disposal Corporation (NJ0033995) in 1994 and 1996 respectively. The effluent load is discharged to the same stream; however, improved treatment at EDC has lead to a reduction in permitted loads to the stream.

Effluent loads at two facilities increased substantially toward the end of the study period. Loads from Readington-Lebanon STP (NJ0098922) increased as a result of a steady increase in effluent flow from 1991 to 1995 and a more substantial increase in flow from 1995 to 1996. Loads for most constituents more than doubled from 1991-95 to 1996-97. The facility discharges to Rockaway Creek upstream from the Rockaway Creek sampling site. Union Township Elementary School (NJ0024091) doubled its effluent load of TSS, BOD and TOC from 1991-94 to 1995-97. The loads are small however and did not have a significant influence on total load at the Mulhockaway Creek sampling site.

Permitted Load at Sampling Sites

The contribution of permitted load to total instream load was computed at the sampling sites each year. The permitted component of instream-load at the sampling point is dependent on four factors. The amount of the permitted load that reaches the sampling site is determined by (1) the amount of load discharged to the stream, (2) the distance between the discharge point and the sampling point, (3) the average velocity through the stream reach and (4) the attenuation rate of the constituent. The USGS computed the velocities and distances along stream reaches and Omni Environmental provided the constituent attenuation rates. The chemical and physical reactions of a constituent in the water column influence the attenuation rate. Attenuation rates increase for most constituents as water temperatures increase. Permitted loads were computed at both 20 degrees and 5 degrees Celsius for this study.

$$\mathrm{Load}_{site} = \mathrm{Load}_{pt} \times e^{(-kt)}$$

where
Load_{site} = load at sampling site (lb/day)
Load_{pt} = load discharged by the point source (lb/day)
k = first order decay rate coefficient, (/day)
t = time of travel from upstream to downstream location (days)

Average annual effluent data were used to compute average instream loads from permitted facilities at each of the sampling sites for each year and for the entire 1991-97 period. The permitted portion of total instream load was computed for three flow conditions; 90th, 50th and 25th percentile flows. The average permitted load for each year was evaluated to identify changes during the study period. The permitted load for most of the constituents at most sampling sites did not change noticeably. When changes occurred, the permitted load representing the most recent period was used in the analysis.

Criteria were established for determining whether the permitted load from 1991-97 or from a later subset of this period was used in the analysis. The permitted portion of total instream load in 1991 was compared to the permitted load in 1997. When the percent change was at least 50 percent, the data were evaluated more closely. When a sudden change occurred, the average permitted load during the years before the change was compared to the average permitted load after the change. The average permitted load for the later period was used when the change was at least 50 percent and the permitted load accounted for more than 10-15 percent of total instream load — depending on the constituent. When a gradual change occurred in permitted load through the period, an average permitted load for the entire period was used.

Analysis of variance (ANOVA) on the ranks of sampled loads was used to test for significant differences in sampled loads at sites before and after the upgrades. If a significant difference exists, the relation of total instream load to streamflow will vary. Test results showed total instream load of one or two constituents varied significantly at 4 sites. Results of the test showed that total instream loads of TKN and TP at North Branch Raritan River at Burnt Mills were significantly lower after the treatment plant upgrades in the basin. Total instream phosphorus loads at South Branch Raritan River at Stanton were significantly lower after upgrades. Total instream BOD loads are significantly higher at Rockaway Creek at Whitehouse in 1996-97 than in 1991-95. TKN and TOC loads at Lamington River at Burnt Mills are significantly higher in 1996-97 than in 1991-95.

Tobit regression analysis of total instream load versus flow was rerun at the four sites with significant changes in sampled loads after treatment facility upgrades. Total instream loads of TP at SB. Raritan River at Stanton and North Branch Raritan River at Burnt Mills and TKN at North Branch Raritan River at Burnt Mills were lower during 1995-97 then 1991-94. Total instream load of BOD at Rockaway Creek at Whitehouse was higher in 1996-97 then in 1991-95 (**table 9**). The ANOVA results for sampled loads of TKN and TOC at North Branch Raritan River at Burnt Mills indicate a significant increase in total instream load from 1991-95 to 1996-97. The Tobit regression analysis for TOC, however, did not produce a valid model using the 10 samples available for the 1996-97 period. The total instream loads for TKN in table 8 is for the 1991-97 period are somewhat less than the total instream load for 1996-97. Therefore the portion of total load originating from permitted sources is higher than the amount shown in the stacked bar charts and tables.

Instream Trends Attributed to Changes in Treatment Plant Effluent

Stream sampling sites with trends in data from 1991-97 were studied to look for a relation between the trend and changes in effluent discharged upstream of the sampling site. Changes in effluent loads were caused by upgraded effluent treatment and by increases in the volume of effluent discharged. The instream concentrations collected before the change were compared to data collected after the change by using the ANOVA test on the ranked data.

Significant trends observed in instream concentrations and loads of TKN and total phosphorus from 1991-97 at some sampling sites (**table 2)** were found to be related to upgraded treatment of effluent during the period. Substantial decreases in total phosphorus loads discharged by Clinton Township STP (NJ0020389)--6.3 miles upstream-- and Mountainview Correctional Institution (NJ0028487)--3.1 miles upstream--beginning in 1994 and 1992 respectively were found to be related to significant decreases in instream loads at South Branch Raritan River at Stanton. The effluent load data for Mountainview Correctional Institution indicate treatment upgrades in 1992 and in 1997. Significant decreases in total phosphorus and TKN concentrations at North Branch Raritan

River at Burnt Mills were found to be related to changes at three facilities in the basin. The Treatment at Bernardsville STP (NJ0026387) was upgraded in 1992. Effluent from Bernardsville STP (NJ0028495) and Peapack/Gladstone STP (NJ0021881) was transferred to Environmental Disposal Corporation (NJ0033995) in 1994 and 1996 respectively. Loads discharged to the stream were lowered as are result of the transfer. Negative trends in TKN and TP at Beden Brook and Millstone River at Grovers Mill are not attributed to upgrades at facilities upstream of these sites.

Trends in instream concentrations at other sites were observed but were not found to be related to changes in the quality of effluent discharged to the stream (**table 2**). The trends observed from 1991 to 1997 were not found to be significantly related to changes in the quality of effluent discharged to the stream but may be a contributing factor to the trend. A significant decreasing trend in total phosphorus concentrations at low flow conditions at Millstone River at Grovers Mill may be influenced by decreases in total phosphorus loads discharged by East Windsor Water Pollution (NJ0023787) and Hightstown Advanced Water Treatment Plant (NJ0029475) beginning in 1992. Significant decreasing trends in total phosphorus, TKN and TOC at the Beden Brook sampling site may be influenced by upgraded treatment at the North Princeton Developmental Center (NJ0022390) in 1993.

Adjustment for Withdrawal

The Elizabethtown Water Company withdraws water for pubic supply from intakes on the Raritan and Millstone Rivers near the confluence of these two rivers. During the period 1991-97, an average of 170 cfs or 110 million gallons per day was withdrawn. This withdrawal affects the streamflow and constituent loads observed at the Raritan River at Bound Brook sampling site, located 3.1 miles downstream. The streamflow just upstream from the withdrawal is supplemented by a mean daily flow (1991-97) of 18.9 cfs diverted from the D&R canal to the Millstone River. The diversion represents 14 percent of the flow in the canal including a small percent of the 0.11 cfs discharged to the canal by 2 permitted sources in the Princeton area. The portion of the permitted load diverted to the Millstone River is considered to be insignificant and is not considered in the estimate of permitted load in the river at the Elizabethtown withdrawal.

Total instream flow on the Raritan River just downstream of the confluence with the Millstone River at the 90th, 50th and 25th percent flow durations, is 303 cfs, 696 cfs and 1,330 cfs, respectively. Withdrawals by the Elizabethtown Water Company account for 56 percent, 24 percent and 13 percent of the streamflow at the 90th, 50th and 25th percent flow durations. A portion of the total, permitted and nonpermitted load is removed from the stream by this withdrawal.

The total instream load including the permitted and nonpermitted portions of the load was estimated at the mouth of the Millstone River and on the Raritan River just upstream from the Millstone River at each flow condition. Permitted and nonpermitted loads were estimated from loads at the Millstone River at Blackwells Mill, and Raritan River at Manville sampling sites. Permitted loads were adjusted by using time of travel and attenuation rates between the sampling sites and the confluence. Nonpermitted loads were estimated at the confluence by applying the observed nonpermitted load per square mile at the sampling sites to the intervening area.

The permitted point source load at the Raritan River at Bound Brook sampling site was adjusted for the Elizabethtown withdrawal. The permitted point source portion of total instream load removed by the withdrawal was removed from the estimated permitted load at the sampling site. The river was assumed to be evenly mixed at the point of withdrawal. A portion of the total instream load in the river is removed when the water is withdrawn. Given the flow and load in the river, a load per unit of flow was estimated at the point of withdrawal. The amount of load removed from the river was calculated from the average flow withdrawn and the load per unit flow. Using the assumption that the river is well mixed, the percent of total load consisting of permitted load was used to estimate the amount of permitted load removed from the river.

The Delaware and Raritan Canal runs through the study area but is not considered a part of the study area. Princeton Plasma Physics Lab (NJ0023922) discharged 0.01 cfs to the canal from 1994-97. American Cyanamid Corporation (NJ0005541) discharged 0.10 cfs to Duck Pond Run that empties into the canal from 1991-97. The mean daily flow coming into the Raritan River basin from the Delaware River basin at the basin divide in the Delaware & Raritan Canal at Port Mercer gauging station was 134 cfs from 1990-97. Water is diverted from the canal at Ten Mile Lock into the Millstone River near the confluence with the Raritan River. The mean daily flow diverted from the canal to the Millstone River for 1991-97 was 18.9 cfs. The mean daily flow diverted from the canal to the river in the growing season months is 11.4 cfs. The permitted loads from the 2 permitted facilities are a minor portion of the total load in the canal. The portion of the permitted loads in the canal being discharged to the Millstone River is considered to be negligible. The remaining flow in the Delaware and Raritan Canal empties into the Raritan River downstream of the Raritan River at Bound Brook site (01403300)-- a portion of the basin outside of the study area.

Time of Travel

The time required for the effluent discharged from permitted facilities to reach the sampling site downstream is an important factor in determining the portion of load at the sampling site contributed by the facility. The time-of-travel (TOT) between sites depends on distance and velocity of the water through the stream reach. The water velocity depends on many factors including volume of streamflow, general morphology of the river and particularly the amount of ponding caused by dams or other manmade works (Jobsen, 1996). The best estimates of travel time are from actual data collected by timing the transport of a tracer along a stream reach (**fig. 14**). However, when no data exists, a prediction equation can be developed from base characteristics (Jobsen, 1996).

Velocities and TOT along stream reaches with multiple TOT studies were compared between subbasins and flow conditions (**table 22**). Velocities and TOT at high flow were 2.4 to 3.5 times higher than velocities and TOT at low flow. Average velocity at low flow was lowest --0.24 ft/sec -- along the Millstone River and highest 0.55 - 0.56 ft/sec along the South Branch Raritan and mainstem Raritan Rivers. At median flow, velocities were over 0.90 ft/sec on the mainstem Raritan, South Branch Raritan, and Lamington River subbasins. The lowest average velocity was 0.52 ft/sec on the Millstone River. At high flow conditions, average velocities were from 1.27 to 1.44 ft/sec on the North Branch Raritan, South Branch Raritan, mainstem Raritan and Lamington River subbasins. The average velocity on the Millstone River was 0.83 ft/sec.

Distances along stream reaches in the study area were derived from the National Hydrologic Dataset GIS coverage. Distances from permitted point sources to sampling sites and between sampling sites were needed to compute TOT. The longest stream reach in the study area is 65.2 miles. This stream reach is between the upstream most permitted source on the Drakes Brook --a tributary to the South Branch Raritan River -- and the most downstream sampling site on the Raritan River at Bound Brook. The longest distances from permitted sources in other subbasins to the Raritan River at Bound Brook sampling site are 47.4 miles, 38.3 miles, 33.4 miles and 30.6 miles, in the Lamington, Stony Brook-lower Millstone, North Branch Raritan, and the upper Millstone Rivers respectively.

Travel times at all three flow conditions are slowest along the Stony Brook-lower Millstone River reach and fastest along the North Branch Raritan River reach. At low flow conditions TOT travel from the most upstream permitted point source on the Stony Brook to the Raritan River at Bound Brook is 19 days. Velocities along the Stony Brook average 0.1 ft/sec and the velocity through Carnegie Lake is 0.04 ft/sec at low flow. The TOT at low flow along the North Branch Raritan River reach was 5.0 days. At high flow conditions, TOT along the Stony Brook-lower Millstone River reach was 5.2 days and 1.5 days along the North Branch Raritan River reach.

Time-of-Travel Studies

The USGS conducted TOT studies along stream reaches in the Raritan River basin in the 1960's and 1970's. Fluorescent Rhodamine dye was used as a water tracer to quantify transport and dispersion along the Drakes Brook, South Branch and North Branch Raritan Rivers, Lamington River, Millstone River and Raritan River mainstem (written communication, Edward Pustay, USGS). Fifty of the 62 stream reaches studied have more than one TOT study at 2 or more flow conditions. Some of the reaches studied however, are subreaches of a longer reach. The lowest flow conditions studied in a reach are typically between the 80th and 50th percentile and the highest flow is typically between the 50th and 25th percentiles. Regression equations were developed for reaches with multiple studies to predict velocity at different flow conditions. Ordinary least squares regression was performed on the log base-10 transformed discharges and velocities.

Two to four time-of-travel studies were conducted along stream reaches on Drakes Brook, South Branch and North Branch Raritan Rivers, Lamington River, the Raritan River mainstem, and the Millstone River downstream from Carnegie Lake. Stream velocity was estimated at the 90th, 50th, and 25th flow durations along these stream reaches from the OLS regression equations (**fig. 14**). Average distance weighted velocities were used between a point source and a sampling site, and between sampling sites when more than one TOT study reach exists along the stream reach. If the point source and sampling site exist within one TOT study reach, the velocity computed for the entire reach was used.

A single time-of-travel study is available on the upper Millstone River, 2 reaches on the Matchaponix Brook and through Carnegie Lake on the Millstone River. For these reaches, an estimate of velocity at the three flow conditions was derived from a procedure developed by the USGS (Jobson, 2000). The velocity, flow, and average channel width from the study and the slope (S) of the reach are needed to predict velocities at other flow conditions in the reach. The Manning's resistance equation is used as a basis for computing velocity through a stream reach. The manning equation relates discharge, Q, to measurable quantities as:

$$Q=1/n\ A(A/P)^{0.667}\ S^{\ 0.5} \quad (1)$$

in which Q is discharge, n is Manning's resistance coefficient, A is the active flow area, P is wetted perimeter, and S is slope. This equation is used to solve for the active flow area of the reach during the TOT study and another equation is used to estimate channel width during the TOT study, if not available. The method developed by Jobson (Jobson, 2000) defines an inactive flow area that does not change as flow changes. The inactive area is computed by subtracting the total area (Q/velocity) from the active area. The width and active area are recomputed for any flow event and an estimated velocity is calculated by dividing the event flow by the total area (active + inactive area).

Time-of-Travel through lakes

The Round Valley Reservoir, Spruce Run Reservoir, and Budd Lake are the largest water bodies in the study area. No TOT data are available through these lakes. Round Valley and Spruce Run Reservoirs are the only water supply reservoirs in the basin. Round Valley is a pump-storage reservoir with a maximum capacity of 55.4 billion gallons with no streams flowing into the impoundment. Water is pumped into the reservoir from South Branch Raritan River at Hamden and released to the South Branch Raritan River and Rockaway Creek to supplement releases from Spruce Run Reservoir during periods of low flow. Mulhockaway Creek and Spruce Run feed

Spruce Run Reservoir. The maximum capacity of Spruce Run Reservoir is 11.82 billion gallons, with contents varying from 11.82 to 4.28 billion gallons during 1991-97. Spruce Run releases most of the water needed to supplement flow in the South Branch Raritan River for water purveyors downstream. Budd Lake is located at the headwaters of the South Branch Raritan River basin and is used for recreation. Budd Lake has no regulated releases for water supply.

Three small facilities discharge to streams that drain into large impoundments. The Hagedorn Center for Geriatrics (NJ0022144) discharged 0.04 cfs to Spruce Run and Union Township Elementary School (NJ0024091) discharged 0.004 cfs to Mulhockaway Creek during the study period. Both of these streams drain into Spruce Run Reservoir. One small permitted point source Gold Mine Estates Water System (NJ0063002) discharges 0.0003 cfs, to an unnamed tributary that drains into Budd Lake. Time-of-travel through Spruce Run Reservoir is slow enough that the load of nonconservative constituents entering the reservoir from the two point sources, discharging a total of 0.044 cfs, will be insignificant by the time the discharge reaches the reservoir outlet. The volume of the reservoir allows for sufficient dilution of conservative constituents. A combination of the capacity of the reservoir and TOT from point of entry to the outlet of the reservoir makes the point source loads insignificant to the total load leaving the reservoir. The same assumption is made for the 0.0003 cfs and small load entering Budd Lake.

Carnegie Lake, Lake Solitude, and Ravine Lake are located along the Millstone, South Branch Raritan, and North Branch Raritan Rivers respectively. A single TOT study exists through Carnegie Lake and two studies at two different flow conditions exist through Lake Solitude. No TOT data are available through Ravine Lake.

Carnegie Lake from the upstream end on the Millstone River to the dam is 2.2 miles long with an approximate average width of over 600 feet. The single TOT study through Lake Carnegie found an average velocity of 0.04 ft/s at approximately the 60th percentile flow. The velocity through Carnegie Lake was not included in the regression analysis because it is much lower than the velocities in the stream reaches. The prediction of velocity from the regression equation was an order of magnitude higher (0.4 vs. 0.04) than the actual velocity measured. The 0.04 ft/s velocity was used to compute TOT through Carnegie Lake for both the 50th and 90th percentile flow conditions. A velocity of 0.07 ft/s was computed for the 25th percentile flow from the method described in Jobson, (2000).

Lake Solitude, located downstream from the South Branch Raritan River at High Bridge gauging station, is 0.5 miles long with an average width of approximately 200 feet. Two TOT studies were conducted at approximately the 60th and 40th percentile flows. OLS regression was used to estimate velocities through the lake at the 90th, 50th and 25th percentile flows. Average velocity ranged from 0.08 ft/s at 90th percentile flow to 0.45 ft/s at 25th percentile flow.

The dam on Ravine Lake is located at the gage on the North Branch Raritan River near Far Hills (01398500). The lake is 1.04 miles long and approximately 300 feet wide. No TOT data are available for this reach. Estimates of velocity were based on the TOT studies through Lake Solitude. The drainage area and flow through Ravine Lake is 1/3 that of Lake Solitude. Velocities were estimated to be 0.04, 0.10 and 0.2 ft/s at 90th, 50th and 25th percentile flows respectively.

Estimating Time-of-Travel

Time-of-travel was estimated along stream reaches without any TOT data. Results from three estimation methods were compared: 1) a prediction equation developed by the USGS (Jobson, 1996); 2) a modification to the existing prediction equation; 3) a new prediction equation based on velocities in the study area and 7 explanatory variables. Permitted point sources discharge to 21 small streams without TOT studies in the study area. Sixteen of these streams are located in the piedmont and highlands physiographic provinces and 5 are located in the coastal plain. The drainage areas of these tributaries range in size from 2.93 mi^2 (Cuckles Brook) to 50.0 mi^2 (Beden Brook).

A study by Jobson compiled velocities and hydraulic data for more than 980 subreaches for about 90 different rivers in the United States representing a wide range of river sizes, slopes and geomorphic features (Jobson, 1996). Four explanatory variables were available in a sufficient number of reaches for regression analysis with velocity. The variables included drainage area (D_a), reach slope (S), mean annual river discharge (Q_a), and the discharge of the event studied (Q).

The prediction equation (2), developed by Jobson (Jobson, 1996) has an r-squared value of 0.70. The equation accounts for 70 percent of the variation in velocity and was used to compute stream velocity at the 90th, 50th and 25th percentile flow durations for all reaches in the basin. The velocities predicted along reaches with existing TOT data, were used for comparative purposes. Velocities were converted to English units for this study.

$$\text{Velocity} = 0.094 + 0.0143 \times (D'_a)^{0.919} \times (Q'_a)^{-0.469} \times S^{0.159} \times Q/D_a \qquad (2)$$

where
Q is the instantaneous streamflow in cubic meters per second
Q_a is the annual average flow in cubic meters per second
$Q'_a = Q/Q_a$
D_a is the average drainage area of the stream reach, in square kilometers
g is acceleration of gravity
$D'a = D_a^{1.25} \times g^{0.5} / Q_a$
S is slope in meters per meter

Drainage areas were derived from GIS coverages and from USGS quad maps containing the original delineated drainage basin divides. Mean annual discharge, 90th, 50th and 25th percentile flows were computed from mean-daily streamflow data at all continuous-record gages. Estimates of these flow statistics were computed at low-flow partial-record sites using MOVE1 correlation analysis. A drainage area adjustment (flow per square mile) technique was used to estimate flows on streams with no flow data available. The flow at nearby sites was divided by drainage area to get an average flow/square mile for the area.

GIS was used to compute distances and slopes along stream reaches. Distances were derived from the USGS National hydrologic dataset coverage. Distances were computed from point sources to stream confluences, point sources to sampling sites, and between sampling sites. Elevation data were derived from digital elevation maps. The USGS National Elevation dataset with 30-meter grid spacing was used to compute the elevation at point source locations, sampling sites, and stream confluences. Slopes were computed from this data.

Comparison of Velocities from Jobson Method to Time-of-Travel Study Velocities

Velocities computed from TOT study data were compared to velocities estimated using the Jobson regression equation (2). In general, the Jobson method is under predicting high velocities and over predicting low velocities in the Raritan River basin. The method did not accurately predict the full range of average reach velocities found in the basin. At 90th percentile flows, average reach velocities from the TOT studies varied from 0.20 ft/s along Drakes Brook tributary, to the South Branch Raritan River to 0.8 ft/s on the South Branch Raritan River. Velocities from the Jobson method varied from 0.35 ft/s to 0.55 ft/s. The average percent difference for all reaches showed the velocities from the Jobson method were 4.2 percent higher than velocities from TOT studies. The largest difference between velocities from TOT studies and the Jobson method along a reach was -39 percent to +126 percent.

At 50th percentile flows, average reach velocities from the TOT studies varied from 0.40 ft/s on Drakes Brook tributary to the South Branch Raritan River to 1.3 ft/s on the South Branch Raritan River and mainstem Raritan River. Velocities from the Jobsen method varied from 0.4 ft/s to 0.65 ft/s. On average for all reaches, the Jobsen method under predicted velocities by 32 percent. The largest difference between velocities from TOT studies and the Jobson method along a reach was -56 percent to +28 percent. The average difference is -32 percent. At 25th percentile flows, average reach velocities from TOT studies vary from 0.68 ft/s on Matchaponix Brook to 2.0 ft/s on the Lamington and mainstem Raritan Rivers. Flows along all reaches were under estimated, from -67 percent to -29 percent. The average difference is -51 percent.

The Jobson method for predicting stream velocities was modified to better fit the TOT data in the Raritan River basin. A least squares linear regression equation was developed between velocities computed from TOT studies in the Raritan River basin and the variables used in Jobsen's equation. Velocity was regressed against a dimensionless variable created by multiplying the variables from the Jobson method $[(D'_a)^{0.919} \text{ X } (Q'_a)^{-0.469} \text{ X } S^{0.159} \text{ X } Q/D_a]$ (**fig. 14**). As a result, the equation is essentially the same, except the slope and constant vary from equation 2.

$$\text{Velocity} = -0.0487 + 0.0569\,[(D'_a)^{0.919} \text{ X } (Q'_a)^{-0.469} \text{ X } S^{0.159} \text{ X } Q/D_a\,] \qquad (3)$$

The modified method is better at predicting the variability in velocities existing throughout the basin, however percent differences were still large.

Regression Methods Selected

Seven explanatory variables were considered in an exploratory analysis to find a regression model with the best ability to predict velocity. A linear relation was developed between TOT velocity and seven explanatory variables. The 7 variables were chosen because the data were available for all reaches studied and the variables were found to relate significantly to velocity in the study by Jobson, (1996). The variables used in the analysis were event flow (Q), average flow (Q_a), drainage area (D_a) and the four variables used in the Jobson regression equation, (Q/Qa, Q/D_a, slope, and $D_a^{1.25}$x $9.81^{0.5}/Q_a$). A log transformation of the explanatory variables and velocity resulted in a better model with higher r-squared value, lower Mallow's CP and smaller residuals.

Pearson correlation analysis was used to examine the relation between velocity and each independent variable and the relation between independent variables. All 7 independent variables were found to be significantly related ($p<0.05$) to velocity. This indicates that each variable may be useful in estimating velocity. A comparison of pairs of independent variables indicated some pairs have high correlation coefficients and a low probability level of significance. Highly correlated variables were not used in the same model.

A procedure in SAS called the R-square selection method was used to summarize information on the estimated coefficients from the 7-variable model to predict a suitable subset of variables for a final model (SAS, System for regression, 1995). A two variable model appeared to be the best choice. The four best 2-variable models were evaluated by looking at statistics describing the model's prediction quality and multi-collinearity: R squared value, mallows CP, Press statistic and VIF. The 2 variable models showed the best combination of low mallow's CP, press, standard error as measured by the coefficient of variation and VIF and a high r-square. A low mallows CP and low VIF were the statistics most influential in choosing a model.

A stepwise regression procedure was the second approach used to choose the best models (SAS Institute Incorporated, 1995). This method starts with the best univariate model and adds variables one by one that result in the largest increase in R-square. Variables with a greater than 5 percent probability level of significance were removed from the model. The models chosen by this method were not necessarily the best as defined by the statistics that describe the model's prediction quality and multicollinearity. Models were selected based on the summary from the R-square selection method, analysis of multicollinearity, and the stepwise method.

Two models were developed for predicting velocity in the Raritan River basin. One model was chosen to predict velocity along reaches in the piedmont and highlands physiographic provinces and a second model was chosen to predict velocities along reaches in the coastal plain. The first model was developed using data from 37 TOT studies on stream reaches less than 50 mi^2 in the highlands province. TOT studies along smaller stream reaches were chosen because all stream reaches needing predictions of velocities are less than 50 mi^2. Three of the 2-variable models were very similar statistically and resulted in similar predictions. A model using the variables event- flow divided by drainage area and average flow was found to give slightly lower differences between estimated velocities and actual TOT study velocities. This was the 2-variable model with the lowest mallows CP, VIF and press statistic, and highest r-square. This model predicts velocities more accurately than was predicted by the Jobson procedure and modifications to the procedure. The model equation (4) was used for predicting stream velocities in 17 tributaries to the N.B and South Branch Raritan Rivers, Lamington River, Millstone River and mainstem Raritan River located in the highlands and piedmont physiographic provinces. R squared is 0.81.

$$\text{Velocity} = 0.352 \times Q/D_a^{0.743948} \times Q_a^{0.191575} \quad (4)$$

This equation is better at predicting the variability in velocities existing throughout the highlands and piedmont portion of the basin than the equation from the Jobson method. At 90th percentile flows, average predicted velocities varied from 0.25 ft/s to 0.80 ft/s along reaches in the basin compared to 0.20 to 0.80 ft/s for TOT studies. The largest difference between velocities from TOT studies and those predicted from this equation along a reach was -29 percent to +39 percent. At 50th percentile flows, average predicted velocities varied from 0.47 to 1.26 ft/s, compared to 0.40 to 1.5 ft/s for TOT studies. The largest difference between velocities from TOT studies and those predicted from this method along a reach was -20 percent to +36 percent. At 25th percentile flows, predicted velocities varied from 0.79 to 1.96 ft/s, compared to 0.68 to 2.00 ft/s for TOT studies. The largest differences along a reach were -16 percent to +36 percent. On average for all reaches this method was within 4.8 percent at 90th percentile flow, 6.9 percent at 50th percentile and 7.2 percent at 25th percentile.

A second model was developed to predict velocities on 4 tributaries to the Millstone River in the coastal plain province. The tributaries are located upstream from Carnegie Lake. Not enough TOT data exist from the coastal plain portion of the study area to develop a model for the area. Only 3 TOT studies exist in the coastal plain portion of the study area; one on a Millstone River reach averaging 60 mi^2 and 2 on Matchaponix Brook along reaches averaging 26 and 27 mi^2. The 3 TOT studies from the coastal plain were added to the 37 TOT studies used in the model for the highlands and piedmont tributaries. These 40 TOT studies were used to develop model equation (5).

A 2-variable model using the variables event-flow divided by drainage area and average flow was found to have the best fit to velocity. This model predicts velocities more accurately than was predicted by the Jobson and modified Jobson procedures along the Millstone River. However, this model does not improve upon the Jobson predictions of velocity on the Matchaponix Brook. The second model, equation (5), predicts velocities more accurately then the first model on coastal plain streams.

The model equation (5) was used for predicting stream velocities in 4 tributaries to the Millstone River. R-squared value = 0.75.

$$\text{Velocity} = 0.3505 \times Q/D_a^{0.696969} \times Q_a^{\ 0.192168} \qquad (5)$$

The velocities predicted from the equations were compared to velocities computed from the 3 TOT studies on the Matchaponix Brook and Millstone River. At 90th percentile flow, the velocities predicted for 3 reaches, from point sources to the sampling site, varied from -35 to +30 percent. At 50th percentile flow, estimates varied from -8 to +46 percent. At 25th percentile flow velocities varied from +2.1 to +59 percent. The predicted velocity along the Millstone River TOT study reach upstream of Carnegie Lake varied from -30 percent at 90th percentile flow to +2.1 percent at 25th percentile flow.

The estimated velocities for Millstone River tributaries compared favorably to velocities measured using flow meters along those streams. Stream flow measurements exist at USGS sites on all tributaries in the Millstone River where point sources discharge except Devils Brook.

Attenuation Rates

The load discharged to a stream from a permitted point source will be attenuated for most constituents as the effluent travels downstream. Chloride and TDS typically do not attenuate and were found to behave conservatively in this basin. Loads of these 2 constituents were found to increase at sites further downstream in the basin. The other 6 constituents studied-- BOD, NO2+NO3, TKN, TOC, TP, and TSS-- will attenuate due to biological, chemical, and physical processes in the stream. The reduction of constituent loads between point sources and instream sampling sites is a function of time-of-travel and attenuation rate through the stream reach.

No attenuation rates for TOC were available from Omni Environmental's models or from a literature review. Particulate organic carbon rates from a literature review varied from 0.001 /day to 0.1 /day (written communication, Omni, 2001). TOC load from permitted sources is generally small and not a major concern in the study area. TOC was considered conservative for this study.

Attenuation rates for BOD, NO2+NO3, TKN, TP, and TSS are used in this study. First order decay rates were established from the results of modeling studies completed by Omni Environmental Corporation (Omni). Omni provided average first order decay rates for all stream reaches studied (written communication, Omni Environmental Corporation, 2001). The attenuation rate coefficients were spatially averaged and applied to long stream reaches. The rates vary along each reach and these average rates cannot be appropriately used for shorter distances along the reach. The goal of this project is to estimate the relative impact of permitted sources on total instream load. The average rates for long stream reaches are appropriate for this type of study.

Reducing complicated physical, chemical, and biological processes into one attenuation coefficient should be considered a rough approximation. Since this study is a "screening" type of approach, the simplification of many of the complex processes is appropriate. This project will assist in determining the key sources of pollutant loads in the Watershed; however, far more advanced modeling techniques must be used after the critical issues are identified (written communication, Omni Environmental Corporation, 2001).

Attenuation rates for both growing and nongrowing seasons were analyzed in this study. A growing season rate at 20 degrees Celsius was used for the primary calculation and analysis of permitted load. The results of the load analysis published in this report are for the growing season unless stated otherwise. A nongrowing season rate calculated at 5 degrees Celsius was also applied to the permitted loads for comparative purposes (**table 25**). No attenuation rate is applied to permitted loads of TDS and TOC. The rate for TSS does not vary with changes in water temperature (written communication, Omni, 2001).

Attenuation rates for BOD are generally lower on smaller streams than on larger streams in the basin. The average first order decay rate for BOD at 20 degrees Celsius ranges from 0.4 /day on tributaries in the South Branch Raritan River to 1.5 /day along the mainstem of the South Branch Raritan, North Branch Raritan and Lamington River basins. Growing season attenuation rates for NO2+NO3 vary from 0.1 /day along portions of the South Branch Raritan, North Branch Raritan and Millstone Rivers to 1.0 /day on small tributaries to these rivers. Growing season attenuation rates for TKN vary from 0.0 /day along the downstream portion of the North Branch Raritan River to 1.0 on the Millstone River, 1.1 on the mainstem Raritan River, and 1.2 on Cranbury Brook tributary to the Millstone River. Growing season attenuation rates for TP vary from 0.1 /day along the North Branch Raritan River to 1.6 /day on Cranbury Brook and 1.5 l/day on the Millstone River downstream from Carnegie Lake and on tributaries to the South Branch Raritan River. Growing season attenuation rates for TSS are 0.0 /day along the South Branch Raritan River, the Millstone River downstream from Carnegie Lake and selected tributaries to the South Branch Raritan, North Branch Raritan and Millstone Rivers. The attenuation rate is as high as 2.1 1/ day on Pike Run, a tributary to the Millstone River in the growing season.

Attenuation rates are lower in the nongrowing season then in the growing season. A water temperature of 20 degrees Celsius was used for the growing season. The following equation was used to correct the rates received from Omni for a change in water temperature.

$$K_t = K_{20} \, C^{(T-20)}$$

Where: K_t = Attenuation rate coefficient at water temperature T
K_{20} = Attenuation rate coefficient at 20 degrees Celsius
T = water temperature (degrees Celsius)
C = temperature correction coefficient (1.0 for TSS, 1.05 for other constituents)

Attenuation rates at 5 degrees Celsius are approximately 50 percent less than rates at 20 degrees Celsius for BOD, NO2+NO3, TKN and TP. At 5 degrees Celsius, the decay rate for BOD ranges from 0.2 to 0.7 /day. The rates for NO2+NO3, TKN, and TP range from 0.05 to 0.77, 0 to 0.58, and 0.05 to 0.77 /day, respectively. The rates for TSS are the same at 5 degrees Celsius as at 20 degrees Celsius when the recommended temperature correction coefficient of 1.0 is used.

Summary of Permitted Sources at Sampling Sites

This section summarizes the amount of permitted yield computed at each flow condition at the sampling sites and the percent of total instream yield originating from permitted sources. The summary focuses on the influence of permitted yields at the 7 sites with the highest total yields and at the 7 sites with the highest permitted yields. Permitted loads and permitted yields are summarized for each of the three flow conditions in tables 7-21.

Permitted yields comprise a higher percentage of total yields at low flow than at high flow for all constituents (figs. 15-21). The percentages of NO3+NO2 yields shown in figure 26 are similar to those for the other constituents. The permitted yield of nonconservative constituents is higher at high flow than at low flow at each of the sampling sites. This is caused by higher velocities at high flow leading to a shorter travel time from the point of discharge to the sampling site and therefore less time for attenuation to occur. Nonpermitted yields increase at a faster rate than permitted yields as flows increase from low to high flow.

Ammonia Plus Organic Nitrogen, Total

This section summarizes the amount of TKN yield from permitted sources at the 7 sites with the highest permitted yield and the sites with the highest total yields. Less than 25 percent of the yields at median and high flow at the 7 sites with highest permitted yields are from nonpermitted sources. However, at low flow, from 17 to 48 percent of the total yield at the 7 sites is from permitted sources. The seven sites with the highest total instream yields are not the same 7 sites with the highest permitted yields (**table 7**). The permitted yields at North Branch Raritan River near Chester, Rockaway Creek, and Millstone River at Grovers Mill are the highest permitted TKN yields in the study area (**fig. 15).**

At the 7 sites with the highest permitted point sources, at low flow, --the North Branch Raritan River sites, Rockaway Creek, and Raritan River at Bound Brook-- (**table 7**) have more than 80 percent of total instream TKN load originating from permitted sources. At median flow permitted loads comprise more than 50 percent of total instream load at North Branch Raritan River near Chester and Rockaway Creek. At high flow, North Branch Raritan River near Chester has the highest percentage of total instream load from permitted sources (45 percent).

The sites with the highest total yields at lowflow are the Millstone River sites at Grovers Mill and Blackwells Mill; the South Branch Raritan River sites at Three Bridges, Stanton and Middle Valley; Lamington River at Pottersville and Raritan River at Manville (**table 7**). The Millstone River sites and South Branch Raritan River at Middle Valley have the highest percentage of yield originating from permitted sources (44-48 percent). The permitted yields at the other sites range from 17 to 33 percent of total yield. The Millstone River sites at Grovers Mill and Blackwells Mill and South Branch Raritan River at Three Bridges are among the 7 sites with the highest permitted TKN yields at each flow condition (**table 7**). At median and high flow, the Raritan River at Bound Brook is also among the 7 sites with the highest permitted TKN yields.

The seven sites with the highest total yields at median flow are the same as at low flow except the Raritan River at Bound Brook replaces the Raritan River at Manville. At median flow, 15 to 23 percent of total yields at these sites are from permitted sources. At high flow Matchaponix Brook replaces South Branch Raritan River at Middle Valley as one of the seven sites with the highest yields. The percent of total yield from permitted sources is from 9 to 18 percent at high flow.

Biochemical Oxygen Demand

This section summarizes the amount of BOD yield from permitted sources at the sites with the highest total yields and at the 7 sites with the highest permitted yield. A majority of the yield at these sites is from nonpermitted sources, except at low flow when 59 –60 percent of total instream yield is from permitted sources at two sites. Ninety percent or more of instream yield at median and high flow conditions is from nonpermitted sources at each of the 7 sites with highest total yields. The seven sites with the highest total instream yields are not the same 7 sites with the highest permitted yields (**table 9**). The permitted yields at North Branch Raritan River near Chester, Matchaponix Brook, and Rockaway Creek, are the highest permitted BOD yields in the study area (**fig. 16**)**.**

At lowflow, the sites with the highest total yields are the South Branch Raritan River sites at Stanton, Three Bridges, Middle Valley and High Bridge; Raritan River at Manville, North Branch Raritan River at Chester and Rockaway Creek (**table 9**). The permitted yields at these sites range from 0.03 lb/day/mi^2 at Raritan River at Manville to 2.21 lb/day/mi^2 at North Branch Raritan River at Chester or 0.7 to 59 percent of total instream yield. The permitted yield recorded at North Branch Raritan River at Chester is the highest observed at low flow. At low flow, Matchaponix Brook (1.25 lb/day/mi^2), Millstone River at Grovers Mill (0.88 lb/day/mi^2), and Raritan River at Bound Brook (0.66 lb/day/mi^2) are among the 7 sites with the highest permitted yield, but are not among those sites with the highest total yield. At low flow, more than 33 percent of the total yield originates from permitted sources at 10 of the 21 sites studied, with over 50 percent at North Branch Raritan River near Chester, and Matchaponix Brook sites.

At median flow, the seven sites with the highest yields are the four South Branch Raritan River sites, the two Lamington River sites and Millstone River at Grovers Mill. The permitted yields at these sites range from 0.11 to 0.91 lb/day/mi^2, or 1 to 10 percent of total yields at median flow. The highest permitted yield at median flow is at North Branch Raritan River near Chester (2.3 lb/day/mi^2), a site not among those with the highest total yield. At median flow, more than 30 percent of the total yield originates from permitted sources at 2 of the 21 sites studied: North Branch Raritan River near Chester and Matchaponix Brook.

At high flow, Stony Brook replaces Lamington River at Burnt Mills as one of the seven sites with the highest yields. The permitted yields at these sites range from 0.18 to 0.94 lb/day/mi^2, or 1.0 to 6.0 percent of total yields at high flow (**table 9**). The highest permitted yield at high flow is at North Branch Raritan River near Chester (2.3 lb/day/mi^2), a site not among those with the highest total yield. Millstone River at Grovers Mill was the only site in this group among the 7 sites with the highest permitted yield in the study area. At high flow, less than 22 percent of the total yield originates from permitted sources at all 21 sites studied

Chloride

Total instream loads and yields are summarized for chloride in the section about total instream loads and yields, on page 24. Total instream loads and yields are presented in **table 11**. Permitted and nonpermitted choride load and yield could not be analyzed because no permitted point source data exist for chloride in the study area.

Dissolved Solids, Total

This section summarizes the amount of TDS yield from permitted sources at the sites with the highest permitted yield and the 7 sites with the highest total yields. At median and high flow less than a third of the yields are from permitted sources at 6 of the 7 sites with highest total yields. Half of the yield at Matchaponix Brook is from permitted sources at median flow. More than 60 percent of instream yield at low flow conditions is from permitted sources at 3 sites. Less than 20 percent of the total yield at the other 4 sites is from permitted sources. The seven sites with the highest total instream yields are not the same sites with the highest permitted yields (**table 13**). The permitted yields at Matchaponix Brook (440 lb/day/mi^2), Lamington River at Pottersville (306 lb/day/mi^2), and North Branch Raritan River near Chester 234 lb/day/mi^2), are the highest permitted TDS yields in the study area (**fig. 17**). TDS is a conservative constituent; therefore the permitted yield remains the same at each flow conditon.

At lowflow, the sites with the highest yields are the four South Branch Raritan River sites at Three Bridges, Middle Valley, Stanton and High Bridge, North Branch Raritan River near Chester, Lamington River at Pottersville and Matchaponix Brook (**table 13**). More than 60 percent of instream yields at Matchaponix Brook, Lamington River at Pottersville, and North Branch Raritan River near Chester are from permitted sources. The permitted yields at the other sites range from 6 to 17 percent of total yield. Permitted yields at these sites range from 440 lb/day/mi^2 at Matchaponix Brook, the highest in the study area, to 31.5 lb/day/mi^2 at South Branch Raritan River at Stanton. At low flow, more than 50 percent of the total yield originates from permitted sources at 8 of the 21 sites studied.

At median flow, the seven sites with the highest yields are the three South Branch Raritan River sites at Three Bridges, Middle Valley, and High Bridge, the 2 North Branch Raritan River sites, Lamington River at Potterville and Matchaponix Brook. The percent of yield from permitted sources is 50 percent at Matchaponix Brook, 30 percent at Lamington River at Pottersville, 20 percent at North Branch Raritan River near Chester and less than 10 percent at the other sites. Permitted yields at these sites range from 57.2 to 440 lb/day/mi^2. At median flow, more than 33 percent of the total yield originates from permitted sources at 2 of the 21 sites studied.

The sites with the highest yields at high flow are the 4 South Branch Raritan River sites, the 2 North Branch Raritan River sites, and Lamington River at Pottersville. The percent of total yield from permitted sources ranges from 2 percent at South Branch Raritan River at Stanton to 20 percent at Lamington River at Pottersville. Permitted yields at these sites range from 31.5 to 306 lb/day/mi^2.

At each of the 3 flow conditions, Millstone River at Blackwells Mill (201 lb/day/mi^2), Millstone River at Grovers Mill (158 lb/day/mi^2), Raritan River at Bound Brook (132 lb/day/mi^2), and Lamington River at Burnt Mills (131 lb/day/mi^2), and are among the 7 sites with the highest permitted yield, but not among those sites with the highest total yield. At high flow, less than 20 percent of the total yield originates from permitted sources at all 21 sites studied, except Matchaponix Brook.

Nitrate Plus Nitrite

This section summarizes the amount of NO3+NO2 yield from permitted sources at the sites with the highest permitted yield and at the 7 sites with the highest total yields. The majority of the yield at low and median flows is from permitted sources at 4 of the 7 sites with highest total yields. At high flow the majority of the yield at 2 sites is from permitted sources. The permitted yields at low and median flow are the highest in the study area at 6 of the 7 sites. The permitted yields at high flow are the highest in the study area at 5 of the 7 sites. The seven sites with the highest total instream yields are not the same sites with the highest permitted yields (**table 15**). The permitted yields at Matchaponix Brook, Millstone River at Grovers Mill, and North Branch Raritan River near Chester, are the highest permitted NO3+NO2 yields in the study area (**fig. 18**).

At lowflow, the sites with the highest total yields are Matchaponix Brook, the Millstone River sites at Grovers Mill and Blackwells Mill, North Branch Raritan River near Chester and the South Branch Raritan River sites at Middle Valley, Three Bridges and High Bridge (**table 15**). Permitted yields at these sites range from 13.9 lb/day/mi^2 at Matchaponix Brook, the highest in the study area, to 0.8 lb/day/mi^2 at South Branch Raritan River at High Bridge. At low flow conditions, more than 75 percent of the total yield originates from permitted sources at 8 of the 21 sites studied, including the following sites among the 7 with highest total yield; North Branch Raritan River near Chester, the Millstone River sites at Grovers Mill and Blackwells Mill, and Matchaponix Brook. The permitted yields at the other 3 sites range from 15 to 34 percent of total yield. All sites except South Branch Raritan River at High Bridge are among the 7 sites with the highest permitted NO3+NO2 yields at low and median flow conditions (**table 15**). At low flow, more than 75 percent of the total yield originates from permitted sources at 8 of the 21 sites studied.

At median flow, the seven sites with the highest total yields are the same as at low flow. Permitted yields at these sites range from 16.8 lb/day/mi^2 at Matchaponix Brook, the highest in the study area, to 1.2 lb/day/mi^2 at South Branch Raritan River at High Bridge. The same 4 sites have a majority of yield originating from permitted sources (57 to 82 percent). Permitted yields account for 10 to 24 percent of total yield at median flow at the three South Branch Raritan River sites. At median flow, more than 50 percent of the total yield originates from permitted sources at 6 of the 21 sites studied.

At high flow Beden Brook replaces South Branch Raritan River at Three Bridges as one of the seven sites with with the highest yields. Permitted yields at these sites range from 19.6 lb/day/mi^2 at Matchaponix Brook, the highest in the study area, to 1.4 lb/day/mi^2 at South Branch Raritan River at

High Bridge. The percent of total yield from permitted sources is 70 percent at North Branch Raritan River near Chester and at Matchaponix Brook. The percent of total yield from permitted sources at the other 5 sites is from 8 percent at South Branch Raritan River at High Bridge to 37 percent at Millstone River at Grover Mill. All sites except South Branch Raritan River at High Bridge and Beden Brook are among the 7 sites with the highest permitted NO3+NO2 yields at high flow. At high flow, more than 30 percent of the total yield originates from permitted sources at 6 of the 21 sites studied, with North Branch Raritan River near Chester, Lamington River near Pottersville and Matchaponix Brook exceeding 60 percent.

Organic Carbon, Total

This section summarizes the amount of TOC yield from permitted sources at the sites with the highest permitted yield and at the 7 sites with the highest total yields. No sites studied have more than 33 percent of total instream yields originating from permitted point sources. The yields at all sites are mainly from nonpermitted sources. More than 80 percent of instream yield at low flow conditions is from nonpermitted sources at each of the 7 sites with highest instream yields. At median and high flow from 93 to 99.7 percent of instream load is from nonpermitted sources at the 7 sites with highest total yields. The seven sites with the highest total instream yields are not the same sites with the highest permitted yields (**table 17**). The permitted yields at North Branch Raritan River near Chester (2.4 lb/day/mi^2), Lamington River near Pottersville (2.0 lb/day/mi^2), and Lamington River at Burnt Mills (1.5 lb/day/mi^2), are the highest permitted TOC yields in the study area (**fig. 19**)**.** TOC was treated as a conservative constituent; therefore, the permitted yield remains the same at each flow condition.

At low flow, the sites with the highest yields are Lamington River at Pottersville, Millstone River at Grovers Mill, Raritan River at Manville, and the South Branch Raritan River sites at Stanton, Three Bridges, Middle Valley and High Bridge (**table 17**). Permitted yields at Lamington River at Pottersville and Millstone River at Grovers Mill are 14 to 17 percent of total yields. The permitted yields at the other 5 sites range from 4 to 9 percent of total yield. At low flow, only the permitted yields at Lamington River at Pottersville and Millstone River at Grovers Mill are among the 7 highest permitted TOC yields in the study area (**table 17**). At low flow, more than 30 percent of the total yield originates from permitted sources at 2 of the 21 sites studied; Raritan River at Bound brook and North Branch Raritan River at Burnt Mills.

The seven sites with the highest yields at median flow are the same as at low flow, except Millstone River at Blackwells Mill replaces the South Branch Raritan River at Stanton and Lamington River at Burnt Mills replaces Raritan River at Manville. The percent of total yield from permitted sources is less than at low flow. Permitted sources of instream yields range from 2.5 to 6 percent of the total. At median and high flow the permitted yields at the Millstone River sites at Grovers Mill and Blackwells Mill and the Lamington River sites at Pottersville and Burnt Mills near Pottersville and Raritan River at Bound Brook are among the highest in the study area. At median flow, less than 13 percent of the total yield originates from permitted sources at all 21 sites studied except Millstone River at Grovers Mill (27 percent).

At high flow the sites with the highest yields are the South Branch Raritan River sites at Middle Valley and High Bridge, the Lamington River sites at Pottersville and Burnt Mills, the Millstone River sites at Grovers Mill and Blackwells Mills, and Raritan River at Bound Brook. The percent of total yield from permitted sources ranges from 0.3 to 3.8 percent at high flow at these sites. At high flow, less than 8 percent of the total yield originates from permitted sources at all 21 sites studied.

Phosphorus, Total

This section summarizes the amount of TP yield from permitted sources at the sites with the highest permitted yield and at the sites with the highest total yields. At low flow, more than 60 percent of the yields are from permitted sources at 7 of the 9 sites with highest total yields. At median flow more than half of the total yield originates from permitted sources at 4 of 8 sites with highest total yields. At high flow, from 24 to 47 percent of the total yield originates from permitted sources at the 7 sites with the highest total yields. The seven sites with the highest total instream yields are not the same sites with the highest permitted yields (**table 19**). The sampling sites at Rockaway Creek, Raritan River at Bound Brook, Millstone River at Grovers Mill, and South Branch Raritan River at Three Bridges have the highest permitted TP yields in the study area (**fig. 20**)

At low flow, the 9 sites with the highest total yields are the South Branch Raritan River sites at Middle Valley and Three Bridges, the Millstone River sites at Grover Mill and Blackwells Mill, the Raritan River sites at Manville and Bound Brook, North Branch Raritan River near Chester, Lamington River near Pottersville and Rockaway Creek (**table 19**). Permitted yields at these sites ranged from 0.2 to 0.4 lb/day/mi^2 and accounted for greater than 50 percent of total yields at all sites except Raritan River at Manville and Millstone River at Blackwells Mill. The permitted yield at Raritan River at Manville is 23 percent of total yield and 10 percent of total yield at Millstone River at Blackwells Mill. All of these sites, except Raritan River at Manville and Millstone River at Blackwells Mill, are among the 7 sites with the highest permitted TP yields at low flow (**table 19**). At low flow, more than 50 percent of the total yield originates from permitted sources at 10 of the 21 sites studied, with 5 sites consisting of approximately 100 percent permitted yield.

At median flow, the 8 sites with the highest total yields are the same as at low flow, except North Branch Raritan River near Chester, Lamington River near Pottersville, and Raritan River at Manville are replaced by Lamington River at Burnt Mills and Millstone River at Manalapan. Permitted yields at these sites ranged from 0.3 to 0.4 lb/day/mi^2 and accounted for greater than 50 percent of total yield at South Branch Raritan River sites at Middle Valley and Three Bridges, Rockaway Creek, and Lamington River at Burnt Mills. Permitted sources of instream yields at the other 4 sites range from 0 to 46 percent of the total. Permitted yields at the South Branch Raritan River at Three Bridges, Rockaway Creek, Millstone River at Grovers Mill and Raritan River at Bound Brook are among the highest in the study area. At median flow, more than 50 percent of the total yield originates from permitted sources at 7 of the 21 sites studied.

At high flow the 7 sites with the highest yields are the Millstone River sites at Manalapan, Grovers Mill and Blackwells Mills, Raritan River at Bound Brook, South Branch Raritan River sites at Three Bridges, Lamington River at Burnt Mills, and Beden Brook. The percent of total yield from permitted sources ranges from 24 to 47 percent at these sites. The highest permitted total phosphorus yields in the study area are at Raritan River at Bound Brook, Rockaway Creek, Lamington River at Pottersville and South Branch Raritan River at Three Bridges. At high flow, more than 50 percent of the total yield originates from permitted sources at 4 of the 21 sites studied.

Total Suspended Solids

This section summarizes the amount of TSS yield from permitted sources at the sites with the highest permitted yield and at the 7 sites with the highest total yields. Permitted yields of TSS generally comprise a small percentage of total instream yields at all of the sampling sites. The seven sites with the highest total instream yields are not the same sites with the highest permitted yields (**table 21**). The permitted yields at Lamington River near Pottersville, North Branch Raritan River near Chester, Rockaway Creek, and Millstone River at Grovers Mill, are the highest permitted TSS yields in the study area (**fig. 21**).

At low flow conditions, 0 to 8 percent of total instream yield originates from permitted sources at the 7 sites with the highest total instream yields. Millstone River at Grovers Mill is the only site among the 7 sites with highest total yields that is also among the 7 sites with the highest permitted yield. At the 7 sites with the highest amounts of permitted yield, the percentages of total yield range from 8 to 100 percent. Essentially the entire total TSS yield originates from permitted sources at North Branch Raritan River near Chester.

The sites with the highest total yields at low flow are the South Branch Raritan River sites at High Bridge and Three Bridges, the Millstone River sites at Grovers Mill, and Blackwells Mill, Manalapan Brook and Raritan River at Manville (**table 21**). Permitted yields at all sites are less than 10 percent of total yield.

Permitted sources are not a major contributor to TSS yields at median and high flow conditions. Only 0 to 5 percent of instream yield originates from permitted sources at the 7 sites with the highest total yields. Four of the 8 sites with the highest yields at median flow are the same as at low flow. The sites removed from the list at median flow are North Branch Raritan River near Chester, Lamington River near Pottersville, Rockaway Creek and Raritan River at Manville. Lamington River at Burnt Mills and Millstone River at Manalapan are added to the list.

At high flow the sites with the highest yields are the Millstone River sites at Grovers Mill and Blackwells Mills, Raritan River at Bound Brook, South Branch Raritan River sites at Middle Valley and Three Bridges, Lamington River at Burnt Mills, and Beden Brook. The percent of total yield from permitted sources ranges from 0 to 2.4 percent at high flow at these sites.

Nonpermitted Loads and Yields

Summary of Nonpermitted Sources at Stream Sites

Nonpermitted load is defined as the instream load not attributable to permitted point sources. Nonpermitted loads were computed at three flow conditions by subtracting permitted load from the total instream load at the sampling sites. The estimates of nonpermitted loads at sites with high percentages of permitted sources may be biased low. Estimates of nonpermitted loads at some sites at low flow conditions are estimated to be approximately zero. This typically happens at sampling sites in close proximity to a permitted source. The permitted source can be the predominant instream load at these sites at low flow. The cumulative uncertainty involved in estimating time-of-travel, attenuation rates and stream flows can lead to obvious underestimates in nonpermitted load. Sites with more than 50 percent of total instream load originating from permitted sources are not included in the analysis of estimated nonpermitted loads. Nonpermitted loads are normalized by drainage area to get nonpermitted yield. Nonpermitted yields are discussed in this section.

The nonpermitted yields discussed in this report are estimated for growing season conditions using attenuation rates at 20 degrees celcius, unless otherwise stated. Nonpermitted yields calculated for the growing season are higher than the yields estimated for the nongrowing season. The attenuation rates used to estimate nonpermitted yield in the nongrowing season are approximately half the rate used for the growing season. A summary of the differences in nonpermitted yields in the nongrowing season from yields in the growing season is presented in **table 25**.

In the nongrowing season, permitted yields comprise a higher percentage of the total instream yield for 4 of the 7 constituents studied. The percentage increase is greatest at low flow when the travel time is longest (**table 25**). The percentage difference in permitted yield from growing season to nongrowing season also varies by site based on travel time of effluent from the discharge point to the sampling site. At low flow, permitted yields of TKN, BOD, NO3+NO2 and TP in the nongrowing season are up to 56 percent, 80 percent, 84 percent, and 95 percent higher at some sites than in the growing season.

In this section, nonpermitted yields are summarized at the 7 sites with the highest total yields. The percentages of total instream yield originating from nonpermitted sources are also summarized.

Ammonia Plus Organic Nitrogen, Total

Sites with more than 50 percent of total instream load originating from permitted sources are not included in the following discussion of the lowest nonpermitted yields observed. Estimates of nonpermitted yields at the North Branch Raritan River sites, Rockaway Creek and Raritan River at Bound Brook could be biased low because of the predominance of permitted sources at these sites.

Nonpermitted yields of TKN at low flow conditions are highest (0.8 - 0.9 lb/day/mi^2) at the South Branch Raritan River at Three Bridges, Raritan River at Manville and Millstone River at Grovers Mill sites (**fig. 15**, **table 7**). Nonpermitted yields are lowest (0.1 lb/day/mi^2) at low flow at Neshanic River, and Stony Brook.

Nonpermitted yields of TKN at median flow are highest at the Millstone River at Grovers Mill and Blackwells Mill sites and at South Branch Raritan River at Three Bridges (1.8 - 3.1 lb/day/mi^2). Lowest nonpermitted yields are 0.4 - 0.9 lb/day/mi^2 at North Branch Raritan River at Burnt Mills, Mulhockaway Creek, and Spruce Run.

Nonpermitted yields of TKN at high flow are highest at Millstone River at Grovers Mill (6.3lb/day/mi^2), Raritan River at Bound Brook (3.9 lb/day/mi^2), Millstone River at Blackwells Mill (3.8 lb/day/mi^2), and Stony Brook (3.8 lb/day/mi^2). Lowest nonpermitted yields are 1.4 -1.6 lb/day/mi^2 at Mulhockaway Creek, Spruce Run, Rockaway Creek and North Branch Raritan River near Chester.

No significant differences in nonpermitted yields were found to exist when sites were aggregated by physiographic province. A comparison of sites by subbasin found that at low flow conditions, sites on the Raritan River had significantly higher nonpermitted yields than sites on tributaries to the Millstone River.

A majority of the total TKN yields at the 7 sites with the highest total instream yields are from nonpermitted sources (**fig. 15**, **table 7**). At low flow, from 52 to 83 percent of the total yield at the 7 sites is from nonpermitted sources. The percentages of total instream yield from nonpermitted yields are higher at higher flows. The seven sites with the highest total instream yields are not the same sites with the highest nonpermitted yields (**table 7**). See the previous section for a summary of the percentage of total instream yields originating from permitted sources.

Biochemical Oxygen Demand

Sites with more than 50 percent of total instream load originating from permitted sources are not included in the following discussion of the lowest nonpermitted yields observed. Estimates of nonpermitted yield at the North Branch Raritan River near Chester, and Matchaponix Brook could be biased low because of the predominance of permitted sources at these sites at low flow conditions.

Nonpermitted yields of BOD at low flow are highest at the South Branch Raritan River sites at Stanton and Three Bridges (5.0 - 5.5 lb/day/mi^2). Lowest nonpermitted yields are 0.4 - 0.5 lb/day/mi^2 at Stony Brook, Beden Brook and Millstone River near Manalapan. (**fig. 16**, **table 9**)

Nonpermitted yields of BOD at median flow conditions are highest (9.1 - 9.5 lb/day/mi^2) at the South Branch Raritan River sites at Three Bridges, Stanton and Middle Valley. Lowest nonpermitted yields at median flow are 0.96 lb/day/mi^2 at Millstone River near Manalapan, 3.46 lb/day/mi^2 at Matchaponix Brook and 4.26 lb/day/mi^2 at Stony Brook.

Nonpermitted yields of BOD at high flow are highest at South Branch Raritan River at High Bridge (18.0 lb/day/mi^2), South Branch Raritan River at Three Bridges (16.5 lb/day/mi^2), Millstone River at Grovers Mill (16.4 lb/day/mi^2), and South Branch Raritan River at Middle Valley (15.0 lb/day/mi^2). Lowest nonpermitted yields are 1.5 lb/day/mi^2 at Millstone River near Manalapan, and 7.2 lb/day/mi^2 at Matchaponix Brook and Manalapan Brook.

Nonpermitted yields of BOD were significantly higher at sites in the New England Province than at sites in the coastal plain at median flow conditions. A comparison of sites by subbasin found that at median and low flows, nonpermitted yields of BOD at South Branch Raritan River sites are significantly higher than at sites on Millstone River tributaries and the Raritan River.

Total BOD yields at the 7 sites with the highest total instream yields are mainly from nonpermitted sources (**fig. 16**, **table 9**). More than 90 percent of instream yield at median and high flow conditions is from nonpermitted sources at each of the 7 sites. At lowflow, however, from 20 to 66 percent of instream load is from nonpermitted sources at two sites. The seven sites with the highest total instream yields are not the same sites with the highest nonpermitted yields (**table 9**). See the previous section for a summary of the percentage of total instream yields originating from permitted sources.

Chloride

Total instream loads and yields are summarized for chloride in the section summarizing total instream loads and yields, on page 24. Permitted and nonpermitted chloride load and yield could not be analyzed because no permitted point source data exist for chloride in the study area and estimates of load could not be accurately made from a literature search (oral communication, Omni Environmental, 2001).

Dissolved Solids, Total

Sites with more than 50 percent of total instream load originating from permitted sources are not included in the following discussion of the lowest nonpermitted yields observed. At low flow conditions, more than 50 percent of the total yield originates from permitted sources at North Branch Raritan River near Chester, Lamington River near Pottersville, Millstone River sites at Grovers Mill and Blackwells Mill, Stony Brook, Beden Brook, Raritan River at Bound Brook and Matchaponix Brook. Estimates of nonpermitted yield could be biased low because of the predominance of permitted sources at these sites.

Nonpermitted yields of TDS at low flow conditions are highest (459 - 463 lb/day/mi^2) at the South Branch Raritan River sites at Three Bridges and Middle Valley (**fig. 17**, **table 13**). Lowest nonpermitted yields (25 - 69 lb/day/mi^2) at lowflow are at Neshanic River, and Stony Brook.

Nonpermitted yields of TDS at median flow are highest at the South Branch Raritan River sites at Middle Valley and High Bridge (948 - 974 lb/day/mi^2). Lowest nonpermitted yields are 327 – 330 lb/day/mi^2 at Stony Brook and Manalapan Brook.

Nonpermitted yields of TDS at high flow are highest at North Branch Raritan River at Burnt Mills (1,450 lb/day/mi^2), South Branch Raritan River at Middle Valley (1,364 lb/day/mi^2), and South

Branch Raritan River at Three Bridges (1,310 lb/day/mi^2). Lowest nonpermitted yields are 508 - 592 lb/day/mi^2 at Manalapan Brook, and Millstone River near Manalapan.

No significant differences in nonpermitted yields were found to exist when sites were aggregated by physiographic province. A comparison of sites by subbasin at high flow found nonpermitted yields at sites in the South Branch Raritan River were significantly higher than at sites on the Millstone River, Matchaponix Brook and Manalapan River. At median flow, nonpermitted yields at sites in the South Branch Raritan River were significantly higher than at sites on the Millstone River, Matchaponix Brook, Manalapan Brook, Raritan River and Millstone River tributaries. No significant differences in nonpermitted yields between subbasins at low flow were apparent.

Total TDS yields at the 7 sites with the highest total instream yields are mainly from nonpermitted sources except at North Branch Raritan River near Chester and Lamington River at Pottersville (**fig. 17**, **table 13**). At 3 sites, less than 40 percent of instream yield at low flow conditions is from nonpermitted sources. More than 80 percent of the total yield at the other 4 sites is from nonpermitted sources. The seven sites with the highest total instream yields are not the same sites with the highest nonpermitted yields (**table 13**). See the previous section for a summary of the percentage of total instream yields originating from permitted sources.

Nitrate Plus Nitrite

Sites with more than 50 percent of total instream load originating from permitted sources are not included in the following discussion of the lowest nonpermitted yields observed. At low flow conditions, more than 50 percent of the total yield originates from permitted sources at the North Branch Raritan River sites, Lamington River, the Millstone River sites at Grovers Mill and Blackwells Mill, Beden Brook, Raritan River at Bound Brook, and Matchaponix Brook. Estimates of nonpermitted yield at these sites could be biased low because of the predominance of permitted sources at these sites.

Nonpermitted yields of NO3+NO2 at low flow are highest (3.7 – 4.4 lb/day/mi^2) at the South Branch Raritan River sites at Middle Valley and High Bridge and at Matchaponix Brook (**fig. 18**, **table 15**). Lowest nonpermitted yields (0.1 lb/day/mi^2) at low flow are at Neshanic River, and Stony Brook.

Nonpermitted yields of NO3+NO2 at median flow are highest (8.0 – 9.7 lb/day/mi^2) at the South Branch Raritan River sites at Middle Valley and High Bridge and at Millstone River at Grovers Mill. Lowest nonpermitted yields are 1.1 lb/day/mi^2 at Stony Brook at Princeton and 3.3 lb/day/mi^2 at Beden Brook. Nonpermitted yields of NO3+NO2 at high flow are highest at Millstone River at Grovers Mill (18.1 lb/day/mi^2), and South Branch Raritan River at High Bridge (16.3 lb/day/mi^2). Lowest nonpermitted yields are 4.0 lb/day/mi^2 at Stony Brook and 6.2 lb/day/mi^2 at Manalapan Brook.

No significant differences in nonpermitted yields were found to exist when sites were aggregated by physiographic province. A comparison of sites by subbasin also found no significant differences in nonpermitted yields.

Total NO3+NO2 yields at the 7 sites with the highest total instream yields are primarily from permitted sources at most sites at low and median flow. (**fig. 18**, **table 15**). Less than 50 percent of the yield at 4 sites at low and median flows is from nonpermitted sources. At high flow less than 50 percent of the total instream yield at 2 sites is from nonpermitted sources. The seven sites with the highest total instream yields are not the same sites with the highest nonpermitted yields (**table 15**). Total instream yield at 3 of the sites is essentially all from permitted sources. See the previous section for a summary of the percentage of total instream yields originating from permitted sources.

Organic Carbon, Total

None of the sites had more than 33 percent of total instream yields originating from permitted point sources. All sites are included in this discussion of the lowest nonpermitted yields observed. Nonpermitted yields of TOC at low flow are highest at the South Branch Raritan River sites at Stanton and Three Bridges and at the Lamington River at Pottersville (9.8 – 10.3 lb/day/mi^2). Lowest nonpermitted yields are 0.9 lb/day/mi^2 at Stony Brook, and 1.1 lb/day/mi^2 Neshanic River. (**fig. 19**, **table 17**)

Nonpermitted yields of TOC at median flow conditions are highest (21 - 30 lb/day/mi^2) at the Lamington River at Pottersville and the South Branch Raritan River sites at Middle Valley and High Bridge. Lowest nonpermitted yields at median flow are 10.0 lb/day/mi^2 at Neshanic River, 11.9 lb/day/mi^2 at Mulhockaway Creek and 12.1 lb/day/mi^2 at Stony Brook.

Nonpermitted yields of TOC at high flow are highest at Lamington River at Pottersville (50.6 lb/day/mi^2), Millstone River at Grovers Mill (44.7 lb/day/mi^2), and South Branch Raritan River at High Bridge (40.0 lb/day/mi^2). Lowest nonpermitted yields are 21.1 lb/day/mi^2 at Manalapan Brook, 21.7 lb/day/mi^2 at Mulhockaway Creek and 22.0 lb/day/mi^2 at Rockaway Creek.

No significant differences in nonpermitted yields were found to exist when sites were aggregated by physiographic province. A comparison of sites by subbasin found significant differences at low and median flow conditions. Nonpermitted yields at sites on the South Branch Raritan River are significantly higher than at sites on tributaries to the South Branch Raritan River and tributaries to the Millstone River.

Total TOC yields at the 7 sites with the highest total instream yields are mainly from nonpermitted sources. (**fig. 19**, **table 17**). More than 80 percent of instream yield at low flow conditions is from nonpermitted sources at each of the 7 sites. At median and high flow from 93 to 99.7 percent of instream load is from nonpermitted sources at the 7 sites with highest total yields. The seven sites with the highest total instream yields are the same sites with the highest nonpermitted yields (**table 17).** See the previous section for a summary of the percentage of total instream yields originating from permitted sources.

Phosphorus, Total

Nine sites with more than 50 percent of total instream load originating from permitted sources are not included in the following discussion of the lowest nonpermitted yields observed. At low flow conditions, less than 50 percent of the total yield originates from nonpermitted sources at the South Branch Raritan River sites at Middle Valley and Three Bridges, North Branch Raritan River near Chester, the Lamington River sites at Pottersville and Burnt Mills, Rockaway Creek, Millstone River at Grovers Mill, Raritan River at Bound Brook, and Matchaponix Brook. Nonpermitted yield of TP at low flow is highest at Millstone River at Blackwells Mills (0.5 lb/day/mi^2). Lowest nonpermitted yields at low flow are less than 0.1 lb/day/mi^2 at Beden Brook, Mulhockaway Creek, Neshanic River, and Stony Brook (**fig. 20**, **table 19**)

Nonpermitted yields of TP at median flow conditions are highest (0.8 lb/day/mi^2) at the Millstone River at Blackwells Mills and 0.5 lb/day/mi^2 at Millstone River at Grover Mill and Raritan River at Bound Brook. Lowest nonpermitted yields at median flow are 0.1 lb/day/mi^2 at Lamington River at Burnt Mills, Mulhockaway Creek, Neshanic River, the North Branch Raritan River sites at Burnt Mills and Chester, South Branch Raritan River at Stanton, and Stony Brook.

Nonpermitted yields of TP at high flow are highest at Millstone River at Blackwells Mills (1.2 lb/day/mi^2), Millstone River at Grovers Mill (1.0 lb/day/mi^2), and Raritan River at Bound Brook (1.0

lb/day/mi^2). Lowest nonpermitted yields are 0.1 lb/day/mi^2 at South Branch Raritan River at Stanton, and North Branch Raritan River at Burnt Mills.

Significant differences in nonpermitted yields were found to exist when sites were aggregated by physiographic province. Nonpermitted yields at high flow are significantly higher at sites in the coastal plain than at sites in the highlands province. A comparison of sites by sub-basin found significant differences at high flow conditions. Nonpermitted yields at sites on the Millstone River are significantly higher than at sites on the Lamington River.

Total TP yields at the 9 sites with the highest total instream yields are mainly from permitted sources at low flow (**fig. 20**, **table 19**). At low flow conditions, less than 50 percent of instream yield at 7 of these sites is from nonpermitted sources. At median flow 4 sites have less than 50 percent of total instream load from nonpermitted sources. Nonpermitted yields at high flow range from 53 to 76 percent of total instream load at the 7 sites with highest total yields. The seven sites with the highest total instream yields are the same sites with the highest nonpermitted yields (**table 19).** See the previous section for a summary of the percentage of total instream yields originating from permitted sources.

Total Suspended Solids

At low flow conditions, more than 50 percent of the total yield originates from permitted sources at North Branch Raritan River near Chester. This site is not included in the discussion of the lowest nonpermitted yields observed because of a possible bias in the estimate of nonpermitted yield. Nonpermitted yields of TSS at low flow are highest at Millstone River at Grovers Mill (17.6 lb/day/mi^2), South Branch Raritan River at High Bridge (10.5 lb/day/mi^2), and Manalapan Brook (9.9 lb/day/mi^2). Lowest nonpermitted yields are 0.4 lb/day/mi^2 at Neshanic River and Stony Brook (**fig. 21**, **table 21**).

Nonpermitted yields of TSS at median flow conditions are highest (60.7 lb/day/mi^2) at the Millstone River at Grovers Mill, 45.4 lb/day/mi^2 at Millstone River at Grover Mill and 36.4 lb/day/mi^2 at Millstone River near Manalapan. Lowest nonpermitted yields at median flow are 6.3 lb/day/mi^2 at North Branch Raritan River near Chester, 12.4 lb/day/mi^2 at Neshanic River, and 14.8 lb/day/mi^2 at Stony Brook.

Nonpermitted yields of TSS at high flow are highest at Millstone River at Grovers Mill and Raritan River at Bound Brook (129 lb/day/mi^2), and Millstone River at Blackwells Mill (117 lb/day/mi^2). Lowest nonpermitted yields are 20.3 lb/day/mi^2 at North Branch Raritan River near Chester, 29.2 lb/day/mi^2 at Mulhockaway Creek and 29.8 lb/day/mi^2 at Spruce Run.

No significant differences in nonpermitted yields were found to exist when sites were aggregated by physiographic province. A comparison of sites by subbasin found significant differences at median flow conditions. Nonpermitted yields at sites on the Millstone River are significantly higher than at sites on tributaries to the South Branch Raritan River.

Total TSS yields at the 7 sites with the highest total instream yields are mainly from nonpermitted sources (**fig. 21**, **table 21**). At low flow conditions, 92 to 100 percent of instream yield at all 7 sites is from nonpermitted sources. At median and high flow conditions, 95 to 100 percent of instream yield originates from nonpermitted sources. Permitted sources are not a major contributor to TSS yields in the study area. The seven sites with the highest total instream yields are the same sites with the highest nonpermitted yields (**table 21).** See the previous section for a summary of the percentage of total instream yields originating from permitted sources.

Relation of Nonpermitted Yield Between Sites

A comparison of nonpermitted yields between sites is presented by stacked bar charts (**figures 15-21**). The ANOVA test on ranks of nonpermitted yield and Tukey's test were used to make comparisons between sites at each of the 3 flow conditions studied. Sites were grouped by physiographic province and by subbasin. Permitted point source yield dominated the total yield of a few constituents at some sites. When estimates of permitted point source yield exceeded 50 percent of total instream yield, the nonpermitted yield at that site was not included in the ANOVA test.

Significant differences in nonpermitted yields between sites in the different physiographic provinces were observed for three constituents. Yields of TDS were significantly higher at sites in the highlands province than at sites in the coastal plain. The differences occurred at low and median flow conditions. Nonpermitted yields of phosphorus at high flow conditions were significantly higher at sites in the coastal plain than at sites in the New England province. Nonpermitted yields of BOD were significantly higher at sites in the highlands than at sites in the coastal plain at median flow conditions. These differences did not occur at low or high flow conditions. No significant differences in nonpermitted yields of nitrate, TKN, TOC, and TSS occurred between provinces.

Significant differences in nonpermitted yields of 6 of the 7 constituents were observed between subbasins at one or more flow conditions. Sites were divided into 8 subbasins; South Branch Raritan River mainstem, South Branch Raritan River tributaries, North Branch Raritan River, Lamington River, Millstone River mainstem, Millstone River tributaries, Raritan River mainstem, and South River sites. No significant differences in NO3+NO2 yields were observed. BOD at low and median flow was significantly higher in the mainstem South Branch Raritan River than in the Raritan River mainstem and Millstone River tributaries. TKN at low flow at the mainstem Raritan River sites was significantly higher than in the Millstone River tributaries.

Nonpermitted yields of TOC at low and median flow at the South Branch Raritan River sites were significantly higher than yields at South Branch Raritan and Millstone River tributaries. Nonpermitted yields of TP at high flow were significantly higher at the Millstone River sites than at the Lamington River sites. Nonpermitted yields of TSS at median flows at Millstone River sites were significantly higher than at sites on South Branch Raritan River tributaries. Nonpermitted yields of TDS at high flow at South Branch Raritan River sites are significantly higher than at Millstone River, Matchaponix Brook and Manalapan Brook sites. Nonpermitted yields of TDS at median flow at South Branch Raritan River sites are significantly higher than at sites on the Raritan River, Millstone River mainstem and tributaries, Matchaponix Brook and Manalapan Brook sites.

Relation of Nonpermitted Yield to Basin Characteristics

This section summarizes the investigation into possible explanations for the variability observed in nonpermitted yields in the study area. The statistical methods used to evaluate relations between nonpermitted yield and basin characteristics are presented along with the results from the evaluation. Three general categories of characteristics were considered in this analysis: (1) anthropogenic factors (2) soil and geologic features (3) hydrology and basin features

Methods of Study

Correlation analysis and multiple regression analysis were used to determine relations between nonpermitted yield and basin characteristics from the 21 sites studied. Correlation analysis measured the strength in the association between the nonpermitted yield and each individual environmental variable. Multiple regression considers the effect of multiple environmental variables to each nonpermitted yield. Multiple regression analyzes all the explanatory variables and selects the variables that explain the most variability in the nonpermitted yields.

Forty-one explanatory variables were considered in an exploratory analysis to find a regression model with the best ability to predict nonpermitted yields. All variables were tested for normality. The data for 15 of the variables were normally distributed. Data for 21 of the other variables were normalized using various transformations to reduce variability and to make the data more symmetric and linear. Flashiness, a measure of streamflow variability, could not be fit to a normal distribution using standard transformations. The variable, however, was considered to be a likely contributor to variability in nonpermitted yield and the data were fit to a different distribution. Two measures of flashiness, the ratio of 25th to 75th percentile flow and the ratio of 10th to 90th percentile flow, were fit to a Pareto distribution when no transformation was found to fit the data to a normal distribution. Five other variables-- percentages of Coastal Plain, New England and Piedmont provinces and the percent of metamorphic and unconsolidated bedrock-- were dropped from the multiple regression analysis because the data could not be normalized. Each of these variables was correlated to other explanatory variables used to explain differences in physiographic provinces. The percentages of barren land and open water were a small percentage of land use and were dropped from the multiple regression analysis.

Pearson correlation analysis was used to examine the relation between nonpermitted yield and each independent variable and also the relation between independent variables. Thirty-seven of the 41 variables were found to be significantly related ($p<0.05$) to nonpermitted yield of at least one constituent at one or more flow conditions. This indicates that each of these variables may be useful in estimating nonpermitted yield. Only stream density, and percentages of urban, commercial/industrial and total undeveloped land uses were not related to any nonpermitted yields. Although the statistics show that the percent of urban land and the percent of total undeveloped land are not significantly correlated to yields, other indicators of those types of land use are correlated to nonpermitted yields. For example, impervious surface area and forested land are both correlated to nonpermitted yields of various constituents. The 14 variables not included in the correlation summary table (**table 26**) are those mentioned in the previously, along with percentages of the 3 physiographic provinces, one measure of flashiness, percentages of barren land, residential, and water; horizontal permeability, and percentages of sewered and nonsewered areas.

A comparison of pairs of independent variables indicated some pairs have high correlation coefficients and a low probability level of significance. This indicates a strong linear relation between these independent variables. This increases the possibility that correlated variables measure the same effect on nonpermitted yield (multicollinearity) and if used together in a model, may increase instability in coefficient estimates (SAS, System for regression, 1995). This is referred to as multicollinearity and is measured by computing the variance inflation factor (VIF). Variables with low VIF do not show multicollinearity.

The variance inflation factor is defined as $1/(1-R^2)$. Any variables associated with a VIF exceeding the definition, are more closely related to other independent variables than they are to the dependant variable (SAS, System for regression, 1995). Only models with a VIF less than $1/(1-R^2)$ were considered in this analysis.

A procedure in SAS called the R-square selection method was used to summarize information on the estimated coefficients from many different models. The method was used to assist in selecting a suitable subset of variables for a final model (SAS, System for regression, 1995). The models were evaluated by looking at statistics describing the model's prediction quality and multicollinearity: R squared value, mallows CP, Press statistic and VIF. The best models showed the best combination of low mallow's CP, press, standard error as measured by the coefficient of variation and VIF and a high r-square. A low mallows CP and low VIF were the statistics most influential in choosing a model.

The R-square selection method was applied to 4 subsets of variables to allow the program to run more efficiently. The variables chosen from each of the 4 subsets were combined and the R-square selection method was rerun. The variables selected by this procedure were analyzed further for collinearity by analyzing correlation results. If variables were found to be correlated, the variable with the smallest partial r-squared value was dropped.

A stepwise regression procedure was another approach used to choose the best model (SAS Institute Incorporated, 1995). This method starts with the best univariate model and adds variables one by one that result in the largest increase in R-square. Variables with a greater than 5 percent probability level of significance were removed from the model. The models chosen by this method were not necessarily the best as defined by the statistics that describe the model's prediction quality and multicollinearity. In some cases the variables in the models chosen by the stepwise procedure were correlated. In those cases the variable with the lowest partial r-squared value was removed. Models were selected based on the summary from the R-square selection method, analysis of multicollinearity, and the stepwise procedure.

A linear relation was developed between basin characteristics and nonpermitted yields of all constituents at each of the three flow conditions. The only constituent without a significant model was NO3+NO2 at high flow conditions. The nonpermitted yields estimated for some constituents may be biased low because of the predominance of permitted yields at some sites. Nonpermitted yields at sites with greater than 50 percent of the total yield originating from permitted sources were removed from the multiple regression analysis. This resulted in less than 10 sites with nonpermitted yields of TP at low and median flow and TKN at low flow. The small number of data points makes the models for these constituents less reliable.

Basin Characteristics

Basin characteristics can help to explain the causes of variability in nonpermitted loads in streams throughout the study area. Three general categories of characteristics were considered in this analysis: 1) anthropogenic factors 2) soil and geologic features 3) hydrology and basin features. Basin characteristics such as basin shape, topographic gradient, land use, population density, impervious surface area, bedrock formation, soil properties, stream flashiness, road density, and density of septic systems are considered in this analysis. The influence of each characteristic on nonpermitted load varies among constituents as flow conditions change in the stream. Basin characteristics were derived from GIS coverages and 1990 census data.

The land uses are derived from a GIS coverage developed from 1995/97 digital infrared aerial photos (NJDEP, 2000) using the Anderson method of classification (Anderson, and others, 1976). Land uses are characterized on the basis of percentages of urban, agriculture, forest, wetland, open water, and barren land for each basin. Urban land use was also classified as either residential or commercial/industrial. Percentages of urban and agricultural land use were added to get the percentage of total developed land. The percentages of forest, wetland, open water and barren land were added to create percent undeveloped land. The amount of land covered by impervious surfaces was also available from this coverage.

Physical characteristics of the basin were derived from USGS coverages of basin boundaries, stream channels, geology, and digital elevation maps. Slope of the basin, rotundity and length of perennial streams per square mile were variables considered in the development of the multivariate models. Rotundity is defined as the shape of the basin. The more elongated the basin, the lower the value of rotundity. The lithology of the basin was categorized by percent igneous, metamorphic, sedimentary, and unconsolidated bedrock. Soil characteristics were derived from the Soil Survey Geographic (SSURGO) database (U.S. Department of Agriculture, 1995). Lithology and soils characteristics including hydrologic soils group, soil drainage classification, vertical and horizontal permeability, and percent sand, silt, and clay, were used to explain differences between physiographic provinces. Hydrologic soils groups are based on the depth and texture of the whole soil profile (U.S. Department of Agriculture, 1995). The 4 groups used in this study are classes A through D. Class A soils are deep and very well drained. Class D soils have slow infiltration rates, a high water table or are shallow to an impervious layer (U.S. Department of Agriculture, 1995).

Streamflow per square mile and streamflow variability were the hydrologic features used for comparative purposes. Streamflow per square mile was not used in the multiple regression analysis. The responsiveness of stream flow varies throughout the study area because of differences in substrate, slope and drainage area. Flow duration statistics were used to measure this variability. The ratios of 25th /75th and 10th / 90th flow duration, referred to as flashiness, were used to measure the differences between high and low flow events. In this study area, the sites with the highest values of flashiness are those sites with small drainage areas in the Piedmont province. Low flows at these sites drop off more dramatically during dry periods than in similar sized basins in other physiographic provinces. Streamflow per square mile was included in the correlation analysis to account for variability in stream flows between physiographic provinces.

Data from the 1990 census (U.S. Bureau of the Census, 1991) on population, housing units and septic systems were used to compute population density, housing density and septic system density in each basin. The percentage of sewered and nonsewered area in each basin was derived from a coverage available from NJDEP. A USGS coverage of roads was used to compute total road length per square mile in each basin. This was used as a surrogate for road salt application, but was not found to be correlated to any constituents.

Correlations between independent variables that describe different factors make it more difficult to draw conclusions about the major features contributing to variation in nonpermitted yields in the basin. Basin characteristics describing land use were found to be correlated with characteristics describing soils, lithology, and slope. Forested land is positively correlated with soil group B, excessively well drained soil, metamorphic and igneous bedrock, and slope; all features of the New England Province. Forest is also negatively correlated to well drained soil, soil group A, and unconsolidated bedrock; all features of the coastal plain province. Urban land use is positively correlated with soil group D. Agriculture is negatively correlated to soil group D, excessively well drained soil, and igneous and metamorphic bedrock and positively correlated to well drained soil.

Relation to Nonpermitted Yields

Basin characteristics were related to nonpermitted yields by using correlation analysis and multiple regression analysis. Total instream yield at some sites originates primarily from permitted sources. Nonpermitted yields were removed from the dataset at sites with more than 50 percent of total yield originating from permitted sources. The estimated nonpermitted yields at these sites were not included in the correlation analysis. The lack of variability in nonpermitted yields between sites for most constituents limited the number of significant relations between basin characteristics and nonpermitted yields.

Correlation analysis was initially run on all variables including those unable to be transformed to a normal distribution. Four basin characteristics --urban land use, commercial/industrial land use, total undeveloped land, and stream density-- were not correlated to nonpermitted yields of any constituent at any flow condition. The density of private septic systems, the percent of land area in the Coastal Plain, percent of area underlain by unconsolidated sediments, and percent of area covered by water were correlated to the most constituents at the most flow conditions. The density of septic systems was related to 6 of the 7 constituents at one or more flow conditions. The percent of land area in the Coastal Plain and the land area underlain by unconsolidated sediments were related to 5 of 7 constituents at one or more flow conditions. Five variables-- percentages of Coastal Plain, New England and Piedmont provinces and the percent of metamorphic and unconsolidated bedrock-- were dropped from the multiple regression analysis because the data could not be normalized. The percentages of barren land and open water were also removed from the analysis because percentages are small and results may lead to spurious correlations.

Ammonia Plus Organic Nitrogen, Total

Nonpermitted yields of TKN are correlated to 17 basin characteristics (**table 26**). At high flow and at median flow, nonpermitted yields were most strongly correlated to slope and factors describing land use. Nonpermitted yields increased with decreases in slope and forested land use, and with increases in population density and wetlands. At low flow, nonpermitted yields were most strongly correlated to flashiness, a measure of variability in streamflow. Small streams in the Piedmont Province have significantly lower nonpermitted yields at low flow because streamflow is significantly lower at these sites. Stream flows are most variable on streams in the Piedmont Province.

At high flow nonpermitted yields are positively correlated to 3 basin characteristics associated with the coastal plain -- hydrologic soils group-A, percent wetlands, and unconsolidated sediments. Five variables are negatively correlated to nonpermitted yield at high flow. Each of the 5 variables -- slope, forest, excessively well-drained soil, igneous bedrock and metamorphic bedrock-- is positively correlated to the New England Province. Population density and housing density are also positively correlated to nonpermitted yield. At high flow, nonpermitted yields are generally higher at coastal plain sites than at other sites and lower in the highlands province than at other sites. The regression model that best explained the variation in nonpermitted yields of TKN was a function of slope. The model explained 60 percent of the variability in the study area.

Increases in nonpermitted yields of TKN at low flow, are correlated to increases in rotundity, and hydrologic soils group-D and to decreases in flashiness. Flashiness is essentially an indicator of flow; yields are higher at low flow at sites with a higher volume of flow per unit drainage area. These variables are associated with the New England province, urban areas, and the Piedmont province respectively. The regression model at low flow indicates nonpermitted yields are a function of flashiness. The model at low flow conditions is not statistically valid, however, because only 6 sites had greater than 50 percent of total instream yield from nonpermitted sources. Only those 6 sites were included in the regression analysis.

Nonpermitted yields of TKN at median flow are positively correlated to 7 variables. Five of these variables are indicators of urban land uses—population density, housing density, impervious surface area, septic system density, and hydrologic soils group D.. Rotundity, and permeability are also positively correlated to nonpermitteed yield. Flashiness, slope, and clay in the soil are negatively correlated to yields at median flow. The regression model that best explained the variation in nonpermitted yields of TKN was a function of septic system density and slope. The model explained 66 percent of the variability in the study area. Highest nonpermitted yields are on the mainstem of the South Branch Raritan and Millstone Rivers (**figure 22**)

Biochemical Oxygen Demand

Nonpermitted yields of BOD are correlated to 15 basin characteristics (**table 26**). At high flow, nonpermitted yields were only correlated to soil and lithology. At median flow, yields were most strongly correlated to septic system density and excessively well drained soils. Yields increased with increases in both factors. At low flow, nonpermitted yields were most strongly correlated to population density, septic system density and agriculture. Nonpermitted yields increased with increases in population density and septic system density and decreased with increases in agricultural land.

At high flow, only 2 basin characteristics are correlated to nonpermitted yield. Both variables associated with the coastal plain – well-drained soils and unconsolidated sediments-- are negatively correlated to nonpermitted yield. The regression model that best explained the variation in nonpermitted yields of BOD was a function of well-drained soil. The model explained 26 percent of the variability in the study area.

Nonpermitted yields of BOD at median flow are positively correlated to 6 variables. The variables include rotundity, forested land, septic system density, excessively well-drained soils, and igneous and metamorphic bedrock, all variables positively correlated to the New England province (**figure 23**). Well-drained soils, unconsolidated sediments, and total developed land use are negatively correlated to nonpermitted yield. These 3 variables are correlated to the coastal plain province. The regression model that best explained the variation in nonpermitted yields of BOD at median flow was a function of excessively well-drained soil. The model explained 36 percent of the variability in the study area. Highest nonpermitted yields are on the mainstem of the South Branch Raritan and Lamington Rivers (**figure 23**).

Nonpermitted yields of BOD at low flow are correlated to 6 variables. The variables include 4 measures of urban land use -- population density, housing density, impervious surface area, and septic system density – in addition to flashiness and excessively well drained soils. All the urban land use indicators except septic system density are not correlated to a physiographic province. Septic system density is highest in the New England Province. Flashiness is correlated to the Piedmont province and excessively well-drained soils are correlated to the New England Province. The regression model that best explained the variation in nonpermitted yields of BOD was a function of septic system density. The model explained 39 percent of the variability in the study area. Highest nonpermitted yields are on the mainstem of the South Branch Raritan River.

Dissolved Solids, Total

Nonpermitted yields of TDS are correlated to 19 basin characteristics (**table 26**). At high and median flows, nonpermitted yields were most strongly correlated to lithology, soils and septic system density. Yields increased with increases in soils and lithology characteristic of the New England Province and decreased with increases in soils and lithology characteristic of the Coastal Plain province. At low flow, nonpermitted yields were most strongly correlated to population density, septic system density and agriculture. Nonpermitted yields increased with increases in population density and septic system density and decreased with increases in agricultural land.

At high flow, 5 variables are positively correlated to nonpermitted yield. All 5 --septic system density, forested land, excessively well drained soil, igneous and metamorphic bedrock-- correlate positively to the New England Province. Five variables are negatively correlated to nonpermitted yield. All 5 variables – well-drained soil, hydrologic soil group A, sand, unconsolidated sediments and wetlands – are associated with the coastal plain. The regression model that best explained the variation in nonpermitted yields of TDS was a function of septic system density, hydrologic soil group C and silt content of the soil. Hydrologic soil group C and silt in the soil are characteristic of the New England Province. The model explained 68 percent of the variability in the study area.

Nonpermitted yields of TDS at median flow are correlated to 13 variables. Eight variables positively correlated to nonpermitted yield include three indicators of urban land use --population density, road density and septic system density-- along with forested land and 4 indicators of soil and bedrock in the New England province (**figure 24**). Five variables are negatively correlated to nonpermitted yield. Three of the variables describe soils and lithology in the coastal plain. Total developed land use and agriculture are correlated to the coastal plain and piedmont regions respectively. The regression model that best explained the variation in nonpermitted yields of TDS at median flow was a function of septic system density. The model explained 62 percent of the variability in the study area. Highest nonpermitted yields are on the mainstem of the South Branch Raritan and North Branch Raritan Rivers

Nonpermitted yields of TDS at low flow are correlated to 11 variables. Five of the 7 variables positively correlated to nonpermitted yield include 4 indicators of urban land use – population density, septic system density, housing density and impervious surface – and hydrologic soils group D, which is positively correlated to urban indicators. Two other variables are positively correlated to nonpermitted yield. Excessively well-drained soil and igneous bedrock are both associated with the New England province. The 4 variables negatively correlated to nonpermitted yield, include total developed land, and well-drained soils variables associated with the coastal plain, and agriculture and flashiness correlated to the Piedmont region.

The regression model that best explained the variation in nonpermitted yields of TDS was a function of agricultural land and flashiness. Agriculture and flashiness decrease as nonpermitted TDS yield increases. The model explained 90 percent of the variability in the study area. Highest nonpermitted yields are on the mainstem of the South Branch Raritan River. Lowest nonpermitted yields are on small streams in the Piedmont province. Sites on small streams in the Piedmont province yield very low flows during the driest times of the year and therefore have a high flashiness value. The land use in those areas consists of higher percentages of agricultural land than at other sites in the study area.

Nitrate Plus Nitrite

Nonpermitted yields of NO3+NO2 are correlated to 7 basin characteristics (**table 26**). No variables are correlated to nonpermitted yield at high flow conditions. At median flows, nonpermitted yields were most strongly correlated to lithology, and soils. Yields decreased with increases in clay content of the soil and sedimentary bedrock, both characteristics of the Piedmont Province. At low flow, nonpermitted yields were most strongly correlated to clay content of the soil and septic system density. Nonpermitted yields increased with increases in septic system density and decreased with increases in clay content in the soil.

Nonpermitted yields of NO3+NO2 at median flow are correlated to 4 variables. Poorly drained soil and hydrologic soils group D are positively correlated to nonpermitted yield. Both of these indicators of soil are correlated to urban land use indicators. Clay and sedimentary bedrock are negatively correlated to nonpermitted yield. Both variables are associated with the piedmont province (**figure 25**). The regression model that best explained the variation in nonpermitted yields of NO3+NO2 at median flow was a function of clay content of the soil and urban land use. The model explained 74 percent of the variability in the study area. Highest nonpermitted yields are at sites in the upper portion of the South Branch Raritan River and on the coastal plain.

Nonpermitted yields of NO3+NO2 at low flow are correlated to 5 variables. The clay content of the soil and the flashiness of a stream are characteristics negatively correlated to yield. Both variables are characteristics of soil and hydrology associated with the Piedmont province. The 3 variables positively correlated to nonpermitted yield include septic system density, permeability and hydrologic soil group D. Septic system density and hydrologic soil group D are associated with urban land uses. Permeability is correlated with soil properties in the Coastal Plain Province. The regression model that best explained the variation in nonpermitted yields of NO3+NO2 was a function of septic system density and sandy soil. The model explained 83 percent of the variability in the study area. Highest nonpermitted yields are at sites along the South Branch Raritan River and at selected coastal plain sites.

Organic Carbon, Total

Nonpermitted yields of TOC are correlated to 14 basin characteristics (**table 26**). At high flow conditions, nonpermitted yields were most strongly correlated to factors defining urban land use. Yields increased with increases in population density and housing density. At median flows, nonpermitted yields were most strongly correlated to basin shape, and septic system density. Yields increased with increases in rotundity and septic system density, both characteristics associated with the New England Province. At low flow, nonpermitted yields were most strongly correlated to hydrology, soils and basin shape. Nonpermitted yields increased with increases in rotundity and decreased with increases in flashiness and clay content in the soil.

At high flow, 3 variables are correlated to nonpermitted yield. Nonpermitted yields are positively correlated to population density and housing density. Yields are negatively correlated to slope, which is associated with the New England Province. The regression model that best explained the variation in nonpermitted yields of TOC at high flow was a function of population density. The model explained 21 percent of the variability in the study area.

Nonpermitted yields of TOC at median flow are correlated to 9 variables. Seven of the 9 variables are positively correlated to nonpermitted yield. Five of these variables --population density, housing density, impervious surface area, and septic system density-- are indicators of urban land use. Rotundity and hydrologic soils group D are associated with the New England Province (**figure 26)**. The 2 variables negatively correlated to nonpermitted yields are agriculture and clay content of the soil. Both of these factors are associated with the Piedmont Province. The regression model that best explained the variation in nonpermitted yields of TOC at median flow was a function of rotundity and impervious surface area. The model explained 60 percent of the variability in the study area.

Nonpermitted yields of TOC at low flow are correlated to 8 variables. Five of the 8 variables are positively correlated to nonpermitted yield. The variables include rotundity, septic system density, hydrologic soil group B, and silt associated with the New England province, and permeability associated with the Coastal Plain. The 3 variables negatively correlated to nonpermitted yield, are hydrologic soils group B, clay content of the soil and flashiness. These variables are associated with soils and hydrology in the Piedmont Province. The regression model that best explained the variation in nonpermitted yields of TOC at low flow was a function of flashiness and rotundity. The model explained 71 percent of the variability in the study area.

Phosphorus, Total

Nonpermitted yields of TP are correlated to 14 basin characteristics (**table 26**). At high flow conditions, nonpermitted yields were most strongly correlated to factors of slope, lithology, and forested land. Yields increased with decreases in slope, forested land and metamorphic bedrock. At median flows, nonpermitted yields were most strongly correlated to hydrologic soils group D. Yields increased with increases in rotundity and septic system density, both characteristics associated with the New England Province. At low flow, nonpermitted yields were most strongly correlated to hydrology, soils and basin shape. Nonpermitted yields increased with increases in rotundity --basin elongation-- and decreased with increases in flashiness and clay content in the soil.

At high flow, 3 basin characteristics associated with the coastal plain -- hydrologic soils group-A, percent wetlands, and consolidated sediments – are positively correlated to nonpermitted yield. Four variables are negatively correlated to nonpermitted yield at high flow. Each of the 4 variables -- slope, forested land, igneous bedrock and metamorphic bedrock -- is positively correlated to the New England Province. At high flow, nonpermitted yields are generally higher at coastal plain sites than at other sites and lower in the highlands province than at other sites. The regression model that best explained the variation in nonpermitted yields of TP at high flow was a function of slope. The model explained 54 percent of the variability in the study area. Nonpermitted yields of TP increase at the sites with flatter slopes. Slope is positively correlated with forested land, and total undeveloped land. Slope is negatively correlated to percent of the area that is sewered, an indicator of urban area.

Increases in nonpermitted yields of TP at low flow, are correlated to increases in rotundity, sand, and permeability. The highest values of rotundity (basin elongation) are associated with the New England Province. The soils with the highest percentage of sand and highest permeability are in the Coastal Plain Province. Decreases in nonpermitted yields of TP are correlated to hydrologic soils group B, clay content of the soil and sedimentary bedrock. All 3 variables are associated with the Piedmont Province. The best regression model at low flow indicates nonpermitted yields are a function of rotundity. The model at low flow conditions is not statistically valid, however, because only 5 sites had greater than 50 percent of total instream yield from nonpermitted sources. Only those 5 sites were included in the regression analysis.

Nonpermitted yields of TP at median flow are positively correlated to 4 variables associated with either the Coastal Plain province (**figure 27**) or urban areas. Increases in TP yield are correlated to increases in hydrologic soils group D, hydrologic soils group A, unconsolidated sediments and sand. Hydrologic soils group D is positively correlated to urban land uses. Increases in TP yield are also correlated to decreases in slope. The regression model that best explained the variation in nonpermitted yields of TP at median flow was a function of hydrologic soils group D. The model at low flow conditions is not statistically valid, however, because only 5 sites had greater than 50 percent of total instream yield from nonpermitted sources. Only those 5 sites were included in the regression analysis.

Total Suspended Solids

Nonpermitted yields of TSS are correlated to 18 basin characteristics (**table 26**). At high flow conditions, nonpermitted yields were most strongly correlated to factors of slope, forested land, and soils. Yields increased with decreases in slope, and forested land and increased with increases hydrologic soil group A. At median flows, nonpermitted yields were most strongly correlated to slope, hydrologic soils group A and unconsolidated sediments. Yields increased with decreases in slope and increased with increases hydrologic soils group A and unconsolidated sediments, all characteristics associated with the Coastal Plain Province. At low flow, nonpermitted yields were most strongly correlated to slope, soils and lithology. Nonpermitted yields increased with decreases in slope, sedimentary bedrock and clay and with increases in permeability and sandy soil.

At high flow, 6 basin characteristics associated with the New England Province –slope, septic system density, forested land, excessively well drained soil, igneous and metamorphic bedrock-- are negatively correlated to nonpermitted yield. Five variables are positively correlated to nonpermitted yield at high flow. Four of the 5 variables – hydrologic soil group A, well-drained soil, unconsolidated sediments, and total developed land -- are positively correlated to the Coastal Plain Province. Agricultural land is positively correlated to the Piedmont Province. At high flow, nonpermitted yields are generally higher at coastal plain sites than at other sites and lower in the highlands province than at other sites. The regression model that best explained the variation in nonpermitted yields of TSS at high flow was a function of slope and flashiness. The model explained 62 percent of the variability in the study area. Nonpermitted yields of TSS increase at the sites with flatter slopes and higher variability in flow. Flatter slopes are characteristic of sites in the coastal plain and higher variability in streamflow is characteristic of sites in the piedmont province.

Increases in nonpermitted yields of TSS at low flow, are correlated to increases in 6 basin characteristics. Wetlands, hydrologic soil group A, sandy soil, permeability and unconsolidated sediments are associated with the Coastal Plain Province and silt content of the soil is associated with the New England Province. Decreases in nonpermitted yields of TSS are correlated to clay content of the soil, sedimentary bedrock, and slope. Clay and sedimentary rock are found primarily in the Piedmont Province. Increases in slope are associated with the New England province. The regression model that best explained the variation in nonpermitted yields of TSS at low flow was a function of sand and housing density. The model explained 71 percent of the variability in the study area. Nonpermitted yields of TSS increase at the sites with sander soil and higher housing density.

Nonpermitted yields of TSS at median flow are positively correlated to 4 variables – wetlands, hydrologic soil group A, sandy soil and unconsolidated sediments – associated with the Coastal Plain province (**figure 28**). Increases in nonpermitted yields at median flow are negatively correlated to 3 variables – slope, forested land and igneous rock – associated with the New England province. The regression model that best explained the variation in nonpermitted yields of TSS at median flow was a function of urban land use and slope. The model explained 63 percent of the variability in the study area. Nonpermitted yields of TSS generally increase at the sites with flatter slopes and higher amounts of urban area.

Summary and Conclusions

TOC and TSS loads are mainly from nonpermitted sources. Permitted loads comprise less than a third of the load at all except one site at low flow. Loads from permitted sources comprise more than a third of TP and NO3+NO2 load at low and median flow conditions at more than a third of the sites. Permitted sources of TKN comprise more than a third of the load at low flow at the majority of sites. Permitted sources comprise more than a third of the BOD load at low flow at a few sites. Loads from permitted sources comprise more than a third of TDS load at low flow at nearly half the sites. TDS load at median and high flow is primarily from nonpermitted sources.

The percentage of total instream TKN loads from permitted sources is highest at North Branch Raritan River near Chester, Lamington River at Burnt Mills, and Rockaway Creek. The percentage of BOD loads from permitted sources is highest at North Branch Raritan River near Chester, Rockaway Creek, and Matchaponix Brook. The percentage of NO2+NO3 loads from permitted sources is highest at North Branch Raritan River at Chester, Lamington River at Pottersville and Matchaponix Brook. The percentage of TOC loads from permitted sources is highest at Raritan River at Bound Brook, Millstone River at Grovers Mill, and Raritan River at Bound Brook. The percentage of TP loads from permitted sources is highest at Matchaponix Brook, Lamington River at Pottersville, and Rockaway Creek. The percentage of TSS loads from permitted sources is highest at North Branch Raritan River near Chester, Lamington River at Pottersville, and Matchaponix Brook. The percentage of TSS loads from permitted sources is highest at Matchaponix Brook, Millstone River at Blackwells Mill, and Lamington River at Pottersville.

The Raritan River sampling site at Bound Brook represents a composite of water draining nearly three quarters of the Raritan River basin including effluent from 70 permitted point sources. The percent of total instream load consisting of permitted sources at the Bound Brook sampling site ranges from 4 to 56 percent for the 7 constituents. Permitted sources comprise, 4 percent of total suspended solids; 10 percent of total organic carbon, 14 percent of biochemical oxygen demand, 22 percent of total dissolved solids, 35 percent of total ammonia plus organic nitrogen, 45 percent of total phosphorus, and 56 percent of nitrate plus nitrite loads.

Nonpermitted yields were related to environmental factors such as land use, soils, lithology, basin shape and hydrology. Increases in nonpermitted yields of TKN generally increased most strongly with increases in factors describing both urban areas and the Coastal Plain at high and median flow and with increases in factors describing the New England province at low flow. Nonpermitted yields of BOD generally increased most significantly with increases in factors describing urban areas at low flow and with deceases in factors describing soils and lithology in the Coastal Plain at high flow. Nonpermitted yields of TDS generally increased most significantly with lithology, and soils associated with the New England province at high flow. At low flow, nonpermitted yields were most strongly correlated to factors describing urban and agricultural land use, and flow.

Nonpermitted yields of NO3+NO2 generally increased most significantly with increases in septic system density, flow-per-unit area and soil permeability at low flow. No significant correlations were apparent at high flow, except with flow-per-unit area. Yields at high flow were not correlated with any variables except flow per unit area. Increases in nonpermitted yields of TOC generally were associated most significantly with increases in factors describing urban areas, flow-per unit area and permeability. Nonpermitted yields of TP and TSS generally increase most significantly with factors describing the Coastal Plain.

Summary by Constituent

TKN

TKN yield is primarily from nonpermitted sources except at selected sites at low flow. Total instream yields of TKN are generally highest at sites on the South Branch Raritan, Millstone, and Lamington Rivers at low and median flow. At high flow, the Matchaponix Brook and Raritan River at Bound Brook are also among the sites with the highest total yields. At low flow, more than a third of the total yield is from permitted sources at 10 of 21 sites. At median flow, more than 75 percent of total yield is from nonpermitted sources at 17 of 21 sites. At high flow, more than 80 percent of total yield is from nonpermitted sources at 19 of 21 sites. North Branch Raritan River near Chester, Raritan River at Bound Brook and Rockaway Creek are the sites with the highest percentages of permitted sources.

Nonpermitted yields of TKN were generally highest in the most urban areas and in the coastal plain at high and median flow and highest in the New England province at low flow. Yields were most strongly correlated to slope and factors describing land use, at high flow and at median flow. Slope is positively correlated to forested and total undeveloped land uses. Nonpermitted yields increased with decreases in slope and forested land use, and with increases in population density and wetlands. At low flow, nonpermitted yields were most strongly correlated to flashiness, a measure of variability in streamflow, and rotundity—highest in the New England province..

Significant downward trends in TKN concentrations sampled from 1991 to 1997 were observed at 5 sites. The decreasing trends at South Branch Raritan River at Stanton, North Branch Raritan River at Burnt Mills, and Beden Brook are at least partially related to decreases in TKN load from permitted facilities upstream from the sampling sites. Concentrations were found to increase as concentrations of TSS increase. Median concentrations of TKN significantly decreased as percentages of forested and total undeveloped land uses in the sampling site basins increased. Conversely, median concentrations increased with increasing population density, total developed land, and wetland.

BOD

Total instream yields of BOD at median and high flow conditions are highest at the South Branch Raritan River sites. Ninety-five percent or more of the yield at these sites is from nonpermitted sources. At low flow, yields at the South Branch Raritan River sites in addition to North Branch Raritan River at Chester, Rockaway Creek and Raritan River at Manville are among the highest.

Less than 12 percent of total yield is from permitted sources at the South Branch Raritan and Raritan River at Manville sites. At low flow, permitted sources account for more than half the load at North Branch Raritan River near Chester and Matchaponix Brook. Permitted sources are estimated to account for more than 30 percent of the yield at Rockaway Creek, Raritan River at Bound Brook, and Millstone River at Grovers Mill. At median and high flow, the 7 sites with the highest total instream yields have less than 90 percent of total yield from permitted sources. Eighty percent or more of the total yield is from nonpermitted sources at high flow at all sites.

Nonpermitted yields of BOD are generally highest in urban areas at low flow and lowest in the coastal plain at high flow. Yields at high flow, were only correlated to soil and lithology. At median flow, yields were most strongly correlated to septic system density and excessively well drained soils. Yields increased with increases in both factors. At low flow, nonpermitted yields were most strongly correlated to population density, septic system density and agriculture. Nonpermitted yields increased with increases in population density and septic system density and decreased with increases in agricultural land.

Median concentrations of BOD were not related to any land use category. Concentrations were not found to increase as concentrations of TSS increase. Only one significant trend in BOD concentration was observed on samples collected from 1991 to 1997. An increasing trend was observed at Stony Brook at Princeton. The median BOD concentration (1.7) is the second highest in the study area.

TDS

TDS yields are highest at all flow conditions, at South Branch Raritan, North Branch Raritan and Lamington River sites. Matchaponix Brook is among the seven sites with the highest yields at low and median flows. At high flow conditions, permitted yields are estimated to account for less than 20 percent of yield at these sites. At median flow 50 percent and 31 percent of yield respectively, originates from permitted sources at Matchaponix Brook and Lamington River at Pottersville. Permitted yields at other sites are less than 20 percent of total yield. At low flow conditions, more than 75 percent of yields at Matchaponix Brook and Lamington River at Pottersville and 62 percent of yields at North Branch Raritan River at Chester are estimated to originate from permitted sources. Permitted yields account for less than 18 percent of the total yield at the South Branch Raritan River sites.

Nonpermitted yields of TDS are generally highest in the New England province. At high and median flows, yields were most strongly correlated to lithology, soils and septic system density. Yields increased with increases in soil types and lithology characteristic of the New England Province and decreased with increases in soil type and lithology characteristic of the Coastal Plain province. At low flow, nonpermitted yields were most strongly correlated to population density, septic system density and agriculture. Nonpermitted yields increased with increases in population density and septic system density and decreased with increases in agricultural land.

Median concentrations of TDS significantly increased as the population density and percentage of urban land use at sites increased. A significant trend exists in TDS concentrations at 4 sites. Concentrations significantly increased at 2 sites and decreased at one site. None of these trends was influenced by changes in permitted effluent. TDS was not related to TSS concentrations.

NO2+NO3

NO2+NO3 yields are highest at low and median flow conditions, at the three South Branch Raritan River sites, the two most downstream Millstone River sites, North Branch Raritan River at Chester, and Matchaponix Brook. At high flow, the Beden Brook site replaces South Branch Raritan River at

Three Bridges among the sites with the highest yields. At low and median flow, permitted sources dominant the total yield at the Millstone River sites, North Branch Raritan River near Chester, and Matchaponix Brook. Permitted yields account for between 10 and 40 percent of yield at the South Branch Raritan River sites, with the highest percentage occurring at the Three Bridges site. Even at high flow, permitted sources account for more than two thirds of the yield at Matchaponix Brook and North Branch Raritan River at Chester. Forty percent of yield is from permitted sources at the Millstone River sites. Less than 20 percent is from permitted sources at the South Branch Raritan River and Beden Brook sites.

Nonpermitted yields of NO3+NO2 were generally highest in urban areas with the highest septic system density at low flow and lowest in the Piedmont at median flow. Yields at high flow were not correlated with any variables except flow per unit area. At median flows, nonpermitted yields were most strongly correlated to lithology, and soils. Yields decreased with increases in clay content of the soil and sedimentary bedrock, both characteristics of the Piedmont Province. At low flow, nonpermitted yields were most strongly correlated to clay content of the soil and septic system density. Nonpermitted yields increased with increases in septic system density and decreased with increases in clay content in the soil.

Median concentrations of NO3+NO2 significantly increased as the population density and percentages of urban land and wetland increased at sites. Median concentrations decreased with increasing percentages of forested land and total developed land at sites. Significant decreasing trends exist in NO3+NO2 concentrations exist at 4 sites. None of these trends was influenced by changes in permitted effluent. Concentrations of NO3+NO2 are inversely related to suspended sediment concentration at 5 sites and increased with sediment concentrations at one site.

TOC

At each flow condition TOC yields are among the highest at Lamington River at Pottersville, Millstone River at Grovers Mill and South Branch Raritan River at Middle Valley. At low flow the three other S.B Raritan River sites are also among the seven sites with the highest yields. At median flow, Lamington River at Burnt Mills and Millstone River at Blackwells Mill replace two of the South Branch Raritan River sites among the highest. At high flow, the Raritan River at Bound Brook replaces the Three Bridges site in the list of sites with the highest 7 yields. TOC yields are a nonpermitted source issue at each flow condition. The highest percentage of yield from permitted sources is 17 percent at Lamington River at Pottersville at low flow.

Nonpermitted yields of TOC are generally highest in urban areas, and the New England Province and lowest in the coastal plain. At high flow conditions yields were most strongly correlated to factors defining urban land use. Yields increased with increases in population density and housing density. At median flows, nonpermitted yields were most strongly correlated to basin shape, and septic system density. Yields increased with increases in rotundity and septic system density, both characteristics associated with the New England Province. At low flow, nonpermitted yields were most strongly correlated to hydrology, soils and basin shape. Nonpermitted yields increased with increases in rotundity and decreased with increases in flashiness and clay content in the soil.

Median concentrations of TOC significantly increased as total developed land increased and decreased as forest and total undeveloped land increased at sites. Significant decreasing trends exist in TOC concentrations at 3 sites. The decrease at Beden Brook was possibly influenced by decreases in TOC load from permitted effluent. Concentrations of TOC are inversely related to suspended sediment concentration at 5 sites and increased with sediment concentrations at one site. Concentrations of TOC were found to significantly increase as concentrations of TSS increased at 13 sites.

TP

TP yields are the highest at each flow condition at the Millstone River sites at Grovers Mill and Blackwells Mill, South Branch Raritan River at Three Bridges and Raritan River at Bound Brook. TP yields are a permitted point source issue at most of the sites with the highest yields at low and median flows. The percent of yield from permitted sources increased at Millstone River at Blackwells Mill with flow at the site, from less than 10 percent at low flow to 22 percent at high flow. At low flow, more than 75 percent of yields are from permitted sources at 6 of the 9 sites with highest yields; Lamington River at Pottersville, Rockaway Creek, South Branch Raritan River at Middle Valley, North Branch Raritan River at Chester, Millstone River at Grovers Mill and Raritan River at Bound Brook. More than 50 percent and 23 percent of the yield is from permitted sources at Three Bridges and Raritan River at Manville, respectively. More than 50 percent of the yield at median flow originates from permitted sources at 4 of the 7 sites with highest yields. At high flow over 98 percent of the yield at Beden Brook is from nonpermitted sources. South Branch Raritan River at Middle Valley has the highest percentage of yield from is from permitted sources at high flow (40 percent).

Nonpermitted yields of TP are generally highest in the coastal plain province. At high flow conditions yields were most strongly correlated to factors defining lithology and topography. Yields increased with decreases in slope and metamorphic bedrock. Lowest yields are in the New England province. At median flows, nonpermitted yields were most strongly correlated to hydrologic soils group D, slope and unconsolidated sediments. Yields increased with decreases in slope and increases in hydrologic soils group D and unconsolidated sediments, characteristics associated with the Coastal Plain province. At low flow, nonpermitted yields were most strongly correlated to soils, lithology and basin shape. Nonpermitted yields increased with increases in rotundity – basin elongation – and decreased with increases in clay content in the soil and sedimentary bedrock.

Median concentrations of TP significantly increased as total developed land increased and decreased with increases in forest and total undeveloped land. Significant decreasing trends exist in TP concentrations at 8 sites. The decreases at 2 sites were related to decreases in TP load from permitted effluent. The decrease at 3 other sites is probably influenced by decreases in permitted effluent. Concentrations of TP were found to significantly increase as concentrations of TSS increased at 11 sites.

TSS

TSS yields at each flow condition are among the seven highest at the three Millstone River sites. TSS yield is a nonpermitted source issue at every site. The Millstone River sites at Grovers Mill and Blackwells Mill have the highest percentage of yield from permitted sources; approximately 8 percent at low flow conditions. Median concentrations of TSS significantly increased as agriculture, total developed land, and wetlands increased. Conversely, concentrations increase at forested land and total undeveloped land decrease. No significant trends exist in TSS concentrations.

Nonpermitted yields of TSS are generally highest in the coastal plain. At high flow conditions, yields were most strongly correlated to factors of slope, forested land, and soils. Yields increased with decreases in slope, and forested land and increased with increases in hydrologic soil group A. At median flows, nonpermitted yields were most strongly correlated to slope, hydrologic soils group A and unconsolidated sediments. Yields increased with decreases in slope and increased with increases hydrologic soils group A and unconsolidated sediments, all characteristics associated with the Coastal Plain Province. At low flow, nonpermitted yields were most strongly correlated to slope, soils and lithology. Nonpermitted yields increased with decreases in slope, sedimentary bedrock and clay and with increases in permeability and sandy soil.

References Cited

Anderson, J.R., Hardy. E.E., Roach, J.T., and Witmer, R.E., 1976, A land use and land cover classification system for use with remote sensor data: U.S. Geological Survey Professional Paper 964, 28 p.

Anderson, P.W., and Faust, S.D.,1974, Water quality and streamflow characteristics, Raritan River basin, New Jersey:U.S. Geological Survey Water-Resources Investigations Report 14-74, 82 p.(PB-243 400/AS.)

Buxton, D.E., Hunchak-Kariouk, Kathryn, and Hickman, R.E., 1999, Relations of surface-water quality to streamflow in the Raritan River Basin, New Jersey, water years 1976-93: U.S. Geological Survey Water-Resources Investigations Report 99-4045, 100p.

CH2M Hill, Metcalf & Eddy, Inc., and New Jersey First, Inc., 1992, New Jersey Statewide Water Supply Masterplan, Task 2 Report, Water Supply Baseline Data Development and Analyses: New Jersey Department of Environmental Protection and Energy, Trenton, N.J., 36 p.

Cohn, T.A., 1988, Adjusted maximum estimation of the moments of lognormal populations from type 1 censored samples: U.S. Geological Survey Open-File Report 88-350, 34 p.

Helsel, D.R., and Hirsch, R.M., 1992, Statistical methods in water resources: New York, Elsevier Science Publishing Company Inc., 522 p.

Hem, J.D., 1985, Study and interpretation of the chemical characteristics of natural water: U.S. Geological Survey Water Supply Paper 2254, 263 p.

Hickman, R.E., and Barringer, T.H., 1999, Trends in water quality of New Jersey streams, water years 1986-95: U.S. Geological Survey Water-Resources Investigations Report 98-4204, 174 p.

Hirsch, R.M., 1982, A comparison of four streamflow record extension techniques: Water Resources Research, v. 18, no.4, p. 1081-1088.

Jarrell, W.M., 1999, Getting started with TMDLs: Oregon Graduate Institute of Science and Technology, 86 p.

Jobson, H.E., 1996, Prediction of Travel Time and Longitudinal Dispersion in Rivers and Streams: U.S. Geological Survey Water-Resources Investigation Report 96-4013, 69 p.

Jobson, H.E., 2000, Variation of Travel Time with River Flow: U.S. Geological Survey Water- Resources Investigation Report 00-xxxx, 38 p

Kauffman, L.J., 1999, Simulated Effects of Changes in Nitrate Input in Aquifer Recharge on Nitrate Concentrations in Streams and Water-Supply Wells, New Jersey Coastal Plain [abs]: Third National Workshop on Constructed Wetlands/BMPs for Nutrient Reduction and Coastal Water Protection Abstracts, New Orleans, LA, June 9-12, 1999, p 74-76.

National Oceanic and Atmospheric Administration, National Climatic Data Center, 2000, Climate Division database(Last update: February 2000)(Accessed March 17, 2000, from File Transfer Protocol site at URL ftp://ftp.ncdc.noaa.gov/pub/data/cirs).

New Jersey Department of Environmental Protection, 1992, New Jersey Geological Survey, Geologic map of New Jersey.

______1997, New Jersey 1996 State water quality inventory report: Trenton, N.J., New Jersey Department of Environmental Protection, Office of Environmental Planning, 5 chap.

______1998, Surface water quality standards: N.J.A.C. 7:9B: Trenton, N.J., New Jersey Department of Environmental Protection, Office of Environmental Planning, April 1998, 122 p.

______2000, Land Use /Land Cover and Impervious Surfaces for Watershed Management Areas 8, 9 and 10, 1995/97: Bureau of Geographic Information and Analysis, (Accessed April, 2000, on the World Wide Web at URL http://www.state.nj.us/dep/gis/lulc95shp.html.)

Ott, L., 1988, An introduction to statistical methods and data analysis: Boston, Mass., PWS-Kent Publishing Company, 835 p.

Reed, T.J., Centinaro, G.L., DeLuca, M.J., and Oden, J.H., 1998, Water resources data for New Jersey--Water year 1997, Volume 1. Surface-water data: U.S. Geological Survey Water-Data Report NJ-97-1, 608 p.

Reiser, Robert, 2000, Preliminary Evaluation of Water Quality Status in the Raritan River Basin, Water Years 1991-1997, Access via World Wide Web at URL http://www.raritanbasin.org/water_quality.htm.

Robertson W.D., Cherry, J.A., and Sudicky E.A., 1991, Groundwater contamination from two small septic systems on sand aquifers, Groundwater, v. 29, no. 1, pp. 82-92.

Robinson, K.W., Lazaro, T.R., and Pak, Connie, 1996, Associations between water quality trends in new Jersey streams and drainage-basin characteristics, 1975-86: U.S. Geological Survey Water- Resources Investigation Report 96-4119, 148 p.

Ruffner, J.A., and Bair, F.E., eds., 1977, The weather almanac (2d ed.): New York, Avon Books, 35p.

SAS Institute Inc., 1995, SAS Procedures Guide, version 6, 3rd ed. Cary, N.C. 703 p.

SAS Institute Inc., 1995, SAS System for Regression, SAS series in Statistical Applications, 2nd ed. Cary, N.C. 703 p.

Stackelberg, P.E., 1997, Presence and distribution of chlorinated organic compounds in streambed sediments, New Jersey: Journal of the American Water Resources Association, v. 33, No. 2, p. 271-284.

U.S. Bureau of the Census, 1991, Census of population and housing, 1990: Public Law 94-171 data for New Jersey: Washington, D.C., U.S. Bureau of the Census [machine readable data files (CD ROM)].

U.S. Department of Agriculture, 1995, Soil Survey Geographic (SSURGO) Data Base Data Use Information: U.S. Department of Agriculture, Soil Conservation Service Miscellaneous Publication 1527, 31 p.