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New Jersey Department of Environmental Protection and the
Delaware River Basin Commission

Trends in the Quality of Water in New Jersey Streams, Water Years 1971–2011

Scientific Investigations Report 2016–5176

U.S. Department of the Interior
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Conversion Factors

U.S. customary units to International System of Units

Multiply	By	To obtain
	Area	
square mile (mi^2)	259.0	hectare (ha)
square mile (mi^2)	2.590	square kilometer (km^2)
	Flow rate	
cubic foot per second (ft^3/s)	0.02832	cubic meter per second (m^3/s)
ton per day (ton/d)	0.9072	metric ton per day
ton per day (ton/d)	0.9072	megagram per day (Mg/d)

Temperature in degrees Celsius (°C) may be converted to degrees Fahrenheit (°F) as follows:

$$°F = (1.8 \times °C) + 32.$$

Temperature in degrees Fahrenheit (°F) may be converted to degrees Celsius (°C) as follows:

$$°C = (°F - 32) / 1.8.$$

Datum

Horizontal coordinate information is referenced to the North American Datum of 1983 (NAD 83).

Supplemental Information

Specific conductance is given in microsiemens per centimeter at 25 degrees Celsius (μS/cm at 25 °C).

Concentrations of chemical constituents in water are given in milligrams per liter (mg/L).

Abbreviations

DRBC	Delaware River Basin Commission
EGRET	Exploration and Graphics for RivEr Trends
MOVE1	Maintenance of Variance Extension 1
NJDEP	New Jersey Department of Environmental Protection
WBT	Weighted Regressions on Time, Discharge, and Season Bootstrap Test
WRTDS	Weighted Regressions on Time, Discharge, and Season
USGS	U.S. Geological Survey

Trends in the Quality of Water in New Jersey Streams, Water Years 1971–2011

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Abstract

In a study conducted by the U.S. Geological Survey in cooperation with the New Jersey Department of Environmental Protection and the Delaware River Basin Commission, trend tests were conducted on selected water-quality characteristics measured at stations on streams in New Jersey during selected periods over water years 1971–2011. Tests were conducted on 3 nutrients (total nitrogen, filtered nitrate plus nitrite, and total phosphorus) at 28 water-quality stations. At 4 of these stations, tests were also conducted on 3 measures of major ions (specific conductance, filtered chloride, and total dissolved solids).

Two methods were used to identify trends—Weighted Regressions on Time, Discharge, and Season (WRTDS) models and seasonal rank-sum tests. For this report, the use of WRTDS models included the use of the WRTDS Bootstrap Test (WBT). WRTDS models identified trends in flow-normalized annual concentrations and flow-normalized annual fluxes over water years 1980–2011 and 2000–11 for each nutrient, filtered chloride, and total dissolved solids. WRTDS models were developed for each nutrient at the 20 or 21 stations at which streamflow was measured or estimated. Trends in nutrient concentration were reported for these stations; trends in nutrient fluxes were reported only for 15–17 of these stations.

The results of WRTDS models for water years 1980–2011 identified more stations with downward trends in concentrations of either total nitrogen or total phosphorus than upward trends. For total nitrogen, there were downward trends at 9 stations and an upward trend at 1 station. For total phosphorus, there were downward trends at 8 stations and an upward trend at 1 station. For filtered nitrate plus nitrite, there were downward trends at 6 stations and upward trends at 6 stations. The result of the trend test in flux for a selected nutrient at a selected station (downward trend, no trend, or upward trend) usually matched the trend result in concentration.

Seasonal rank-sum tests, the second method used, identified step trends in water-quality measured in different decades—1970s, 1980s, 1990s, and 2000s. Tests were conducted on all nutrients at 28 stations and on all measures of major ions at the 4 selected stations. Results of seasonal rank-sum tests between the 1980s and the 2000s identified more stations with downward trends in concentrations of total nitrogen (14) than stations with upward trends (2) and more stations with downward trends in concentrations of total phosphorus (18) than stations with upward trends (1).

A combined dataset of trend results for concentrations over water years 1980–2011 was created from the results of the two tests for the period. Results of WRTDS models were included in this combined dataset, if available. Otherwise, the results of the seasonal rank-sum tests between water-quality characteristics measured in the 1980s and 2000s were included.

Trend results over water years 1980–2011 in the combined dataset show that few of the 28 stations had upward trends in concentrations of either total nitrogen or total phosphorus. There were only 2 stations with upward trends in total nitrogen concentration and 1 station with an upward trend in total phosphorus concentration. Results for filtered nitrate plus nitrite show about the same number of stations with upward trends (9) as stations with downward trends (7). Results for all measures of major ions show upward trends at the four stations tested.

Introduction

Water-quality characteristics (including constituents) have been systematically measured at stations on New Jersey streams since the 1970s by the New Jersey Department of Environmental Protection (NJDEP) and the U.S. Geological Survey (USGS). Most characteristics have been collected for the Ambient Surface Water-Quality Monitoring Network operated by the NJDEP in cooperation with the USGS (section "Selected Programs of Water-Quality Measurements of New Jersey Streams"). Other characteristics have been measured by the USGS as part of national water-quality monitoring programs (section "Selected Programs of Water-Quality Measurements of New Jersey Sreams") or in cooperation with other local agencies such as the Delaware River Basin Commission (DRBC). A constituent is a type of water-quality characteristic composed of a measureable substance (either dissolved or particulate) carried in streamflow.

Previous studies (section "Previous Studies of Trends in Water Quality in New Jersey Streams") identified trends in water-quality characteristics and in fluxes at selected water-quality stations. These studies identified monotonic trends, mostly over periods of about 10 years. A trend is a significant decrease or increase in water-quality characteristic value or flux value over time. A monotonic trend is an increase or a decrease in a water-quality characteristic value or flux value over the entire period being analyzed. Flux is the load per unit time of a water-quality constituent carried in the stream.

Purpose and Scope

The purpose of this report is to identify trends in water quality and in fluxes of selected water-quality characteristics at stations on streams in New Jersey over selected periods during water years[1] 1971–2011 by use of methods which do not assume monotonic trends. Trend analyses were conducted on 3 nutrients (filtered nitrate plus nitrite, total nitrogen, and total phosphorus) at 28 stations. At 4 of these stations, tests were also conducted on 3 measures of major ions (specific conductance, filtered chloride, and total dissolved solids). The identification of a monotonic trend in water quality over a long period (about 30 years) may provide misleading results if the values of water quality decrease during part of this period and increase during another part.

In order to meet the overall objective of useful information on trends in the selected water-quality characteristics of New Jersey streams, the approach for this study has four components. The first is to describe the dataset of values of selected water-quality characteristics (including the six water-quality characteristics analyzed in this report) measured at 32 selected stations on streams in New Jersey and the methods used to create the dataset. Reported changes in water-quality values owing to changes in field and laboratory methodology are mentioned.

The second is to use Weighted Regressions on Time, Discharge, and Season (WRTDS; Hirsch and others, 2010) models (including the WRTDS Bootstrap Test; Hirsch and others, 2015) to identify trends in concentration and flux over two periods, water years 1980–2011 and 2000–11. This method was applied to water-quality characteristics at stations with records of daily streamflow. Results of the WRTDS models are displayed with and compared to selected results of previous studies.

The third is to use seasonal rank-sum tests (Dave Lorenz, USGS, written commun., 2015) to identify step trends in values of water-quality characteristics between the following decades: 1970s, 1980s, 1990s, and 2000s. This method was applied to all nutrients at 28 stations and to all measures of major ions at the 4 selected stations. Results are displayed with results of previous trend studies.

The fourth is to create a combined set of results of trend tests on concentrations for the period, water years 1980–2011. This combined dataset contains results of the WRTDS models for water years 1980–2011, if available. Otherwise, the results of the seasonal rank-sum tests between the 1980s and 2000s are included.

Description of Study Area

Water-quality data at 32 water-quality stations mentioned in this report (table 1, fig. 1) are presented in the dataset of long-term water-quality data created for the NJDEP (section "Creation of Dataset of Water-Quality Values in Streams of New Jersey for Water Years 1971–2011"). Of these 32 stations, nutrient concentrations at 28 stations and measures of major ions at 4 of these 28 stations were analyzed for trends. Data at 4 stations were not analyzed for trends.

Water-quality stations are shown along with the NJDEP water management regions (NJDEP, 1997; NJDEP, 2007) in which they are located (fig. 1). Each water management region generally identifies the receiving waters of the streams in that region. Streams in the Lower Delaware water region and nearly all of those in the Northwest water region drain to the Delaware River. For the purposes of this report, the Northwest and Lower Delaware regions, when considered together, generally define the portion of the Delaware River Basin in New Jersey. Streams in the Northeast water region drain to the coastal waters between New Jersey and New York State, those in the Raritan water region drain to Raritan Bay, and those in the Atlantic Coast water region drain to the adjacent coastal waters of the Atlantic Ocean.

New Jersey is geologically divided into northern and southern regions by the Fall Line (fig. 2) which is marked by a series of waterfalls along river courses (Watt, 2000). The land to the north of the Fall Line is underlain by sedimentary and crystalline bedrock and is encompassed by three physiographic provinces—the Valley and Ridge, the Highlands, and the Piedmont Provinces (Dalton, 2006). The Valley and Ridge is characterized by steep-sided, linear ridges, and broad valleys; the Highlands by a series of discontinuous rounded ridges separated by deep, narrow valleys; and the Piedmont by a low rolling plain divided by a series of high ridges. The one province to the south of the Fall Line, the Coastal Plain, consists of flat, low-lying land underlain by gravel, sand, silt, and clay.

Land use in 2011 varied considerably throughout New Jersey (fig. 2). Much of the urban land is close to the Fall Line, near New York City in the northeastern part of the State, and along the Atlantic Coast. Agricultural land tends to be present in the western half of the State, and forest is concentrated in the northwest and southeast.

Selected Programs of Water-Quality Measurements of New Jersey Streams

In general, systematic measurements of the water-quality characteristics at stations on the streams of New Jersey have been made since the 1970s. Most measurements were made

[1] A water year is the 12-month period beginning October 1 and ending September 30. It is identified by the calendar year in which it ends.

Base from U.S. Geological Survey digital data, 1:24,000,
Universal Transverse Mercator projection, Zone 18, North American Datum of 1983

Figure 1. Locations of water-quality stations in New Jersey that are included in the long-term water-quality dataset and characteristics for which trend tests were conducted.

Table 1. Description of selected water-quality stations on streams in New Jersey at which water-quality values were measured during water years 1971–2011.

[Latitude and longitude in degrees minutes seconds; NAD 27, North American Datum of 1927; NAD 83, North American Datum of 1983; nutrients are total nitrogen, filtered nitrate plus nitrite, and total phosphorus; measures of major ions are filtered chloride, total dissolved solids, and specific conductance; NJDEP, New Jersey Department of Environmental Protection; USGS, U.S. Geological Survey; Both, New Jersey Department of Environmental Protection and U.S. Geological Survey; R., River; Cr., Creek; Del., Delaware; L., Little; Pa., Pennsylvania; N.J., New Jersey; n.a., not applicable]

Station number	Station name (short name)	Latitude	Longitude	Datum for latitude and longitude	Drainage area (square miles)	Water-quality characteristics analyzed for trends in this report	Agency primarily responsible for sampling station for Ambient Surface-Water Quality Monitoring Network during water years 1998–2011	[1]Station sampled by USGS as part of selected USGS national water-quality programs
01367770	Wallkill River near Sussex, N.J. (Wallkill R.)	411138	0743431	NAD 83	60.80	Nutrients	USGS	No
01377000	Hackensack River at Rivervale, N.J. (Hackensack R.)	405957	0735921	NAD 83	58.00	Nutrients	NJDEP	No
01381800	Whippany River near Pine Brook, N.J. (Whippany R.)	405042	0742050	NAD 83	68.50	Nutrients	NJDEP	No
01382000	Passaic River at Two Bridges, N.J. (Passaic R. at Two Bridges)	405350	0741622	NAD 83	361.00	Nutrients	USGS	Yes
01387500	Ramapo River near Mahwah, N.J. (Ramapo R.)	410553	0740946	NAD 83	120.00	Nutrients	NJDEP	No
01389500	Passaic River at Little Falls, N.J. (Passaic R. at L. Falls)	405305	0741334	NAD 83	762.00	Nutrients	Both	Yes
01391500	Saddle River at Lodi, N.J. (Saddle R.)	405325	0740450	NAD 83	54.60	Nutrients	NJDEP	No
01394500	Rahway River near Springfield, N.J.	404115	0741842	NAD 83	25.50	n.a.	NJDEP	No
01395000	Rahway River at Rahway, N.J. (Rahway R.)	403708	0741700	NAD 83	40.90	Nutrients	NJDEP	No
01396660	Mulhockaway Creek at Van Syckel, N.J. (Mulhockaway Cr.)	403851	0745808	NAD 83	11.80	Nutrients	Both	No
01398000	Neshanic River at Reaville, N.J. (Neshanic R.)	402824	0744940	NAD 83	25.70	Nutrients	NJDEP	Yes
01399780	Lamington River at Burnt Mills, N.J. (Lamington R.)	403805	0744112	NAD 83	100.00	Nutrients	USGS	No
01403300	Raritan River at Queens Bridge at Bound Brook, N.J. (Raritan R.)	403334	0743140	NAD 83	804.00	Nutrients	Both	Yes
01405340	Manalapan Brook at Federal Road near Manalapan, N.J. (Manalapan Brook)	401746	0742352	NAD 83	20.90	Nutrients	USGS	No
01408500	[2]Toms River near Toms River, N.J. (Toms R.)	395911	0741324	NAD 83	123.00	Nutrients	NJDEP	Yes
01409387	Mullica River at outlet of Atsion Lake at Atsion, N.J. (Mullica R.)	394425	0744336	NAD 83	26.70	Nutrients	USGS	No
01409416	Hammonton Creek at Wescoatville, N.J.	393802	0744304	NAD 83	9.57	n.a.	USGS	No

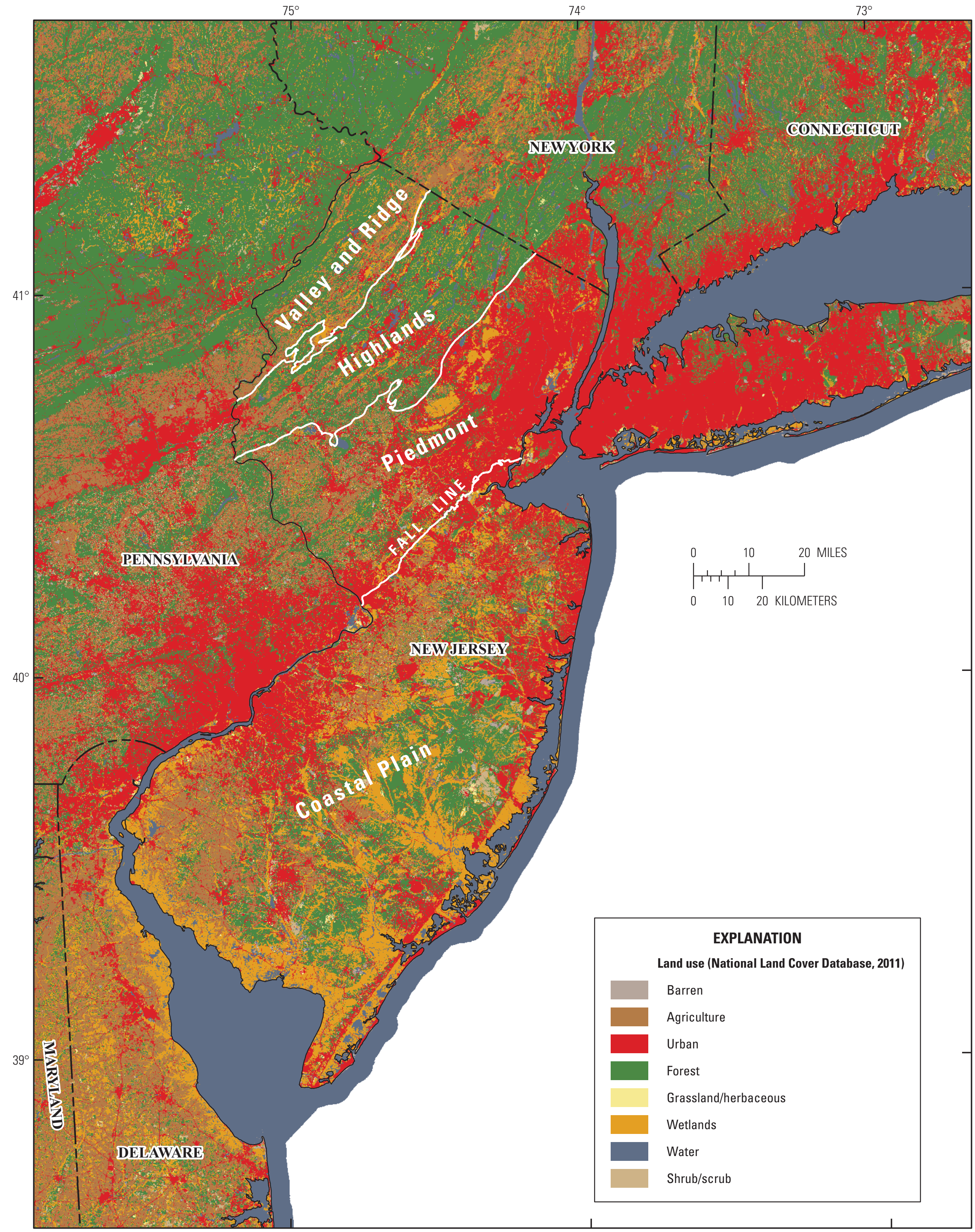
Table 1. Description of selected water-quality stations on streams in New Jersey at which water-quality values were measured during water years 1971–2011.—Continued

[Latitude and longitude in degrees minutes seconds; NAD 27, North American Datum of 1927; NAD 83, North American Datum of 1983; nutrients are total nitrogen, filtered nitrate plus nitrite, and total phosphorus; measures of major ions are filtered chloride, total dissolved solids, and specific conductance; NJDEP, New Jersey Department of Environmental Protection; USGS, U.S. Geological Survey; Both, New Jersey Department of Environmental Protection and U.S. Geological Survey; R., River; Cr., Creek; Del., Delaware; L., Little; Pa., Pennsylvania; N.J., New Jersey; n.a., not applicable]

Station number	Station name (short name)	Latitude	Longitude	Datum for latitude and longitude	Drainage area (square miles)	Water-quality characteristics analyzed for trends in this report	Agency primarily responsible for sampling station for Ambient Surface-Water Quality Monitoring Network during water years 1998–2011	[1]Station sampled by USGS as part of selected USGS national water-quality programs
01409500	Batsto River at Batsto, N.J. (Batsto R.)	393830	0743901	NAD 83	67.80	Nutrients	NJDEP	No
01409815	West Branch Wading River at Maxwell, N.J. (West Branch Wading R.)	394030	0743227	NAD 83	85.90	Nutrients	USGS	Yes
01410150	East Branch Bass River near New Gretna, N.J.	393723	0742629	NAD 83	8.11	n.a.	NJDEP	No
01411110	Great Egg Harbor River at Weymouth, N.J. (Great Egg Harbor R.)	393050	0744647	NAD 83	154.00	Nutrients	USGS	No
01411500	Maurice River at Norma, N.J. (Maurice R.)	392944	0750437	NAD 83	112.00	Nutrients	NJDEP	Yes
01412800	Cohansey River at Seeley, N.J. (Cohansey R.)	392821	0751520	NAD 83	28.00	Nutrients	Both	No
01443000	Delaware River at Portland, Pa. (Del. R. at Portland)	405526	0750546	NAD 27	4,165.00	Nutrients and major ions	USGS	No
01443500	Paulins Kill at Blairstown, N.J. (Paulins Kill)	405851	0745712	NAD 83	126.00	Nutrients	NJDEP	No
01457400	Musconetcong River at Riegelsville, N.J. (Musconetcong R.)	403533	0751110	NAD 27	156.00	Nutrients	USGS	No
01460820	Delaware River at Lumberville, Pa. (Del. R. at Lumberville)	402427	0750216	NAD 83	6,598.00	Nutrients and major ions	NJDEP	No
01463500	Delaware River at Trenton, N.J. (Del. R. at Trenton)	401318	0744641	NAD 83	6,780.00	Nutrients and major ions	USGS	Yes
01464515	Doctors Creek at Allentown, N.J. (Doctors Cr.)	401037	0743556	NAD 83	17.40	Nutrients	USGS	No
01466500	McDonalds Branch in Byrne State Forest, N.J. (McDonalds Branch)	395306	0743019	NAD 83	2.35	Nutrients	NJDEP	Yes
01477120	Raccoon Creek near Swedesboro, N.J. (Raccoon Cr.)	394426	0751533	NAD 83	26.90	Nutrients and major ions	NJDEP	Yes
01482500	Salem River at Woodstown, N.J.	393838	0751949	NAD 83	14.60	n.a.	Both	No

[1]National Stream Quality Accounting Network, Hydrologic Benchmark Network, and (or) National Water-Quality Assessment.

[2]Includes values of water quality measured at Toms River at park footbridge, near Toms River, New Jersey (01408505).



Base from U.S. Geological Survey digital data, 30-meter resolution
Universal Transverse Mercator projection, Zone 18, North American Datum of 1983

Figure 2. Location of the Fall Line, physiographic provinces, and 2011 land use in New Jersey.

for the Ambient Surface Water Quality Monitoring Network by the NJDEP and the USGS since water year 1976. A recent description of the program was published by NJDEP (2016). One of the objectives of the network is "continued tracking of status and trends in ambient water quality" (NJDEP, 2016) Samples were analyzed at the New Jersey Department of Health Laboratory and at USGS laboratories. All data are stored in the USGS National Water Information System (http://waterdata.usgs.gov/nwis). Sampling procedures followed the USGS National Field Manual for the Collection of Water Quality Data described at http://water.usgs.gov/owq/FieldManual/. The quality assurance/quality control plan can be obtained by contacting the New Jersey Water Science Center (http://nj.usgs.gov/contact.html).

Water-quality measurements for New Jersey streams also were made as part of three national water-quality programs operated by the USGS—the Hydrologic Benchmark Network (HBN), the National Stream Accounting Network (NASQAN), and the National Water Quality Assessment (NAWQA). A brief description of the current purpose and scope of these programs can be found at http://water.usgs.gov/owq/programs.html. Selected stations that were sampled for one or more of these programs are listed in table 1. Streamwater samples collected for these national programs were analyzed at USGS laboratories. Samples from some stations were collected for the Ambient Surface-Water Quality Monitoring Network and as part of USGS national programs.

Previous Studies of Trends in Water Quality in New Jersey Streams

Trends in concentrations of nutrients and (or) measures of major ions of the streams in New Jersey have been reported in studies by the USGS in cooperation with NJDEP and by the USGS as part of multi-state studies. Three reports produced by the USGS in cooperation with the NJDEP discuss the use of Tobit regression and Seasonal Kendall methods in ESTREND (Schertz and others, 1991) to identify monotonic trends. Trends in concentrations of nitrogen species and total phosphorus were determined from Tobit regression; trends in specific conductance, filtered chloride concentrations, and concentrations of total dissolved solids were identified from Seasonal Kendall tests. Trends over water years 1976–86 and 1979–86 were identified by Hay and Campbell (1990) at 86 stations. Trends over water years 1986–95 were identified by Hickman and Barringer (1999) at 83 stations. Trends over water years 1998–2007 were identified by Hickman and Gray (2010) at 70 stations.

Two multi-state reports identify trends in concentrations and fluxes of nutrients at stations on streams in New Jersey—Sprague and others (2009) and Trench and others (2012). Sprague and others (2009) report trends in flow-adjusted concentrations, non-flow-adjusted concentrations, and fluxes for total nitrogen, filtered nitrate plus nitrite, and total phosphorus at stations across the United States for water years 1993–2003; 20 of these stations are in New Jersey. Trends in Sprague and others (2009) were determined using (1) models relating daily streamflow to date, and (2) models relating flow-adjusted concentrations to date, streamflow, and season.

Trench and others (2012) report trends in concentrations and fluxes for several water-quality characteristics at stations on streams throughout the Northeastern United States for water years 1975–2003 and 1993–2003; 31 stations in New Jersey were included. Water-quality characteristics in the study included total phosphorus, total nitrogen, and filtered nitrate plus nitrite. Trends in flow-adjusted concentrations over the shorter period were identified using (1) coupled water-quality and streamflow statistical models and (2) Tobit regression. Trends in flow-adjusted concentrations and in fluxes at 10 stations over water years 1975–2003 were identified using coupled water-quality and streamflow statistical models.

A third multi-state study done by Anning and Flynn (2014) determined fluxes, concentrations, and sources of dissolved solids in streams throughout the conterminous United States by use of the Fluxmaster program (Schwarz and others, 2006). Trends in flow-adjusted concentrations at 41 stations in New Jersey during water years 1980–2009 are identified.

Methods

In general, three groups of methods were used in this study. The first group consists of the methods used to create the dataset from which was trends were determined. The second group consists of the methods associated with using WRTDS models and the WRTDS Bootstrap Test to identify trends, and the third group consists of seasonal rank-sum tests and related procedures.

Creation of Dataset of Water-Quality Values in Streams of New Jersey for Water Years 1971–2011

The dataset contains 12 selected water-quality characteristics measured at 32 selected stream stations in New Jersey (fig. 2; table 1) over water years 1971–2011. The water-quality characteristics are water temperature, specific conductance, pH, dissolved oxygen concentration, dissolved oxygen saturation, and concentrations of total nitrogen, filtered nitrate plus nitrite, total phosphorus, total dissolved solids, filtered chloride, total suspended solids, and suspended sediment. Instantaneous streamflows at the time of water-quality measurements are included in the dataset to allow trend tests to consider the variation in water quality with instantaneous streamflow. The dataset was created using the following steps:

1. Retrieval of water-quality data from the USGS National Water Information System (NWIS, http://waterdata.usgs.gov/nj/nwis/qw/) for the indicated stations for water years 1971–2011. Parameter codes shown were used in the NWIS water-quality data files to identify selected

water-quality characteristics. Water-quality data for the station on the Toms River near Toms River, New Jersey (station number 01408500) include data measured at the station, Toms River at park footbridge, near Toms River, New Jersey (01408505) sited just downstream from the other station on Toms River.

2. Estimation of some missing data for instantaneous streamflow, specific conductance, nitrate plus nitrite, and total nitrogen either by substitution of data for different water-quality characteristics or by calculation from other water-quality data (described in Hickman and Gray, 2010). A summary of the substitutions and calculations is given in table 2.

3. Conversion of zero data to censored (“less-than”) concentrations with reporting limits from other censored data measured at about the same time.

4. Identification of outlying data from plots of the data and from using the data in the WRTDS models. Outlying data were not included in the analyses for trends.

5. Changing the reporting level of a small number of censored data for filtered nitrate plus nitrite from 1.0 milligrams per liter as nitrogen to 0.1 milligrams per liter as nitrogen. WRTDS models were created with the original reporting level of 1.0 milligrams per liter as nitrogen.

6. Addition of a character variable for each water-quality characteristic to the dataset. The contents of this character variable indicated whether the water-quality result was (1) determined from substitution or calculation, or (2) considered an outlier.

Some reported changes in water-quality data resulting from biases and (or) changes in methods used either to collect field measurements or to determine values in a laboratory are briefly discussed in the section, “Dataset of water-quality values at selected stations on streams in New Jersey, water years 1971–2011.” Laboratory bias and (or) changes are only reported for USGS facilities.

Identification of Trends Using Weighted Regressions on Time, Discharge, and Season Models

Trends in concentration and flux of each nutrient and two measures of major ions (filtered chloride and total dissolved solids) were identified using WRTDS models (Hirsch and others, 2010) over two periods—water years 1980–2011 and 2000–11. Trends in specific conductance were not identified using this method because specific conductance is not a constituent but rather a physical property of water. WRTDS models were used only for stations at which a record of daily streamflow was measured or could be estimated. WRTDS models were selected because this method (1) determines trends in fluxes and (2) does not assume a monotonic change in concentrations over time. For this study, the use of WRTDS models includes use of the WRTDS Bootstrap Test (WBT; Hirsch and others, 2015).

Flow-Normalized Daily Concentrations and Fluxes

The first step in identifying trends was to determine, for a selected constituent at a selected station over a specified period of analysis, the series of WRTDS models that relate daily concentration to year, daily streamflow, and season. The form of each WRTDS model is given below; sine and cosine functions account for seasonality (Hirsch and others, 2010). The units for daily concentration and daily streamflow vary with the application of this method.

$$\ln(c) = \beta_0 + \beta_1 * t + \beta_2 * \ln(Q) + \beta_3 * \sin(2\pi t) + \beta_4 * \cos(2\pi t) + \varepsilon \quad (1)$$

where

$\ln()$ = natural logarithym function;
c = daily concentration;
t = time, in years;
Q = daily streamflow;
$\sin()$ = sine function;
$\cos()$ = cosine function;
$\beta_0, \beta_1, \beta_2, \beta_3, \beta_4$ = fitted coefficients; and
ε = unexplained variation.

Each WRTDS model was determined by use of weighted regression (Hirsch and others, 2010) on measured concentrations and values of daily streamflow. The measured concentrations with the greatest weights were those measured on days that were closest in time (year), season, and streamflow to the day, season, and streamflow specified in the model being fitted. Calculations were done using commands in the Exploration and Graphics for RivEr Trends (EGRET) and dataRetrieval R packages (Hirsch and De Cicco, 2014).

Daily values of concentration, flow-normalized concentration, flux, and flow-normalized flux were determined for each day of the period analyzed by linear interpolation of the results of the WRTDS models (Hirsch and others, 2010). Flow-normalized concentration is a concentration without the influence of the year-to-year variation in streamflow; flow-normalized flux is similarly defined.

The value of flow-normalized concentration on a given day in the period of analysis (such as March 1, 2000) was determined from the daily streamflow in each water year on the same day of the year (March 1, in this case). A value of daily concentration for March 1, 2000, was determined using each of these daily streamflows (30 streamflows for a 30-year period of analysis). The flow-normalized daily concentration for March 1, 2000, is the average of each of these 30 concentrations. Daily values of flow-normalized fluxes were calculated in a similar manner.

Table 2. Water-quality characteristics in the dataset for selected stations on New Jersey streams during water years 1971–2011.

[Each parameter code identifies a specific water-quality characteristic; n.a., not applicable]

Selected water-quality characteristic			Methods of estimation of some missing values of selected water-quality characteristics from values of other water-quality characteristics	
Parameter code	Name	Description	Substitution from values of indicated water-quality characteristic (parameter code)	Calculation from values of indicated water-quality characteristics (parameter code)
00061	Instantaneous streamflow	Instantaneous streamflow, in cubic feet per second	Daily streamflow (00060)	n.a.
00010	Water temperature	Temperature, water, degrees Celsius	n.a.	n.a.
00095	Specific conductance	Specific conductance, water, unfiltered, in microsiemens per centimeter at 25 degrees Celsius	Laboratory specific conductance (90095)	n.a.
00300	Dissolved oxygen concentration	Dissolved oxygen concentration, in milligrams per liter	n.a.	n.a.
00301	Dissolved oxygen saturation	Dissolved oxygen saturation, in percentage of saturation concentration	n.a.	n.a.
00400	pH	pH, water, unfiltered, field, standard units	n.a.	n.a.
00665	Total phosphorus	Phosphorus, water, unfiltered, in milligrams per liter as phosphorus	n.a.	n.a.
00631	Filtered nitrate plus nitrite	Nitrate plus nitrite, water, filtered, in milligrams per liter as nitrogen	Total nitrate plus nitrite (00630), or total nitrate (00620), or filtered nitrate (00618)	n.a.
00600	Total nitrogen	Total nitrogen (nitrate + nitrite + ammonia + organic-N), water, unfiltered, in milligrams per liter as nitrogen	Total nitrogen (62855)	One of the following methods[1] was used: (1) Sum of filtered nitrate plus nitrite after substitution (00631) and total organic nitrogen plus ammonia (00625), or (2) Sum of filtered nitrate plus nitrite after substitution (00631), particulate nitrogen (49570), and filtered organic nitrogen plus ammonia (00623)
00940	Filtered chloride	Chloride, water, filtered, in milligrams per liter	n.a.	n.a.
70300	Total dissolved solids	Dissolved solids dried at 180 degrees Celsius, water, filtered, in milligrams per liter	n.a.	n.a.
00530	Total suspended solids	Suspended solids, water, unfiltered, in milligrams per liter	n.a.	n.a.
80154	Suspended sediment	Suspended sediment concentration, in milligrams per liter	n.a.	n.a.

[1]See Hickman and Gray (2010) for more information on calculation.

Data requirements for a series of WRTDS models are daily streamflow and 200 measurements of concentration over a 20-year period (Hirsch and others, 2010). However, a series of models has been created with fewer concentration measurements (Medalie and others, 2012).

Records of daily streamflow measured at 14 water-quality stations were available (table 3; fig. 3). The period of record of each of these streamgages is displayed in table 4.

Records of streamflow at each of nine water-quality stations were estimated from records of streamgages at a water-quality station not at the water-quality station by use of either drainage-area correction or Maintenance of Variance Extension 1 (MOVE1; Hirsch, 1982) (table 3; fig. 3). More information on the methods of streamflow estimation is given in appendix 1.

Results of the WRTDS models were not reported if more than 40 percent of measured concentrations were censored or if the flux bias statistic calculated as part of the regression was less than -0.20 or greater than 0.20 (Hirsch and De Cicco, 2014). Both limits were suggested by Robert Hirsch (USGS, written commun., 2015). Results of models for nutrients were not reported for McDonalds Branch in Byrne State Forest, New Jersey (01466500), because more than 40 percent of the concentrations of each nutrient were censored.

Changes in Flow-Normalized Annual Concentrations and Fluxes

The second step was to determine (1) annual concentrations, flow-normalized concentrations, fluxes, and flow-normalized fluxes for each water year and (2) changes in annual flow-normalized concentrations and fluxes between selected water years. These values were determined by using commands in the EGRET R package (Hirsch and De Cicco, 2014).

Annual concentrations and flow-normalized annual concentrations were reported for all 13 of the water-quality stations at which streamflow was measured (except McDonalds Branch in Byrne State Forest, New Jersey, 01466500) and at the 9 stations at which streamflow was estimated (table 3). Annual values were reported for each water year, except when periods were longer than 2 years and concentrations were not measured.

Annual fluxes and flow-normalized annual fluxes were reported for all the water-quality stations at which streamflow was measured and at only four of the stations (discussed below) at which streamflow was estimated (appendix 1). The use of estimated streamflows to create the WRTDS models but not to report fluxes and flow-normalized fluxes was suggested by Robert Hirsch (USGS, written commun., 2016).

For this study, annual fluxes and flow-normalized annual fluxes were reported for each of the four water-quality stations at which streamflow was estimated from a streamgage near that water-quality station. These water-quality stations were arbitrarily designated as those where the (1) streamgage was on the same stream as the water-quality station and (2) the ratio of the drainage area of the water-quality station to that of the streamgage was between 0.92 and 1.11 (table 3). For the remaining five water-quality stations for which fluxes were not reported, streamflow was estimated from a streamgage either on a different stream and (or) further away from the water-quality station.

The selected water years over which changes in flow-normalized annual concentrations and fluxes were determined were the first and last water years in which concentrations were measured and water years 1980, 1990, and 2000. If flow-normalized annual concentrations were not available for 1980, 1990, or 2000, changes were reported for similar periods for which annual concentrations could be determined.

Changes in flow-normalized annual concentrations and flow-normalized annual fluxes have been accepted as trends in previous reports. Examples are given in Sprague and others, (2011), Murphy and others (2013), Moyer and others (2012), and Medalie and others (2012).

Trends in Flow-Normalized Annual Concentrations and Fluxes

The third step was to determine whether changes in flow-normalized annual concentrations or changes in flow-normalized annual fluxes over two periods—water years 1980–2011 and water years 2000–11—constituted trends. Trends were identified by use of the WRTDS Bootstrap Test (WBT) contained in the EGRETci R package (Hirsch and others, 2015).

Using WBT, a random sampling procedure was to create multiple synthetic datasets containing measured concentrations in the original dataset. Flow-normalized annual concentrations and fluxes were then determined from each synthetic dataset. Results of all models identified (1) the uncertainty of the flow-normalized annual values of concentration and flux and (2) the level of significance of changes in flow-normalized values between selected water years. For this report, a two-way level of significance of 0.05 was chosen to identify a trend. A discussion of the WBT method and its results is given in appendix 2.

Identification of Trends From Seasonal Rank-Sum Tests

Step trends in water quality were identified between water-quality data measured in each the following decades: 1970s (water years 1971–79), 1980s (water years 1980–89), 1990s (water years 1990–99), and 2000s (water years 2000–11). The step trends are differences in water quality measured (1) in consecutive decades, (2) in the 1970s and the 2000s, and (3) in the 1980s and the 2000s. This method was selected because it does not make assumptions about whether water quality changed over time with a monotonic pattern or not.

For each water-quality characteristic at each station, step trends were determined from a reduced dataset consisting of only one value in each season in each water year. The seasons were fall (October–December), winter (January–March), spring (April–June), and summer (July–September). Each

Table 3. Sources of daily streamflow data used for Weighted Regressions on Time, Discharge, and Season models for water-quality stations in New Jersey, water years 1971–2011.

[WRTDS, Weighted Regressions on Time, Discharge, and Season; n.a., not applicable or not available; Measured, measured at water-quality station; Estimated, estimated from record of streamflow at a streamgage not located at water-quality station; MOVE1, Maintenance of Variance Extension 1; R., River; Cr., Creek; L., Little; Del., Delaware; N.J., New Jersey]

Station number	Short name	WRTDS models		Record of daily streamflow at water-quality station			
				Source of values of daily streamflow at water-quality station	Information used to estimate daily streamflow at water-quality station		
		WRTDS models reported	Annual fluxes reported		Method of estimation (described in appendix 1)	Streamgage (station number), the record of which is used to estimate daily flow at water-quality station	Ratio of drainage area of water-quality station to drainage area of streamgage
01367770	Wallkill R.	No	No	n.a.	n.a.	n.a.	n.a.
01377000	Hackensack R.	Yes	Yes	Measured	n.a.	n.a.	1
01381800	Whippany R.	No	No	n.a.	n.a.	n.a.	n.a.
01382000	Passaic R. at Two Bridges	No	No	n.a.	n.a.	n.a.	n.a.
01387500	Ramapo R.	Yes	Yes	Measured	n.a.	n.a.	1
01389500	Passaic R. at L. Falls	Yes	Yes	Measured	n.a.	n.a.	1
01391500	Saddle R.	Yes	Yes	Measured	n.a.	n.a.	1
01395000	Rahway R.	Yes	Yes	Measured	n.a.	n.a.	1
01396660	Mulhockaway Cr.	Yes	Yes	Measured	n.a.	n.a.	1
01398000	Neshanic R.	Yes	Yes	Measured	n.a.	n.a.	1
01399780	Lamington R.	Yes	No	Estimated	Drainage-area correction	North Branch Raritan River near Raritan, N.J. (01400000)	0.53
01403300	Raritan R.	Yes	Yes	Estimated	Drainage-area correction	Raritan River below Calco Dam at Bound Brook, N.J. (01403060)	1.02
01405340	Manalapan Brook	Yes	No	Estimated	MOVE1	Manalapan Brook at Spotswood, N.J. (01405400)	0.51
01408500	Toms R.	Yes	Yes	Measured	n.a.	n.a.	1
01409387	Mullica R.	Yes	No	Estimated	MOVE1	Mullica River near Batsto, N.J. (01409400)	0.57
01409500	Batsto R.	Yes	Yes	Measured	n.a.	n.a.	n.a.
01409815	West Branch Wading R.	Yes	No	Estimated	MOVE1	Oswego River at Harrisville, N.J. (01410000)	1.18
01411110	Great Egg Harbor R.	Yes	No	Estimated	MOVE1	Great Egg Harbor River at Folsom, N.J. (01411000)	2.70
01411500	Maurice R.	Yes	Yes	Measured	n.a.	n.a.	n.a.
01412800	Cohansey R.	No	No	n.a.	n.a.	n.a.	n.a.
01443000	Del. R. at Portland	Yes	Yes	Estimated	Drainage-area correction	Delaware River at Belvidere, N.J. (01446500)	0.92
01443500	Paulins Kill	Yes	Yes	Measured	n.a.	n.a.	n.a.
01457400	Musconetcong R.	Yes	Yes	Estimated	Drainage-area correction	Musconetcong River near Bloomsbury, N.J. (01457000)	1.11
01460820	Del. R. at Lumberville	Yes	Yes	Estimated	Drainage-area correction	Delaware River at Trenton, N.J. (01463500)	0.97
01463500	Del. R. at Trenton	Yes	Yes	Measured	n.a.	n.a.	1
01464515	Doctors Cr.	No	No	n.a.	n.a.	n.a.	n.a.
01466500	McDonalds Branch	No	No	Measured	n.a.	n.a.	1
01477120	Raccoon Cr.	Yes	Yes	Measured	n.a.	n.a.	1

Base from U.S. Geological Survey digital data, 1:24,000,
Universal Transverse Mercator projection, Zone 18, North American Datum of 1983

Figure 3. Location of water-quality stations for which trends in characteristics were determined and selected streamgages in New Jersey.

Table 4. Description of, and periods of record for, streamgages used to develop Weighted Regressions on Time, Discharge, and Season models for water-quality stations on streams in New Jersey during water years 1971–2011.

[Latitude and longitude are in degrees minutes seconds; datum for the latitude and longitude is the North American Datum of 1983; drainage area in square miles; --, period of streamflow record is not different from 1971–2011; WRTDS, Weighted Regressions on Time, Discharge, and Season; N.J., New Jersey]

Station number	Station name	Latitude	Longitude	Drainage area	Period of record during water years 1971–2011 used for WRTDS models, if different from 1971–2011, in water years
01377000	Hackensack River at Rivervale, N.J.	405957	0735921	58.00	--
01387500	Ramapo River near Mahwah, N.J.	410553	0740946	120.00	--
01389500	Passaic River at Little Falls, N.J.	405305	0741334	762.00	--
01391500	Saddle River at Lodi, N.J.	405325	0740450	54.60	--
01395000	Rahway River at Rahway, N.J.	403708	0741700	40.90	--
01396660	Mulhockaway Creek at Van Syckel, N.J.	403851	0745808	11.80	1978–2011
01398000	Neshanic River at Reaville, N.J.	402824	0744940	25.70	--
01400000	North Branch Raritan River near Raritan, N.J.	403414	0744045	190.00	--
01403060	Raritan River below Calco Dam at Bound Brook, N.J.	403304	0743254	785.00	--
01405400	Manalapan Brook at Spotswood, N.J.	402322	0742326	40.70	--
01408500	Toms River near Toms River, N.J.	395911	0741324	123.00	--
01409400	Mullica River near Batsto, N.J.	394028	0743954	46.70	--
01409500	Batsto River at Batsto, N.J.	393830	0743901	67.80	1971–2005
01410000	Oswego River at Harrisville, N.J.	393948	0743125	72.50	--
01411000	Great Egg Harbor River at Folsom, N.J.	393541	0745106	57.10	--
01411500	Maurice River at Norma, N.J.	392944	0750437	112.00	--
01443500	Paulins Kill at Blairstown, N.J.	405851	0745712	126.00	[1]1978–2011
01446500	Delaware River at Belvidere, N.J.	404935	0750457	4,535.00	--
01457000	Musconetcong River near Bloomsbury, N.J.	404020	0750339	141.00	--
01463500	Delaware River at Trenton, N.J.	401318	0744641	6,780.00	--
01466500	McDonalds Branch in Byrne State Forest, N.J.	395306	0743019	2.35	--
01477120	Raccoon Creek near Swedesboro, N.J.	394426	0751533	26.90	--

[1]Records for water years 1971–1976 are complete, but the record for water year 1977 is not.

reduced dataset contained, for each station, the first measured water-quality value in each season of each water year; other measurements at that station in that season were disregarded.

The seasonal rank-sum test is an extension of the rank-sum test described in Helsel and Hirsch (1992). The rank-sum test is a nonparametric test to determine whether two independent sets of data are significantly different from one another. The results of the test indicate the direction of the change from the first dataset to the second dataset (upward or downward) and the level of significance of this change.

A separate seasonal rank-sum test was conducted on measurements of each water-quality characteristic at each station between each pair of selected decades. A rank-sum test was applied to water-quality values in each season. The following information was determined from the number of measurements in each decade and the ranks of the measurements in each decade: test statistic (W_{rs}), expected value of the test statistic (E_w), and the standard deviation of the expected value of the test statistic (σ_w); equations used to calculate each are given in Helsel and Hirsch (1992). Tests were run using the NPAR1Way procedure (SAS Institute, Inc., 2014a).

The results of the seasonal rank-sum test of a selected water-quality characteristic at a station between two selected decades were determined by combining the results of the rank sum tests of the four seasons (equations are given below). Values of each of the following were summed for all four seasons: test statistics, expected values of the test statistic, and the variances of expected values of the test statistic (the variance is the square of standard deviation). Then, the standardized form of the test statistic for the seasonal rank-sum test (Z) was determined by use of the following equation:

$$Z = \frac{(\Sigma W_i + ca - \Sigma E_i)}{\sqrt{(\Sigma \sigma_i^2)}} \quad (2)$$

where

Z = standardized form of test statistic for seasonal rank-sum test;

ΣW_i = sum of test statistics over all four seasons, i;
ΣE_i = sum of expected values of test statistics over all four seasons, i;
σ_i = standard deviationof the expected value of all four seasons, i;
$\Sigma(\sigma_i^2)$ = sum of variance of expected values of test statistics over all four seasons, i; and
ca = continuity correction

where
ca = -1/2, if $\Sigma W_i > \Sigma E_i$,
ca = 0, if $\Sigma W_i = \Sigma E_i$, and
ca = 1/2, if $\Sigma W_i < \Sigma E_i$.

Three types of information were determined from the results of the seasonal rank-sum tests: the direction of the change in water quality from the earlier to the later decade, the level of significance of this change in water quality, and whether this change was considered a trend. The direction of the change (downward or upward) was determined from the sign of the value of the standardized test statistic (Z); negative indicates a downward change, and positive indicates an upward change. The level of significance of the change is indicated by the value of the standardized test statistic compared to a standard normal distribution. A trend was considered to exist if the value had a 0.05 two-sided level of significance; that is, if the value of Z was less than or equal to 0.025. Results are reported only if there were 20 or more measurements in each decade and 4 or more measurements in each season of each decade.

The size of each identified step trend (change) was estimated by determining the differences between the median of the concentrations in the reduced dataset in each decade. These differences are reported only for trends.

Seasonal Rank-Sum Tests of Nutrients

Seasonal rank-sum tests for total phosphorus, total nitrogen, and filtered nitrate plus nitrite were conducted on concentrations after adjustment for a general threshold. Censored and uncensored concentrations below the threshold were set to one-half of the threshold value and considered uncensored. Threshold values had been previously determined so that when applied, censored values composed about 5 percent (or less) of the concentrations in each decade. Threshold values for each seasonal rank-sum test of each nutrient at each station were presented with the results of the seasonal rank-sum test.

The size of the step change in nutrient concentrations was estimated by the change in median water quality from the earlier decade to the later decade. Median nutrient concentrations in each decade were calculated from the reduced dataset by use of the Kaplan Meier method as described in Helsel (2005). These tests were run using the Lifetest procedure (SAS Institute, Inc., 1999). Medians from the Kaplan Meier tests are not reported if 50 percent or more of the results for a station in the reduced dataset were censored.

Seasonal Rank-Sum Tests of Measures of Major Ions

Seasonal rank-sum tests were run on flow-adjusted measures (filtered chloride, total dissolved solids, and specific conductance). Flow adjustment involved first creating a smoothed curve between the water-quality measure and instantaneous streamflow by use of the LOESS procedure (SAS Institute, Inc., 2014b). Flow-adjusted results are the differences between the measured water-quality results and the corresponding results of the LOESS curve.

The size of each step trend in flow-adjusted measures of major ions was estimated as the difference between the median of the flow-adjusted measure of major ions in the earlier decade and the corresponding measure in the later decade. Medians were determined from the reduced dataset. Differences are reported only for identified trends.

Trends in the Quality of Water in New Jersey Streams, Water Years 1971–2011

The discussion is divided into four sections. The long-term water-quality dataset is first discussed. Then, the results of trend analyses from Weighted Regressions on Time, Discharge, and Season (WRTDS) models are given, followed by results from seasonal rank-sum tests. Finally, combined test results from both methods over water years 1980–2011 are presented.

Dataset for Water-Quality at Selected Stations on Streams in New Jersey, Water Years 1971–2011

The dataset is not published as part of this report but is available to the public in Hickman (2016). The number of measurements of each of the 12 water-quality characteristics at each station is given in appendix 3.

Known changes in water-quality data due to changes in field methods or to changes in methodology at USGS laboratories are presented below. There were no corrections applied to this dataset to account for these reported biases.

Two changes in methods of pH measurement resulted in small changes in pH at stations sampled by the USGS (table 1, main text). One change occurred at the end of water year 2001 (Hickman and Gray, 2010); as a result of this change, trends in pH were not reported in Hickman and Gray (2010) for stations sampled by the USGS. A second change in method of pH measurement was made on May 1, 2010 (Anna Deetz, USGS, written commun., 2014).

In addition, Hickman and Gray (2010) determined that pH and dissolved oxygen concentration measured during water years 1998–2007 could have been affected by trends in the time of day of measurement. Trends in pH and dissolved oxygen concentration during these water years were reported only if there was no trend in the times of measurements of pH and dissolved oxygen concentrations.

For samples analyzed at the USGS laboratories, studies have identified reports of bias in concentrations of phosphorus and nitrogen species collected up through water year 1991. These reports are described below.

- Laboratory contamination of ammonia and Kjeldahl (organic plus ammonia) nitrogen during 1980–82 is reported in Zimmerman and others (1996). Given the type of problem, it is likely that reported concentrations were greater than actual; the magnitude of the contamination is not known.

- Reported concentrations of total phosphorus (P) for samples between (1) sometime after 1973 and (2) October 1, 1991, were smaller than actual values (USGS, 1992). The problem was that the procedure for sample digestion was incorrectly described and that the sample digestion was incomplete. Bias for concentrations in unfiltered surface water was about -0.02 milligram per liter (mg/L) as P.

- Reported concentrations of total and dissolved Kjeldahl nitrogen (N) concentrations in samples from about 1986 to October 1, 1991, were biased high because of a lack of digestion blank correction (Patton and Truitt, 2000). Reported concentrations were about 0.1 mg/L as N greater than actual.

Results of Weighted Regressions on Time, Discharge, and Season Model Results

Results of the WRTDS models are given in two datasets in Hickman (2016). One dataset contains annual values of streamflow, concentration, flux, flow-normalized concentration, and flow-normalized flux. The second dataset contains (1) changes in flow-normalized annual concentrations and flow-normalized annual fluxes over selected periods, and (2) levels of significance of the changes over water years 1980–2011 and 2000–11. These levels of significance identify whether the changes over these periods constitute trends.

Example of Results for Total Nitrogen in the Toms River near Toms River, N.J. (01408500)

Results from WRTDS models for total nitrogen in the Toms River near Toms River, N.J. (01408500), are presented and discussed as an example of the use of this method to identify trends. The annual and flow-normalized annual concentrations appear to have increased over water years 1971–2011 (fig. 4); the corresponding fluxes also appear to have increased over this period (fig. 5). In both cases, the flow-normalized annual concentrations show less scatter than the corresponding annual values because the variation of water quality with daily streamflow has been greatly reduced for the flow-normalized annual concentrations.

The apparent increase in flow-normalized annual concentrations of total nitrogen at Toms River near Toms River, N.J. (01408500), over time appears to be similar to the apparent increase in measured concentrations (fig. 6). The reader should keep in mind that the flow-normalized annual concentrations are very different from the measured concentrations. Flow-normalized concentrations represent the concentration in each water year without the variation in water quality due to the year-to-year variation in streamflow. Measured concentrations are instantaneous concentration and composed of uncensored, estimated, and “less-than” values. The LOESS smoothed curve through measured concentrations indicates how the central tendency of concentration changed over time; the LOESS curve was determined with the LOESS procedure (SAS Institute Inc., 2014b).

The uncertainty in the flow-normalized annual concentrations of total nitrogen concentration in the Toms River near Toms River, N.J. (01408500), is shown in figure 7. Flow-normalized annual concentrations and the 90-percent confidence band for the flow-normalized annual concentrations at this station are shown. The 90-percent confidence band is composed of concentrations between the 5th percent line and the 95th percent line. The wider the confidence band at a selected water year, the more uncertainty there is in the flow-normalized annual concentration for that water year. The widening of the confidence band at the beginning and end of the period analyzed as compared to the middle is common in these graphs because there is greater uncertainty in the flow-normalized annual concentrations at the beginning and end of the period of analysis as compared to the middle of the period (Hirsch and others, 2015).

The results of the WBT (Hirsch and others, 2015) indicates that there was a significant increase (an upward trend) in flow-normalized annual concentrations of total nitrogen at Toms River near Toms River, N.J. (01408500), between water years 1980 and 2011 (Hickman, 2017). The plot of flow-normalized annual concentrations with 90-percent confidence band provides a visual check of this trend (fig. 7). The concentrations in the 90-percent confidence band during the 1980 water year appear to be clearly smaller than the corresponding concentrations during the 2011 water year.

Summary of Results of Trend Tests, Water Years 1980–2011

Trends over water years 1980–2011 identified using the WRTDS models are shown in Hickman (2016) and summarized in tables 5*A* (total nitrogen), 5*B* (filtered nitrate plus nitrite), 5*C* (total phosphorus), and 5*D* (filtered chloride and total dissolved solids). The contents of these tables indicate either that there was an upward trend, a downward trend, no trend or that a trend test was not conducted.

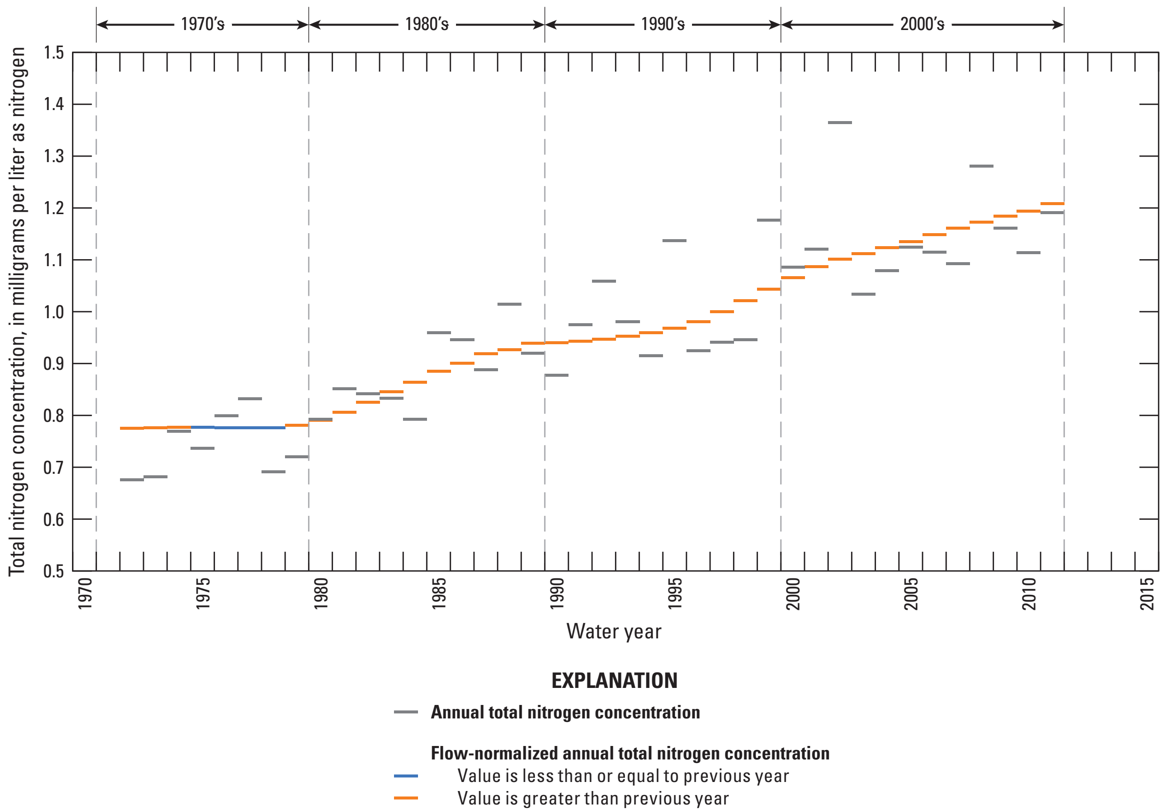


Figure 4. Annual and flow-normalized annual concentrations of total nitrogen at Toms River near Toms River, New Jersey (01408500), water years 1971–2011.

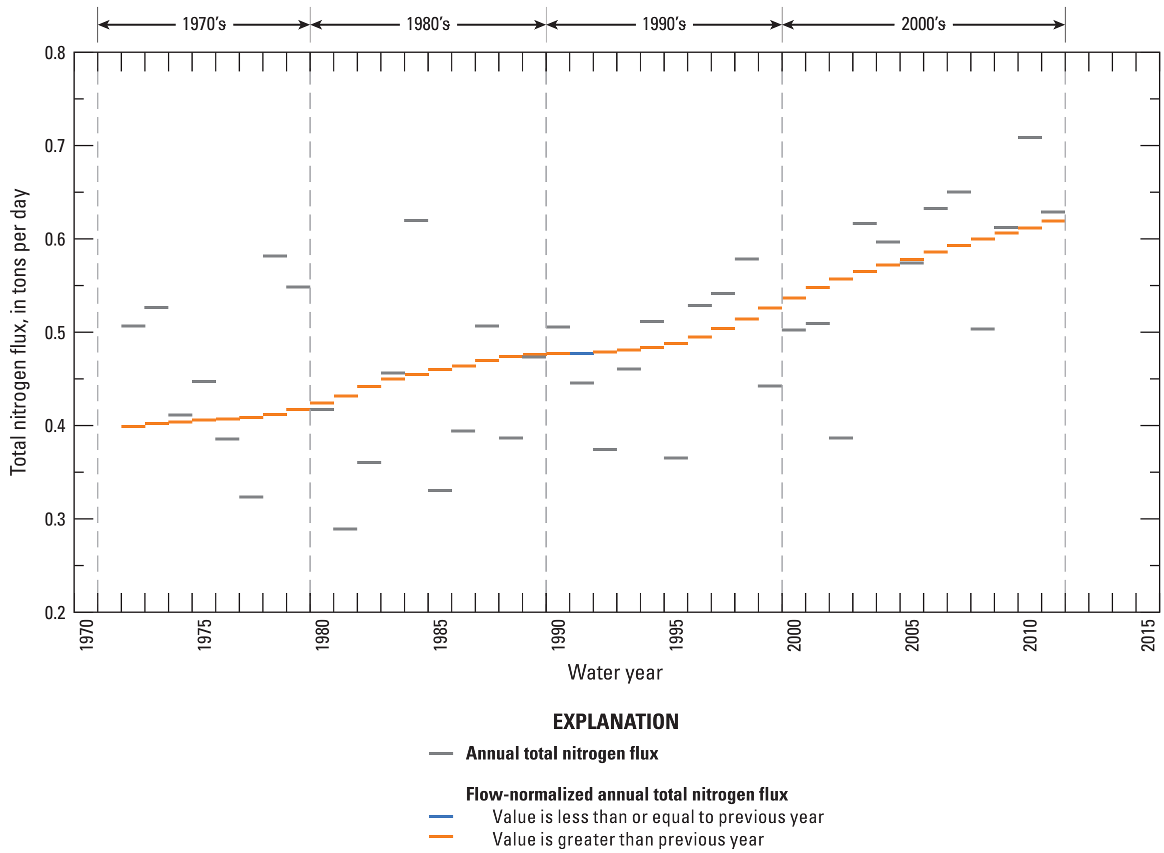


Figure 5. Annual and flow-normalized annual fluxes of total nitrogen at Toms River near Toms River, New Jersey (01408500), water years 1971–2011.

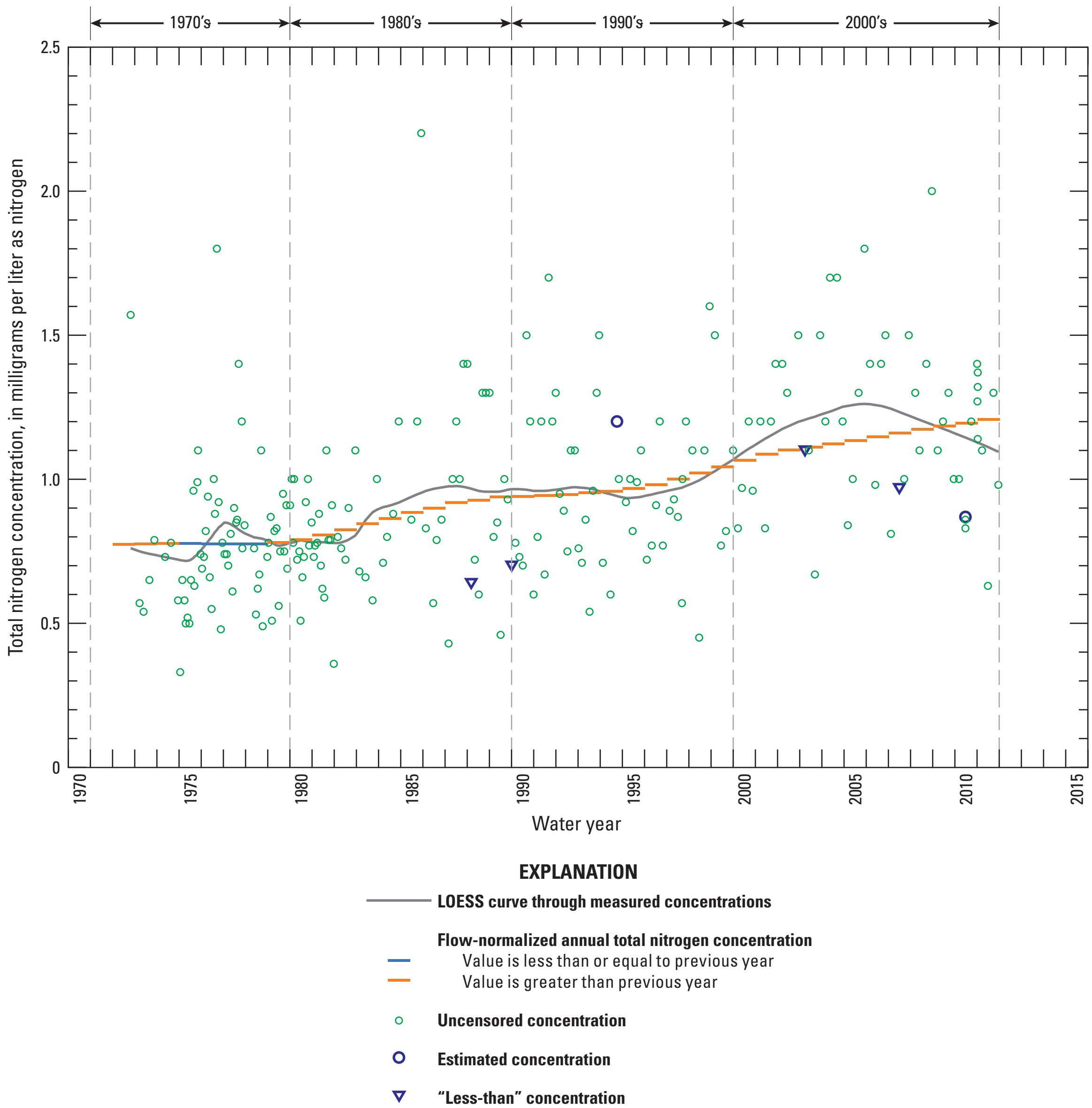


Figure 6. Measured concentrations and flow-normalized annual concentrations of total nitrogen at Toms River near Toms River, New Jersey (01408500), water years 1971–2011.

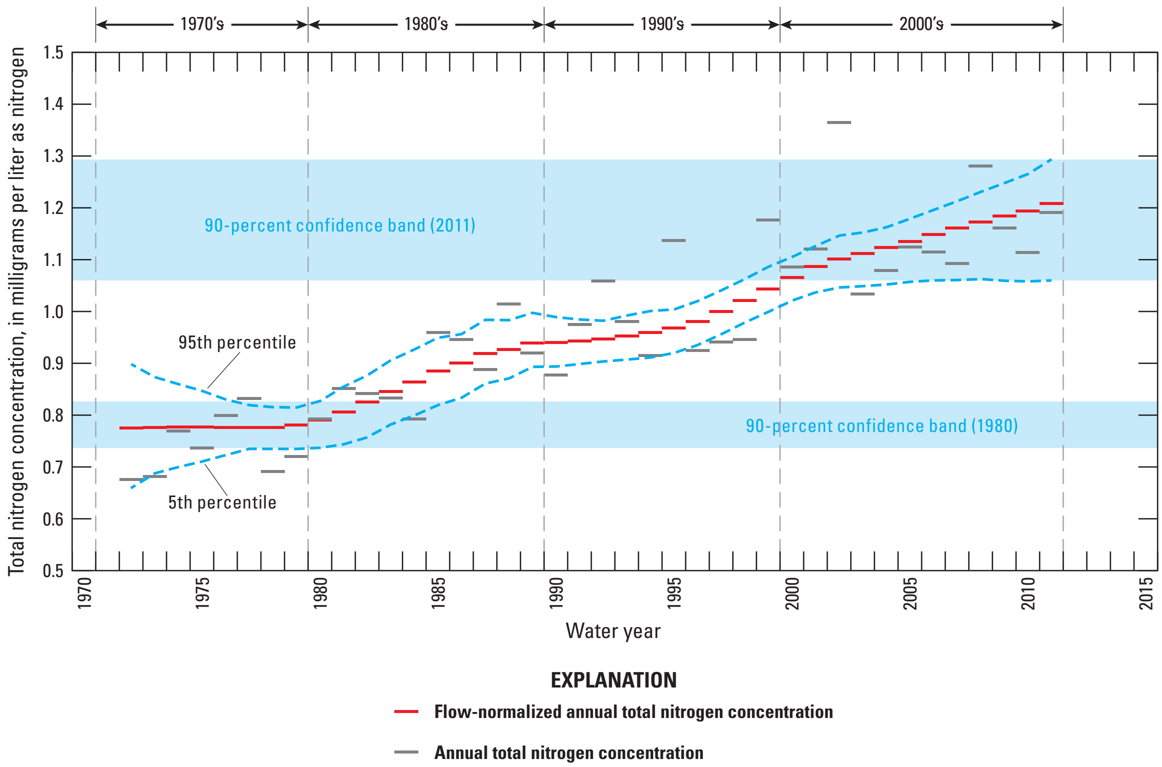


Figure 7. Flow-normalized annual concentrations of total nitrogen at Toms River near Toms River, New Jersey (01408500), with 90-percent confidence band, water years 1971–2011.

Table 5*A*. Summary of results of trend tests of concentrations and fluxes of total nitrogen at water-quality stations on streams in New Jersey over water years 1980–2011.

[Step trends were identified from seasonal rank-sum tests. Trends in flow-normalized annual concentrations and fluxes were identified from Weighted Regressions on Time, Discharge, and Season models. Results from Trench and others (2012) are included. nd, not determined; --, no trend; Downward, trend tests indicated values decreased; Upward, trend tests indicated values increased; R. River; Cr., Creek; Del., Delaware; L., Little]

Station number	Short name	Results of trend tests of				
		Concentrations			Fluxes	
		This study		Trench and others (2012)	This study	Trench and others (2012)
		Step trends between concentrations in the 1980s and those in the 2000s (Hickman, 2017)	Trends in flow-normalized annual concentrations over water years 1980–2011 (Hickman, 2017)	Trends in flow-adjusted concentrations over water years 1975–2003	Trends in flow-normalized annual fluxes over water years 1980–2011 (Hickman, 2017)	Trends in fluxes over water years 1975–2003
01367770	Wallkill R.	--	nd	nd	nd	nd
01377000	Hackensack R.	Downward	--	Downward	--	Downward
01381800	Whippany R.	Downward	nd	nd	nd	nd
01382000	Passaic R. at Two Bridges	Downward	nd	nd	nd	nd
01387500	Ramapo R.	--	--	--	--	--
01389500	Passaic R. at L. Falls	Downward	Downward	Downward	Downward	Downward
01391500	Saddle R.	--	--	Upward	--	--
01395000	Rahway R.	--	--	nd	--	nd
01396660	Mulhockaway Cr.	Downward	Downward	nd	Downward	nd
01398000	Neshanic R.	Downward	Downward	nd	Downward	nd
01399780	Lamington R.	Downward	--	nd	nd	nd
01403300	Raritan R.	--	Downward	--	Downward	--
01405340	Manalapan Brook	Downward	--	nd	nd	nd
01408500	Toms R.	Upward	Upward	Upward	Upward	Upward
01409387	Mullica R.	Downward	Downward	nd	nd	nd
01409500	Batsto R.	--	--	nd	--	nd
01409815	West Branch Wading R.	--	nd	nd	nd	nd
01411110	Great Egg Harbor R.	Downward	--	nd	nd	nd
01411500	Maurice R.	--	--	--	--	--
01412800	Cohansey R.	Upward	nd	nd	nd	nd
01443000	Del. R. at Portland	Downward	Downward	nd	--	nd
01443500	Paulins Kill	Downward	Downward	Downward	Downward	--
01457400	Musconetcong R.	--	--	nd	--	nd
01460820	Del. R. at Lumberville	Downward	Downward	nd	Downward	nd
01463500	Del. R. at Trenton	Downward	Downward	Downward	Downward	Downward
01464515	Doctors Cr.	--	nd	nd	nd	nd
01466500	McDonalds Branch	--	nd	nd	nd	nd
01477120	Raccoon Cr.	--	--	--	--	--

Table 5*B*. Summary of results of trend tests of concentrations and fluxes of filtered nitrate plus nitrite at water-quality stations on streams in New Jersey over water years 1980–2011.

[Step trends were identified from seasonal rank-sum tests. Trends in flow-normalized annual concentrations and fluxes were identified from Weighted Regressions on Time, Discharge, and Season models. Results from Trench and others (2012) are included. nd, not determined; --, no trend; Downward, trend tests indicated values decreased; Upward, trend tests indicated values increased; R. River; Cr., Creek; Del., Delaware; L., Little]

Station number	Short name	Results of trend tests				
		Concentrations			Fluxes	
		This study		Trench and others (2012)	This study	Trench and others (2012)
		Step trends between concentrations in the 1980s and those in the 2000s (Hickman, 2017)	Trends in flow-normalized annual concentrations over water years 1980–2011 (Hickman, 2017)	Trends in flow-adjusted concentrations over water years 1975–2003	Trends in flow-normalized annual fluxes over water years 1980–2011 (Hickman, 2017)	Trends in fluxes over water years 1975–2003
01367770	Wallkill R.	Upward	nd	nd	nd	nd
01377000	Hackensack R.	Downward	Downward	Downward	Downward	Downward
01381800	Whippany R.	--	nd	nd	nd	nd
01382000	Passaic R. at Two Bridges	Upward	nd	nd	nd	nd
01387500	Ramapo R.	--	Upward	Upward	Upward	Upward
01389500	Passaic R. at L. Falls	Upward	Upward	Upward	--	Upward
01391500	Saddle R.	Upward	Upward	Upward	Upward	Upward
01395000	Rahway R.	Upward	--	nd	--	nd
01396660	Mulhockaway Cr.	Downward	Downward	nd	--	nd
01398000	Neshanic R.	Downward	Downward	nd	Downward	nd
01399780	Lamington R.	--	--	nd	nd	nd
01403300	Raritan R.	Upward	Upward	Upward	--	--
01405340	Manalapan Brook	--	--	nd	nd	nd
01408500	Toms R.	Upward	Upward	Upward	Upward	Upward
01409387	Mullica R.	Downward	--	nd	nd	nd
01409500	Batsto R.	Upward	--	nd	--	nd
01409815	West Branch Wading R.	--	nd	nd	nd	nd
01411110	Great Egg Harbor R.	--	--	nd	nd	nd
01411500	Maurice R.	Upward	--	--	--	--
01412800	Cohansey R.	Upward	nd	nd	nd	nd
01443000	Del. R. at Portland	Downward	Downward	nd	--	nd
01443500	Paulins Kill	Downward	Downward	--	Downward	--
01457400	Musconetcong R.	Upward	Upward	nd	Upward	nd
01460820	Del. R. at Lumberville	Downward	--	nd	--	nd
01463500	Del. R. at Trenton	Downward	Downward	Downward	Downward	--
01464515	Doctors Cr.	Downward	nd	nd	nd	nd
01466500	McDonalds Branch	--	nd	nd	nd	nd
01477120	Raccoon Cr.	Downward	--	--	--	Downward

Table 5*C*. Summary of results of trend tests of concentrations and fluxes of total phosphorus at water-quality stations on streams in New Jersey over water years 1980–2011.

[Step trends were identified from seasonal rank-sum tests. Trends in flow-normalized annual concentrations and fluxes were identified from Weighted Regressions on Time, Discharge, and Season models. Results from Trench and others (2012) are included. nd, not determined; --, no trend; Downward, trend tests indicated values decreased; Upward, trend tests indicated values increased; R. River; Cr., Creek; Del., Delaware; L., Little]

Station number	Short name	Results of trend tests				
		Concentrations			Fluxes	
		This study		Trench and others (2012)	This study	Trench and others (2012)
		Step trends between concentrations in the 1980s and those in the 2000s (Hickman, 2017)	Trends in flow-normalized annual concentrations over water years 1980–2011 (Hickman, 2017)	Trends in flow-adjusted concentrations over water years 1975–2003	Trends in flow-normalized annual fluxes over water years 1980–2011 (Hickman, 2017)	Trends in fluxes over water years 1975–2003
01367770	Wallkill R.	Downward	nd	nd	nd	nd
01377000	Hackensack R.	--	--	--	--	--
01381800	Whippany R.	Downward	nd	nd	nd	nd
01382000	Passaic R. at Two Bridges	--	nd	nd	nd	nd
01387500	Ramapo R.	--	--	--	--	--
01389500	Passaic R. at L. Falls	Downward	Downward	Downward	Downward	Downward
01391500	Saddle R.	Downward	--	--	--	--
01395000	Rahway R.	--	--	nd	--	nd
01396660	Mulhockaway Cr.	Downward	nd	nd	nd	nd
01398000	Neshanic R.	--	--	nd	--	nd
01399780	Lamington R.	Downward	--	nd	nd	nd
01403300	Raritan R.	--	--	--	--	--
01405340	Manalapan Brook	--	--	nd	nd	nd
01408500	Toms R.	Downward	Downward	Downward	Downward	Downward
01409387	Mullica R.	Downward	Downward	nd	nd	nd
01409500	Batsto R.	Downward	--	nd	--	nd
01409815	West Branch Wading R.	Upward	Upward	nd	nd	nd
01411110	Great Egg Harbor R.	Downward	Downward	nd	nd	nd
01411500	Maurice R.	--	Downward	Downward	Downward	Downward
01412800	Cohansey R.	Downward	nd	nd	nd	nd
01443000	Del. R. at Portland	Downward	Downward	nd	Downward	nd
01443500	Paulins Kill	Downward	--	Downward	--	Downward
01457400	Musconetcong R.	Downward	--	nd	--	nd
01460820	Del. R. at Lumberville	Downward	Downward	nd	--	nd
01463500	Del. R. at Trenton	Downward	Downward	Downward	--	Downward
01464515	Doctors Cr.	Downward	nd	nd	nd	nd
01466500	McDonalds Branch	Downward	nd	nd	nd	nd
01477120	Raccoon Cr.	--	nd	Upward	nd	--

Table 5*D*. Summary of results of trend tests of concentrations and fluxes of measures of major ions at water-quality stations on streams in New Jersey over water years 1980–2011.

[Step trends were identified from seasonal rank-sum tests. Trends in flow-normalized annual concentrations and fluxes were identified from Weighted Regressions on Time, Discharge, and Season models. Results from Anning and Flynn (2014) are included. nd, not determined; --, no trend; Upward, trend tests indicated values increased; R. River; Cr., Creek; Del., Delaware]

Station number	Short name	Results of trend tests			
		Concentrations			Fluxes
		This study			This study
		Step trends between concentrations in the 1980s and those in the 2000s (Hickman, 2017)	Trends in flow-normalized annual concentrations over water years 1980–2011 (Hickman, 2017)	1980–2009 Anning and Flynn (2014)	Trends in fluxes over water years 1975–2003
Specific conductance					
01443000	Del. R. at Portland	Upward	nd	nd	nd
01460820	Del. R. at Lumberville	Upward	nd	nd	nd
01463500	Del. R. at Trenton	Upward	nd	nd	nd
01477120	Raccoon Cr.	Upward	nd	nd	nd
Filtered chloride					
01443000	Del. R. at Portland	Upward	Upward	nd	Upward
01460820	Del. R. at Lumberville	Upward	Upward	nd	Upward
01463500	Del. R. at Trenton	Upward	Upward	nd	Upward
01477120	Raccoon Cr.	Upward	Upward	nd	Upward
Total dissolved solids					
01443000	Del. R. at Portland	Upward	Upward	nd	Upward
01460820	Del. R. at Lumberville	Upward	Upward	nd	Upward
01463500	Del. R. at Trenton	--	Upward	Upward	Upward
01477120	Raccoon Cr.	Upward	Upward	nd	Upward

For a selected nutrient at a selected station, the result of the test for trends in flow-normalized annual flux usually, but not always, matches the corresponding result for the test for flow-normalized annual concentration (tables 5*A*, 5*B*, and 5*C*). Differences between the two results can be attributed to the fact that (1) trends in concentration are uniformly influenced by concentrations on days of low streamflow, medium streamflow, and highest streamflow, but (2) trends in flux are highly influenced by concentrations on days of highest streamflow and little influenced by concentrations on days of low and medium streamflows (Hirsch and others, 2015).

The numbers of stations with downward trends, upward trends, or no trends in concentrations or fluxes of each water-quality characteristic over water years 1980–2011 as determined from WRTDS models are given in table 6. Trends in concentration of each nutrient are reported for 20–21 stations; trends in flux are reported for 15–17 stations. Selected results are given below.

Tests of total nitrogen identified only one station with an upward trend in either concentration or flux. Upward trends in both concentration and flux were shown at the Toms River near Toms River, N.J. (01408500). Tests of concentrations and fluxes at all other stations showed either no trend or a downward trend.

Tests of filtered nitrate plus nitrite identified the same number of stations with upward trends in concentration (6) as downward trends (6) and the same number of upward trends in flux (4) as downward trends (4).

Tests of total phosphorus identified only one station at which there was an upward trend in concentration, West Branch Wading River at Maxwell, N.J. (01409815). Tests of flux showed no station at which there was an upward trend in flux; trends in flux were not determined at the West Branch Wading River at Maxwell, N.J. (01409815). Either no trend or a downward trend in concentration and (or) flux was identified at each of the other stations tested. Tests of filtered chloride and total dissolved solids at all four station showed upward trends in concentration and flux (table 5*D*).

Summary of Results of Trend Tests Over Water Years 2000–11

Trends in concentration and flux over water years 2000–11 identified from WRTDS models are presented in Hickman (2016) and summarized in tables 7*A* (total nitrogen), 7*B* (filtered nitrate plus nitrite), 7*C* (total phosphorus), and 7*D* (filtered chloride and total dissolved solids). The contents of these tables indicate either that there was an upward trend, a downward trend, no trend, or that a trend was not determined.

Results of WRTDS models for each nutrient over water years 2000–11 identified more downward trends in concentration than upward trends and more downward trends in flux than upward trends (table 8). For example, for total nitrogen, there were 6 stations with downward trends in concentration and 3 stations with upward trends; corresponding results of trends in flux identified 6 stations with downward trends and 1 station with an upward trend.

Results of WRTDS models for water years 2000-11 sometimes identified trends different from the corresponding trends for water years 1980–2011 (tables 5*A*, 5*B*, 5*C*, 7*A*, 7*B*, and 7*C*). For example, upward trends in concentrations were identified in results of tests for water years 2000–11 but not in the corresponding results of tests for water years 1980–2011

Table 6. Numbers of water-quality stations on streams in New Jersey with downward and upward trends identified using Weighted Regressions on Time, Discharge, and Season models and seasonal rank-sum tests, water years 1980–2011.

[WRTDS, Weighted Regressions on Time, Discharge, and Season; na., not applicable; Downward, values decreased; Upward, values increased; No trend, values did not change significantly]

Water-quality characteristic	Results of WRTDS models to identify trends in flow-normalized annual values, years 1980–2011 (Hickman, 2017)								Results of seasonal rank-sum tests to identify step trends between values of water-quality characteristics in the 1980s and those in the 2000s (Hickman, 2017)			
	Trends in concentration				Trends in flux							
	Number of stations tested	Number of stations with indicated results			Number of stations tested	Number of stations with indicated results			Number of stations tested	Number of stations with indicated results		
		Downward	Upward	No trend		Downward	Upward	No trend		Downward	Upward	No trend
Total nitrogen	21	9	1	11	17	7	1	9	28	14	2	12
Filtered nitrate plus nitrite	21	6	6	9	17	4	4	9	28	10	11	7
Total phosphorus	20	8	1	11	15	4	0	11	28	18	1	9
Specific conductance	0	na	na	na	0	na	na	na	4	0	4	0
Filtered chloride	4	0	4	0	4	0	4	0	4	0	4	0
Total dissolved solids	4	0	4	0	4	0	4	0	4	0	3	1

Table 7*A*. Summary of results of trend tests of concentrations and fluxes of total nitrogen at water-quality stations on streams in New Jersey over water years 2000–2011.

[Trends in flow-normalized annual concentrations and fluxes are from Weighted Regressions on Time, Discharge, and Season models. nd, not determined; --, no trend; Downward, values decreased; Upward, values increased; R. River; L., Little; Cr., Creek, Del., Delaware]

Station number	Short name	Trends in concentration	Trends in fluxes
		Trends in flow-normalized annual concentrations over water years 2000–2011 (Hickman, 2017)	Trends in flow-normalized annual fluxes over water years 2000–2011 (Hickman, 2017)
01367770	Wallkill R.	nd	nd
01377000	Hackensack R.	--	--
01381800	Whippany R.	nd	nd
01382000	Passaic R. at Two Bridges	nd	nd
01387500	Ramapo R.	--	--
01389500	Passaic R. at L. Falls	Downward	--
01391500	Saddle R.	--	--
01395000	Rahway R.	--	--
01396660	Mulhockaway Cr.	Downward	--
01398000	Neshanic R.	--	Downward
01399780	Lamington R.	--	nd
01403300	Raritan R.	Downward	Downward
01405340	Manalapan Brook	Upward	nd
01408500	Toms R.	--	--
01409387	Mullica R.	--	nd
01409500	Batsto R.	--	--
01409815	West Branch Wading R.	nd	nd
01411110	Great Egg Harbor R.	Upward	nd
01411500	Maurice R.	Upward	Upward
01412800	Cohansey R.	nd	nd
01443000	Del. R. at Portland	Downward	Downward
01443500	Paulins Kill	Downward	Downward
01457400	Musconetcong R.	--	--
01460820	Del. R. at Lumberville	--	Downward
01463500	Del. R. at Trenton	Downward	Downward
01464515	Doctors Cr.	nd	nd
01466500	McDonalds Branch	nd	nd
01477120	Raccoon Cr.	--	--

Table 7*B*. Summary of results of trend tests of concentrations and fluxes of filtered nitrate plus nitrite at water-quality stations on streams in New Jersey over water years 2000–2011.

[Trends in flow-normalized annual concentrations and fluxes are from Weighted Regressions on Time, Discharge, and Season models. nd, not determined; --, no trend; Downward, values decreased; Upward, values increased; R. River; L., Little; Cr., Creek, Del., Delaware]

Station number	Short name	Trends in concentration		Trends in fluxes
		Trends in flow-normalized annual concentrations over water years 2000–2011 (Hickman, 2017)	Trends in flow-adjusted concentrations [1]1998–2007 (Hickman and Gray, 2010)	Trends in flow-normalized annual fluxes over water years 2000–2011 (Hickman, 2017)
01367770	Wallkill R.	nd	Downward	nd
01377000	Hackensack R.	--	--	--
01381800	Whippany R.	nd	--	nd
01382000	Passaic R. at Two Bridges	nd	--	nd
01387500	Ramapo R.	--	--	--
01389500	Passaic R. at L. Falls	--	--	--
01391500	Saddle R.	--	Upward	--
01395000	Rahway R.	--	--	--
01396660	Mulhockaway Cr.	--	Upward	--
01398000	Neshanic R.	Downward	--	Downward
01399780	Lamington R.	--	--	nd
01403300	Raritan R.	--	nd	--
01405340	Manalapan Brook	--	Upward	nd
01408500	Toms R.	Upward	Upward	Upward
01409387	Mullica R.	--	--	nd
01409500	Batsto R.	Downward	Upward	Downward
01409815	West Branch Wading R.	nd	nd	nd
01411110	Great Egg Harbor R.	Upward	Upward	nd
01411500	Maurice R.	--	Upward	--
01412800	Cohansey R.	nd	Upward	nd
01443000	Del. R. at Portland	Downward	--	Downward
01443500	Paulins Kill	Downward	--	Downward
01457400	Musconetcong R.	--	Upward	Upward
01460820	Del. R. at Lumberville	--	--	Downward
01463500	Del. R. at Trenton	--	--	--
01464515	Doctors Cr.	nd	--	nd
01466500	McDonalds Branch	nd	nd	nd
01477120	Raccoon Cr.	--	--	--

[1]Range of water years over which trends in published reports were determined.

Table 7*C*. Summary of results of trend tests of concentrations and fluxes of total phosphorus at water-quality stations on streams in New Jersey over water years 2000–2011.

[Trends in flow-normalized annual concentrations and fluxes are from Weighted Regressions on Time, Discharge, and Season models. nd, not determined; --, no trend; Downward, values decreased; Upward, values increased; R. River; L., Little; Cr., Creek, Del., Delaware]

Station number	Short name	Trends in concentration		Trends in fluxes
		Trends in flow-normalized annual concentrations over water years 2000–2011 (Hickman, 2017)	Trends in flow-adjusted concentrations, [1]1998–2007 (Hickman and Gray, 2010)	Trends in flow-normalized annual fluxes over water years 2000–2011 (Hickman, 2017)
01367770	Wallkill R.	nd	--	nd
01377000	Hackensack R.	--	--	--
01381800	Whippany R.	nd	Downward	nd
01382000	Passaic R. at Two Bridges	nd	Downward	nd
01387500	Ramapo R.	--	--	--
01389500	Passaic R. at L. Falls	Downward	--	--
01391500	Saddle R.	--	--	--
01395000	Rahway R.	--	--	--
01396660	Mulhockaway Cr.	nd	--	nd
01398000	Neshanic R.	--	--	--
01399780	Lamington R.	Downward	--	nd
01403300	Raritan R.	--	nd	--
01405340	Manalapan Brook	--	--	nd
01408500	Toms R.	--	Downward	--
01409387	Mullica R.	--	Upward	nd
01409500	Batsto R.	Downward	--	Downward
01409815	West Branch Wading R.	Upward	Upward	nd
01411110	Great Egg Harbor R.	--	--	nd
01411500	Maurice R.	--	--	--
01412800	Cohansey R.	nd	--	nd
01443000	Del. R. at Portland	Downward	--	--
01443500	Paulins Kill	--	--	--
01457400	Musconetcong R.	--	Downward	--
01460820	Del. R. at Lumberville	--	Downward	--
01463500	Del. R. at Trenton	Downward	Downward	Downward
01464515	Doctors Cr.	nd	--	nd
01466500	McDonalds Branch	nd	nd	nd
01477120	Raccoon Cr.	nd	--	nd

[1]Range of water years over which trends in published reports were determined.

Table 7*D*. Summary of results of trend tests of concentrations and fluxes of measures of major ions at water-quality stations on streams in New Jersey over water years 2000–2011.

[Trends in flow-normalized annual concentrations and fluxes are from Weighted Regressions on Time, Discharge, and Season models. nd, not determined; --, no trend; Upward, values increased; R. River; Del., Delaware; Cr. , Creek]

Station number	Short name	Trends in concentration: Trends in flow-normalized annual concentrations over water years 2000–2011 (Hickman, 2017)	Trends in concentration: Trends in flow-adjusted concentrations, [1]1998–2007 (Hickman and Gray, 2010)	Trends in flux: Trends in flow-normalized annual fluxes over water years 2000–2011 (Hickman, 2017)
Specific conductance				
01443000	Del. R. at Portland	nd	nd	nd
01460820	Del. R. at Lumberville	nd	nd	nd
01463500	Del. R. at Trenton	nd	nd	nd
01477120	Raccoon Cr.	nd	nd	nd
Filtered chloride				
01443000	Del. R. at Portland	Upward	nd	Upward
01460820	Del. R. at Lumberville	Upward	nd	Upward
01463500	Del. R. at Trenton	Upward	nd	Upward
01477120	Raccoon Cr.	Upward	nd	--
Total dissolved solids				
01443000	Del. R. at Portland	Upward	--	Upward
01460820	Del. R. at Lumberville	Upward	--	--
01463500	Del. R. at Trenton	Upward	--	--
01477120	Raccoon Cr.	Upward	Upward	Upward

[1]Range of water years over which trends in published reports were determined.

Table 8. Numbers of stations with downward and upward trends identified using Weighted Regressions on Time, Discharge, and Season models at water-quality stations on streams in New Jersey, water years 2000–2011.

[WRTDS, Weighted Regressions on Time, Discharge, and Season; na, not applicable]

Water-quality characteristic	Results of trend tests from WRTDS models over water years 2000–2011 (Hickman, 2017): Results for concentration				Results for flux			
	Number of stations tested	Number of stations with indicated results			Number of stations tested	Number of stations with indicated results		
		Downward	Upward	No trend		Downward	Upward	No trend
Total nitrogen	21	6	3	12	17	6	1	10
Filtered nitrate plus nitrite	21	4	2	15	17	5	2	10
Total phosphorus	20	5	1	14	15	2	0	13
Specific conductance	0	na	na	na	0	na	na	na
Filtered chloride	4	0	4	0	4	0	3	1
Total dissolved solids	4	0	4	0	4	0	2	2

for the following nutrients and stations: total nitrogen and filtered nitrate plus nitrite at Great Egg Harbor River at Weymouth, N.J. (01411110); total nitrogen at Manalapan Brook at Federal Road near Manalapan, N.J. (01405340); and total nitrogen at the Maurice River at Norma, N.J. (01411500). These results may be due to nonmonotonic changes in concentration over time.

Results of the WRTDS models showed upward trends in concentration of filtered chloride and total dissolved solids over water years 2000–11 for all four stations tested (table 7*D*). Upward trends in fluxes of filtered chloride and total dissolved solids were identified at 3 and 2 stations, respectively.

Comparison with Results of Previous Studies

Results of selected previous trend studies do not always match the results of WRTDS. For a selected station and period of analysis, the difference between the result of WRTDS models and the corresponding results from the previous studies usually took the form of one result identifying a trend and the other result not identifying a trend. Differences can be attributed to differences in methods and to differences in the periods over which trends tests were conducted.

For three reasons, results of the WRTDS models over water years 1980–2011 and 2000–11 are expected to be more accurate than corresponding trend results of previous reports. First, trend results identified in the previous studies generally identified monotonic trends with slopes significantly different from zero, even when the variation of concentrations over time was not monotonic. In contrast, the results of the WRTDS models identified differences in flow-normalized annual concentrations or fluxes between the first and last years of the period of analysis; whether the concentrations or fluxes exhibited a monotonic or nonmonotonic pattern over time was irrelevant. Second, the number of concentrations used to identify trends over water years 1980–2011 and 2000–11 with WRTDS models was greater than that used to identify trends in most previous studies. WRTDS models used all measured concentrations during water years 1971–2011 to determined trends over 1980–2011 and 2000–11. Trends in previous studies during selected periods were identified from analyses of concentrations measured only during those periods. Third, the trends identified in the previous studies were determined for different periods from those in this study.

The results of WRTDS models for concentrations and fluxes of nutrients over water years 1980–2011 often, but not always, agreed with the results from Trench and others (2012) over water years 1975–2003 (tables 5*A*, 5*B*, and 5*C*). For example, results for total nitrogen concentration and flux agreed at 7 of 10 stations.

Results of WRTDS models to identify trends in concentrations of filtered nitrate plus nitrite and total phosphorus over water years 2000–11 agreed with about half of the results from Hickman and Gray (2010) over water years 1998–2007 (tables 7*B* and 7*C*, respectively). For example, results of trend tests in concentrations of filtered nitrate plus nitrite agreed at 11 of 20 stations.

The results of WRTDS models over water years 2000–11 for concentrations of total dissolved solids matched the results from Hickman and Gray (2010) over water years 1998–2007 at only 1 of the 4 stations (table 7*D*). The result of WRTDS models for concentrations of total dissolved solids at the Delaware River Trenton, N.J. (01463500) over water years 1980–2011 agreed with the result reported by Anning and Flynn (2014) for water years 1980–2009 (table 5*D*).

Results from Seasonal Rank-Sum Tests

Results of the seasonal rank-sum tests of water-quality characteristics in different decades are given in a dataset in Hickman (2016). The results of each test include (1) the direction of the step change between each decade, (2) the level of significance of this step change, (3) the direction of each identified trend, and (4) the difference between the medians in each decade associated with each trend. Results for nutrient concentrations also include the threshold used in the test.

The seasonal rank-sum test was selected to identify decade-to-decade trends in water-quality characteristics which could not be identified with WRTDS models. This test was used to identify trends in (1) the three nutrients at all 28 stations and (2) all three measures of major ions at the 4 selected stations.

Summaries of results of seasonal rank-sum tests for each nutrient are given in tables 9*A* (total nitrogen), 9*B* (filtered nitrate plus nitrite), and 9*C* (total phosphorus); summaries of results for measures of major ions are given in table 9*D*. Each of these tables contains the results of three tests between consecutive decades (1970s to 1980s, 1980s to 1990s, and 1990s to 2000s) and two tests between nonconsecutive decades (1970s to 2000s and 1980s to 2000s). In general, there were an insufficient number of water-quality measurements in the 1970s to conduct the tests between the 1970s and 1980s and between the 1970s and 2000s.

For some water-quality characteristics at some stations, results of all tests between water quality in consecutive decades (1970s to 1980s if available, 1980s to 1990s, and 1990s to 2000s) identified either a downward trend or an upward trend (tables 9*A*, 9*B*, and 9*D*). Upward trends at the following stations were identified by all tests: total nitrogen at Toms River near Toms River, N.J. (01408500) and Cohansey River at Seeley, N.J. (01412800); filtered nitrate plus nitrite concentration at Cohansey River at Seeley, N.J. (01412800); filtered chloride at Delaware River at Portland, Pa. (01443000), Delaware River at Lumberville, Pa. (01460820), and Delaware River at Trenton, N.J. (01463500).

For other water-quality characteristics and stations, the results of tests between consecutive decades identified a monotonic pattern; one or more tests identified a downward trend and one or more tests identified an upward trend

Table 9*A*. Summary of results of seasonal rank-sum tests to identify step trends in concentrations of total nitrogen at water-quality stations on New Jersey streams between decades, 1970s to 2000s.

[Trends are identified by a two-sided 0.05 level of significance. --, no trend; nd, not determined; Upward, water-quality value increased between decades; Downward, water-quality value decreased between decades; R. River; L., Little; Cr., Creek; Del., Delaware]

Station number	Short name	Results of seasonal rank-sum tests (Hickman, 2017)				
		Consecutive decades			Nonconsecutive decades	
		1970s to 1980s	1980s to 1990s	1990s to 2000s	1970s to 2000s	1980s to 2000s
01367770	Wallkill R.	nd	--	--	nd	--
01377000	Hackensack R.	--	Downward	--	--	Downward
01381800	Whippany R.	nd	Downward	--	nd	Downward
01382000	Passaic R. at Two Bridges	nd	Downward	--	nd	Downward
01387500	Ramapo R.	Upward	--	--	Upward	--
01389500	Passaic R. at L. Falls	nd	--	--	nd	Downward
01391500	Saddle R.	Upward	--	--	Upward	--
01395000	Rahway R.	nd	--	--	nd	--
01396660	Mulhockaway Cr.	nd	Downward	Downward	nd	Downward
01398000	Neshanic R.	nd	--	Downward	nd	Downward
01399780	Lamington R.	nd	Downward	--	nd	Downward
01403300	Raritan R.	nd	Downward	--	nd	--
01405340	Manalapan Brook	nd	Downward	--	nd	Downward
01408500	Toms R.	Upward	Upward	Upward	Upward	Upward
01409387	Mullica R.	nd	--	Downward	nd	Downward
01409500	Batsto R.	nd	--	--	nd	--
01409815	West Branch Wading R.	nd	--	--	nd	--
01411110	Great Egg Harbor R.	nd	Downward	Upward	nd	Downward
01411500	Maurice R.	--	--	Upward	Upward	--
01412800	Cohansey R.	nd	Upward	Upward	nd	Upward
01443000	Del. R. at Portland	nd	Downward	Downward	nd	Downward
01443500	Paulins Kill	nd	Downward	Downward	nd	Downward
01457400	Musconetcong R.	nd	--	--	nd	--
01460820	Del. R. at Lumberville	nd	Downward	Downward	nd	Downward
01463500	Del. R. at Trenton	Upward	Downward	Downward	Downward	Downward
01464515	Doctors Cr.	nd	--	--	nd	--
01466500	McDonalds Branch	nd	--	--	nd	--
01477120	Raccoon Cr.	--	Downward	--	--	--

Table 9*B*. Summary of results of seasonal rank-sum tests to identify step trends in concentrations of filtered nitrate plus nitrite at water-quality stations on New Jersey streams between decades, 1970s to 2000s.

[Trends are identified by a two-sided 0.05 level of significance. --, no trend; nd, not determined; Upward, water-quality value increased between decades; Downward, water-quality value decreased between decades; R. River; L., Little; Cr., Creek; Del., Delaware]

Station number	Short name	Results of seasonal rank-sum tests (Hickman, 2017)				
		Consecutive decades			Nonconsecutive decades	
		1970s to 1980s	1980s to 1990s	1990s to 2000s	1970s to 2000s	1980s to 2000s
01367770	Wallkill R.	nd	--	--	nd	Upward
01377000	Hackensack R.	--	--	Downward	Downward	Downward
01381800	Whippany R.	nd	--	--	nd	--
01382000	Passaic R. at Two Bridges	nd	Upward	--	nd	Upward
01387500	Ramapo R.	Upward	--	--	Upward	--
01389500	Passaic R. at L. Falls	nd	Upward	--	nd	Upward
01391500	Saddle R.	--	Upward	--	Upward	Upward
01395000	Rahway R.	nd	--	--	nd	Upward
01396660	Mulhockaway Cr.	nd	--	Downward	nd	Downward
01398000	Neshanic R.	nd	--	Downward	nd	Downward
01399780	Lamington R.	nd	--	Upward	nd	--
01403300	Raritan R.	nd	--	--	nd	Upward
01405340	Manalapan Brook	nd	--	--	nd	--
01408500	Toms R.	--	Upward	Upward	Upward	Upward
01409387	Mullica R.	nd	--	Downward	nd	Downward
01409500	Batsto R.	nd	Upward	--	nd	Upward
01409815	West Branch Wading R.	nd	--	--	nd	--
01411110	Great Egg Harbor R.	nd	--	Upward	nd	--
01411500	Maurice R.	--	--	--	--	Upward
01412800	Cohansey R.	nd	Upward	Upward	nd	Upward
01443000	Del. R. at Portland	nd	--	Downward	nd	Downward
01443500	Paulins Kill	nd	--	--	nd	Downward
01457400	Musconetcong R.	nd	--	Upward	nd	Upward
01460820	Del. R. at Lumberville	nd	--	--	nd	Downward
01463500	Del. R. at Trenton	Upward	Downward	--	--	Downward
01464515	Doctors Cr.	nd	--	Downward	nd	Downward
01466500	McDonalds Branch	--	--	--	--	--
01477120	Raccoon Cr.	--	--	--	--	Downward

Table 9*C*. Summary of results of seasonal rank-sum tests to identify step trends in concentrations of total phosphorus at water-quality stations on New Jersey streams between decades, 1970s to 2000s.

[Trends are identified by a two-sided 0.05 level of significance. --, no trend; nd, not determined; Upward, water-quality value increased between decades; Downward, water-quality value decreased between decades; R. River; L., Little; Cr., Creek; Del., Delaware]

Station number	Short name	Results of seasonal rank-sum tests (Hickman, 2017)				
		Consecutive decades			Nonconsecutive decades	
		1970s to 1980s	1980s to 1990s	1990s to 2000s	1970s to 2000s	1980s to 2000s
01367770	Wallkill R.	nd	Downward	--	nd	Downward
01377000	Hackensack R.	--	Downward	--	--	--
01381800	Whippany R.	nd	Downward	Downward	nd	Downward
01382000	Passaic R. at Two Bridges	nd	--	--	nd	--
01387500	Ramapo R.	--	--	--	--	--
01389500	Passaic R. at L. Falls	nd	--	--	nd	Downward
01391500	Saddle R.	--	Downward	Upward	--	Downward
01395000	Rahway R.	nd	--	--	nd	--
01396660	Mulhockaway Cr.	nd	--	Downward	nd	Downward
01398000	Neshanic R.	nd	--	--	nd	--
01399780	Lamington R.	nd	--	--	nd	Downward
01403300	Raritan R.	nd	--	--	nd	--
01405340	Manalapan Brook	nd	--	--	nd	--
01408500	Toms R.	Downward	--	Downward	Downward	Downward
01409387	Mullica R.	nd	--	Downward	nd	Downward
01409500	Batsto R.	nd	--	--	nd	Downward
01409815	West Branch Wading R.	nd	--	Upward	nd	Upward
01411110	Great Egg Harbor R.	nd	Downward	--	nd	Downward
01411500	Maurice R.	Downward	--	--	Downward	--
01412800	Cohansey R.	nd	Downward	--	nd	Downward
01443000	Del. R. at Portland	nd	--	Downward	nd	Downward
01443500	Paulins Kill	nd	Downward	--	nd	Downward
01457400	Musconetcong R.	nd	Downward	--	nd	Downward
01460820	Del. R. at Lumberville	nd	Downward	--	nd	Downward
01463500	Del. R. at Trenton	--	Downward	--	Downward	Downward
01464515	Doctors Cr.	nd	Downward	Downward	nd	Downward
01466500	McDonalds Branch	--	--	--	Downward	Downward
01477120	Raccoon Cr.	--	--	--	--	--

Table 9*D*. Summary of results of seasonal rank-sum tests to identify step trends in concentrations of measures of major ions at water-quality stations on New Jersey streams between decades, 1970s to 2000s.

[Trends are identified by a two-sided 0.05 level of significance. --, no trend; nd, not determined; Upward, water-quality value increased between decades; R. River; Cr., Creek; Del., Delaware]

Station number	Short name	Results of seasonal rank-sum tests (Hickman, 2017)				
		Consecutive decades			Nonconsecutive decades	
		1970s to 1980s	1980s to 1990s	1990s to 2000s	1970s to 2000s	1980s to 2000s
		Specific conductance				
01443000	Del. R. at Portland	nd	Upward	--	nd	Upward
01460820	Del. R. at Lumberville	nd	--	Upward	nd	Upward
01463500	Del. R. at Trenton	--	--	Upward	Upward	Upward
01477120	Raccoon Cr.	--	Upward	Upward	Upward	Upward
		Filtered chloride				
01443000	Del. R. at Portland	nd	Upward	Upward	nd	Upward
01460820	Del. R. at Lumberville	nd	Upward	Upward	nd	Upward
01463500	Del. R. at Trenton	Upward	Upward	Upward	Upward	Upward
01477120	Raccoon Cr.	--	Upward	Upward	Upward	Upward
		Total dissolved solids				
01443000	Del. R. at Portland	nd	--	Upward	nd	Upward
01460820	Del. R. at Lumberville	nd	--	Upward	nd	Upward
01463500	Del. R. at Trenton	--	--	Upward	--	--
01477120	Raccoon Cr.	--	Upward	Upward	Upward	Upward

(tables 9*A*, 9*B*, and 9*C*). These results were identified for (1) total phosphorus concentration at the Saddle River at Lodi, N.J. (01391500); (2) total nitrogen concentration at the Great Egg Harbor River at Weymouth, N.J. (0141110); and (3) concentrations of both total nitrogen and filtered nitrate plus nitrite at Delaware River at Trenton, N.J. (01463500).

As one example of a nonmonotonic pattern, measured concentrations of total nitrogen at the Delaware River at Trenton, N.J. (01463500) are shown in figure 8. Results of the seasonal rank-sum tests of total nitrogen concentration at this station identified an upward trend from 1970s to 1980s and downward trends from 1980s to 1990s and 1990s to 2000s (table 9*A*). The LOESS curve through the measured concentrations shows an increase in concentration from the 1970s to 1980s and decreases in concentration from 1980s to 1990s and 1990s to 2000s. The flow-normalized annual concentrations show a similar pattern.

Summary of Results of Seasonal Rank-Sum Tests Between the 1980s and the 2000s

Summaries of the results of seasonal rank-sum tests between the 1980s and the 2000s are listed in tables 5*A* for total nitrogen, 5*B* for filtered nitrate plus nitrite, 5*C* for total phosphorus, and 5*D* for measures of major ions. The number of stations with downward trends, upward trends, and no trends in each water-quality characteristic identified from seasonal rank-sum tests is presented in table 6.

Results of the seasonal rank-sum tests between the 1980s and the 2000s showed the same relative number of (1) stations with upward trends and (2) stations with downward trends as shown by results of the WRTDS models for water years 1980–2011 (table 6). For total nitrogen concentration, there were more stations with downward trends (14) than upward trends (2). Results for total phosphorus were similar; there were more stations with downward trends in total phosphorus (18) than upward trends (1). The number of stations with downward trends in filtered nitrate plus nitrite (10) was about equal to the number of stations with upward trends (11). Upward trends in specific conductance and filtered chloride concentrations were identified at all four stations. Upward trends in concentrations of total dissolved solids were identified at 3 of 4 stations; there was no trend at 1 station.

Comparison of Results of Seasonal Rank-Sum Tests to Results of Other Trend Studies

Results of the seasonal rank-sum tests are different from the results of other methods mentioned in this report. The results of the seasonal rank-sum tests identified trends between water-quality characteristics in different decades, whereas other methods identified trends in water quality over periods between selected water years.

Results of the seasonal rank-sum tests are more likely to match the results of other tests if the changes in a water-quality characteristic over time within each the two decades

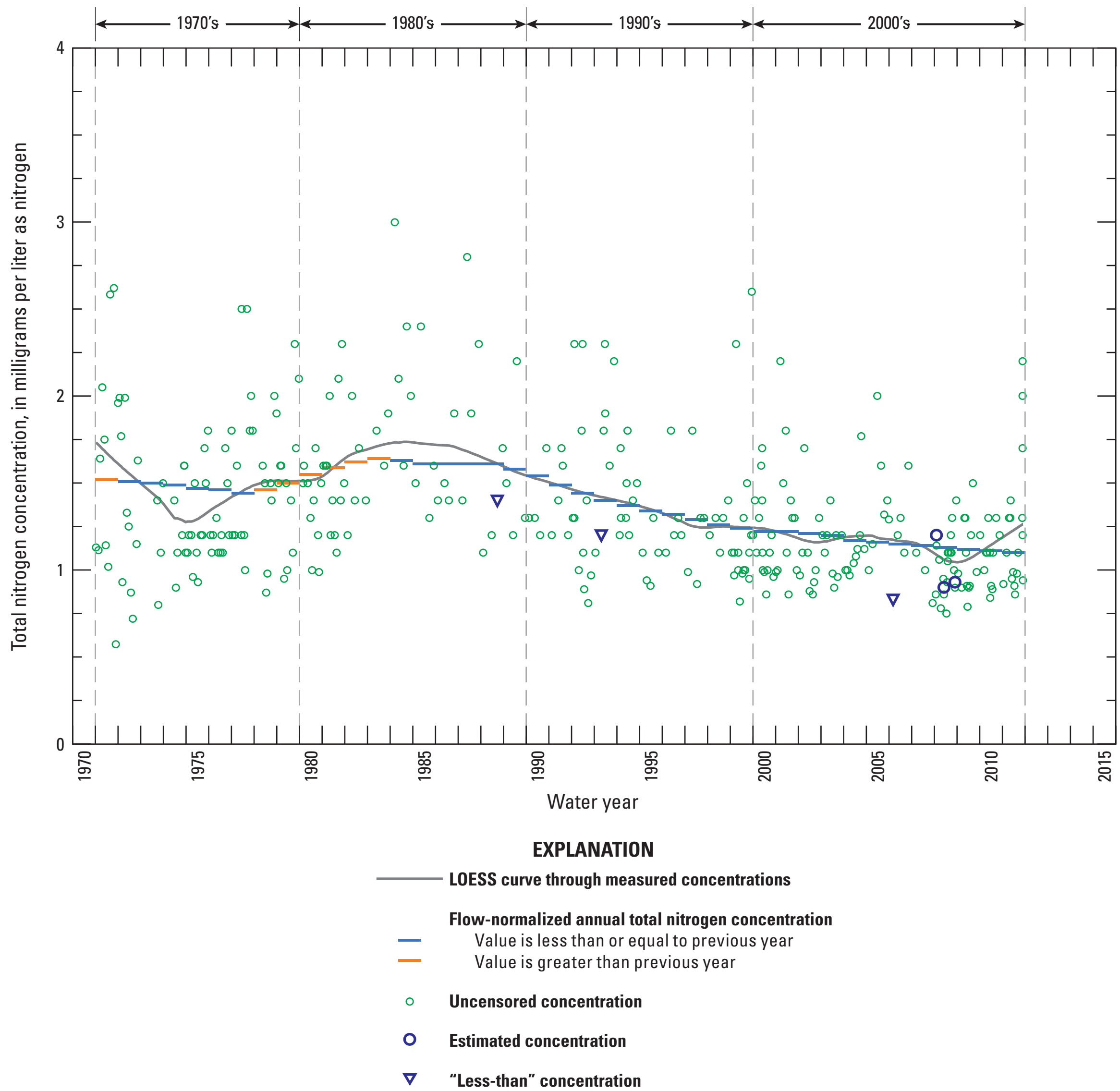


Figure 8. Measured concentrations and flow-normalized annual concentrations of total nitrogen at Delaware River at Trenton, New Jersey (01463500), water years 1971–2011.

of the rank-sum test were small as compared to the changes in water quality between the two decades. The seasonal rank-sum test only identifies changes in water quality between the two decades; it does not include the changes in water quality within each of the two decades.

Also, the results of the seasonal rank-sum tests for nutrient concentrations do not adjust water quality for streamflow, as other methods do. However, the comparison of about 40 water-quality measurements in each decade tends to minimize the influence of a few number of water-quality values collected when the streamflow was extremely high or low.

Result of the seasonal rank-sum tests between the 1980s and the 2000s matched those trends in nutrient concentration from the WRTDS (Weighted Regressions on Time, Discharge, and Season) models over water years 1980–2011 at most stations (tables 5*A*, 5*B*, and 5*C*). Results for total nitrogen matched at 15 of 21 stations, for filtered nitrate plus nitrite at 14 of 21 stations, and for total phosphorus at 14 of 20 stations. Results of the seasonal rank-sum tests for filtered chloride and total dissolved solids matched the results of the WRTDS models at 4 of 4 stations and 3 of 4 stations, respectively (table 5*D*).

Results of seasonal rank-sum tests between values of water-quality characteristics in consecutive decades only sometimes matched results from selected previous studies (tables in appendix 4). Presentation of all these results allows the reader to compare them.

Combined Results of Trend Tests over Water Years 1980 to 2011

A combined dataset summarizing the results of trend tests over water years 1980–2011 was created from the results of both methods used in this report (table 10). The combined results of trends consisted of the results of WRTDS models, if available. Otherwise, the step trends from seasonal rank-sum tests from the 1980s to the 2000s were included. The numbers of stations with each trend result (downward trend, upward trend, no trend, or not tested) in the combined dataset are given in table 11.

Nearly all stations showed either downward trends or no trends in concentrations of total nitrogen over water years 1980–2011 (table 11); a map of the combined results for trends in total nitrogen is shown in figure 9. There are downward trends at 11 stations and no trends at 15 stations. The two stations with upward trends are Toms River near Toms River, N.J. (01408500), and Cohansey River at Seeley, N.J. (01412800) (table 10).

Combined results of trend tests in concentrations of filtered nitrate plus nitrite over water years 1980–2011 are shown in a map in figure 10. There are 7 stations with a downward trend, 9 stations with an upward trend, and 12 stations with no trend (table 11).

Filtered nitrate plus nitrite is a component of total nitrogen. However, combined results of trend tests for concentrations of filtered nitrate plus nitrite concentration did not always match the combined results for concentrations of total nitrogen (table 10). Factors controlling the trends in nitrate plus nitrite appear to be different than those controlling trends in total nitrogen. There were 9 stations with an upward trend in concentrations of filtered nitrate plus nitrite; there were upward trends in concentration of total nitrogen at only 2 of these stations.

All but one station showed either downward trends or no trends in concentrations of total phosphorus over water years 1980–2011 (table 11); a map of the combined results for trends in total nitrogen is shown in figure 11. There were 14 stations with downward trends and 13 stations with no trends. The only station with an upward trend in total phosphorus concentration was the West Branch Wading River at Maxwell, N.J. (01409815).

There were upward trends in each measure of major ions (specific conductance, concentration of filtered chloride, and concentration of total dissolved solids) at each of the 4 stations at which they were tested (table 11). A map showing these stations is shown in figure 12.

Table 10. Combined results of trend tests of values of water-quality characteristics at water-quality stations on streams in New Jersey, water years 1980–2011.

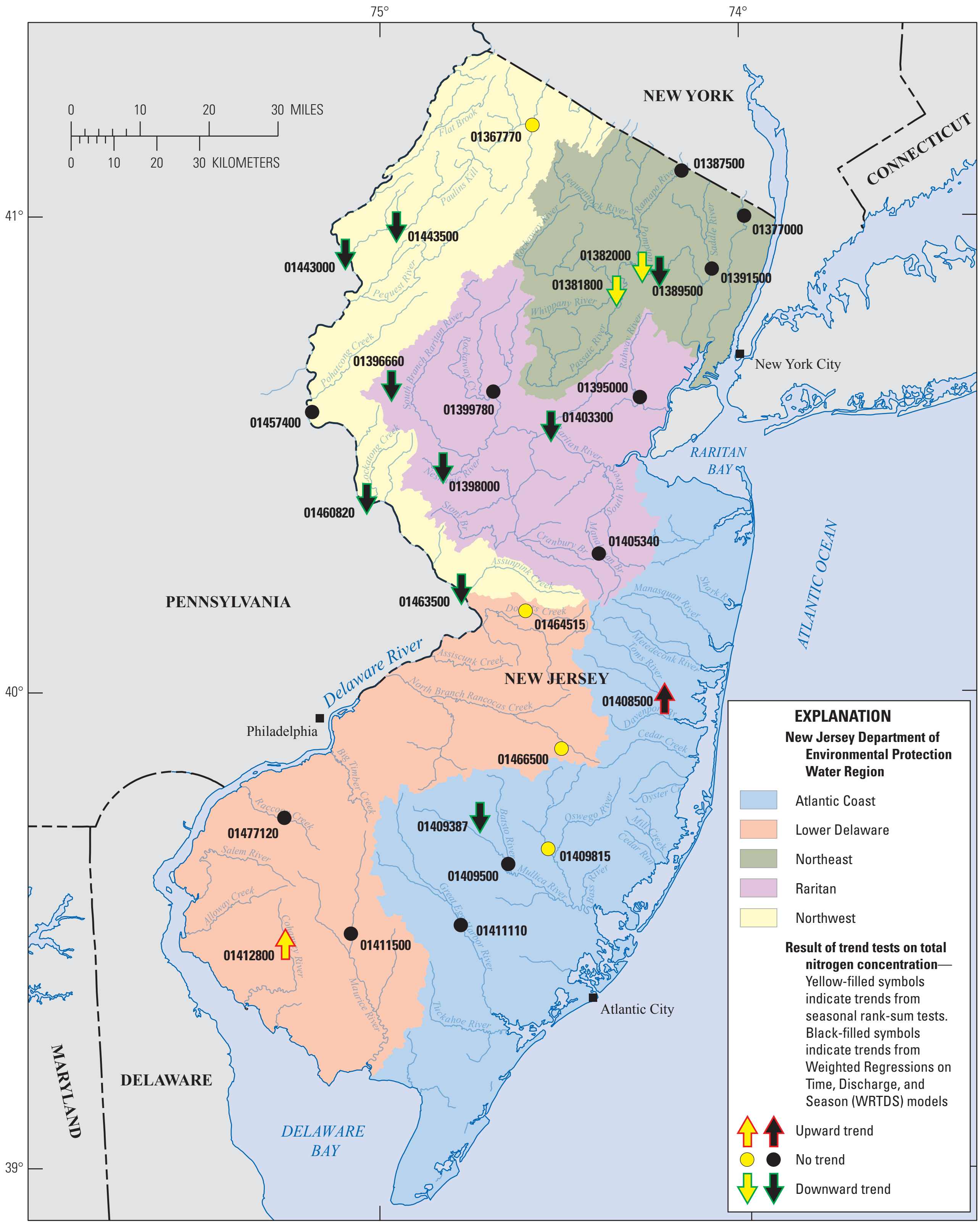
[WRTDS, Weighted Regression on Time, Discharge, and Season; nd, not determined; --, no trend; Downward, values decreased; Upward, value increased; n.a. not applicable; R. River; L., Little, Cr., Creek]

Station number	Short name	Results of trend tests (Hickman, 2017)											
		On concentrations of nutrients						On measures of major ions					
		Total nitrogen		Filtered nitrate plus nitrite		Total phosphorus		Specific conductance		Concentrations of filtered chloride		Concentrations of total dissolved solids	
		Method	Result	Method	Result	Method	Result	Method	Result	Method	Result	Method	Result
01367770	Wallkill R.	Seasonal rank-sum	--	Seasonal rank-sum	Upward	Seasonal rank-sum	Downward	n.a.	nd	n.a.	nd	n.a.	nd
01377000	Hackensack R.	WRTDS models	--	WRTDS models	Downward	WRTDS models	--	n.a.	nd	n.a.	nd	n.a.	nd
01381800	Whippany R.	Seasonal rank-sum	Downward	Seasonal rank-sum	--	Seasonal rank-sum	Downward	n.a.	nd	n.a.	nd	n.a.	nd
01382000	Passaic R. at Two Bridges	Seasonal rank-sum	Downward	Seasonal rank-sum	Upward	Seasonal rank-sum	--	n.a.	nd	n.a.	nd	n.a.	nd
01387500	Ramapo R.	WRTDS models	--	WRTDS models	Upward	WRTDS models	--	n.a.	nd	n.a.	nd	n.a.	nd
01389500	Passaic R. at L. Falls	WRTDS models	Downward	WRTDS models	Upward	WRTDS models	Downward	n.a.	nd	n.a.	nd	n.a.	nd
01391500	Saddle R.	WRTDS models	--	WRTDS models	Upward	WRTDS models	--	n.a.	nd	n.a.	nd	n.a.	nd
01395000	Rahway R.	WRTDS models	--	WRTDS models	--	WRTDS models	--	n.a.	nd	n.a.	nd	n.a.	nd
01396660	Mulhockaway Cr.	WRTDS models	Downward	WRTDS models	Downward	Seasonal rank-sum	Downward	n.a.	nd	n.a.	nd	n.a.	nd
01398000	Neshanic R.	WRTDS models	Downward	WRTDS models	Downward	WRTDS models	--	n.a.	nd	n.a.	nd	n.a.	nd
01399780	Lamington R.	WRTDS models	--	WRTDS models	--	WRTDS models	--	n.a.	nd	n.a.	nd	n.a.	nd
01403300	Raritan R.	WRTDS models	Downward	WRTDS models	Upward	WRTDS models	--	n.a.	nd	n.a.	nd	n.a.	nd
01405340	Manalapan Brook	WRTDS models	--	WRTDS models	--	WRTDS models	--	n.a.	nd	n.a.	nd	n.a.	nd
01408500	Toms R.	WRTDS models	Upward	WRTDS models	Upward	WRTDS models	Downward	n.a.	nd	n.a.	nd	n.a.	nd
01409387	Mullica R.	WRTDS models	Downward	WRTDS models	--	WRTDS models	Downward	n.a.	nd	n.a.	nd	n.a.	nd
01409500	Batsto R.	WRTDS models	--	WRTDS models	--	WRTDS models	--	n.a.	nd	n.a.	nd	n.a.	nd
01409815	West Branch Wading R.	Seasonal rank-sum	--	Seasonal rank-sum	--	WRTDS models	Upward	n.a.	nd	n.a.	nd	n.a.	nd

Table 10. Combined results of trend tests of values of water-quality characteristics at water-quality stations on streams in New Jersey, water years 1980–2011.—Continued

[WRTDS, Weighted Regression on Time, Discharge, and Season; nd, not determined; --, no trend; Downward, values decreased; Upward, value increased; n.a. not applicable; R. River; L., Little, Cr., Creek]

Station number	Short name	Results of trend tests (Hickman, 2017)											
		On concentrations of nutrients						On measures of major ions					
		Total nitrogen		Filtered nitrate plus nitrite		Total phosphorus		Specific conductance		Concentrations of filtered chloride		Concentrations of total dissolved solids	
		Method	Result	Method	Result	Method	Result	Method	Result	Method	Result	Method	Result
01411110	Great Egg Harbor R.	WRTDS models	--	WRTDS models	--	WRTDS models	Downward	n.a.	nd	n.a.	nd	n.a.	nd
01411500	Maurice R.	WRTDS models	--	WRTDS models	--	WRTDS models	Downward	n.a.	nd	n.a.	nd	n.a.	nd
01412800	Cohansey R.	Seasonal rank-sum	Upward	Seasonal rank-sum	Upward	Seasonal rank-sum	Downward	n.a.	nd	n.a.	nd	n.a.	nd
01443000	Del. R. at Portland	WRTDS models	Downward	WRTDS models	Downward	WRTDS models	Downward	Seasonal rank-sum	Upward	WRTDS models	Upward	WRTDS models	Upward
01443500	Paulins Kill	WRTDS models	Downward	WRTDS models	Downward	WRTDS models	--	n.a.	nd	n.a.	nd	n.a.	nd
01457400	Musconetcong R.	WRTDS models	--	WRTDS models	Upward	WRTDS models	--	n.a.	nd	n.a.	nd	n.a.	nd
01460820	Del. R. at Lumberville	WRTDS models	Downward	WRTDS models	--	WRTDS models	Downward	Seasonal rank-sum	Upward	WRTDS models	Upward	WRTDS models	Upward
01463500	Del. R. at Trenton	WRTDS models	Downward	WRTDS models	Downward	WRTDS models	Downward	Seasonal rank-sum	Upward	WRTDS models	Upward	WRTDS models	Upward
01464515	Doctors Cr.	Seasonal rank-sum	--	Seasonal rank-sum	Downward	Seasonal rank-sum	Downward	n.a.	nd	n.a.	nd	n.a.	nd
01466500	McDonalds Branch	Seasonal rank-sum	--	Seasonal rank-sum	--	Seasonal rank-sum	Downward	n.a.	nd	n.a.	nd	n.a.	nd
01477120	Raccoon Cr.	WRTDS models	--	WRTDS models	--	Seasonal rank-sum	--	Seasonal rank-sum	Upward	WRTDS models	Upward	WRTDS models	Upward



Base from U.S. Geological Survey digital data, 1:24,000,
Universal Transverse Mercator projection, Zone 18, North American Datum of 1983

Figure 9. Combined results of trend tests on concentrations of total nitrogen at water-quality stations on streams in New Jersey, water years 1980–2011.

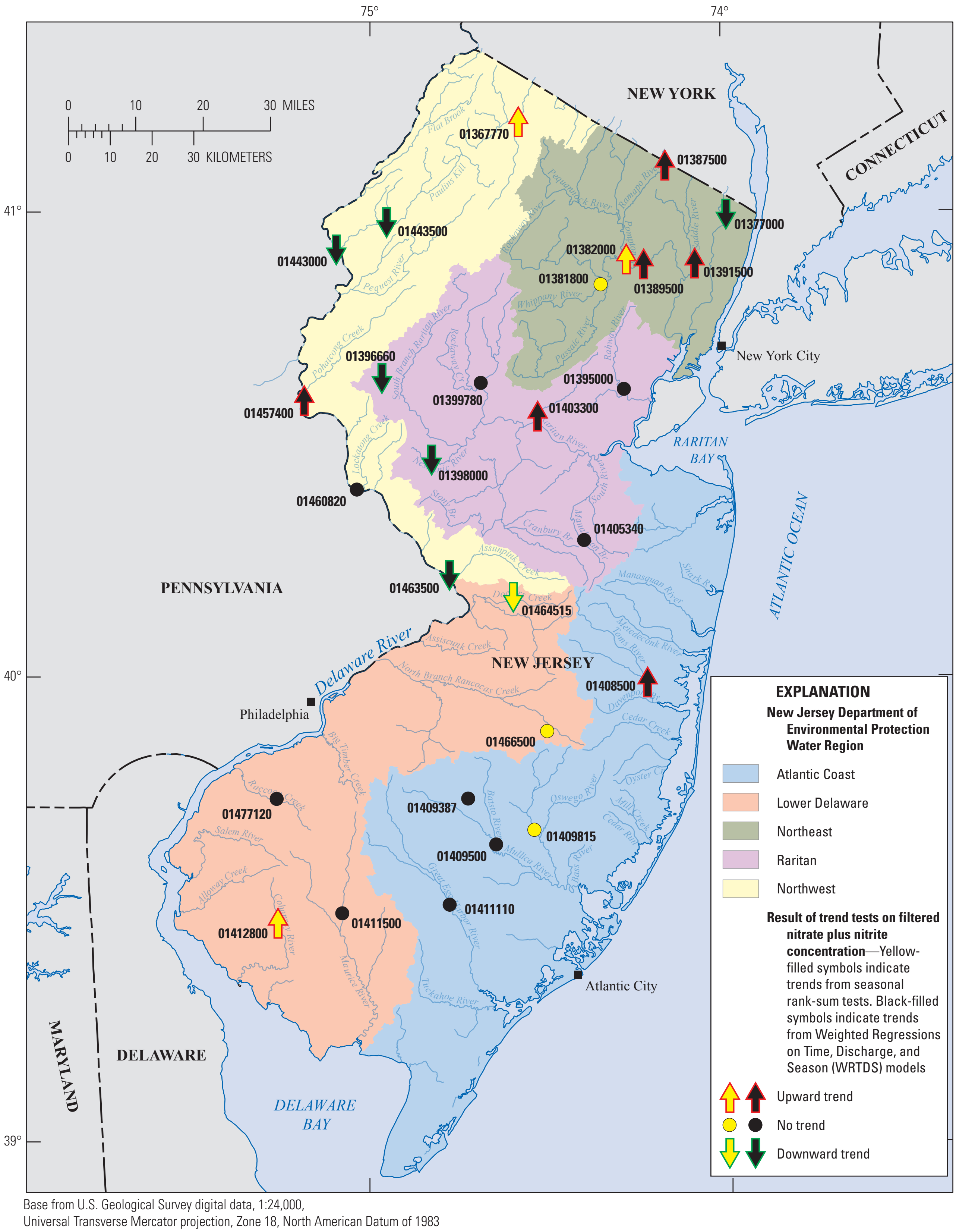
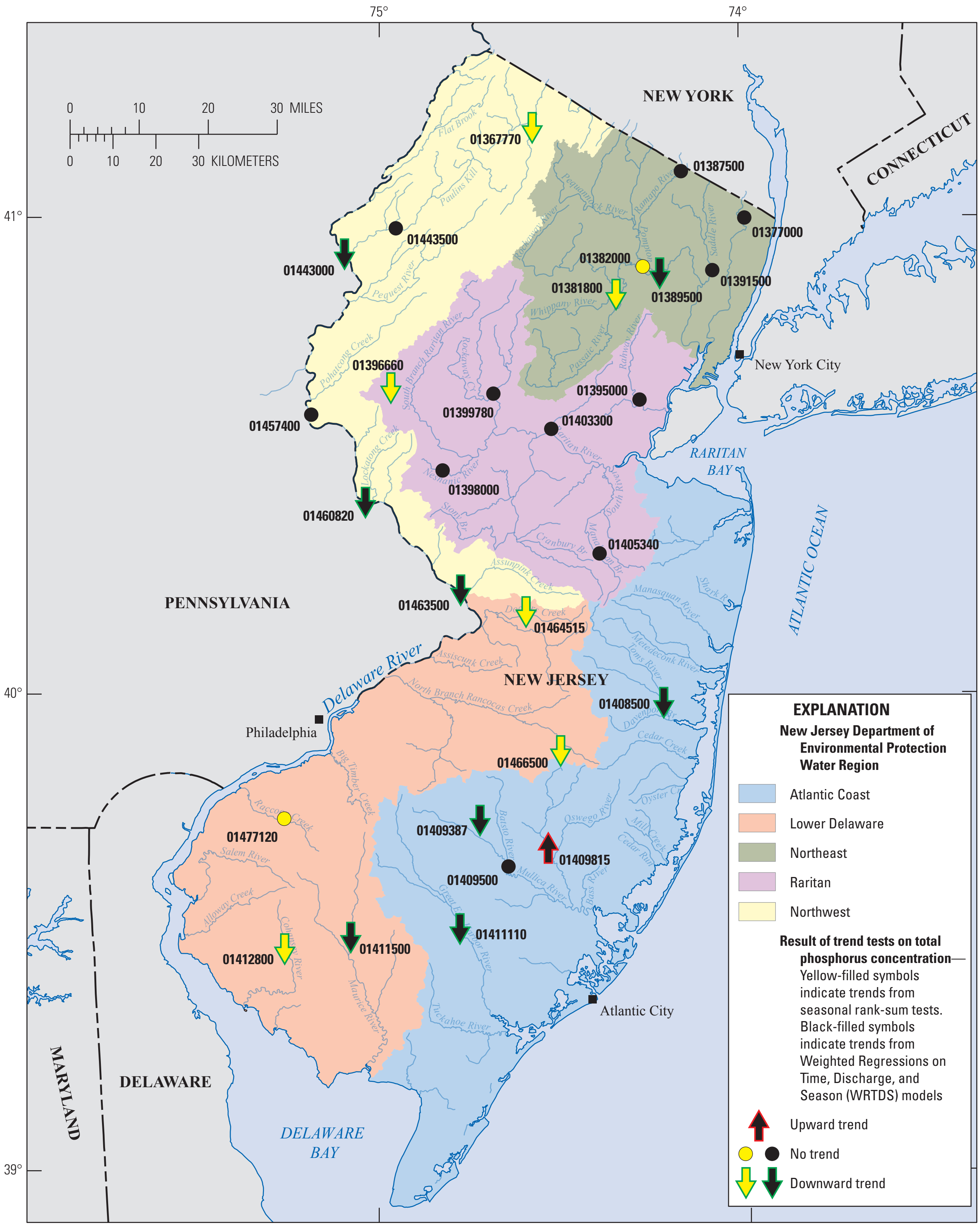
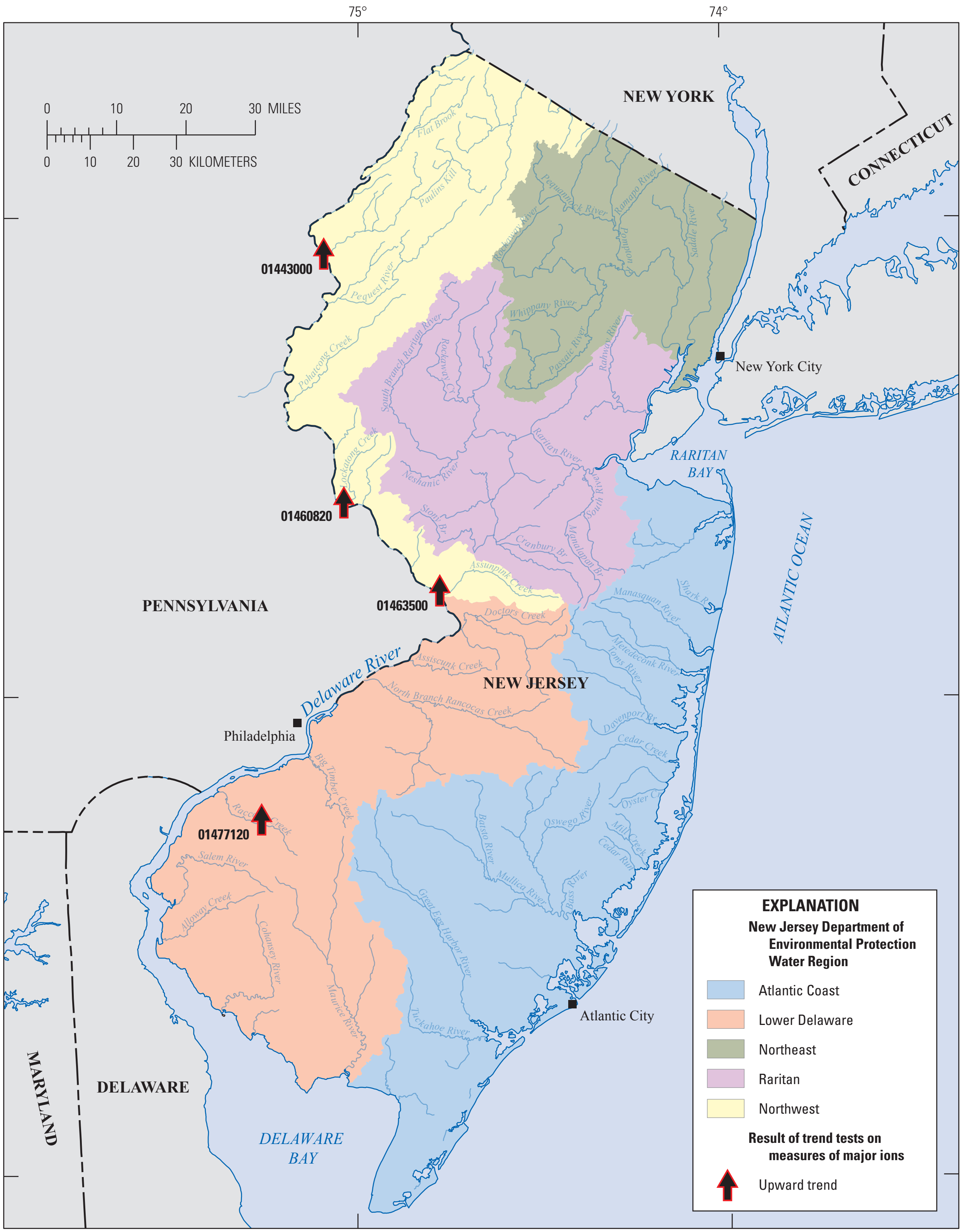


Figure 10. Combined results of trend tests on concentrations of filtered nitrate plus nitrite at water-quality stations on streams in New Jersey, water years 1980–2011.



Base from U.S. Geological Survey digital data, 1:24,000,
Universal Transverse Mercator projection, Zone 18, North American Datum of 1983

Figure 11. Combined results of trend tests on concentrations of total phosphorus at water-quality stations on streams in New Jersey, water years 1980–2011.



Base from U.S. Geological Survey digital data, 1:24,000,
Universal Transverse Mercator projection, Zone 18, North American Datum of 1983

Figure 12. Combined results of trend tests on measures of major ions at water-quality stations on streams in New Jersey, water years 1980–2011.

Table 11. Numbers of stations with trends in water quality indicated by combined results of Weighted Regressions on Time, Discharge, and Season models and seasonal rank-sum tests at stations on streams in New Jersey, water years 1980 to 2011.

[Downward, water quality decreased; Upward, water quality increased; No trend, water quality did not change significantly]

Water-quality characteristic	Number of stations tested	Number of stations with indicated results of trend tests		
		Downward	Upward	No trend
Total nitrogen concentration	28	11	2	15
Filtered nitrate plus nitrite concentration	28	7	9	12
Total phosphorus concentration	28	14	1	13
Specific conductance	4	0	4	0
Filtered chloride concentration	4	0	4	0
Total dissolved solids concentration	4	0	4	0

Summary and Conclusions

A study was conducted by the U.S. Geological Survey in cooperation with the New Jersey Department of Environmental Protection and the Delaware River Basin Commission to identify trends in water-quality characteristics. Trend tests were conducted on selected water-quality characteristics measured at stations on streams in New Jersey during selected periods over water years 1971–2011. Tests were conducted on 3 nutrients (total nitrogen, filtered nitrate plus nitrite, and total phosphorus) at 28 stations and on 3 measures of major ions (specific conductance, filtered chloride, and total dissolved solids) at 4 of the 28 stations.

The water-quality data on which trend tests were conducted were taken from a reviewed compilation of 12 water-quality characteristics at 32 selected stations over water years 1971–2011. Some missing data for water quality were estimated by either calculation or substitution from other water-quality data; methods of estimation are presented in this report. Information on how the public can get a copy of this dataset is provided.

Two methods were used to identify trends—(1) Weighted Regressions on Time, Discharge, and Season (WRTDS) models (which included the use of the WRTDS Bootstrap Test) and (2) seasonal rank-sum tests. WRTDS models were used to identify trends in flow-normalized annual concentrations and flow-normalized annual fluxes over water years 1980–2011 and 2000–11 for each nutrient and for filtered chloride and total dissolved solids. WRTDS models were developed only for stations at which streamflow was measured or estimated. Trends in fluxes are not reported for some stations at which streamflows were estimated. The following additional information produced by WRTDS models is reported: (1) annual and flow-normalized annual concentrations and fluxes for each water year, and (2) changes in flow-normalized annual concentrations and fluxes between selected water years.

Trends from WRTDS models for concentrations of each nutrient were reported for 20–21 stations; trends in fluxes of each nutrient were reported for 15–17 stations. The result of the trend test in flux for a selected nutrient at a selected station (downward trend, no trend, or upward trend) usually, but not always, matched the trend result in concentration.

The results of WRTDS models for water years 1980–2011 identified more stations with downward trends in concentrations of either total nitrogen or total phosphorus than upward trends. For total nitrogen, there were downward trends at 9 stations and an upward trend at 1 station. For total phosphorus, there were downward trends at 8 stations and an upward trend at 1 station. For filtered nitrate plus nitrite, there were downward trends 6 stations and upward trends at 6 stations.

The results of trend tests of concentrations and fluxes of each nutrient from WRTDS models for water years 2000–11 identified more stations with downward trends than upward trends. For example, results for total nitrogen concentration identified 6 stations with downward trends and 3 stations with upward trends.

Seasonal rank-sum tests identified step trends between values of water-quality characteristics measured in different decades from the 1970s to the 2000s. Seasonal rank-sum tests were conducted on each of three nutrients at all 28 stations and on the three measures of major ions at the four selected stations.

Results of the seasonal rank-sum tests between the 1980s and the 2000s show a pattern similar to the results of WRTDS models for water years 1980–2011. More stations have downward trends in concentrations of total nitrogen and total phosphorus than have upward trends. The numbers of stations with downward trends in filtered nitrate plus nitrite concentrations and upward trends in filtered nitrate plus nitrite concentrations were equal (6 stations). Nearly all tests of each measure of major ions identified an upward trend.

A combined dataset of trend results for concentrations of water-quality characteristics over water years 1980–2011 was created from the results of the two tests for the period. Results of WRTDS models were included in this combined dataset, if available. Otherwise, the results of the seasonal rank-sum tests of water-quality characteristics measured in the 1980s and 2000s were included. Results of trends tests for each measure of major ions (specific conductance, filtered chloride concentration, and total dissolved solids concentration) in the combined dataset show upward trends at each of the four stations analyzed.

Trend results for water years 1980–2011 in the combined set show that few of the 28 stations have upward trends in concentrations of either total nitrogen or total phosphorus. For total nitrogen, there were downward trends at 11 stations, no trends at 15 stations, and upward trends at 2 stations; the two stations with upward trends are the Toms River near Toms River, N.J. (01408500) and the Cohansey River at Seeley, N.J. (01412800). For total phosphorus, there were 14 stations with downward trends, 13 stations with no trends, and 1 station with an upward trend. The one station with an upward trend in total phosphorus concentration is the West Branch Wading River at Maxwell, N.J. (01409815). Combined results for filtered nitrate plus nitrite from the dataset show the number of stations with upward trends (9) and the number of stations with downward trends (7) to be nearly the same.

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Appendixes 1–4

Appendix 1. Methods of Estimation of Daily Streamflows at Selected Water-Quality Stations on Streams in New Jersey

Daily streamflows at nine water-quality stations were estimated using one of two methods described below. The method used for each station is given in table 3 in the main text.

Drainage-Area Correction

At five water-quality stations, streamflows were estimated from drainage-area correction of daily streamflows at a nearby streamgage using equation 1-1. Ratios of the drainage area of water-quality station to the drainage area of the streamgage are given in table 3 in the main text.

$$estdv_{qw} = dv_{gage} * ratio_{drainage} \qquad (1\text{-}1)$$

where

- $estdv_{qw}$ = estimated daily streamflow at water-quality station, in cubic feet per second;
- dv_{gage} = measured daily streamflow at streamgage, in cubic feet per second; and
- $ratio_{drainage}$ = ratio of drainage area of water-quality station to the drainage area of streamgage.

MOVE1 Relations

Maintenance of Variance Extension 1 (MOVE1) relations (Hirsch, 1982) were used to estimate daily streamflows at four water-quality stations in New Jersey (table 3 in main text) because streamflow per unit area of streams in the Coastal Plain increases with drainage area. If streamflows had been estimated with the drainage-area correction method, streamflows would have been biased high or low. Annual fluxes were not reported for any water-quality station at which daily streamflows were estimated using this method.

Each MOVE1 relation (Hirsch, 1982) was determined from (1) discrete streamflow measured at a water-quality site and (2) daily streamflows at the indicated streamgage on the same days. The form of a MOVE1 relation is given in equation 1-2. The intercept and slope of each MOVE1 relation used for this study are given in table 1-1. For this report, the MOVE1 equation shown below (equation 1-2) has separate terms in brackets for the slope and the intercept.

$$\log_{10}(estdv_{qw}(i)) = \log_{10}(dv_{gage}) * \left[\frac{S(\log_{10}(q_{qw}))}{S(\log_{10}(dv_{gage}))}\right]_{\text{slope}} + \left[m(\log_{10}(q_{qw})) - \left(\frac{S(\log_{10}(q_{qw}))}{S(\log_{10}(dv_{gage}))}\right) * m(\log_{10}(dv_{gage}))\right]_{\text{intercept}} \qquad (1\text{-}2)$$

and

$$estdv_{qw}(i) = 10^{\log_{10}(estdv_{qw}(i))}$$

where

- $\log_{10}$ = base-10 logarithm;
- $estdv_{qw}(i)$ = estimated daily streamflow at water-quality station on day i, in cubic feet per second;
- q_{qw} = discrete measured streamflow at water-quality station, in cubic feet per second;
- $m(\log_{10}(q_{qw}))$ = mean of base-10 logarithms of discrete measured streamflows at water-quality station, in cubic feet per second;
- $S(\log_{10}(q_{qw}))$ = standard deviation of base-10 logarithms of discrete streamflow measurements at water-quality station, in cubic feet per second;
- $dv_{gage}(i)$ = daily flow at streamgage on day i, in cubic feet per second;
- $m(\log_{10}(dv_{gage}))$ = mean of base-10 logarithms of daily flows at streamgage on days when streamflow was measured at water-quality station, in cubic feet per second, and
- $S(\log_{10}(dv_{gage}))$ = standard deviation of base-10 logarithms of daily streamflows at streamgage on days when streamflows were measured at water-quality station, in cubic feet per second.

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Table 1-1. Description of Maintenance of Variance Extension 1 equation components used to estimate daily streamflows at selected water-quality stations from corresponding streamflows at selected streamgages in New Jersey.

[Values of slope and intercept define equation between base-10 logarithms of instantaneous streamflow at a water-quality station and and base-10 logarithms of daily streamflows at the selected streamgage. MOVE1, Maintenance of Variance Extension 1; Dates in year-month-day; equation is for daily streamflows at streamgage and instantaneous streamflows at water-quality station, in cubic feet per second; N.J. New Jersey]

Water-quality station (station number)	Streamgage (station number)	Period of instantaneous streamflow measurements at the water-quality station		Number of streamflow measurements at water-quality station	MOVE1 equation components	
		Date of first measurement	Date of last measurement		Slope	Intercept
Manalapan Brook at Federal Road near Manalapan, N.J. (01405340)	Manalapan Brook at Spotswood , N.J. (01405400)	1971-06-24	2011-09-19	75	1.212	-0.688
Mullica River at outlet of Atsion Lake at Atsion, N.J. (01409387)	Mullica River near Batsto, N.J. (01409400)	1980-01-28	2011-08-01	74	1.061	-0.502
West Branch Wading River at Maxwell, N.J. (01409815)	Oswego River at Harrisville, N.J. (01410000)	1985-05-17	2009-05-27	52	1.160	-0.100
Great Egg Harbor River at Weymouth, N.J. (01411110)	Great Egg Harbor River at Folsom, N.J. (01411000)	1977-11-03	2009-05-27	68	1.000	0.390

Appendix 2. Discussion of the Weighted Regressions on Time, Discharge, and Season Bootstrap Test

By Robert M. Hirsch

Weighted Regressions on Time, Discharge, and Season (WRTDS) models (Hirsch and others, 2010) make only very limited assumptions about the nature of trends in either flow-normalized concentrations or fluxes. The nature of each trend—whether it is linear, monotonic, similar in magnitude at high streamflows as opposed to low streamflows—is not specifically determined by this method. As a result, there is no simple way to determine significance levels or confidence intervals to the trend results computed by the method.

The WRTDS Bootstrap Test (WBT; Hirsch and others, 2015) was developed to determine the level of significance of (1) the differences between flow-normalized annual concentrations in two different water years and (2) the differences between flow-normalized annual fluxes in two different water years; flow normalized annual concentrations and fluxes are products of WRTDS models (Hirsch and others, 2010). WBT is implemented with the R-package EGRETci available from the Comprehensive R Archive Network (CRAN) at https://cran.r-project.org/.

The WBT utilizes a particular implementation of the bootstrap method of statistical inference. For a general overview of the concept of the bootstrap see Efron (2005). The bootstrap approach provides a means of computing these statistical results by using a system of random resampling of the available data. The method is computationally intensive, and estimating a level of significance for a single trend result (for example, the change in flux from 1980 to 2011) can take several minutes of computational time.

For this study, the WBT was applied to the two trend periods of water years 1980–2011 and 2000–11. Results of the WBT, given in Hickman (2016), include a level of significance (“p value”) which indicated whether or not the changes in flow-normalized annual concentration or flux between the first and last water years constitute a trend.

The interpretation of these p values is as follows. Consider the results for total nitrogen concentration at the Hackensack River at Rivervale, N.J. (01377000), for the period water years 1980–2011 (Hickman, 2017). Results indicate a decrease of 19 percent in flow-normalized annual concentration over this period; the p-value reported for this change is 0.026. This is a “two-sided p-value.” To understand the meaning of this one can begin by defining the null hypothesis: that concentrations are “stationary” over the period 1980–2011. Stationarity means that the probability distribution of concentration, as a function of the time of year and discharge, has not changed over time. However, the set of actual observations typically will indicate some degree of change. There is a good deal of randomness in the water-quality record and this is why statistical methods are needed to identify changes that are larger than those that would arise from randomness. Also, it is likely that there will be extended periods of weeks or months when concentrations may be lower than expected (for the given time of year and discharge) and other periods when they may be higher than expected. This is known as serial correlation, which the WBT is designed to account for. What the p-value (0.026 in this case) means is that if concentrations were truly stationary at this site over this time period, there is a 0.026 chance (2.6% chance) that the WRTDS method would estimate a change of at least 19 percent (in either direction).

Results may be categorized into three groups—those that show strong evidence of a downward trend, those that show strong evidence of an upward trend, and those for which the evidence is inconclusive. After categorizing, an arbitrary probability of a Type I error (frequently denoted as alpha) is selected. Assume that an alpha = 0.1 is selected. This would mean that, in many applications of this test, one is willing to accept the risk of 0.1 (10%) of falsely inferring a trend when, in fact, the concentrations were stationary. If the two-sided p-value is smaller than the selected alpha value, the null hypothesis of stationarity is rejected, and the conclusion is that this record is one of those that shows a decrease. Of course, if alpha is set at a very low value, such as 0.01, then one would fail to reject the null hypothesis, in this case. Selection of the alpha level is subjective and is related to one’s level of concern about Type I error (stating there is a trend when there really isn’t) and Type II error (failing to state that there is a trend when there really is). In this report, the alpha value has been set to 0.05 in order to facilitate comparison with the results of other statistical tests in which the alpha values were set to 0.05.

The change in filtered nitrate plus nitrite concentration at the Hackensack River at Rivervale, N.J. (01377000) over water year 1980–2011 is a decrease of 1.3 percent (Hickman, 2017). The level of significance for this change is <0.02, which is less than or equal to half of the alpha value (0.05). For this reason, this change is considered a trend.

In contrast with this result, consider the p-value for the change in total nitrogen concentration in the Hackensack River at Rivervale, N.J. (01377000) for the period 2000–11, which is reported as 0.46 (Hickman, 2017). The estimate of change is +6.2 percent, so the result overall means that under the null hypothesis one could expect a change of at least 6.2 percent in either direction with a probability of 0.46. These results indicate a tendency towards an increase in concentration, but the size of the increase could easily arise by chance alone and does not provide strong evidence for an upward trend.

Because of the computationally intensive nature of the WBT, the bootstrap process was truncated at 100 replicates; this means that a p-value lower than 0.02 cannot be determined from the test. The table shows cases where p is denoted as “<0.02.” This means that the evidence for a trend is quite strong, and if substantially more computer time were used, it is quite possible that a p-value much less than 0.02 could be found. The decision to stop the process at 100 replicates reflects the idea that a p of <0.02 is very strong evidence of a trend, and little additional meaning is gained by trying to refine that estimate.

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Appendix 3. The Number of Measurements of Selected Water-Quality Characteristics at Selected Stations on Streams in New Jersey during Water Years 1971–2011

The number of measurements of each water-quality characteristic at each station is listed in tables 3-1 to 3-3. The water years of the first and last measurements are also listed.

Table 3-1. Number of measurements of instantaneous streamflow, water temperature, specific conductance, dissolved oxygen concentration, and dissolved oxygen saturation at selected water-quality stations on streams in New Jersey during water years 1971–2011.

[Period is in water years; number is number of measurements; N.J., New Jersey; Pa., Pennsylvania]

Station number	Name	Instantaneous streamflow		Water temperature		Specific conductance		Dissolved oxygen concentration		Dissolved oxygen saturation	
		Period	Number[1]	Period	Number	Period	Number	Period	Number	Period	Number
01367770	Wallkill River near Sussex, N.J.	1976–2011	190	1976–2011	217	1976–2011	214	1976–2011	198	1984–2011	139
01377000	Hackensack River at Rivervale, N.J.	1971–2011	273	1971–2011	263	1971–2011	222	1971–2011	215	1983–2011	134
01381800	Whippany River near Pine Brook, N.J.	1976–2011	210	1971–2011	243	1971–2011	228	1971–2011	225	1983–2011	141
01382000	Passaic River at Two Bridges, N.J.	1976–2011	314	1971–2011	362	1971–2011	347	1971–2011	342	1983–2011	253
01387500	Ramapo River near Mahwah, N.J.	1971–2011	246	1971–2011	253	1971–2011	222	1971–2011	218	1983–2011	137
01389500	Passaic River at Little Falls, N.J.	1971–2011	329	1971–2011	445	1971–2011	592	1971–2011	400	1983–2011	225
01391500	Saddle River at Lodi, N.J.	1971–2011	264	1971–2011	267	1971–2011	239	1971–2011	230	1983–2011	144
01394500	Rahway River near Springfield, N.J.	1971–2011	263	1971–2011	265	1979–2011	169	1979–2011	163	1983–2011	137
01395000	Rahway River at Rahway, N.J.	1971–2011	257	1971–2011	266	1979–2011	435	1979–2011	163	1983–2011	138
01396660	Mulhockaway Creek at Van Syckel, N.J.	1976–2011	209	1976–2011	209	1977–2011	186	1976–2011	183	1984–2011	125
01398000	Neshanic River at Reaville, N.J.	1971–2011	251	1971–2011	254	1979–2011	197	1979–2011	191	1984–2011	155
01399780	Lamington River at Burnt Mills, N.J.	1976–2011	448	1976–2011	446	1977–2011	200	1976–2011	196	1984–2011	124
01403300	Raritan River at Queens Bridge at Bound Brook, N.J.	1971–2011	361	1971–2011	420	1978–2011	361	1978–2011	384	1983–2011	292
01405340	Manalapan Brook at Federal Road near Manalapan, N.J.	1976–2011	172	1976–2011	187	1976–2011	171	1976–2011	171	1984–2011	124
01408500	Toms River near Toms River, N.J.	1971–2011	272	1971–2011	380	1971–2011	307	1971–2011	354	1983–2011	140
01409387	Mullica River at outlet of Atsion Lake at Atsion, N.J.	1976–2011	176	1975–2011	193	1975–2011	184	1975–2011	182	1984–2011	132
01409416	Hammonton Creek at Wescoatville, N.J.	1976–2011	190	1974–2011	207	1974–2011	190	1974–2011	188	1983–2011	133
01409500	Batsto River at Batsto, N.J.	1971–2007	184	1971–2008	197	1975–2008	166	1975–2008	165	1984–2008	108
01409815	West Branch Wading River at Maxwell, N.J.	1976–2011	180	1976–2011	215	1976–2011	199	1976–2011	198	1983–2011	123
01410150	East Branch Bass River near New Gretna, N.J.	1976–2011	205	1975–2011	203	1975–2011	182	1975–2011	180	1984–2011	129
01411110	Great Egg Harbor River at Weymouth, N.J.	1976–2011	193	1975–2011	213	1975–2011	196	1975–2011	192	1983–2011	143
01411500	Maurice River at Norma, N.J.	1971–2011	255	1971–2011	363	1971–2011	319	1971–2011	347	1983–2011	142
01412800	Cohansey River at Seeley, N.J.	1976–2011	208	1975–2011	210	1975–2011	193	1975–2011	189	1983–2011	125
01443000	Delaware River at Portland, Pa.	1976–2009	185	1976–2009	183	1976–2009	168	1976–2009	166	1984–2009	110
01443500	Paulins Kill at Blairstown, N.J.	1971–2011	214	1971–2011	220	1976–2011	187	1976–2011	181	1984–2011	130
01457400	Musconetcong River at Riegelsville, N.J.	1976–2011	185	1976–2011	199	1976–2011	185	1976–2011	184	1984–2011	129
01460820	Delaware River at Lumberville, Pa.	1976–2009	183	1976–2009	184	1976–2009	168	1976–2009	166	1984–2009	112
01463500	Delaware River at Trenton, N.J.	1971–2011	468	1971–2011	498	1971–2011	459	1971–2011	422	1983–2011	226
01464515	Doctors Creek at Allentown, N.J.	1976–2011	185	1976–2011	199	1976–2011	184	1976–2011	182	1983–2011	134
01466500	McDonalds Branch in Byrne State Forest, N.J.	1971–2011	483	1971–2011	506	1971–2011	483	1971–2011	282	1983–2011	195
01477120	Raccoon Creek near Swedesboro, N.J.	1971–2011	311	1971–2011	304	1971–2011	272	1971–2011	259	1983–2011	165
01482500	Salem River at Woodstown, N.J.	1971–2011	249	1971–2011	260	1973–2011	232	1973–2011	232	1983–2011	141

[1]Number of measurements of instantaneous streamflow made at the times of measurements of the other water-quality characterististics.

Table 3-2. Number of measurements of pH, total suspended solids concentration, total nitrogen concentration, filtered nitrate plus nitrite concentration, and total phosphorus concentration at selected water-quality stations on streams in New Jersey during water years 1971–2011.

[Period is in water years; Number is number of measurements; N.J., New Jersey; Pa., Pennsylvania]

Station number	Name	pH		Total suspended solids concentration		Total nitrogen concentration		Filtered nitrate plus nitrite concentration		Total phosphorus concentration	
		Period	Number	Period	Number	Period	Number	Period	Number	Period	Number
01367770	Wallkill River near Sussex, N.J.	1976–2011	196	1976–2011	95	1976–2011	170	1976–2011	189	1977–2011	170
01377000	Hackensack River at Rivervale, N.J.	1971–2011	225	1975–2011	94	1973–2011	189	1971–2011	200	1973–2011	197
01381800	Whippany River near Pine Brook, N.J.	1971–2011	231	1975–2011	96	1973–2011	190	1971–2011	202	1973–2011	173
01382000	Passaic River at Two Bridges, N.J.	1971–2011	360	1975–2011	96	1973–2011	307	1971–2011	326	1973–2011	285
01387500	Ramapo River near Mahwah, N.J.	1971–2011	224	1971–2011	98	1971–2011	195	1971–2011	197	1971–2011	178
01389500	Passaic River at Little Falls, N.J.	1971–2011	369	1978–2011	56	1973–2011	260	1971–2011	270	1973–2011	256
01391500	Saddle River at Lodi, N.J.	1971–2011	236	1975–2011	105	1973–2011	203	1971–2011	215	1973–2011	208
01394500	Rahway River near Springfield, N.J.	1979–2011	164	1995–2011	65	1979–2011	160	1979–2011	162	1983–2011	134
01395000	Rahway River at Rahway, N.J.	1979–2011	165	1995–2011	64	1979–2011	159	1979–2011	161	1983–2011	134
01396660	Mulhockaway Creek at Van Syckel, N.J.	1976–2011	182	1977–2011	84	1976–2011	169	1976–2011	173	1976–2011	146
01398000	Neshanic River at Reaville, N.J.	1979–2011	195	1995–2011	66	1979–2011	186	1979–2011	189	1981–2011	166
01399780	Lamington River at Burnt Mills, N.J.	1976–2011	196	1977–2011	83	1976–2011	164	1976–2011	188	1976–2011	146
01403300	Raritan River at Queens Bridge at Bound Brook, N.J.	1978–2011	358	1978–2000	13	1982–2011	301	1978–2011	301	1978–2011	301
01405340	Manalapan Brook at Federal Road near Manalapan, N.J.	1976–2011	167	1976–2011	79	1976–2011	165	1976–2011	166	1976–2011	167
01408500	Toms River near Toms River, N.J.	1971–2011	306	1975–2011	109	1972–2011	230	1971–2011	243	1972–2011	239
01409387	Mullica River at outlet of Atsion Lake at Atsion, N.J.	1975–2011	178	1975–2011	82	1976–2011	165	1976–2011	166	1976–2011	145
01409416	Hammonton Creek at Wescoatville, N.J.	1974–2011	188	1975–2011	86	1974–2011	178	1974–2011	183	1974–2011	156
01409500	Batsto River at Batsto, N.J.	1975–2008	163	1975–2007	67	1975–2007	148	1975–2007	150	1976–2007	128
01409815	West Branch Wading River at Maxwell, N.J.	1976–2011	192	1976–2011	71	1976–2011	167	1976–2011	171	1976–2011	175
01410150	East Branch Bass River near New Gretna, N.J.	1975–2011	178	1975–2011	80	1975–2011	164	1975–2011	168	1976–2011	140
01411110	Great Egg Harbor River at Weymouth, N.J.	1975–2011	195	1975–2011	88	1975–2011	182	1975–2011	186	1975–2011	164
01411500	Maurice River at Norma, N.J.	1971–2011	309	1975–2011	89	1973–2011	201	1971–2011	212	1973–2011	209
01412800	Cohansey River at Seeley, N.J.	1975–2011	188	1975–2011	96	1975–2011	177	1975–2011	181	1975–2011	160
01443000	Delaware River at Portland, Pa.	1976–2009	164	1976–2009	77	1976–2009	157	1976–2009	160	1977–2009	132
01443500	Paulins Kill at Blairstown, N.J.	1976–2011	182	1976–2011	89	1976–2011	170	1976–2011	176	1977–2011	175
01457400	Musconetcong River at Riegelsville, N.J.	1976–2011	184	1976–2011	85	1976–2011	174	1976–2011	175	1977–2011	146
01460820	Delaware River at Lumberville, Pa.	1976–2009	162	1976–2009	76	1976–2009	160	1976–2009	159	1977–2009	137
01463500	Delaware River at Trenton, N.J.	1971–2011	439	1971–2010	88	1971–2011	344	1971–2011	380	1971–2011	370
01464515	Doctors Creek at Allentown, N.J.	1976–2011	179	1976–2011	87	1976–2011	174	1976–2011	175	1976–2011	157
01466500	McDonalds Branch in Byrne State Forest, N.J.	1971–2011	293	1972–2011	71	1973–2011	223	1971–2011	463	1972–2011	251
01477120	Raccoon Creek near Swedesboro, N.J.	1971–2011	268	1975–2011	95	1973–2011	226	1971–2011	237	1973–2011	231
01482500	Salem River at Woodstown, N.J.	1973–2011	231	1975–2011	107	1973–2011	209	1973–2011	212	1973–2011	189

Table 3-3. Number of measurements of filtered chloride concentration, total dissolved solids concentration, and suspended-sediment concentration at selected water-quality stations on streams in New Jersey during water years 1971–2011.

[Period is in water years; number is number of measurements; N.J., New Jersey; Pa., Pennsylvania]

Station number	Name	Filtered chloride concentration		Total dissolved solids concentration		Suspended-sediment concentration	
		Period	Number	Period	Number	Period	Number
01367770	Wallkill River near Sussex, N.J.	1976–2011	197	1976–2011	177	1978–2005	30
01377000	Hackensack River at Rivervale, N.J.	1971–2011	203	1971–2011	194	1971–2005	62
01381800	Whippany River near Pine Brook, N.J.	1971–2011	207	1971–2011	198	1978–2009	37
01382000	Passaic River at Two Bridges, N.J.	1971–2011	331	1971–2011	316	1978–2009	60
01387500	Ramapo River near Mahwah, N.J.	1971–2011	208	1971–2011	198	1978–2005	31
01389500	Passaic River at Little Falls, N.J.	1971–2011	271	1971–2011	262	1978–2009	373
01391500	Saddle River at Lodi, N.J.	1971–2011	217	1971–2011	208	1978–2009	36
01394500	Rahway River near Springfield, N.J.	1979–2011	163	1979–2011	159	1979–2005	37
01395000	Rahway River at Rahway, N.J.	1979–2011	162	1979–2011	160	1979–2005	304
01396660	Mulhockaway Creek at Van Syckel, N.J.	1977–2011	181	1977–2011	180	1978–2005	42
01398000	Neshanic River at Reaville, N.J.	1979–2011	189	1979–2011	186	1979–2008	97
01399780	Lamington River at Burnt Mills, N.J.	1977–2011	197	1977–2011	196	1977–2005	294
01403300	Raritan River at Queens Bridge at Bound Brook, N.J.	1982–2011	302	1982–2011	139	1971–2011	349
01405340	Manalapan Brook at Federal Road near Manalapan, N.J.	1976–2011	169	1976–2011	165	1979–2006	29
01408500	Toms River near Toms River, N.J.	1971–2011	230	1971–2011	217	1975–2005	166
01409387	Mullica River at outlet of Atsion Lake at Atsion, N.J.	1975–2011	175	1977–2011	169	1979–2005	30
01409416	Hammonton Creek at Wescoatville, N.J.	1974–2011	186	1974–2011	183	1978–2007	31
01409500	Batsto River at Batsto, N.J.	1975–2007	161	1976–2007	153	1979–2005	39
01409815	West Branch Wading River at Maxwell, N.J.	1976–2011	174	1976–2011	173	1978–2005	114
01410150	East Branch Bass River near New Gretna, N.J.	1975–2011	175	1976–2011	168	1979–2005	36
01411110	Great Egg Harbor River at Weymouth, N.J.	1975–2011	194	1975–2011	185	1979–2007	39
01411500	Maurice River at Norma, N.J.	1971–2011	216	1971–2011	206	1978–2008	136
01412800	Cohansey River at Seeley, N.J.	1975–2011	192	1975–2011	184	1978–2005	33
01443000	Delaware River at Portland, Pa.	1976–2009	168	1976–2009	158	1979–2005	28
01443500	Paulins Kill at Blairstown, N.J.	1976–2011	182	1976–2011	180	1979–2005	39
01457400	Musconetcong River at Riegelsville, N.J.	1976–2011	183	1976–2011	180	1978–2005	34
01460820	Delaware River at Lumberville, Pa.	1976–2009	169	1976–2009	163	1979–2005	29
01463500	Delaware River at Trenton, N.J.	1971–2011	381	1971–2011	320	1971–2011	380
01464515	Doctors Creek at Allentown, N.J.	1976–2011	184	1976–2011	182	1979–2005	28
01466500	McDonalds Branch in Byrne State Forest, N.J.	1971–2011	460	1971–2011	256	1971–2005	245
01477120	Raccoon Creek near Swedesboro, N.J.	1971–2011	242	1971–2011	229	1971–2007	90
01482500	Salem River at Woodstown, N.J.	1973–2011	213	1974–2011	209	1978–2005	34

Appendix 4. Selected Results of Seasonal Rank-Sum Tests and Results of Trend Tests Reported in Previous Studies at Stations on Streams in New Jersey, for Periods during Water Years 1971–2011.

Results of seasonal rank-sum tests to identify step trends between the 1970s and 1980s, 1980s and 1990s, and 1990s and 2000s are given in tables 4-1 (total nitrogen), 4-2 (filtered nitrate plus nitrite), 4-3 (total phosphorus), and 4-4 (measures of major ions). Also presented are selected results of trend tests reported by Hay and Campbell (1990) for water years 1979–1986; Hickman and Barringer (1999) for water years 1986–1995; Hickman and Gray (2010) for water years 1998–2007; Sprague and others (2009) for water years 1993–2003; and Trench and others (2012) for water years 1993–2003.

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Table 4-1. Selected results of seasonal rank-sum tests of total nitrogen concentration and results of trend tests reported in previous studies for water-quality stations on streams in New Jersey, for periods during water years 1971–2011.

[Trends are defined by a one- or two-sided 0.05 level of significance. --, no trend; Downward, value decreased; Upward, value increased; nd, not determined; R., River; Cr., Creek; L., Little; Del., Delaware]

Station number	Short name	Results of trend tests over selected periods								
		1970s to 1980s		1980s to 1990s		1990s to 2000s				
		[1]1979–1986 Flow-adjusted concentrations (Hay and Campbell, 1990)	Step trends from seasonal rank-sum tests (Hickman, 2017)	[1]1986–1995 Flow-adjusted concentrations (Hickman and Barringer, 1999)	Step trends from seasonal rank-sum tests (Hickman, 2017)	[1]1993–2003 Flow-adjusted concentrations (Sprague and others, 2009)	[1]1993–2003 (Trench and others, 2012) Flow-adjusted[2] concentrations	[1]1993–2003 (Trench and others, 2012) Flow-adjusted[3] concentrations	[1]1998–2007 Hickman and Gray (2010)	Step trends from seasonal rank-sum tests (Hickman, 2017)
01367770	Wallkill R.	--	nd	--	--	nd	--	nd	nd	--
01377000	Hackensack R.	Downward	--	--	Downward	--	--	--	nd	--
01381800	Whippany R.	nd	nd	Downward	Downward	nd	Downward	nd	nd	--
01382000	Passaic R. at Two Bridges	nd	nd	--	Downward	nd	Downward	nd	nd	--
01387500	Ramapo R.	--	Upward	Downward	--	--	--	--	nd	--
01389500	Passaic R. at L. Falls	nd	nd	--	--	Downward	Downward	Downward	nd	--
01391500	Saddle R.	--	Upward	--	--	Upward	Upward	Upward	nd	--
01395000	Rahway R.	--	nd	Downward	--	--	--	--	nd	--
01396660	Mulhockaway Cr.	--	nd	Downward	Downward	--	--	--	nd	Downward
01398000	Neshanic R.	--	nd	nd	--	--	--	--	nd	Downward
01399780	Lamington R.	nd	nd	Downward	Downward	nd	nd	nd	nd	--
01403300	Raritan R.	nd	nd	--	Downward	--	--	--	nd	--
01405340	Manalapan Brook	--	nd	Downward	Downward	nd	--	nd	nd	--
01408500	Toms R.	--	Upward	--	Upward	nd	Upward	Upward	nd	Upward
01409387	Mullica R.	nd	nd	nd	--	nd	Downward	nd	nd	Downward
01409500	Batsto R.	nd	nd	nd	--	--	--	--	nd	--
01409815	West Branch Wading R.	nd	nd	nd	--	nd	nd	nd	nd	--
01411110	Great Egg Harbor R.	nd	nd	Downward	Downward	nd	--	nd	nd	Upward
01411500	Maurice R.	--	--	nd	--	nd	Upward	Upward	nd	Upward
01412800	Cohansey R.	--	nd	--	Upward	nd	--	nd	nd	Upward
01443000	Del. R. at Portland	nd	nd	--	Downward	nd	nd	nd	nd	Downward
01443500	Paulins Kill	--	nd	Downward	Downward	--	--	--	nd	Downward
01457400	Musconetcong R.	nd	nd	--	--	nd	--	nd	nd	--
01460820	Del. R. at Lumberville	nd	Upward	Downward	Downward	nd	--	nd	nd	Downward
01463500	Del. R. at Trenton	--	nd	Downward	Downward	Downward	Downward	Downward	nd	Downward
01464515	Doctors Cr.	nd	nd	--	--	nd	--	nd	nd	--
01466500	McDonalds Branch	nd	nd	nd	--	nd	nd	nd	nd	--
01477120	Raccoon Cr.	--	--	Downward	Downward	--	--	--	nd	--

[1]Range of water years over which trends in published report were determined.

[2]Determined with Tobit regression.

[3]Determined with coupled streamflow and water-quality models.

Table 4-2. Selected results of seasonal rank-sum tests of filtered nitrate plus nitrite concentration and results of trend tests reported in previous studies for water-quality stations on streams in New Jersey, for periods during water years 1971–2011.

[Trends are defined by a one- or two-sided 0.05 level of significance. --, no trend; Downward, value decreased; Upward, value increased; nd, not determined; R., River; Cr., Creek; L., Little; Del., Delaware]

Station number	Short name	Results of trend tests over selected periods								
		1970s to 1980s		1980s to 1990s		1990s to 2000s				
		[1]1979–1986 Flow-adjusted concentrations (Hay and Campbell, 1990)	Step trends from seasonal rank-sum tests (Hickman, 2017)	[1]1986–1995 Flow-adjusted concentrations (Hickman and Barringer, 1999)	Step trends from seasonal rank-sum tests (Hickman, 2017)	[1]1993–2003 Flow-adjusted concentrations (Sprague and others, 2009)	[1]1993–2003 (Trench and others, 2012)		[1]1998–2007 Hickman and Gray (2010)	Step trends from seasonal rank-sum tests (Hickman, 2017)
							Flow-adjusted[2] concentrations	Flow-adjusted[3] concentrations		
01367770	Wallkill R.	nd	nd	--	--	nd	nd	nd	Downward	--
01377000	Hackensack R.	nd	--	--	--	--	nd	--	--	Downward
01381800	Whippany R.	nd	nd	Upward	--	nd	nd	nd	--	--
01382000	Passaic R. at Two Bridges	nd	nd	Upward	Upward	nd	nd	nd	--	--
01387500	Ramapo R.	nd	Upward	--	--	--	nd	--	--	--
01389500	Passaic R. at L. Falls	nd	nd	Upward	Upward	Downward	nd	Downward	--	--
01391500	Saddle R.	nd	--	Upward	Upward	Upward	nd	Upward	Upward	--
01395000	Rahway R.	nd	nd	--	--	--	nd	--	--	--
01396660	Mulhockaway Cr.	nd	nd	--	--	--	Downward	--	Upward	Downward
01398000	Neshanic R.	--	nd	nd	--	--	--	--	--	Downward
01399780	Lamington R.	nd	nd	--	--	nd	--	nd	--	Upward
01403300	Raritan R.	nd	nd	--	--	--	--	--	nd	--
01405340	Manalapan Brook	nd	nd	--	--	nd	--	nd	Upward	--
01408500	Toms R.	nd	--	Upward	Upward	nd	nd	--	Upward	Upward
01409387	Mullica R.	nd	nd	nd	--	nd	nd	nd	--	Downward
01409500	Batsto R.	nd	nd	nd	Upward	Downward	nd	Downward	Upward	--
01409815	West Branch Wading R.	nd	nd	nd	--	nd	nd	nd	Upward	--
01411110	Great Egg Harbor R.	nd	nd	--	--	nd	nd	nd	Upward	Upward
01411500	Maurice R.	nd	--	Upward	--	--	nd	--	Upward	--
01412800	Cohansey R.	nd	nd	Upward	Upward	nd	nd	nd	Upward	Upward
01443000	Del. R. at Portland	nd	nd	--	--	nd	nd	nd	--	Downward
01443500	Paulins Kill	nd	nd	--	--	--	nd	--	--	--
01457400	Musconetcong R.	nd	nd	Upward	--	nd	nd	nd	Upward	Upward
01460820	Del. R. at Lumberville	nd	nd	--	--	nd	nd	nd	--	--
01463500	Del. R. at Trenton	nd	Upward	--	Downward	Downward	nd	Downward	--	--
01464515	Doctors Cr.	nd	nd	Downward	--	nd	nd	nd	--	Downward
01466500	McDonalds Branch	nd	--	nd	--	nd	nd	nd	nd	--
01477120	Raccoon Cr.	--	--	--	--	--	nd	--	--	--

[1]Range of water years over which trends in published report were determined.

[2]Determined with Tobit regression.

[3]Determined with coupled streamflow and water-quality models.

Table 4-3. Selected results of seasonal rank-sum tests of total phosphorus concentration and results of trend tests reported in previous studies for water-quality stations on streams in New Jersey, for periods during water years 1971–2011.

[Trends are defined by a one- or two-sided 0.05 level of significance. --, no trend; Downward, value decreased; Upward, value increased; nd, not determined; R., River; Cr., Creek; L., Little; Del., Delaware]

Station number	Short name	Results of trend tests over selected periods								
		1970s to 1980s		1980s to 1990s		1990s to 2000s				
		[1]1979–1986 Flow-adjusted concentrations (Hay and Campbell, 1990)	Step trends from seasonal rank-sum tests (Hickman, 2017)	[1]1986–1995 Flow-adjusted concentrations (Hickman and Barringer, 1999)	Step trends from seasonal rank-sum tests (Hickman, 2017)	[1]1993–2003 Flow-adjusted concentrations (Sprague and others, 2009)	[1]1993–2003 (Trench and others, 2012) Flow-adjusted[2] concentrations	[1]1993–2003 (Trench and others, 2012) Flow-adjusted[3] concentrations	[1]1998–2007 Hickman and Gray (2010)	Step trends from seasonal rank-sum tests (Hickman, 2017)
01367770	Wallkill R.	nd	nd	nd	Downward	nd	--	nd	--	--
01377000	Hackensack R.	nd	--	--	Downward	--	--	--	--	--
01381800	Whippany R.	nd	nd	Downward	Downward	nd	Downward	nd	Downward	Downward
01382000	Passaic R. at Two Bridges	nd	nd	--	--	nd	--	nd	Downward	--
01387500	Ramapo R.	nd	--	--	--	--	--	--	--	--
01389500	Passaic R. at L. Falls	nd	nd	--	--	--	--	--	--	--
01391500	Saddle R.	nd	--	Downward	Downward	Upward	Upward	Upward	--	Upward
01395000	Rahway R.	nd	nd	--	--	--	--	--	--	--
01396660	Mulhockaway Cr.	nd	nd	nd	--	nd	--	--	--	Downward
01398000	Neshanic R.	nd	nd	--	--	--	--	--	--	--
01399780	Lamington R.	nd	nd	Downward	--	nd	--	nd	--	--
01403300	Raritan R.	nd	nd	--	--	--	Upward	--	nd	--
01405340	Manalapan Brook	nd	nd	--	--	nd	--	nd	--	--
01408500	Toms R.	nd	Downward	nd	--	--	--	--	Downward	Downward
01409387	Mullica R.	nd	nd	nd	--	nd	Downward	nd	--	Downward
01409500	Batsto R.	nd	nd	nd	--	nd	nd	--	--	--
01409815	West Branch Wading R.	nd	nd	nd	--	nd	nd	nd	--	Upward
01411110	Great Egg Harbor R.	nd	nd	nd	Downward	nd	--	nd	--	--
01411500	Maurice R.	nd	Downward	nd	--	--	--	--	--	--
01412800	Cohansey R.	nd	nd	nd	Downward	nd	nd	nd	--	--
01443000	Del. R. at Portland	nd	nd	nd	--	nd	--	nd	--	Downward
01443500	Paulins Kill	nd	nd	nd	Downward	--	--	--	--	--
01457400	Musconetcong R.	nd	nd	nd	Downward	nd	--	nd	Downward	--
01460820	Del. R. at Lumberville	nd	nd	--	Downward	nd	--	nd	Downward	--
01463500	Del. R. at Trenton	nd	--	--	Downward	--	--	--	Downward	--
01464515	Doctors Cr.	nd	nd	Downward	Downward	nd	--	nd	--	Downward
01466500	McDonalds Branch	nd	--	nd	--	nd	nd	nd	nd	--
01477120	Raccoon Cr.	nd	--	--	--	--	--	--	--	--

[1]Range of water years over which trends in published report were determined.

[2]Determined with Tobit regression.

[3]Determined with coupled streamflow and water-quality models.

Table 4-4. Selected results of seasonal rank-sum tests of measures of major ions and results of trend tests reported in previous studies for water-quality stations on streams in New Jersey, for periods during water years 1971–2011.

[Trends are defined by a one- or two-sided 0.05 level of significance. --, no trend; Upward, value increased; nd, not determined; R., River; Cr., Creek; Del., Delaware]

Station number	Short name	Results of trend tests over selected periods					
		1970s to 1980s		1980s to 1990s		1990s to 2000s	
		[1]1979–1986 Flow-adjusted values (Hay and Campbell, 1990)	Step trends from seasonal rank-sum tests	[1]1986–1995 Flow-adjusted values (Hickman and Barringer, 1999)	Step trends from seasonal rank-sum tests	[1]1998–2007 Flow-adjusted values (Hickman and Gray, 2010)	Step trends from seasonal rank-sum tests
			Specific conductance				
01443000	Del. R. at Portland	nd	nd	--	Upward	nd	--
01460820	Del. R. at Lumberville	nd	nd	--	--	nd	Upward
01463500	Del. R. at Trenton	--	--	--	--	nd	Upward
01477120	Raccoon Cr.	--	--	Upward	Upward	nd	Upward
			Filtered chloride				
01443000	Del. R. at Portland	nd	nd	--	Upward	nd	Upward
01460820	Del. R. at Lumberville	nd	nd	--	Upward	nd	Upward
01463500	Del. R. at Trenton	Upward	Upward	--	Upward	nd	Upward
01477120	Raccoon Cr.	Upward	--	Upward	Upward	nd	Upward
			Total dissolved solids				
01443000	Del. R. at Portland	nd	nd	--	Upward	--	Upward
01460820	Del. R. at Lumberville	nd	nd	--	Upward	--	Upward
01463500	Del. R. at Trenton	Upward	--	--	Upward	--	--
01477120	Raccoon Cr.	--	--	--	Upward	Upward	Upward

[1]Range of water years over which trends in published report were determined.

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