Prepared in cooperation with the
N.J. Department of Environmental Protection

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Scientific Investigations Report 2008-5077

U.S. Department of the Interior
U.S. Geological Survey

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By Rachel A. Esralew and Ronald J. Baker

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Conversion Factors, Datums, Abbreviations and Acronyms

Conversion Factors

Multiply	By	To obtain
acre	0.004047	square kilometer (km^2)
acre	0.4047	hectare (ha))
acre	4,047	square meter (m^2)
cubic foot per second (ft^3/s)	0.02832	cubic meter per second (m^3/s)
foot (ft)	0.3048	meter (m)
gallon (gal)	0.003785	cubic meter (m^3)
gallon (gal)	3.785	liter (L)
gallon (gal)	3.785	cubic decimeter (dm^3)
gallon per day (gal/d)	0.003785	cubic meter per day (m^3/d)
gallon per minute (gal/min)	0.06309	liter per second (L/s)
mile (mi)	1.609	kilometer (km)
million gallons per day (Mgal/d)	0.04381	cubic meter per second (m^3/s)
square foot (ft^2)	0.09290	square meter (m^2)
square foot (ft^2)	929.0	square centimeter (cm^2)

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

°F=(1.8×°C)+32

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

°C=(°F-32)/1.8

Vertical coordinate information is referenced to the insert datum name (and abbreviation) here for instance, “North American Vertical Datum of 1988 (NAVD 88).”

Horizontal coordinate information is referenced to the insert datum name (and abbreviation) here for instance, “North American Datum of 1983 (NAD 83).”

Elevation, as used in this report, refers to distance above the vertical datum.

Conversion Factors, Datums, Abbreviations and Acronyms—Continued

Abbreviations and Acronyms Meaning

Abbreviations and Acronyms	Meaning
7Q10	The lowest streamflow for 7 consecutive days that occurs on average once every10 years
BA	Score for breakpoint appearance in a double-mass curve
BP	Score for breakpoint prominence in a double-mass curve
BR	Breakpoint rating, the final weighted score used to determine the relative strength of the breakpoint on the double-mass curve
ERHIs	Ecologically Relevant Hydrologic Indices
FH	The set of ERHIs that express high-flow values
FL	The set of ERHIs that express low-flow values
FORTRAN (HSPF)	A comprehensive package for simulation of watershed hydrology and water quality for both conventional and toxic organic pollutants
GIS	Geographic information system
HIP	Hydroecological Integrity Assessment Process
LMM	Local-minimum method of hydrograph-base-flow separation
MA24	The ERHI that expresses the variability of January flow values
ML	The set of ERHIs that express magnitude of low-flow values
NATHAT	National Hydrologic Assessment Tool
NJDEP	New Jersey Department of Environmental Protection
NJHAT	New Jersey Hydrological Assessment Toll
NJHIP	New Jersey Hydroecological Integrity Assessment Process
NJSCT	New Jersey Stream Classification Tool
P	Probability
PCA	Principal Component Analysis
r^2	Coefficient of determination
SR	Score for slope ratio in a double-mass curve
TH	The set of ERHIs that express timing of high-flow values
TL	The set of ERHIs that express timing of low-flow values
USGS	U.S. Geological Survey

Determination of baseline periods of record for selected streamflow-gaging stations in New Jersey for determining Ecologically Relevant Hydrologic Indices (ERHI)

By Rachel A. Esralew and Ronald J. Baker

Abstract

Hydrologic changes in New Jersey stream basins resulting from human activity can affect the flow and ecology of the streams. To assess future changes in streamflow resulting from human activity an understanding of the natural variability of streamflow is needed. The natural variability can be classified using Ecologically Relevant Hydrologic Indices (ERHIs). ERHIs are defined as selected streamflow statistics that characterize elements of the flow regime that substantially affect biological health and ecological sustainability. ERHIs are used to quantitatively characterize aspects of the streamflow regime, including magnitude, duration, frequency, timing, and rate of change. Changes in ERHI values can occur as a result of human activity, and changes in ERHIs over time at various stream locations can provide information about the degree of alteration in aquatic ecosystems at or near those locations. New Jersey streams can be divided into four classes (A, B, C, or D), where streams with similar ERHI values (determined from cluster analysis) are assigned the same stream class.

In order to detect and quantify changes in ERHIs at selected streamflow-gaging stations, a "baseline" period is needed. Ideally, a baseline period is a period of continuous daily streamflow record at a gaging station where human activity along the contributing stream reach or in the stream's basin is minimal. Because substantial urbanization and other development had already occurred before continuous streamflow-gaging stations were installed, it is not possible to identify baseline periods that meet this criterion for many reaches in New Jersey. Therefore, the baseline period for a considerably altered basin can be defined as a period prior to a substantial human-induced change in the drainage basin or stream reach (such as regulations or diversions), or a period during which development did not change substantially.

Index stations (stations with minimal urbanization) were defined as streamflow-gaging stations in basins that contain less than 15 percent urban land use throughout the period of continuous streamflow record. A minimum baseline period of record for each stream class was determined by comparing the variability of selected ERHIs among consecutive 5-, 10-, 15-, and 20-year time increments for index stations. On the basis of this analysis, stream classes A and D were assigned a minimum of 20 years of continuous record as a baseline period and stream classes B and C, a minimum of 10 years.

Baseline periods were calculated for 85 streamflow-gaging stations in New Jersey with 10 or more years of continuous daily streamflow data, and the values of 171 ERHIs also were calculated for these baseline periods for each station. Baseline periods were determined by using historical streamflow-gaging station data, estimated changes in impervious surface in the drainage basin, and statistically significant changes in annual base flow and runoff.

Historical records were reviewed to identify years during which regulation, diversions, or withdrawals occurred in the drainage basins. Such years were not included in baseline periods of record. For some sites, the baseline period of record was shorter than the minimum period of record specified for the given stream class. In such cases, the baseline period was rated as "poor."

Impervious surface was used as an indicator of urbanization and change in streamflow characteristics owing to increases in storm runoff and decreases in base flow. Percentages of impervious surface were estimated for 85 streamflow-gaging stations from available municipal population-density data by using a regression model. Where the period of record was sufficiently long, all years after the impervious surface exceeded 10 to 20 percent were excluded from the baseline period. The percentage of impervious surface also was used as a criterion in assigning qualitative ratings to baseline periods.

Changes in trends of annual base flow and runoff were determined by using double-mass curves, in which cumulative discharge at a test station (x-axis) is plotted in relation to cumulative discharge at an index station (y-axis) of the same stream class. The slope of the double-mass curve is expected to remain constant unless there have been changes in the drainage basin of the test station that altered hydrologic processes. The significance of changes in the slope of the relation (breakpoints) was evaluated by analysis of covariance and visual inspection.

A final baseline period was determined for each test station by using a combination of historical records, changes in impervious surface, and double-mass analysis. The baseline period for each station was rated as excellent, good, fair, or poor by using a numerical rating procedure based on length of record, percentage of impervious surface and the results of double-mass analysis. Values for all 171 ERHI were calculated for the baseline periods of each of the 85 stations. Stream class was then determined for each test station.

Introduction

The population of New Jersey has increased from about 5 million in 1950 to 8.1 million in 2000 and continues to increase (United States Census Bureau, 2000). As the population increases, demands on the State's water resources also increase. Withdrawals of ground water and diversions of surface water lead to reduced stream base flow, and increases in impervious surface lead to increased stormwater runoff. Because of these changes, water-resources managers have regulated peak streamflow to protect property from flood damage and low flow to maintain minimum passing flows. Changes to the natural flow regime that result from increased development and direct physical alteration of streamflow patterns can affect aquatic ecosystems. Because human activity in New Jersey basins is increasing, an improved understanding of the relations between development, streamflow, and aquatic ecosystems is needed. An understanding of the natural variability of streamflow will enable water managers to assess the effects of future changes in streamflow that may threaten the ecological health of streams and surrounding areas. This natural variability can be quantified by using Ecologically Relevant Hydrologic Indices (ERHIs), which are statistics calculated from the seasonal patterning of flows; timing of extreme flows; the frequency, predictability, and duration of floods, droughts, and intermittent flows; daily, seasonal, and annual flow variability; and rates of change (Poff and others, 1997). ERHI values are determined for a baseline period for areas where human alteration to the environment along the stream reach or in a basin is relatively minimal. ERHI values for future periods can be compared to those for a baseline period to determine the change in streamflow.

The purpose of this investigation, conducted in cooperation with the New Jersey Department of Environmental Protection (NJDEP), was to determine ERHIs for streams throughout New Jersey during baseline periods. Changes in values of ERHIs from the baseline period to current or future streamflow conditions can be used as indicators of ecological conditions of a stream because central tendencies and extremes of the flow regime directly affect the habitats of biota in and near the stream. Baseline periods were determined by (A) defining the minimum period of record for each stream class, (B) determining when alterations occurred in drainage basins by reviewing historical records, (C) estimating changes in impervious surface in each basin over time, and (D) using double-mass curves to determine when hydrologic changes occurred in streams by comparing cumulative discharge to that of index streams. The baseline periods determined from this investigation are considered refinements of the baseline period of record selected for the original New Jersey Hydroecological Integrity Assessment Process (NJHIP) stream classification (Henriksen and others, 2006; Kennen and others, 2007).

Purpose and Scope

This report describes the determination of baseline periods of record for 85 gaged streams in New Jersey with over 10 years of continuous streamflow data available. Methods of utilizing historical information about stations and basins, and double-mass-curve analysis, to assign baseline periods are presented. Also described is the calculation of values for the 171 ERHIs for the 85 selected gaging stations using streamflow data collected during the baseline period of record.

Background

The New Jersey Department of Environmental Protection (NJDEP) has responsibilities, through regulatory and planning programs, for the management of water resources and land use, while concurrently protecting and managing riverine-associated fish and wildlife resources (New Jersey Department of Environmental Science, 2008). A "passing flow" is often required as part of a water allocation permit (Wahl and others, 1995). This passing flow requirement typically uses the 7-day, 10-year low-flow statistic (7Q10). This flow requirement focuses only on duration and magnitude of low flows, and does not consider the full scope of hydrologic characteristics needed to adequately preserve in-stream aquatic ecology. Consequently there is a need to identify an ecologically based and scientifically defensible approach for establishing flow regulations that adequately protect the natural ecology of streams. To achieve this, minimum-flow approaches (for example, 7Q10) may be complemented with interdisciplinary approaches that consider the complex nature of the flow regime and the ways in which human activities in the drainage basin affect the ecology of streams.

Streamflow characteristics that constitute the natural flow regime include magnitude, frequency, duration, timing, and the rate of change of low, average, and peak streamflow (Poff and others, 1997). Researchers have developed 171 ERHIs to assess the variability of the flow regime and its effect on biological resources (Olden and Poff, 2003). These ERHIs have been developed to characterize the flow regime in terms of biologically relevant flow variables, quantify short-term and long-term variability in patterns of the flow regime, and identify characteristics of streamflow that may be sensitive to human alterations in the drainage basin. Examples of ERHIs that have been investigated for their role in ecosystem functionality include average flow conditions, variations in mean daily flow, predictability of high- and low-flow events, skewness in flow and peak discharges, flood frequency and frequency curve slopes, seasonal distributions of monthly flows, duration of high and low flows, and rates of change in patterns of annual discharges (Olden and Poff, 2003).

Previous and Ongoing Investigations

Poff and Ward (1989) examined 78 U.S. streams for overall flow variability and predictability, flood regime patterns, the extent of intermittency, and associated lotic population and community attributes with these parameters. They used cluster analysis to identify nine stream types based on streamflow variability in long-term discharge records. The stream types were described as harsh intermittent, intermittent flashy, intermittent runoff, perennial flashy, perennial runoff, snowmelt, snow plus rain, winter rain, and mesic ground water. Stream types were found to be geographically affiliated.

Olden and Poff (2003) studied 171 ERHIs that had been reported in previous literature. Their objective was to create a smaller set of ERHIs that adequately describe streamflow characteristics without redundancy. Through the use of principal component analysis (PCA), they found that many of the 171 ERHIs describe similar characteristics of the flow regime and, therefore, are redundant. Ten important streamflow characteristics were identified as the magnitudes of high, low, and average flows; the frequency, duration, and timing of high and low flows; and the rate of change of average flow. Six stream classes were identified on the basis of streamflow patterns observed for 420 streamflow-gaging stations. PCA was then used to select nine statistically significant, nonredundant ERHIs, referred to as primary ERHIs, for each of the six stream classes. Additional ERHIs were identified that can be used as surrogates (Olden and Poff, 2003).

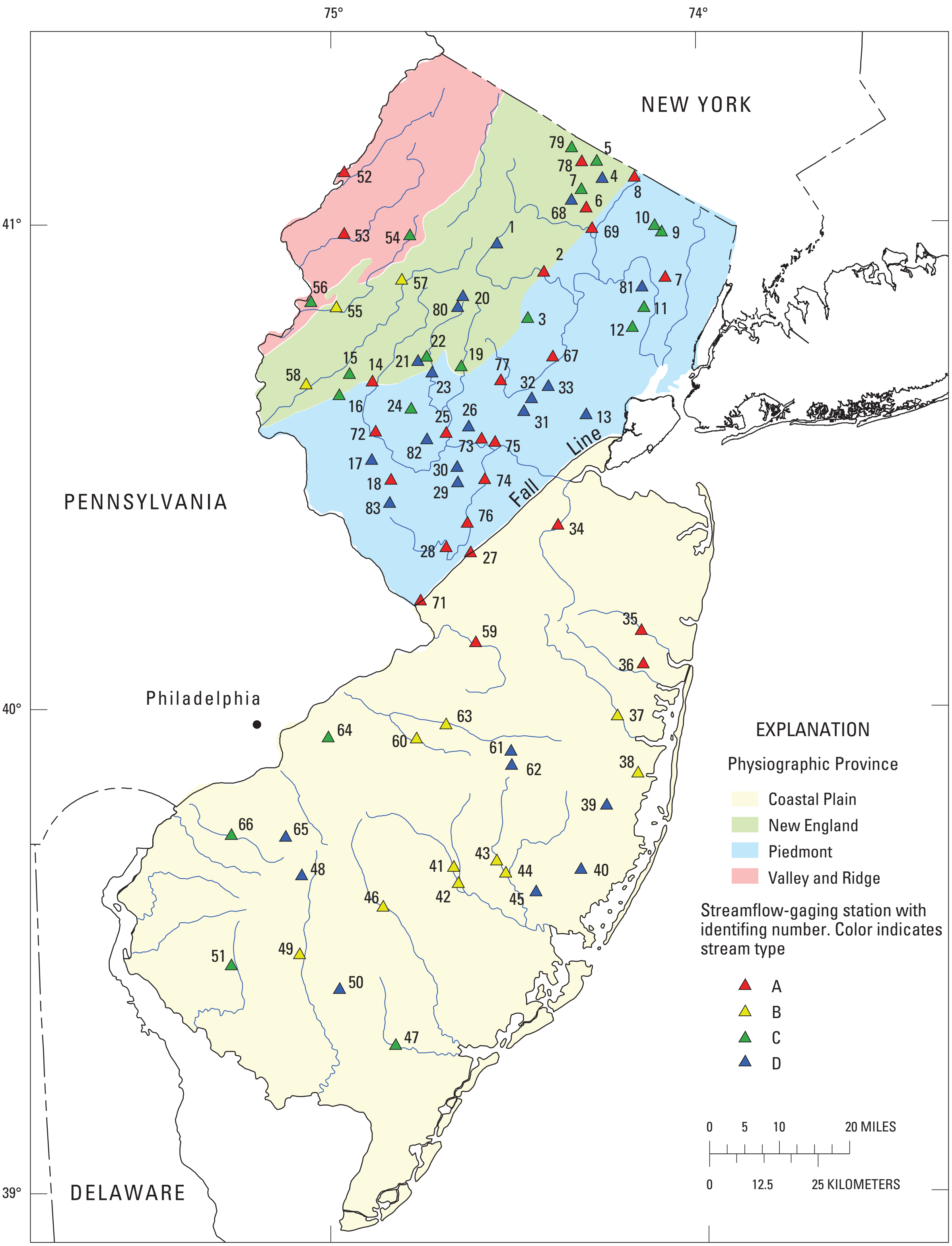
Using methods developed by Olden and Poff (2003), U.S. Geological Survey (USGS) researchers (Henriksen and others, 2006) developed the Hydroecological Integrity Assessment Process (HIP), which is a software tool that can identify a set of 10 primary ERHIs that describe the streamflow characteristics at a gaging station and calculate the values of those ERHIs. USGS researchers also developed the National Hydrologic Assessment Tool (NATHAT), a software application that can be used to determine variability in values of ERHIs based on daily hydrographs. This software application can be used to calculate ERHIs for any stream with daily streamflow and peak-flow data.

To use NATHAT a stream reach is first classified as one of six stream classes. This method at the national level may not yield results that are specific enough to adequately classify streams at a local level and could result in non-optimal selection of ERHIs for a local stream reach. For example, in the national study, seven streams in New Jersey were evaluated and were classified as only two of the perennial stream classes (Olden and Poff, 2003). To make HIP and the NATHAT program more applicable to specific regions or basins, USGS has been working with agencies in several States, including New Jersey, Massachusetts, and Missouri, to develop new sets of stream classifications that more adequately reflect streamflow conditions in local stream reaches. Henriksen and others (2006) adapted the stream classification and ERHI determination procedure from the national HIP and applied the process to hydrologic conditions that are present in New Jersey streams, and created the tool NJHIP.

NJHIP involved development of new stream classifications for New Jersey streams and subsequent identification of sets of primary and surrogate ERHIs for each stream class. In order to classify streams in New Jersey, a preliminary baseline period of record was identified as the period during which streamflow was least affected by human activity. This baseline was selected on the basis of the history of the streamflow-gaging station, such as visual interpretation of anomalies in hydrographs, and trends in streamflow data reported in previous studies (J.G. Kennen, U.S. Geological Survey written commun., 2006). Those baseline periods for 95 streamflow-gaging stations are listed in Henriksen and others (2006). Cluster analysis was used to categorize streams in New Jersey at 95 gaging stations into four stream classes (A,B,C, and D). The four stream classes are characterized by differences in basin area, relative degree of skewness of daily flows, and frequency of low-flow events (Henriksen and others, 2006). Streams with high skewness of daily flows reach peak flow rapidly compared to the rate at which they return to base flow and are termed flashy. It was determined that streams belonging to stream class A tend to be moderately flashy with moderately low base flow. Class B streams tend to be stable with high base flow. Class C streams tend to be moderately stable with moderately high base flow, and class D streams tend to be flashy with low base flow. Classification can differ among the streams. The spatial distribution of stream classes throughout New Jersey is shown in figure 1. PCA was used to identify the 10 primary and additional surrogate ERHIs from the 171 ERHIs investigated by Olden and Poff (2003) for each stream class (Henriksen and others, 2006).

Watson and others (2005) evaluated trends in streamflow and the relation between these trends and land-use patterns in New Jersey. Annual streamflow variability and trends in 1-, 7- and 30-day low and high flows were evaluated for 111 streamflow-gaging stations (including the 85 used in this investigation) with 20 or more years of record. They found significant relations between high flows and streams that are regulated, and high flows and development in the basin. The study also demonstrated that the relation between low-flow trends and development was not as strong as that for the high-flow trends. Streamflow variability was found to be significantly greater at streamflow-gaging stations located outside the Coastal Plain than in the Coastal Plain.

Urbanization is defined here as the conversion of agricultural and forested areas to urban land use. Impervious surface (highly compacted soil, pavements, and roof tops) is increased during urbanization, and infiltration of water into the soil is decreased (Arnold and Gibbons, 1996). Thus, the volume and



Base from U.S. Geological Survey digital line data, 1:24,000 and 1:2,000,000 Universal Transverse Mercator Projection, Zone 18, NAD83

Figure 1. Location of selected streamflow-gaging stations with stream types and physiographic provinces in New Jersey.

rate of streamflow in urban areas can increase during times of stormwater runoff and decrease during times of low flow compared with streamflow in agricultural and forested areas. Also, periods of low flow can be extended between precipitation events. These changes in the flow regime can cause disturbance to aquatic habitats (Konrad, 2003; Konrad and Booth, 2002; Kennen and Ayers, 2002).

Impervious surfaces can serve as an indicator of urban development and other human activity in the basin. The increase in impervious surfaces as a result of population growth accelerated in the early 20th century with the proliferation of the automobile and construction of road systems (Arnold and Gibbons, 1996). Improved transportation networks generally stimulate and facilitate growth, leading to further urbanization and increases in impervious surface.

Stankowski (1972) found a significant correlation between the percentage of impervious surface and population density in 570 municipalities in New Jersey. He found that impervious surface varies with, and can be reliably estimated from, land-use type. Alley and Veenhuis (1983) found that percentages of total impervious surface in the Denver, Colorado, area were related to land-use patterns. They assigned values of 20 percent total impervious surface for low-density residential development, 35 percent for medium-density suburban development, 60 percent for high-density urban development, and 90 percent for commercial, industrial, and transportation facilities.

Change in impervious surface can be used to define boundaries of baseline periods as impervious surface is easily measurable and is strongly correlated with urbanization. Previous investigations have considered the relations between impervious surface and hydrologic processes and its effects on the health of aquatic habitat. Brun and Band (2000) used digital spatial data and the Hydrologic Simulation Program - Fortran (HSPF) to assess the effects of land-use changes on basin behavior in Baltimore, Maryland, from “pre-urbanized times” to 1990. They identified a threshold of impervious cover, 20 percent, above which the ratio of runoff to base flow changes substantially.

When relating impervious surface to aquatic health, it is difficult to separate the effects of other environmental stressors resulting from human activity, including non-point sources constituent loading from runoff and vegetation removal. Arnold and Gibbons (1996) and Schueler (1994) reviewed the results of previous stream water-quality studies and concluded that 10 percent impervious surface was a generally accepted threshold for “impacted stream health” and 30 percent for “degraded” status. Kennen and Ayers (2002) used principal component analyses and multiple-linear regression to evaluate the response of fish, invertebrates, and algae in 36 basins in New Jersey to environmental characteristics along a gradient of urban land use that ranged from 3 to 96 percent of the drainage basin. Environmental characteristics that substantially affected species assemblages included impervious surface, human population, nutrient concentrations, and forested and wetland areas. By eliminating redundant variables, they were able to relate impervious surface to aquatic health and found that an impervious surface coverage greater than 18 percent was associated with moderate to severe ecological impairment.

Natural vegetative land cover helps to regulate streamflow. Forest canopy and leaf litter, for example, increase evapotranspiration and reduce runoff, erosion, and sedimentation (Field, 1997). By replacing natural land cover with crop or pasture land, agricultural land use can increase sedimentation and channel-bed erosion, which may alter flood plain and channel dynamics (Fitzpatrick and others, 1999).

Use of Hydrologic Indices in Regulatory Planning

NJHIP can be used by water-resources managers to assess the effects of past and proposed alterations to the flow regime on the values and patterns in ERHIs. The USGS, in a 4-year cooperative study with NJDEP, has used NJHIP to develop two software applications to assist in the use of NJHIP. These software applications are the New Jersey Stream Classification Tool (NJSCT) and the New Jersey Hydrologic Assessment Tool (NJHAT). NJSCT can be used to classify streams that were previously unclassified in the NJHIP as class A, B, C, or D. NJHAT calculates values of all 171 ERHIs and identifies on the basis of stream class those ERHIs that serve as primary or surrogate indices. These software tools are used with publicly available USGS streamflow data.

The ERHIs identified by NJHIP can be defined as either temporal or spatial (Henriksen and others, 2006). Temporal indices are calculated from long-term multi-year daily flow records for a single streamflow-gaging station. For example, to calculate the ERHI MA24—variability of January flow values—the standard deviation of January daily mean flow values is divided by the corresponding mean daily flow for each year of record, and the median of these values is the index value. NJHAT provides an option for calculating upper and lower percentile limits for temporal indices, and the 25th and 75th percentiles (first and third quartiles) are the default values.

Water managers can use hydrologic indices to predict the effects of proposed water withdrawals on streamflow characteristics, which can help them to meet a regulatory objective of protecting in-stream aquatic ecology while managing water use. Definitions of all 171 hydrological indices are given by Kennen and others (2007). The set of primary and surrogate indices specified by NJHIP and selected by the program NJHAT does not meet the regulatory objectives of NJDEP (J.L. Hoffman, New Jersey Department of Environmental Protection, written commun., 2006). Therefore, new primary indices were developed that are more suitable for use by water managers (table 1). The criteria used to select the new set of indices are described in this section.

Many of the frequency of high flow and frequency of low flow indices (FH and FL, respectively) are based on a

Table 1. Description of primary and surrogate ecologically relevant hydrologic Indexes (ERHIs) determined by using the New Jersey Hydrologic Integrity Assessment Process for streams in New Jersey.

[NJDEP, primary regulatory index for the New Jersey Department of Environmental Protection; NJHIP, primary index as determined from the New Jersey Hydrologic Integrity Assessment Process[1]; --, indicates that the index specified in the row is not a primary or a surrogate for the stream class listed in the corresponding column]

Index category	Type of flow (subcomponent)	Index type	Index code[1]	Stream class A		Stream class B		Stream class C		Stream class D	
				Primary[2] index for:	NJHIP[3] surrogate for:	Primary index for:	NJHIP surrogate for:	Primary index for:	NJHIP surrogate for:	Primary index for:	NJHIP surrogate for:
Magnitude	Average flow (MA)	Spatial	MA9	--	--	NJHIP	--	--	--	--	MA39
		Spatial	MA11	--	--	--	--	--	MA24	--	--
		Temporal	MA13	--	--	--	--	--	--	NJDEP	MA39
		Temporal	MA15	--	--	NJDEP	MA9	--	--	--	--
		Temporal	MA18	NJDEP, NJHIP	--	--	--	--	--	--	--
		Temporal	MA24	--	--	--	--	NJDEP, NJHIP	--	--	--
		Temporal	MA26	--	MA18	--	--	--	--	--	--
		Temporal	MA32	--	--	--	MA9	--	--	--	--
		Temporal	MA33	--	--	--	MA9	--	--	--	--
		Spatial	MA37	--	MA18	--	--	--	--	--	--
		Spatial	MA39	--	MA18	--	--	--	--	NJHIP	--
		Spatial	MA40	--	--	--	--	--	MA24	--	MA39
		Spatial	MA43	--	--	--	--	--	MA24	--	--
		Spatial	MA44	--	--	--	--	--	--	--	MA39
		Spatial	MA45	--	--	--	--	--	MA24	--	--
	Low flow (ML)	Temporal	ML1	NJDEP	--	NJDEP	--	NJDEP	--	NJDEP	--
		Temporal	ML2	NJDEP	--	NJDEP	--	NJDEP	--	NJDEP	--
		Temporal	ML3	NJDEP	--	NJDEP	--	NJDEP, NJHIP	--	NJDEP	--
		Temporal	ML4	NJDEP	--	NJDEP	ML20	NJDEP	--	NJDEP	--
		Temporal	ML5	NJDEP	--	NJDEP	--	NJDEP	--	NJDEP	--
		Temporal	ML6	NJDEP, NJHIP	--	NJDEP	--	NJDEP	--	NJDEP	--
		Temporal	ML7	NJDEP	--	NJDEP	--	NJDEP	--	NJDEP	--
		Temporal	ML8	NJDEP	--	NJDEP	--	NJDEP	--	NJDEP	--
		Temporal	ML9	NJDEP	--	NJDEP	--	NJDEP	--	NJDEP	--
		Temporal	ML10	NJDEP	--	NJDEP	--	NJDEP	--	NJDEP	--
		Temporal	ML11	NJDEP	--	NJDEP	--	NJDEP	--	NJDEP	--
		Temporal	ML12	NJDEP	--	NJDEP	--	NJDEP	--	NJDEP	--
		Temporal	ML13	--	ML6	--	--	--	ML3	--	--
		Temporal	ML15	--	--	--	--	--	--	NJDEP	ML20
		Temporal	ML16	--	ML6	--	ML20	--	--	--	--
		Temporal	ML19	--	--	--	--	--	ML3	--	--
		Spatial	ML20	--	--	NJHIP	--	--	ML3	NJHIP	--
		Spatial	ML21	--	--	--	ML20	--	--		ML20

Table 1. Description of primary and surrogate ecologically relevant hydrologic Indexes (ERHIs) determined by using the New Jersey Hydrologic Integrity Assessment Process for streams in New Jersey.—Continued

[NJDEP, primary regulatory index for the New Jersey Department of Environmental Protection; NJHIP, primary index as determined from the New Jersey Hydrologic Integrity Assessment Process[1]; --, indicates that the index specified in the row is not a primary or a surrogate for the stream class listed in the corresponding column]

Index category	Type of flow (subcomponent)	Index type	Index code[1]	Stream class A		Stream class B		Stream class C		Stream class D	
				Primary[2] index for:	NJHIP[3] surrogate for:	Primary index for:	NJHIP surrogate for:	Primary index for:	NJHIP surrogate for:	Primary index for:	NJHIP surrogate for:
	High flow (MH)	Temporal	MH1	--	--	--	--	--	--	--	MH16
		Temporal	MH2	--	--	--	--	--	--	NJDEP	MH16
		Temporal	MH3	--	--	--	--	--	--	--	MH16
		Temporal	MH4	--	--	NJDEP	--	--	--	--	--
		Temporal	MH5	NJDEP, NJHIP	--	--	--	--	--	--	--
		Temporal	MH12	--	--	--	--	--	MH14	--	--
		Spatial	MH13	--	--	--	--	--	MH14	--	--
		Temporal	MH14	--	--	--	--	NJDEP, NJHIP	--	--	--
		Spatial	MH16	--	MH5	--	--	--	MH14	NJHIP	--
		Spatial	MH17	--	--	--	--	--	MH14	--	--
		Spatial	MH18	--	MH5	--	MH24	--	--	--	--
		Temporal	MH20	--	MH5	--	--	--	--	--	--
		Temporal	MH21	--	--	--	--	--	--	--	MH16
		Temporal	MH24	--	--	NJHIP	--	--	--	--	--
		Temporal	MH26	--	--	--	MH24	--	--	--	--
Frequency	Low flow (FL)	Spatial	FL1	NJDEP	FL3	NJDEP	FL3	NJDEP, NJHIP	--	NJDEP	FL3
		Spatial	FL2	--	--	--	FL3	--	FL1	--	FL3
		Temporal	FL3	NJHIP	--	NJHIP	--	--	FL1	NJHIP	--
	High flow (FH)	Temporal	FH1	--	FH4	--	FH4	--	--	--	--
		Temporal	FH3	NJDEP	FH4	--	--	NJDEP	FH7	NJDEP, NJHIP	--
		Temporal	FH4	NJHIP	--	NJHIP	--	--	FH7	--	--
		Temporal	FH5	--	--	--	--	--	--	--	FH3
		Temporal	FH7	--	--	--	--	NJHIP	--	--	--
		Temporal	FH9	--	FH4	--	--	--	--	--	FH3
		Temporal	FH10	--	--	NJDEP	FH4	--	--	--	FH3
		Temporal	FH11	--	--	--	--	--	FH7	--	FH3
Duration	Low flow (DL)	Temporal	DL1		--	NJDEP	--	--	--	--	--
		Temporal	DL4	NJDEP, NJHIP	--	--	--	--	--	NJDEP, NJHIP	--
		Temporal	DL5	--	--	--	--	--	DL16	--	--
		Spatial	DL6	--	DL4	--	--	--	--	--	--
		Spatial	DL7	--	--	--	--	--	--	--	DL4
		Spatial	DL9	--	--	--	--	--	DL16	--	--
		Temporal	DL11	--	--	--	--	--	--	--	DL4
		Temporal	DL12	--	DL4	--	DL15	--	--	--	--
		Temporal	DL14	--	--	--	--	--	DL16	--	--
		Temporal	DL15	--	--	NJHIP	--	--	--	--	--
		Temporal	DL16	--	DL4	--	DL15	NJDEP, NJHIP	--	--	DL4
		Spatial	DL17	--	--	--	--	--	DL16	--	--

Table 1. Description of primary and surrogate ecologically relevant hydrologic Indexes (ERHIs) determined by using the New Jersey Hydrologic Integrity Assessment Process for streams in New Jersey.—Continued

[NJDEP, primary regulatory index for the New Jersey Department of Environmental Protection; NJHIP, primary index as determined from the New Jersey Hydrologic Integrity Assessment Process[1]; --, indicates that the index specified in the row is not a primary or a surrogate for the stream class listed in the corresponding column]

Index category	Type of flow (subcomponent)	Index type	Index code[1]	Stream class A		Stream class B		Stream class C		Stream class D	
				Primary[2] index for:	NJHIP[3] surrogate for:	Primary index for:	NJHIP surrogate for:	Primary index for:	NJHIP surrogate for:	Primary index for:	NJHIP surrogate for:
	High flow (DH)	Temporal	DH1	--	--	--	--	NJDEP	DH11	--	--
		Temporal	DH2	NJDEP, NJHIP	--	NJDEP	DH12	--	--	NJDEP	DH14
		Spatial	DH8	--	DH2	--	--	--	--	--	--
		Spatial	DH9	--	--	--	--	--	DH11	--	--
		Temporal	DH11	--	--	--	--	NJHIP	--	--	--
		Temporal	DH12	--	--	NJHIP	--	--	--	--	DH14
		Spatial	DH13	--	DH2	--	--	--	--	--	--
		Spatial	DH14	--	--	--	--	--	DH11	NJHIP	--
		Temporal	DH17	--	--	--	--	--	--	--	DH14
		Temporal	DH20	--	DH2	--	DH12	--	--	--	--
		Temporal	DH23	--	--	--	--	--	DH11	--	DH14
		Temporal	DH24	--	--	--	DH12	--	--	--	--
		Spatial	TL1	NJHIP	--	--	--	--	TL2	NJHIP	--
Timing	Low flow (TL)	Spatial	TL2	--	--	NJHIP	--	NJHIP	--	--	--
	High flow (TH)	Spatial	TH1	NJHIP	--	--	--	--	--	--	
		Spatial	TH2	--	--	NJHIP	--	--	--	--	TH3
		Spatial	TH3	--	--	--	TH2	NJHIP	--	NJHIP	
Rate of change	Average flow (RA)	Temporal	RA1	--	--	--	RA7	--	RA6	--	RA7
		Spatial	RA2	--	--	--	RA7	--	RA6	--	
		Temporal	RA3	NJDEP, NJHIP	--	--	--	--	RA6	--	RA7
		Spatial	RA4	--	--	--	--	--	RA6	--	
		Spatial	RA5	--	RA3	--	--	--	--	--	
		Temporal	RA6	--	--	--	RA7	NJDEP, NJHIP	--	--	RA7
		Temporal	RA7	--	RA3	NJDEP, NJHIP	--	--	--	NJDEP, NJHIP	
		Temporal	RA8	--	RA3		--	--	--	--	RA7

[1] Henriksen, J.A., Heasley, J., Kennen, J.G., and Nieswand, S.P., 2006, Users' manual for the Hydroecological Integrity Assessment Process software (including the New Jersey Assessment Tools): U.S. Geological Survey Open-File Report 2006-1093, 71 p.

[2]These primary indexes were determined by the New Jersey Hydrologic Integrity Assessment Process (NJHIP) and are defined as those indexes that describe the majority of the variability for each flow sub-component as determined by principal component analysis (Henriksen and others, 2006) or primary as determined by NJDEP (J.L. Hoffman, NJDEP, written commun., 2007).

[3]These surrogate indexes were determined by the NJHIP and are defined as those indexes that are collinear to the primary indexes for each flow sub-component as determined by principal component analysis.

variable of frequency of occurrence. If there is little variability in streamflow, these ERHI values may equal zero, meaning that event described by the ERHI never occurs. This has limited regulatory value where upper and lower percentiles of frequency of occurrence are used as regulatory thresholds. Therefore, temporal primary and surrogate frequency indices were selected that are expected to yield more dynamic ranges of index values (non-zero values). Removal of spatial indices from consideration resulted in the elimination of all indices that describe timing of low flow and timing of high flows (TL and TH indices). To compensate for this, NJDEP designated 12 magnitude-of-low-flow (ML) indices as primary indices. This provides information about the seasonal variability of streamflow (J.L. Hoffman, New Jersey Department of Environmental Protection, written commun., 2006).

Many index values can be calculated using median values instead of mean values. For example, index MA24—variability (coefficient of variation) of January flow values—uses the standard deviation of January daily mean flow values divided by the corresponding mean daily flow for each year of record, and the mean of these values is the index value. In place of a mean, a median of these values also can be calculated as an index value. The mean is the default calculation for many indices in NJHAT, but calculation of a median can be selected as a default in the software configuration. All primary and surrogate temporal indices selected by NJDEP use only median (not mean) streamflow values.

Description of the Study Area

Eighty-five streamflow-gaging stations throughout New Jersey with 10 or more years of continuous streamflow data (table 2) were selected for this investigation. Originally 95 stations had been proposed, but 10 of these stations did not have sufficient years of baseline record as a result of extensive regulation, diversion, ground-water withdrawal, or other human alterations (R.D. Schopp, U.S. Geological Survey, oral commun., 2006).

The study area (fig. 1), which includes the entire state of New Jersey and parts of New York, covers approximately 8,100 square miles. All streamflow-gaging stations are located in New Jersey; however, portions of drainage basins upstream from eight stations are located in New York State. The study area has a population of more than 8.6 million people and includes some of the most densely populated metropolitan areas in the United States (United States Census Bureau, 2005). New Jersey comprises four physiographic provinces, as described by the NJDEP (2007)—the Valley and Ridge; New England; Piedmont, which is north of the Fall Line; and the Coastal Plain, south of the Fall Line. The lithology of the provinces north of the Fall Line consists mostly of sedimentary and crystalline rock, shale, and sandstone. The Valley and Ridge Physiographic Province is characterized by a series of parallel ridges and valleys trending northeast-southwest with mountainous topography and elevations exceeding 480 m. The New England Physiographic Province consists of broad, flat-topped highlands and long, narrow valleys that range in elevation from 150 to 460 m. The Piedmont Physiographic Province consists of northwestward-dipping sedimentary rocks that form broad, gently sloping lowlands and rolling hills, where elevations typically reach only 120 m. The Coastal Plain is dominated by gravel, sand, silt, and clays. About 55 percent of the study area is in the Coastal Plain physiographic province, which is characterized by flat to gently rolling topography and unconsolidated sedimentary deposits (Wolfe, 1977).

Streamflow in the Piedmont Physiographic Province is highly variable (flashy) owing to limited ground-water recharge. In the Coastal Plain, however, ground-water discharge is substantial, and streamflow is relatively stable. In the Highlands and Valley and Ridge Provinces, streamflow tends to fall somewhere between the flashy flows of the Piedmont and the more stable ground-water-supported flows of the Coastal Plain. Ground water contributes 65 to 95 percent of the base flow in the Coastal Plain. North of the Fall Line the ground-water contribution to base flow ranges from approximately 22 to 88 percent. In general, streamflow in the northern part of the study area is dominated by surface runoff; in the Coastal Plain, it is dominated by flow from ground-water sources (Watt, 2000).

Over the past century, New Jersey has experienced extensive human alteration with the conversion of large areas of agricultural and some undeveloped land to urban and suburban developments. Such changes are likely to cause changes in the hydrologic flow regime in streams (Kennen and Ayers, 2002). These large-scale changes in population and land-use have left few streams unaffected by human activities. Stream regulation, addition of dams and reservoirs, wastewater discharge, surface-water and ground-water withdrawal in the drainage basin, and changes resulting from the suburbanization of farmland and forest or the reforestation of farmland are all capable of altering the streamflow regime. From 1970 to 2000 there has been a greater than 40-percent increase in urbanized land and a subsequent decrease in other land-use categories, most notably agricultural land. As a result of these changes, most of northeastern New Jersey and the corridor between New York City and Philadelphia have experienced urbanization of land, ranging from small roads and suburban tracts to high-density commercial, industrial, and residential development. This urbanization increases the amount of impervious surface area, which results in an increased rate of runoff during precipitation, and delays and decreases base-flow contributions to streams in these areas. Water-supply systems in the study area are highly interconnected, and transfer of water across drainage divides and among basins is common. For example, nearly 80 million gallons per day of water is transferred from the Delaware River to the Raritan River basin by way of the Delaware and Raritan canal (Ayers and others, 2000).

The climate in New Jersey is considered temperate, with an average temperature of 52.1 °F and average annual precipitation of 113.6 cm based on data from 1895 to 2002. Precipitation in the study area can be further subdivided into three

Table 2. Land use at, and continuous period of record for, selected streamflow-gaging stations in New Jersey.

[USGS, U.S. Geological Survey; mi², square miles; --, no data]

Site number (fig. 1)	USGS station identifier	Station name	Drainage area (mi²)	Percentage of basin outside New Jersey	Continuous period of record[1]	Stream class[2]	Land use: Urban[3] (in percent)	Land use: Agriculture[3] (in percent)	Land use: Total developed[3] (in percent)	Watershed management area[4]
1	01379773	Green Pond Brook at Picatinny Arsenal, NJ	7.65	0.0	1983-2005	D	11.5	0.3	11.8	06
2	01380500	Rockaway River Above Reservoir at Boonton, NJ	116	0.0	1937-2005	A	29.1	0.9	30.0	06
3	01381500	Whippany River at Morristown, NJ	29.4	0.0	1921-2005	C2	49.2	2.6	51.8	06
4	01384500	Ringwood Creek near Wanaque, NJ	19.1	78.9	1934-1977, 1987-2005	C	14.0	0.0	14.0	03
5	01385000	Cupsaw Brook near Wanaque, NJ	4.37	0.0	1934-1958	D	19.3	0.3	19.6	03
6	01386000	West Brook near Wanaque, NJ	11.8	0.0	1934-1978	C	17.7	0.3	18.0	03
7	01386500	Blue Mine Brook near Wanaque, NJ	1.01	0.0	1934-1958	D	5.0	0.5	5.5	03
8	01387500	Ramapo River near Mahwah, NJ	120	95.0	1902-1906, 1923-2005	A	18.9	1.6	20.5	03
9	01390500	Saddle R at Ridgewood, NJ	21.6	36.4	1954-1977, 1979-2005	C	79.3	1.0	80.3	04
10	01391000	Hohokus Brook at Ho-Ho-Kus, NJ	16.4	0.0	1954-1973, 1978-1996, 2003-2005	C	74.9	0.7	75.7	04
11	01392210	Third River at Passaic, NJ	11.8	0.0	1977-1997	C	91.0	0.0	91.1	04
12	01392500	Second River at Belleville, NJ	11.6	0.0	1937-1964	C	93.0	0.0	93.0	04
13	01396000	Robinsons Branch at Rahway, NJ	21.6	0.0	1939-1996	D4	78.7	0.3	79.0	07
14	01396500	South Branch Raritan River near High Bridge, NJ	65.3	0.0	1918-2005	A	28.0	14.6	42.6	08
15	01396580	Spruce Run at Glen Gardner, NJ	11.3	0.0	1978-1988, 1991-2005	C	17.7	23.4	41.1	08
16	01396660	Mulhockaway Creek at Van Syckel, NJ	11.8	0.0	1977-2005	C	24.1	20.9	45.0	08
17	01397500	Walnut Brook near Flemington, NJ	2.24	0.0	1936-1961	D	21.4	21.6	43.1	08
18	01398000	Neshanic River at Reaville, NJ	25.7	0.0	1930-2005	A	24.1	45.7	69.8	08

Table 2. Land use at, and continuous period of record for, selected streamflow-gaging stations in New Jersey.—Continued

[USGS, U.S. Geological Survey; mi², square miles; --, no data]

Site number (fig. 1)	USGS station identifier	Station name	Drainage area (mi²)	Percentage of basin outside New Jersey	Continuous period of record[1]	Stream class[2]	Land use: Urban[3] (in percent)	Land use: Agriculture[3] (in percent)	Land use: Total developed[3] (in percent)	Watershed management area[4]
19	01398500	North Branch Raritan River near Far Hills, NJ	26.2	0.0	1921-2005	C	32.1	10.3	42.4	08
20	01399200	Lamington (Black) River near Ironia, NJ	10.9	0.0	1975-1987	D	44.4	1.7	46.1	08
21	01399500	Lamington (Black) River near Pottersville, NJ	32.8	0.0	1921-2005	C	29.4	11.9	41.3	08
22	01399510	Upper Cold Brook near Pottersville, NJ	2.18	0.0	1972-1996	D	20.2	29.3	49.5	08
23	01399525	Axle Brook near Pottersville, NJ	1.22	0.0	1977-1988	D	6.0	49.6	55.7	08
24	01399670	South Branch Rockaway Creek at Whitehouse Station, NJ	12.3	0.0	1977-2005	C	30.7	22.1	52.8	08
25	01400000	North Branch Raritan River near Raritan, NJ	190	0.0	1923-2005	A	28.2	21.9	50.1	08
26	01400350	Macs Brook at Somerville, NJ	0.77	0.0	1982-1996	D	71.8	0.3	72.0	10
27	01400730	Millstone River at Plainsboro, NJ	65.8	0.0	1964-1975, 1987-1989	A	26.1	39.6	65.8	10
28	01401000	Stony Brook at Princeton, NJ	44.5	0.0	1953-2005	A	24.9	24.2	49.0	10
29	01401650	Pike Run at Belle Mead, NJ	5.36	0.0	1979-2005	D	25.3	27.9	53.2	10
30	01402600	Royce Brook Tributary near Belle Mead, NJ	1.2	0.0	1966-1975, 1980-1996	D4	76.7	1.3	78.0	10
31	01403400	Green Brook at Seeley Mills, NJ	6.23	0.0	1978-2005	D	42.2	1.0	43.2	09
32	01403535	East Branch Stony Brook at Best Lake at Watchung, NJ	1.57	0.0	1980-2000	D	73.3	0.0	73.3	09
33	01403540	Stony Brook at Watchung, NJ	5.51	0.0	1974-2005	D	63.6	0.8	64.3	09
34	01405300	Matchaponix Brook at Spotswood, NJ	43.9	0.0	1957-1967	A	44.8	13.7	58.5	09
35	01408000	Manasquan River at Squankum, NJ	44	0.0	1931-2005	A	33.6	19.3	52.9	12
36	01408120	North Branch Metedeconk River near Lakewood, NJ	34.9	0.0	1972-2005	A4	36.5	6.9	43.4	13

Table 2. Land use at, and continuous period of record for, selected streamflow-gaging stations in New Jersey.—Continued

[USGS, U.S. Geological Survey; mi², square miles; --, no data]

Site number (fig. 1)	USGS station identifier	Station name	Drainage area (mi^2)	Percentage of basin outside New Jersey	Continuous period of record[1]	Stream class[2]	Land use			Watershed management area[4]
							Urban[3] (in percent)	Agriculture[3] (in percent)	Total developed[3] (in percent)	
37	01408500	Toms River near Toms River, NJ	123	0.0	1928-2005	B	17.6	3.4	21.0	13
38	01409000	Cedar Creek at Lanoka Harbor, NJ	53.3	0.0	1932-1958, 1969-1971, 2003-2005	B	5.4	0.5	5.9	13
39	01409095	Oyster Creek near Brookville, NJ	7.43	0.0	1965-1985	D	2.7	0.6	3.3	13
40	01409280	Westecunk Creek at Stafford Forge, NJ	15.8	0.0	1973-1988, 2003-2005	D	0.8	0.5	1.3	13
41	01409400	Mullica River near Batsto, NJ	46.7	0.0	1957-2005	B	6.3	6.0	12.3	14
42	01409500	Batsto River at Batsto, NJ	67.8	0.0	1927-2005	B	5.6	11.8	17.4	14
43	01409810	West Branch Wading River near Jenkins, NJ	84.1	0.0	1974-1996, 2004-2005	B	0.8	6.6	7.4	14
44	01410000	Oswego River at Harrisville, NJ	72.5	0.0	1930-2005	B	0.9	1.8	2.8	14
45	01410150	East Branch Bass River near New Gretna, NJ	8.11	0.0	1978-2005	D	2.0	0.0	2.0	14
46	01411000	Great Egg Harbor River at Folsom, NJ	57.1	0.0	1925-2005	B	29.0	8.3	37.3	15
47	01411300	Tuckahoe River at Head of River, NJ	30.8	0.0	1969-2005	C	4.0	7.7	11.7	15
48	01411456	Little Ease Run near Clayton, NJ	9.77	0.0	1987-2005	D	21.6	15.5	37.0	17
49	01411500	Maurice River at Norma, NJ	112	0.0	1932-2005	B	22.6	23.8	46.4	17
50	01412000	Menantico Creek near Millville, NJ	23.2	0.0	1931-1985	D	26.8	40.6	67.4	17
51	01412800	Cohansey River at Seeley, NJ	28	0.0	1977-1988, 2003-2005	C	50.0	0.0	50.0	17
52	01440000	Flat Brook near Flatbrookville, NJ	64	0.0	1923-2005	A	3.0	5.3	8.4	01
53	01443500	Paulins Kill at Blairstown, NJ	126	0.0	1921-2005	A	14.3	19.3	33.6	01
54	01445000	Pequest River at Huntsville, NJ	31	0.0	1939-1962	C	15.3	15.1	30.3	01

Table 2. Land use at, and continuous period of record for, selected streamflow-gaging stations in New Jersey.—Continued

[USGS, U.S. Geological Survey; mi^2, square miles; --, no data]

Site number (fig. 1)	USGS station identifier	Station name	Drainage area (mi^2)	Percentage of basin outside New Jersey	Continuous period of record[1]	Stream class[2]	Land use: Urban[3] (in percent)	Land use: Agriculture[3] (in percent)	Land use: Total developed[3] (in percent)	Watershed management area[4]
55	01445500	Pequest River at Pequest, NJ	106	0.0	1921-2005	B	12.2	23.4	35.6	01
56	01446000	Beaver Brook near Belvidere, NJ	36.7	0.0	1922-1961	C	56.5	6.1	62.6	01
57	01456000	Musconetcong River near Hackettstown, NJ	68.9	0.0	1921-1973	B	20.2	0.4	20.6	01
58	01457000	Musconetcong River near Bloomsbury, NJ	141	0.0	1903-1907, 1921-2005	B	19.9	17.0	36.9	01
59	01464500	Crosswicks Creek at Exton-ville, NJ	81.5	0.0	1940-2005	A	15.5	32.0	47.5	20
60	01465850	South Branch Rancocas Creek at Vincentown, NJ	64.5	0.0	1961-1975	B	10.0	22.2	32.2	19
61	01466000	Middle Branch Mt Misery Brook In Lebanon State Forest, NJ	3	0.0	1952-1964	D	0.0	0.0	0.0	19
62	01466500	Mcdonalds Branch in Lebanon State Forest, NJ	2.35	0.0	1953-2005	D	0.0	0.0	0.0	19
63	01467000	North Branch Rancocas Creek at Pemberton, NJ	118	0.0	1921-2005	B	11.8	4.7	16.5	19
64	01467081	South Branch Pennsauken Creek at Cherry Hill, NJ	8.98	0.0	1967-2005	C	80.1	1.1	81.2	18
65	01475000	Mantua Creek at Pitman, NJ	6.05	0.0	1940-1976, 2003-2005	D	59.8	15.2	75.0	18
66	01477120	Raccoon Creek near Swedesboro, NJ	26.9	0.0	1966-2005	C4	20.1	48.8	68.9	18
67	01379500	Passaic River near Chatham, NJ	100	0.0	1903-1911, 1938-2005	A	43.4	6.7	50.1	06
68	01387000	Wanaque R at Wanaque, NJ	90.4	30.0	1912-1914, 1918-2005	A	11.6	0.4	12.0	03
69	01388000	Ramapo River at Pompton Lakes, NJ	160	70.6	1921-2005	A	23.2	1.4	24.6	03
70	01391500	Saddle River at Lodi, NJ	54.6	16.4	1923-2005	A	81.0	0.6	81.6	04
71	01464000	Assunpink Creek at Trenton, NJ	91	0.0	1923-2005	A	43.0	24.9	67.9	20

Table 2. Land use at, and continuous period of record for, selected streamflow-gaging stations in New Jersey.—Continued

[USGS, U.S. Geological Survey; mi^2, square miles; --, no data]

Site number (fig. 1)	USGS station identifier	Station name	Drainage area (mi^2)	Percentage of basin outside New Jersey	Continuous period of record[1]	Stream class[2]	Land use: Urban[3] (in percent)	Land use: Agriculture[3] (in percent)	Land use: Total developed[3] (in percent)	Watershed management area[4]
72	01397000	South Branch Raritan River at Stanton, NJ	147	0.0	1903-1905, 1919-2005	A	24.8	21.6	46.5	08
73	01400500	Raritan River at Manville, NJ	490	0.0	1903-1907,1921-2005	A	28.3	25.9	54.3	09
74	01402000	Millstone River at Blackwells Mills, NJ	258	0.0	1921-2005	A	30.3	28.2	58.5	10
75	01403060	Raritan River Below Calco Dam at Bound Brook, NJ	785	0.0	1903-1909,1945-2005	A	29.6	26.5	56.1	09
76	01401500	Millstone River near Kingston, NJ	171	0.0	1933-1949	A	31.0	29.0	60.0	10
77	01379000	Passaic River near Millington, NJ	55.4	0.0	1903-2005	A	36.2	8.7	44.9	06
78	01384000	Wanaque River at Monks, NJ	40.4	25.0	1934-1985	A	12.7	0.6	13.3	03
79	01383500	Wanaque River at Awosting, NJ	27.1	33.3	1919-2005	C	16.3	0.8	17.1	03
80	01399190	Lamington (Black) River at Succasunna, NJ	7.37	0.0	1976-1987	D	39.8	1.4	41.2	08
81	01392000	Weasel Brook at Clifton, NJ	4.45	0.0	1937-1962	D	91.0	0.9	91.9	04
82	01398107	Holland Brook at Readington, NJ	9	0.0	1978-1996	D	37.0	25.6	62.6	08
83	01398045	Back Brook Tributary near Ringoes, NJ	1.98	0.0	1977-1988	D	13.4	49.4	62.8	08
84	01387450	Mahwah River near Suffern, NY	--	100.0	1958-1995, 2005	C	--	--	--	na
85	01437500	Neversink River at Godeffroy, NY	--	100.0	1937-2005	A	--	--	--	--

[1] Continuous period of record indicates the water year, and ends at the last year of data analysis.

[2] Stream classes are statistically similar groupings of streams based on a cluster analysis of selected ecologically relevent hydrologic streamflow statistics developed as part of the New Jersey Hydrologic Integrity Process (Henriksen and others, 2006) and are referenced from Henriksen and others (2006) unless otherwise noted.

[3] Land-use information was from Watson and others (2005) who derived this information from the 1995/97 GIS land-use coverage (New Jersey Department of Environmental Protection, 2000).

[4] New Jersey is divided into 20 hydrologically defined watershed management areas, each having a management structure comprised of private corporations, non-profit and citizen-based organizations, and government entities.

general climate divisions (division 1 or northern, division 2 or southern, and the near southern coastal area). In general, division 1 is the area north of the Fall Line, and division 2 occupies most of the area south of the Fall Line. The southern coastal area is that portion of the study area located south of the Fall Line that is proximal to the Atlantic coastline. Long-term average precipitation (1895-2002) for division 1 is 116.8 cm, division 2 is 112.4 cm, and the coastal area is 106.4 cm. (Precipitation and temperature data are summarized on the basis of information from the Office of the New Jersey State Climatologist, 2007).

Methods of Investigation

This investigation was conducted in three steps. First, the minimum period of record required for calculating values of ERHIs for the four stream classes in New Jersey was determined. This process was based on statistical analysis of ERHIs for streams that are believed to have no substantial change in flow regime (index stations) and on previous investigations in which minimum periods of record were assigned (Henriksen and others, 2006). Because of the subjective nature of the process, a conservative approach was taken; a longer than necessary minimum period was selected rather than risk the possibility that the ERHIs would be dominated by temporary conditions such as droughts or wet periods.

In the second step, baseline periods were determined for each of the 85 streams. Historical records relating to streams and basins, and institutional knowledge of the hydrology of New Jersey, were examined. Historical land use was estimated for each basin to determine the least urbanized period of record for which continuous streamflow record was available, and a statistical approach was used to determine whether there were significant changes in streamflow characteristics based on annual streamflow data. For the statistical approach, the null hypothesis of no difference among the rate of increase in cumulative annual runoff and base flow relative to index streams was tested in order to confirm that no sudden and permanent changes in flow regime had occurred during the period being considered as baseline.

In the third step hydrologic index values were calculated for the 85 streams. The program NJHAT (Henriksen and others, 2006) was used, and values of 171 ERHI were calculated for each stream. All values of ERHIs for all streams will be listed in tabular form on the USGS World Wide Web site.

Selection of Index Stations and Minimum Period of Record

Streamflow data have been collected for streams in New Jersey over periods ranging from a few years to nearly a century. Shorter periods of record may coincide with aberrant weather and streamflow patterns that are not representative of typical conditions. Longer periods of record are more likely to provide a representative sample of central tendencies and variability of streamflow. Therefore, a minimum period of record was required for each stream class. Each of the four stream classes was assigned a minimum period of record, which is the least number of years of continuous record for which selected ERHIs maintain stable hydrologic conditions. These minimums were selected primarily by analyzing the variability of hydrologic indices calculated for seven index stations with drainage basins that have less than 15 percent urban development (table 3).

Index stations were selected on the basis of the criteria of Watson and others (2005) in which drainage basins with less than 15 percent urban development were considered undeveloped. Most streamflow-gaging stations in New Jersey that meet this criterion do not have a lengthy period of record. In order to include additional stations with sufficiently long periods of record, it was necessary to include one station (West Brook near Wanaque Reservoir) that has 17.7 percent urban development in the drainage basin. Two index stations each were selected for stream classes A, B, and C. Only one index station was selected for class D streams because no other index station of class D had a sufficiently long period of record.

Durations of 5 to 20 years were evaluated as possible minimum periods of record for the four stream classes. The entire period of record for each index stream was divided into non-overlapping sub-periods of 5, 10, 15, and 20 years. A range of percentile values (5, 10, 20, 30, 40, 50 (median), 60, 70, 80, and 90) was calculated for selected hydrologic indices for each sub-period. For example, the index ML6 is defined as the median of June minimum flow values over the entire period of record. The remaining June minimum flows compose a frequency distribution of values for which a percentile (5, 10, 20, …) was calculated. Thus, a distribution was determined for each selected hydrologic index for each sub-period of record. The program NJHAT was used to calculate a range of values for selected ERHIs for each index station. From the initial 171 from previous analysis using the NJHIP, 10 ERHIs (one for each subcomponent of flow) were selected. These ERHIs were determined to be statistically significant and non-redundant for each stream class. Not all of the 10 indices were used for this analysis. In order to develop a meaningful percentile distribution for index values, those indices that were considered to be spatial were not included because calculation of these indices would result in a single value for which a distribution cannot be determined. The indices used for determining minimum periods of record are described in table 4.

For each index station and selected ERHI, the distribution of values was compared for each consecutive non-overlapping 5-year period over the entire period of record using the Kruskal-Wallis test. This test was repeated for 10-, 15-, and 20-year periods. The null hypothesis specified no difference in the distributions of index values among sub-periods for a given index at each station. A p-value was calculated from the Kruskal Wallis test, which presents the probability that there is a difference in ERHI values between the sub-periods

Table 3. Description of seven out (type) streamflow-gaging index stations in New Jersey used to determine minimum periods of record for calculating hydrologic indices and used to develop double-mass curves.

[USGS, U.S. Geological Survey; ID, identifier]

USGS station ID	Station name	Stream class[1]	Drainage area (square miles)	Available period of record[2]	Total years of continuous record	New Jersey water management area	Percentage developed land[3,4]	Percentage of agricultural land[3,4]	Percentage of urban land[3,4]
01384500	Ringwood Creek near Wanaque, NJ	C	19.1	1934-1977, 1987-2005	67	03	14.03	0.00	14.03
01386000	West Brook near Wanaque, NJ	C	11.8	1935-1978, 2002-2005	43	03	18.01	0.32	17.70
01409500	Batsto River at Batsto, NJ	B	67.8	1927-2005	74	14	17.36	11.77	5.59
01410000	Oswego River at Harrisville, NJ	B	72.5	1930-2005	71	14	2.78	1.85	0.93
01440000	Flat Brook near Flatbrookville, NJ	A	64	1924-2005	77	01	8.37	5.34	3.03
01443500	Paulins Kill at Blairstown, NJ	A	126	1921-2005	80	01	33.57	19.28	14.30
01466500	Mcdonalds Branch in Lebanon State Forest, NJ	D	2.35	1953-2005	48	19	0.00	0.00	0.00

[1]Stream classes are statistically similar groupings of streams based on a cluster analysis of selected ecologically relevent hydrologic streamflow statistics and are referenced in Henriksen and others (2006).

[2]Indicates water year, which is the 12-month period beginning October 1 and ending September 30. It is named for the year in which it ends.

[3]Land-use information is from Watson and others (2005) who derived this information from the 1995/97 GIS land-use coverage (New Jersey Department of Environmental Protection, 2000).

[4]Station basins are considered undeveloped unless otherwise noted.

Table 4. Selected primary Ecologically Relevant Hydrologic Indices (ERHIs) used to compute the minimum period of record for each stream class at selected streamflow-gaging stations in New Jersey.

[Index type, the element of the flow regime that the ERHI describes; flow event, the description of the type of hydrologic event that the ERHI describes; definition of percentile distribution values, the calculation methods used to compute a dataset of values where a frequency distribution can be generated so that percentile values (25th or 75th percentile) can be determined; No index selected, an index under the given flow type and (or) stream type not selected for computation of the minimum period of record; No indices selected, no index was selected for any stream type for computation of the minimum period of record]

Index type	Flow event	Stream class[1]	ERHI code[2]	Definition of percentile distribution values
Magnitude	Average	A	MA18	Median July flow values for the entire period
		B	No index selected	
		C	MA24	Standard deviation of January flow values for the entire period
		D	No index selected	
	Low	A	ML6	Median of June minimum flow values for the entire period
		B	No index selected	
		C	ML3	Median of March minimum flow values for the entire period
		D	No index selected	
	High	A	MH5	Median of May maximum flow values for the entire period
		B	No index selected	
		C	MH14	Ratio of the annual median of monthly maximum flow to the annual median flow for the the entire period
		D	No index selected	
Frequency	Low	A	FL3	Annual frequency of flow events less than 5 percent of the median flow value for the entire period
		B	FL3	Annual frequency of flow events less than 5 percent of the median flow value for the entire period
		C	FL1	Annual frequency of flow events less than the 25th percentile flow value for the entire period
		D	FL3	Annual frequency of flow events less than 5 percent of the median flow value for the entire period
	High	A	FH4	Median number of days per year that the flow exceeds 7 times the median flow for the entire preiod
		B	FH4	Median number of days per year that the flow exceeds 7 times the median flow for the entire preiod
		C	FH7	Number of flow events per year with values that exceed 7 times the median flow for the entire period
		D	FH3	Median number of days per year that the flow exceeds 3 times the median flow for the entire preiod
Duration	Low	A	DL4	Minimum annual 30-day moving average for the entire period
		B	No index selected	
		C	DL16	Annual average pulse durations for the the entire period for flow events below the 25th percentile flow
		D	No index selected	
	High	A	DH2	Annual maximum 3-day moving average of flows for the the period
		B	DH12	Annual maximum 7-day moving average of flows divided by the median flow for the the period
		C	DH11	Annual maximum 1-day moving average of flows divided by the median flow for the the period
		D	No index selected	
Timing	Average	A-D	No indices selected	
	Low	A-D	No indices selected	
	High	A-D	No indices selected	
Rate of Change	Average	A	RA3	Change in flow for all days where the change in flow was negative for the the entire period
		B	RA7	Change in log of flow for all days where the change in flow was negative for the the entire period
		C	RA6	Change in log of flow for all days where the change in flow was positive for the the entire period
		D	RA7	Change in log of flow for all days where the change in flow was negative for the the entire period

[1] Stream classes are statistically similar groupings of streams determined by cluster analysis of selected ecologically relevent hydrologic streamflow statistics and are referenced from Henriksen and others (2006).

[2] Definitions of ERHIs are given in Henriksen, J.A., Heasley, J., Kennen, J.G., and Nieswand, S.P., 2006, Users' manual for the Hydroecological Integrity Assessment Process software (including the New Jersey Assessment Tools): U.S. Geological Survey Open-File Report 2006-1093, 71 p.

of record, with the critical p-value set at 0.05. The minimum period of record for each stream class was defined as the shortest duration for which the null hypothesis was not rejected for all of the ERHIs tested. If the null hypothesis was rejected for any index for all groups of years, 20 years was accepted as the minimum period of record for that stream class. For stream classes A, B, and C, the procedure was done for each of the two index stations, and the longer of the two minimum periods of record was selected for each stream class.

Baseline Periods of Record for Selected Streams in New Jersey

Calculation of hydrologic indices for baseline periods requires streamflow data from a continuous range of years during which the stream and the drainage basin were least altered by human activities. Changes such as regulation, landscape alteration, and surface-water and ground-water withdrawals in the drainage basin can affect streamflow characteristics and hydrologic indices.

For streams in relatively undeveloped and unregulated basins, the baseline period of record may include the entire period of record. For streams in highly developed basins, substantial human alteration and degraded ecological conditions can occur during many years of the period of record. For such streams, a range of years during which the level of development remained relatively constant can be used as the baseline period.

A baseline period of record was assigned for each stream on the basis of three criteria: (1) historical stream and basin information, (2) measured and estimated impervious surface in the drainage basin, and (3) statistically significant changes in annual runoff and base-flow volumes as determined with double-mass-curve analysis. Each baseline period of record was then compared to the minimum period of record determined for the appropriate stream class to determine whether the station had a sufficiently long record to generate meaningful ERHIs.

Use of Historical Stream and Basin Information to Eliminate Non-Baseline Years and Define Preliminary Baseline Periods

The preliminary baseline period of record is the continuous time period that remained after eliminating years that are clearly not baseline as determined from historical basin information. Historical information about each station was obtained from Annual Data Reports published each year by the USGS, New Jersey Water Science Center (Bauersfeld and others, 1983-95; Centarino and others, 2005; Reed and others, 1996-2004; U.S. Geological Survey, 1936-82; White and others, 2006) and from information provided by the staff at the USGS New Jersey Water Science Center (written and oral commun., 2007). All information related to stream regulation, sewage-effluent discharge, water withdrawal, and other information pertinent to the stream and drainage basin was considered. A preliminary baseline period was determined for each stream as the period during which the stream was least regulated or did not have any known major ground-water withdrawals or surface-water withdrawals or diversions affecting the drainage basin. For example, flows from the Ramapo River at Pompton Lakes have been diverted into the Wanaque Reservoir since 1953 (Centenary and others, 2004). Therefore, the preliminary baseline period is the beginning of the period of record (1921) to 1953.

Use of Impervious Surface to Eliminate Non-Baseline Years

Impervious-surface data were used to assess when substantial development had occurred in a basin, and to define the end of the baseline period. Where impervious surface data were not available, impervious surface was estimated from population density, land use, and other factors. Percentages of impervious surface and land use for drainage areas entirely within New Jersey were derived from geographic information system (GIS) coverages developed from 1986 and 1995-97 digital infrared aerial photos (New Jersey. Department of Environmental Protection, 2000) through use of the Anderson method of classification. This coverage divides land into a series of geographical areas (or GIS polygons) that are each assigned a single land-use classification, including Level I and Level II classifications in the Anderson system (Anderson and others, 1976). Level I classification consists of major categories, including, but not limited to, agricultural, urban, wetland, forested, barren, and water. Level II categories are more specific subcategories within Level I categories and include, for example, low- or high-density residential, deciduous or coniferous forest, or forested or unforested wetland.

For each station, a 30-meter-grid digital elevation coverage of New Jersey was used to create the basin boundary. A 1995/97 land-use coverage, which includes information about land-use changes from 1986, was overlaid on the basin coverage. The 1995-97 land-use data also includes estimates of impervious surface for each land-use polygon (fig. 2). Land-use data for the basins draining into Mahwah River near Suffern, N.Y. (01387450), and Neversink River at Godeffroy, N.Y. (01437500), were not included in this analysis because the data for New York State watersheds were not available at the time of the investigation. The size of each basin and the size of land-use areas within each basin were used to estimate the percentages of agricultural, urban, and undeveloped land, and to estimate the percentage of impervious surface. Percentages of each land-use type were calculated as the sum of the areas of that land-use type divided by the total area of the basin. At the time of this investigation (2006-07), land-use data were not available for areas outside of New Jersey. The drainage basins of eight stations encompass areas outside of New Jersey, and of those stations, five stations have drainage

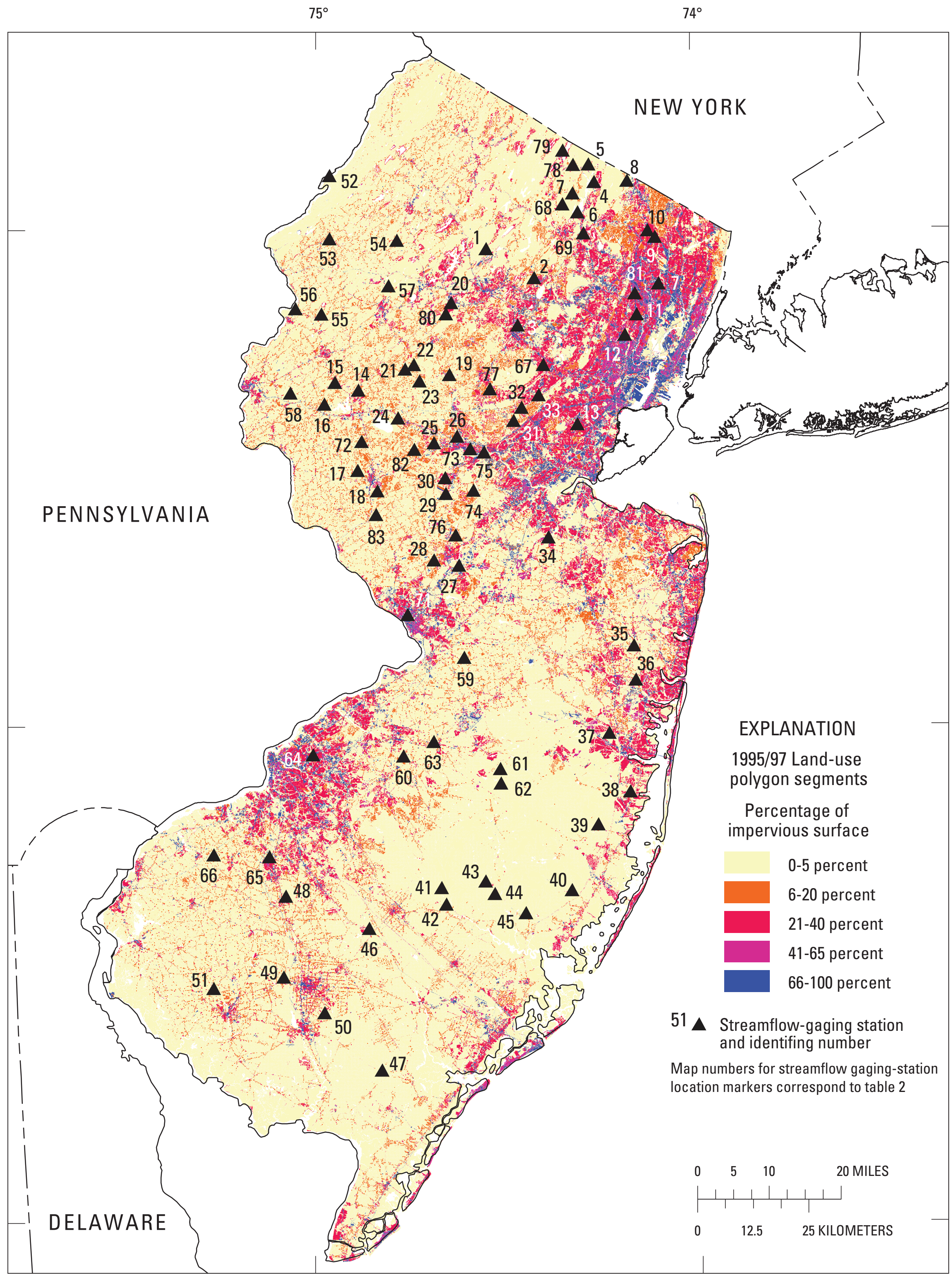


Figure 2. Impervious surface from the 1995/97 land-use coverage for all land-use polygon segments and locations of selected streamflow-gaging stations in New Jersey. (Data from New Jersey Department of Environmental Protection, 2000.)

areas in which more than 50 percent of the basin is in New Jersey. For these stations, the percentage of the basin outside of New Jersey is listed in table 2. The percentages of land use and impervious surface in those basins were calculated by assuming that the percentage of a land-use type in the New Jersey portion of the basin was uniform throughout the entire basin. For the purposes of this investigation it was decided that any error introduced by using this assumption was acceptable because only 8 of the 85 stations were affected.

Impervious surface was not reported in the 1986 land-use survey; therefore, a method of estimating impervious surface from land-use data was developed. For each polygon of the GIS land-use coverage that did not change between the 1986 and 1995/97 coverages, the percentage of impervious surface was assumed to have remained constant. For polygons where the percentages of land use changed, the mean percentage of impervious surface for each Anderson Level II land use represented by the polygon in the 1995/97 land-use coverages was assigned to the 1986 land-use polygons. A list of the mean percentages of impervious surface and standard deviations for all Level II land uses in the New Jersey 1995/97 land-use coverage are listed in table 5. For the 1986 coverage, the fraction of impervious surface of the basin was the sum of impervious surface of each polygon multiplied by the fraction of the basin occupied by that polygon.

For years prior to 1986, only limited land-use and impervious-surface data are available. A 1973 land-use coverage is available (Anderson and others, 1976), but this coverage lacks sufficient Level II land-use data for estimating impervious surface. Therefore, the 1995/97 population-density data from the United States Census Bureau (2007) were used to relate population density to impervious surface, and this relation was used to estimate impervious surface for years that population density data were available. This method is similar to that developed by Stankowski (1972), where population-density data for 570 municipalities were used to estimate impervious-surface data (based on State of New Jersey surveyed land-use data). It was assumed that the relation of impervious surface to population density for municipalities was more strongly correlated than the relation of impervious surface to population density for drainage basins because municipality boundaries contain more homogeneous community structures than are indicated by the land-use patterns within drainage-basin boundaries.

A GIS coverage was created that contained census data, area, and population density for 570 municipalities for 10-year intervals (1930-2000). Population data for each municipality were obtained from historic U.S. Census Bureau archives (United States Census Bureau, 2007). Population density was computed for each municipality by dividing the municipality area by the total population from the census data. Land-use and impervious-surface data for municipalities also were obtained from the 1995/97 GIS coverage in order to correlate impervious surface to population density from the New Jersey municipality GIS coverage. The1995/97 land-use coverage was overlaid on the municipality coverage. The area of the municipality and the area of each land-use type within the municipality were used to compute the land-use percentages for each municipality. The percentage of impervious surface in relation to population density for all municipalities in New Jersey is shown in figure 3. The relation developed by Stankowski (1972) also is shown. A relation (Equation 1) was developed between impervious surface in 1996 and population density using the interpolated population-density information and impervious-surface percentages for municipalities. This regression was developed using a third-order polynomial least-squares regression of the log of values of population density, and predicts an increase in the percentage of impervious surface as a function of increasing population density for population densities between 0 and about 14,000 persons per square mile. The coefficient of determination (r^2) is 0.91.

The relation then was expressed in terms of the impervious surface variable:

$$IE = 10^{((0.26 - (1.2(logP)) + (0.83(logP)^2) - 11\ (logP)^3)} \quad (1)$$

where,

IE = estimated percentage impervious surface and

P = population density, in people per square mile.

The municipality coverage was overlaid on the basin polygon for each gaging station. The area of the basin and the area of each municipality within the basin were used to compute the population density for the basin. Population density for those basins with drainage areas not completely included in New Jersey was estimated by assuming that the population density in the New Jersey portion of the basin represented the density of the entire basin. Population densities for 1986 and 1996 were estimated by linear interpolation of the population densities between 1980 and 1990, and 1990 and 2000, respectively. Using population-density data for each drainage basin, equation 1 was used to estimate percentages of impervious surface.

Not all types of urban development result in increased population density or predictable amounts of impervious surface. For example, according to the 1995/97 Land-use GIS coverage, the impervious surface for Teterboro Borough in Bergen County was 56.0 percent, and the population density was 16.8 people per square mile (United States Census Bureau, 1996). For Cliffside Park Borough, also in Bergen County, the impervious surface was 56.8 percent of the municipality with a population density of 23,486 people per square mile. The large difference in population densities are due to the Teterboro Airport located in the boroughs of Teterboro and Moonachie. The airport covers an area of 1.3 square miles and accounts for 47 percent of the combined area of Teterboro Borough and Moonachie Borough. An airport would have little to no population density but extensive amounts of impervious surface. In order to improve the relation between population density and impervious surface, a correction factor was

Table 5. Means and standard deviations of the percentages of impervious surface for each Type II land use for each polygon segment from the 1995/97 land-use coverage of New Jersey[1].

[>, greater than; <, less than; %, percent]

Type I land-use for polygons	Type II land use for polygons	Mean percentage of impervious surface for all polygons	Standard deviation of the percentage of impervious surface for all polygons
	Recreational Land	25.8	30.2
	Residential, High Density, Multiple Dwelling	57.2	15.2
	Residential, Rural, Single Unit	13.3	4.0
	Residential, Single Unit, Low Density	21.6	2.9
	Residential, Single Unit, Medium Density	32.0	2.9
	Transportation/Communications/Utilities	39.8	36.0
Water	Artificial Lakes	0.0	0.2
	Atlantic Ocean	0.0	0.0
	Dredged Lagoon	0.0	0.0
	Natural Lakes	0.0	0.0
Wetlands	Agricultural Wetlands (Modified)	0.0	0.5
	Atlantic White Cedar Swamp	0.0	0.3
	Coniferous Scrub/Shrub Wetlands	0.0	0.2
	Coniferous Wooded Wetlands	0.0	0.3
	Deciduous Scrub/Shrub Wetlands	0.0	0.3
	Deciduous Wooded Wetlands	0.0	0.6
	Disturbed Wetlands (Modified)	1.0	4.1
	Former Agricultural Wetland (Becoming Shrubby, Not Built-Up)	0.1	0.8
	Freshwater Tidal Marshes	0.0	0.4
	Herbaceous Wetlands	0.0	0.4
	Managed Wetland In Built-Up Maintained Recreation Area	2.1	7.1
	Managed Wetland In Maintained Lawn Greenspace	1.7	4.0
	Mixed Forested Wetlands (Coniferous Dom.)	0.0	0.6
	Mixed Forested Wetlands (Deciduous Dom.)	0.0	0.3
	Mixed Scrub/Shrub Wetlands (Coniferous Dom.)	0.0	0.0
	Mixed Scrub/Shrub Wetlands (Deciduous Dom.)	0.0	0.2
	Mixed Srcub/Shrub Wetlands (Coniferous Dom.)	0.0	0.0
	Saline Marshes	0.0	0.3
	Severe Burned Wetlands	0.0	0.0
	Vegetated Dune Communities	0.2	1.2
	Wetland Rights-Of-Way (Modified)	0.4	3.7

[1]New Jersey Department of Environmental Protection, 2000, 1995/97 Landuse/Landcover by Basin Management Area (WMA): Trenton, N.J., accessed March 15, 2006, at *http://www.state.nj.us/dep/dsr/map-integration/LULC95.htm*.

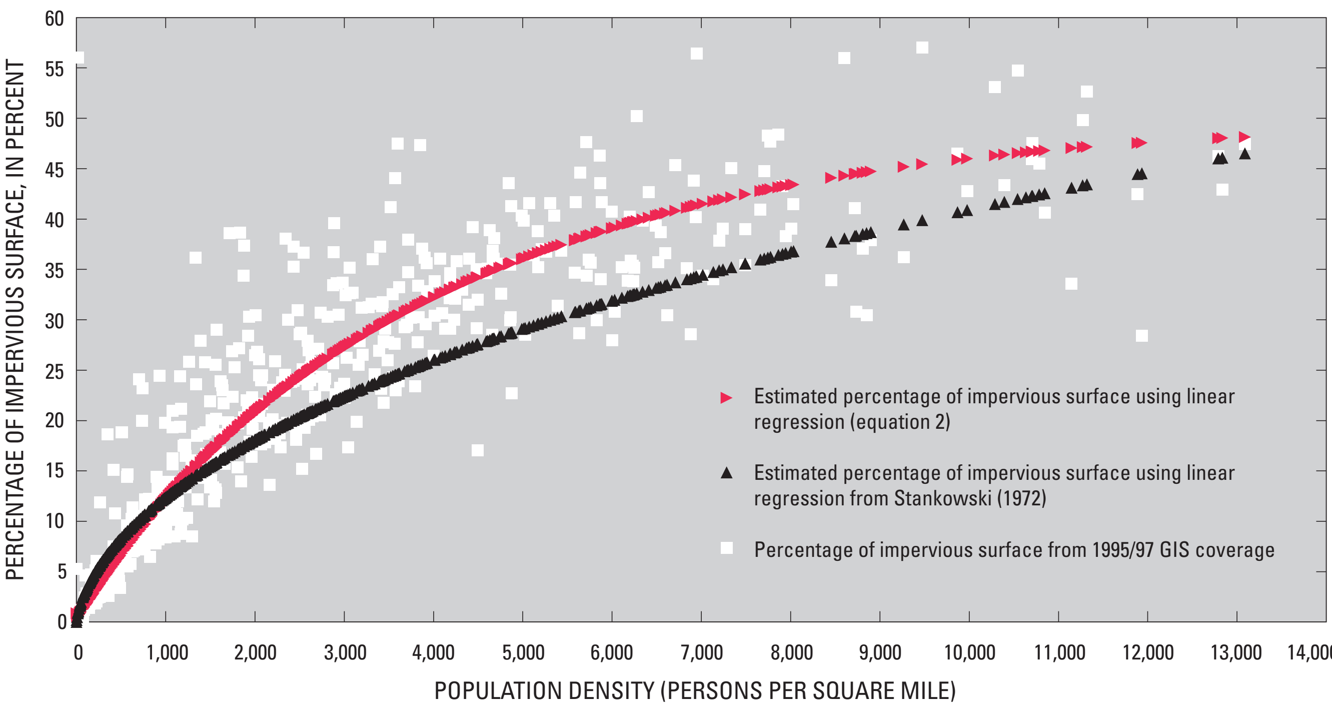


Figure 3. Relation of the percentage of impervious surface from 1995-1997 geographic information system (GIS) digital land-use information to population density in persons per square mile for all 570 municipalities in New Jersey.

(Impervious-surface data were derived from a digital geographic information system coverage of land use in New Jersey during 1995-1997 (New Jersey Department of Environmental Protection, 2000). Municipality and population density information are from U.S. Census Bureau for the years 1930-2000 (U.S. Census Bureau, 2007).)

applied to equation 1 for each basin to account for the land use within drainage basins that are related to impervious surface but not to population density. The adjusted impervious surface estimate IA in equation 2 is a linear interpolation between the impervious surface estimated by population density from equation 1 and that estimated from 1986 and 1995 land use.

$$IA = C^* IE, \tag{2}$$

where

- IA = estimated adjusted impervious surface percentage estimated,
- C = correction factor, and
- IE = estimated impervious surface percentage from equation 1.

The correction factor, C, is used to represent the percentage difference between the impervious surface estimated from population density in equation 1 and from the impervious surface from both the 1986 and 1995/97 land-use coverages. The percentage difference between impervious surface estimated from equation 2 and the impervious surface from the 1986 land-use coverages, and the percentage difference between estimated impervious surface and the 1995/97 land-use coverage, may not be consistent because the relation between population density and impervious surface may have changed between 1986 and 1996 as a result of the higher resolution of the later dataset or due to error inherent in the regression. To account for these differences, a simplified linear calculation of the correction was used to obtain one correction factor. In order to obtain one correction factor, the percentage differences for the two datasets were averaged (equation 3).

$$C = ([(IE_{1986} / (IG_{1986})]+[(IE_{1996} / (IG_{1995/97}]) / 2, \tag{3}$$

where

- IE_{1986} = estimated impervious surface percentage from equation 1 for the estimated population density in 1986 using a linear interpolation of population density between the years 1980 and 1990,
- $IE_{1995/97}$ = estimated impervious surface percentage from equation 1 for the estimated population density in 1996 using a linear interpolation of population density between the years 1990 and 2000,
- IG_{1986} = impervious surface percentage estimated from the 1986 land-use coverage, and
- $IG_{1995/97}$ = impervious surface percentage from the 1995/97 land-use coverage.

Values for IA were calculated by linear interpolation for each selected station for every 10 years from 1930 to 2000 and for every year between decades.

Percentages and changes in impervious surface were then used to help determine baseline periods. Four thresholds of increasing impervious surface were defined:

- Less than 10 percent impervious surface,
- Greater than 10 percent and less than 20 percent impervious surface,
- Greater than 20 percent and less than 15 percent increase in impervious surface, and
- Greater than 20 percent and greater than 15 percent increase in impervious surface.

Ideally, a baseline period would not cross an impervious-surface threshold, indicating a relatively stable percentage of impervious surface during the baseline period. For example, the basin of station 1387500 (Ramapo River at Mahwah, NJ) had less than 10 percent impervious surface in the first year of continuous hydrologic record (1923) The first threshold (greater than 10 percent and less than 20 percent) was not crossed until 1964. This period of 41 years exceeds the minimum baseline period of the station's stream class (class A, 20 years); therefore, the preliminary baseline period was ended at 1964. If the threshold had been reached before the minimum baseline period of record, then additional years of record would have been added until the next threshold was reached. If the minimum period was still not achieved, additional years would be added up to the next threshold, and so on.

The percentage of impervious surface in the drainage basin upstream from each streamflow-gaging station was used to evaluate the quality of the baseline period. A basin having less than 10 percent impervious surface is ranked "excellent," 10 to 20 percent impervious surface with less than 15 percent increase is ranked "good," greater than 20 percent impervious surface with less than 15 percent increase is ranked "fair," and greater than 20 percent impervious surface with greater than 15 percent increase is ranked "poor." A summary of this rating scale is shown in table 6. Results from double-mass analysis (next section) were combined with these rankings to assign final baseline periods and overall baseline-period-quality.

Table 6. Baseline period-of-record quality classification based on estimated impervious surface in selected drainage basins in New Jersey.

[<, less than; >, greater than]

Estimated impervious surface (in percent)	Estimated increase in impervious surface (in percent)	Baseline quality ranking
<10	<10	Excellent
10-20	<15	Good
>20	<15	Fair
>20	>15	Poor

Double-Mass-Curve Analysis

Analysis of covariance of double-mass curves (Searcy and Hardison, 1960) was used as an additional tool for determining baseline periods of record for the 85 gaging stations. A double-mass curve is a linear plot of the cumulative value of one variable as a function of the cumulative value of a second variable. Here, the variables are streamflow at two locations, a test station (x-axis) and an index station (y-axis). Baseline conditions are assumed for the index station for the period of record being tested. An abrupt change in the slope of the double-mass curve, referred to as a "breakpoint," indicates a change in hydrologic conditions at the test station and can be interpreted as the end of the baseline period for that test station. A straight line without breakpoints indicates that the period of record being tested for the test station can be considered "baseline" with respect to the double-mass analysis. The assumption is made that climatological variables will have similar effects on the index station and the test station, and that a breakpoint in the double-mass curve indicates a hydrological change only in the test stream. Double-mass curves were prepared separately for runoff and base-flow data.

Annual total runoff and annual total base flow were calculated by using the HYSEP (Hydrograph Separation) program (Sloto and Crouse, 1996). The method used for hydrograph separation was the Local-Minimum Method (LMM) (Pettyjohn and Henning, 1979). For the three stream classes that are each associated with two index stations, both index stations were subjected to double-mass analysis. The fourth stream class is associated with only one index station.

Analysis of Covariance of the Double-Mass Curve

Analysis of covariance was used to test the significance of potential breakpoints on each double-mass curve, as described by Searcy and Hardison (1960). In this method, a variance-ratio test (or "F-test") (Snedecor, 1934) is used to determine the probability (p) that the null hypothesis of no difference between slopes of the line segments before and after the breakpoint can be rejected with a critical value of $p = 0.05$.

The F-test is sensitive to the variability (scatter) of points in each of the two line segments. Since the F-test compares the variability between periods to variability within periods, comparing line segments with high coefficients of determination (r^2) may lead to the designation of a minor inflection in slope as significant. For example, a double-mass curve for runoff and base flow for Ringwood Creek near Wanaque as a test station and West Brook near Wanaque as an index station is shown in figure 4. Because both sites are stream class C index stations, a double-mass curve should not have any breakpoints; however, several minor breakpoints were detected.

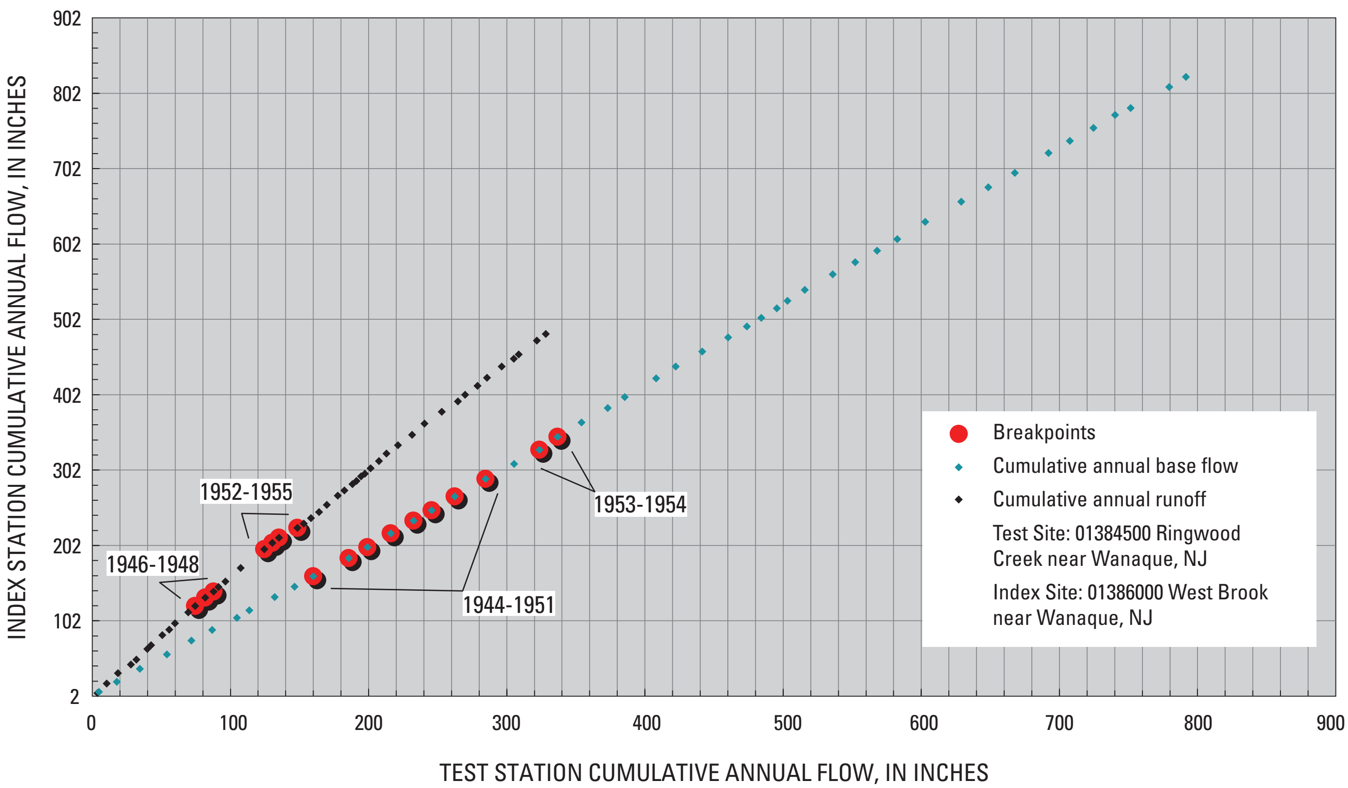


Figure 4. Example of double-mass curves for cumulative annual runoff and base flow at sites with low variability of annual values for selected streamflow gaging stations in New Jersey.

(Breakpoints are changes in the slope of the relation between streamflow at the index station and streamflow at the test station.)

Although the deflection of the slope (quantified by the ratio of regression-line slope before the breakpoint to that after the breakpoint) is statistically significant, these breakpoints do not appear to represent real changes in streamflow. Therefore, in addition to significance as determined by analysis of covariance, slope ratios and visual inspection of double-mass curves were used to determine whether substantial changes in streamflow occurred in years where a breakpoint is identified on a double-mass curve.

Searcy and Hardison (1960) recommend applying the analysis of covariance test only after visually inspecting the double-mass curve to identify possible breakpoints. For this investigation, it was decided that in doing so one might overlook minor breakpoints and identify only the breakpoints that are most apparent visually. Therefore, all points on each double-mass curve were tested as potential breakpoints, and slopes of the line segments before and after each point were compared. This facilitated the interpretation of breakpoints that are not apparent visually as single points but occur as gradual changes in slope, which may occur where land-use changes are gradually altering streamflow characteristics.

Interpretation of Double-Mass Curves

Two double-mass curves were prepared for each stream, one for annual cumulative runoff and the other for annual cumulative base flow. Only test stations that had at least 10 years of record in common with the appropriate index station were subjected to double-mass-curve analysis.

For each double-mass curve, all years in which the analysis-of-covariance critical F-value ($p = 0.05$ significance level) was exceeded were identified as possible breakpoints. Additional possible breakpoints were identified by visual inspection of double-mass curves. A method of assessing overall breakpoint quality was devised, where the criteria were breakpoint appearance, breakpoint prominence, and slope ratio.

Breakpoint appearance is a numerical scale based on a visual assessment of whether the change in streamflow at the test station relative to that of the index station was abrupt or gradual, and of the severity of inflection. A single, distinct breakpoint can indicate a substantial change in the basin, such as regulation of a stream leading to immediate increases in discharge during low flow or decreases during peak flow. A slight but gradual inflection at the breakpoint, often accompanied by other significant breakpoints of lower inflection, could indicate a gradual change in the basin, such as a slowly increasing percentage of urban land use leading to a gradual increase in runoff and decrease in base flow. Breakpoint appearance scores were assigned as follows:

- Breakpoint-appearance score of 5: Inflection is strongly distinct and associated with a single breakpoint,
- Breakpoint-appearance score of 4: Inflection is moderately distinct and associated with a single breakpoint,
- Breakpoint-appearance score of 3: Inflection is moderately distinct and associated with more than one breakpoint,
- Breakpoint-appearance score of 2: Inflection is slight but distinct and associated with a single breakpoint,
- Breakpoint-appearance score of 1: Inflection is slight and gradual or curved, and
- Breakpoint-appearance score of 0: No inflection is visible.

Breakpoint prominence is a numeric scale used to assess the strength of each breakpoint relative to other breakpoints on the same double-mass curve. Where more than one significant breakpoint is present, this scale is used to decide when the most substantial change in hydrological conditions occurred at the test station and to assign the beginning or end of the baseline period. Breakpoint-prominence scores were assigned as follows:

- Breakpoint prominence score of 4: Breakpoint has the highest F-values and is the most visually prominent breakpoint on the double-mass curve;
- Breakpoint-prominence score of 3: Breakpoint has the highest F-values but is not the most visually prominent breakpoint on the double-mass curve, or breakpoint does not have the highest F-value but is the most visually prominent;
- Breakpoint-prominence score of 2: Breakpoint does not have the highest F-value and was not the most visually prominent breakpoint on the double-mass curve, or breakpoint has the highest F-value, but the correlation between the cumulative discharge at the index station and the test station was weak; and
- Breakpoint-prominence score of 1: Any additional breakpoints identified by visual inspection or by analysis-of-covariance hypothesis testing that are less prominent than a breakpoint that has a score of 2.

Breakpoint-slope ratio is defined as the slope of the regression line after the breakpoint, divided by the slope of the regression line before the breakpoint. A slope ratio of greater than 1 indicates a decrease in flow relative to the flow at the index station; a slope ratio of less than 1 indicates an increase in flow. The slope ratio is an indication of the magnitude of a breakpoint. A rating system of slope ratios was devised, where

- Breakpoint-slope ratios score of 1: Slope ratio 0.9-1.1,
- Breakpoint-slope ratios score of 2: Slope ratio 0.7-0.9 and 1.1-1.3,
- Breakpoint-slope ratios score of 3: Slope ratio 0.5-0.7 and 1.3-1.5, and
- Breakpoint-slope ratios score of 4: Slope ratio less than 0.5 or greater than 1.5.

The three criteria (breakpoint appearance, breakpoint prominence, and slope ratio) were used with Equation 4 to calculate an overall breakpoint rating for each breakpoint:

$$BR = (BA/BP + SR/BP), \quad (4)$$

where

BR	=	breakpoint rating, the final weighted score used to determine the relative strength of the breakpoint on the double-mass curve,
BA	=	score for breakpoint appearance,
BP	=	score for breakpoint prominence, and
SR	=	score for slope ratio.

A breakpoint rating of 0 to 8 indicates that the apparent breakpoint was not significant, a value of 9 to 15 indicates a weak breakpoint, a value of 16 to 22 is considered a moderate breakpoint, a value of 22 to 32 is considered a strong breakpoint, and a value greater than 32 is considered very strong.

Baseline Period of Record Determination from Double-Mass Analysis

The year in which the earliest substantial breakpoint was identified was considered the end of the baseline period if the minimum period of record was equaled or exceeded. Typically, the earlier period before a significant breakpoint was considered the baseline period unless historical information or other evidence indicated that a later range of years should be used as the baseline period. If the minimum period of record included a year that was considered a significant breakpoint, the earliest minimum period of record was used as baseline, but the quality of the baseline period was rated as poor.

Ranking the Baseline Period

After the three baseline determination procedures were completed (historical information, land use, and double-mass analysis), results were combined to assign a baseline period of record for each station (figure 5). A ranking (excellent, good, fair, or poor) was then assigned to each baseline period.

Preliminary baseline periods were first determined by analyzing historical information for each station (step 1). Then all years that were considered baseline were analyzed further by evaluating historical land use (step 2) and by using analysis

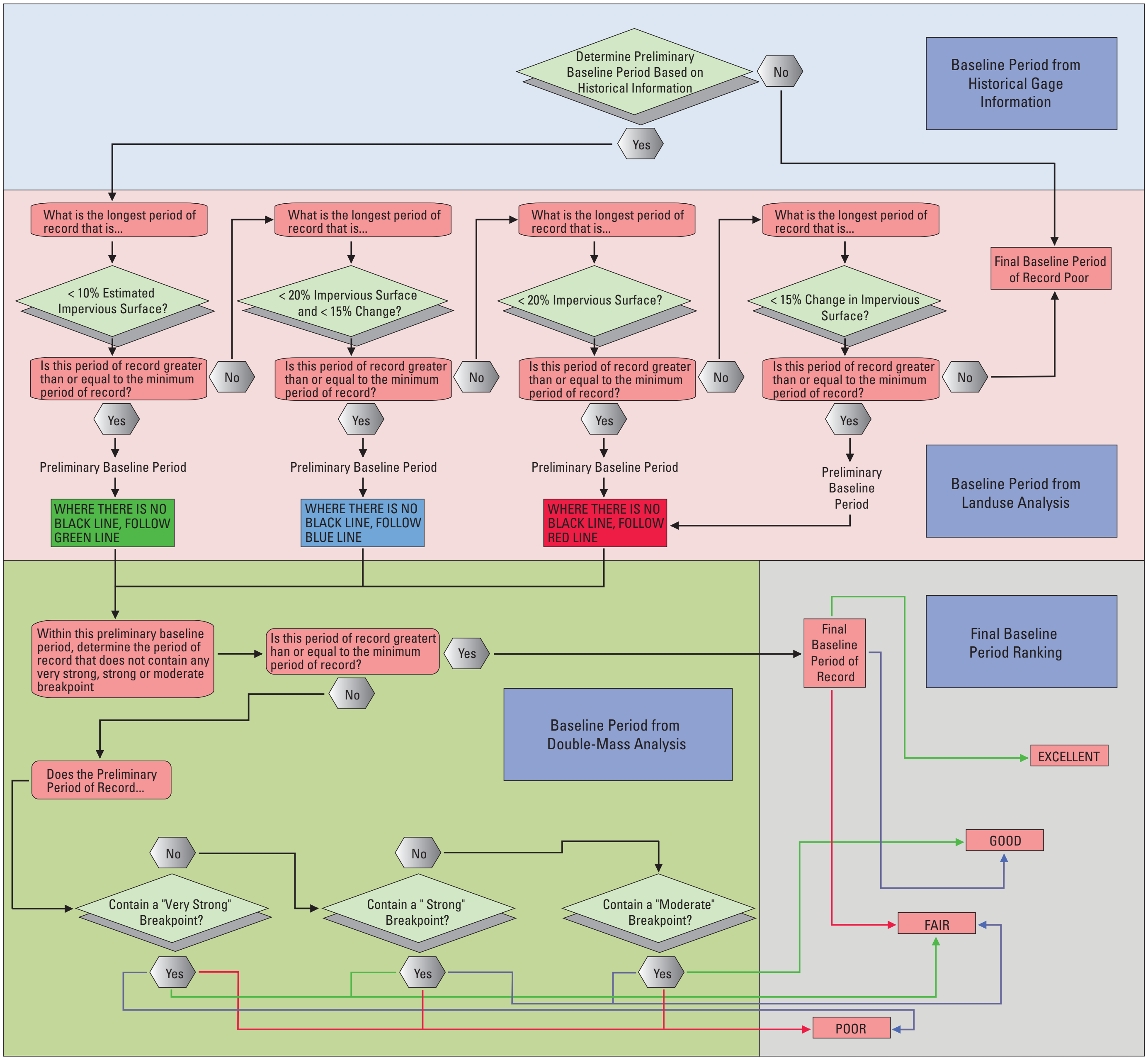


Figure 5. Flowchart showing the steps for determining baseline periods and the quality of baseline period.

of covariance of double-mass curves (step 3). If the preliminary baseline period determined in step 1 was less than the minimum period of record, it was categorized as poor.

For the latter two steps, the record was not reduced below the minimum period of record for any reason, but the quality of the baseline period was determined by how many impervious surface criteria thresholds were exceeded (10 percent, 20 percent, or a change in impervious surface that exceeds 15 percent since the start of the period of record) and how many breakpoints (weak, strong, or very strong) were evident within the minimum period of record.

Determination of Baseline Period for 85 Selected Streamflow-Gaging Stations

Baseline periods were quantified for each streamflow-gaging station by determining the minimum period of record for the stream class that the station belongs to, analyzing the history of the station and its basin, and conducting a double-mass-curve analysis.

Minimum Period of Record

Results from the Kruskall-Wallis test for 5-,10-, 15- and 20-year periods at the seven index sites with stream classes A, B, C and D are listed in table 7. For each index station, a Kruskall-Wallis p-value was calculated to test the null hypothesis of no difference among index values calculated for each 5-, 10-, 15- and 20-year increments of the period of record. The critical p-value was set at 0.05. A conservative approach was taken in assigning the minimum period of record based on these results by selecting the sub-period with the least number of years in which the null hypothesis was accepted for all temporal hydrologic indices.

Based on these results, a minimum period of record of 10 years was applied for stations that are considered stream classes B or C, and a minimum period of record of 20 years was applied for stations that are considered stream classes A or D. For stream class B, the results indicate that there is no difference in the periods of record, but 10 years was selected as a minimum period of record owing to guidelines suggesting the minimum use of 10 years for all frequency and duration statistics (Hofmann, 1973), which are used to compute values of many ERHIs.

Historical Analysis

The preliminary historical baseline periods for 85 streamflow-gaging stations, with a general summary of the human alterations along the stream or in the drainage basin are presented in table 8. Details on historical flow for each station along with considerations in the determination of the historical baseline period are provided in appendix 1

Land-Use/Land-Cover and Impervious Surface

The percentages of Level I land use from the 1995/97 land-use coverage are listed in table 2, and the estimated percentages of impervious surface from 1986 and 1995/97 land-use data are listed in table 9. The years in which the percentage of impervious surface was estimated to have exceeded thresholds (previously defined) are shown in table 10.

The estimated average population densities from 1930 to 2000 for the drainage basin areas of 83 stations are listed in table 11. For 22 of the 83 drainage basins, the impervious surface exceeded 10 percent of the area for part or all of the period of record. For 11 basins, the value exceeded 20 percent.

In order to estimate the year that the percentage of impervious surface changed by 15 percent from the first year of the continuous period of record for stations where the period of record started before 1930, the exponential relation between population density and impervious surface (figure 3) was used to estimate the impervious surface for the first year of record. Then the subsequent year for which the population density indicated a 15 percent increase in impervious surface was identified. For example, the impervious surface increased 15 percent at Ramapo River near Mahwah (01387500) (from 2.6 percent to 17.6 percent between 1923 and 1981).

Evaluation of Breakpoints on Double-Mass Curves

The 85 streamflow-gaging stations used to develop double-mass curves to relate cumulative annual streamflow to that at the index station are listed in table 12. The number of years of record available for each station, the index stations used to develop double-mass curves, and whether or not double-mass analysis was performed also are listed. Results of double-mass analysis for 85 gages are presented in tables 13 and 14. The years of record for the test station must coincide with the years of record for the index station in order to develop a meaningful double-mass curve. Stations from stream class A had an average of 67 years of record, stations from stream class B had an average of 57 years, stations from stream class C had an average of 30 years, and stations from stream class D had an average of 19 years.

Double-mass curves were created for the 85 stations that had 10 or more years of record in common with the appropriate index station. Of these, 67 stations had one or more statistically significant breakpoints for either the base-flow or runoff datasets. Several stations had multiple significant breakpoints. Each breakpoint was visually inspected and selected for further analysis if the curve indicated a substantial change took place in the slope, or if the analysis of covariance identified the point as being the most significant breakpoint on the double-mass plot. Using these criteria, 64 stations with significant breakpoints were selected for further evaluation (table 13). These stations were assigned values for breakpoint appearance, slope ratio, and breakpoint prominence scores. A final rating then was calculated for each breakpoint.

Results of the rating of all breakpoints that were considered “moderate” or stronger are given in table 14. Those breakpoints that were interpreted as “weak” were not considered for determination of the baseline period. Of a total of 64 sites with statistically significant breakpoints selected for further analysis, 36 sites had breakpoints that were “moderate” or stronger.

Three stations had prominently visible breakpoints that were not significant according to the analysis of covariance unless one or more years of record were not considered in the analysis. The station at Raritan River below Calco Dam at Bound Brook (01403060), when related to index station 01443500 (Paulins Kill at Blairstown) had a significant breakpoint in 1981 but only when cumulative annual runoff data from 1944 -1960 were not considered. Similarly, the station at Crosswicks Creek at Extonville (01464500), when related to index station 01443500 (Paulins Kill at Blairstown), had a significant breakpoint only when data from 1939 to 1958 were not considered. This breakpoint had a p-value of 0.0008 and an F-value of 13.1. The station at Musconetcong River

Table 7. Results of the Kruskall-Wallis test to determine the probability of no difference among groups of numbers of years for seven index stations for each primary hydrologic index type for class A, B, C and D, and the minimum number of years for a baseline period[1].

[Index type, specific primary indices selected for analysis for each stream type are grouped into elements of the flow regime (magnitude, frequency, duration, and rate of change) and type of flow (average, low, and high) where appropriate; p-value, probability that there is no difference in distribution of index values for the given time period, values highlighted in red are less than 0.05 and indicate that the null hypothesis can be rejected; NA, the distribution of index values in the dataset analyzed contained many index values that were equal to zero; therefore, the analysis of variance was not meaningful; --, there were no hydrologic indices selected for analysis that were defined by the index type]

Stream class[2]	Index Station and duration of test period			Index type and p-value								Minimum years selected[4]
	Station number	Station name	Number of years	Magnitude			Frequency[3]		Duration[3]		Rate of change[3]	
				Average	Low	High	Low	High	Low	High	(average)	
A	01440000	Flat Brook near Flatbrookville	5	<0.01	<0.01	<0.01	NA	<0.01	<0.01	<0.01	0.08	20
			10	0.03	0.03	0.02	NA	0.10	0.35	0.04	0.99	
			15	0.04	0.03	0.11	NA	0.24	0.06	0.20	0.97	
			20	0.96	0.73	0.41	NA	0.13	0.70	0.37	0.99	
	01443500	Paulins Kill at Blairstown	5	<0.01	<0.01	<0.01	NA	<0.01	<0.01	<0.01	0.85	
			10	0.02	<0.01	0.01	NA	0.35	0.10	0.05	0.92	
			15	0.01	0.01	0.01	NA	0.52	0.05	0.52	0.88	
			20	0.63	0.39	0.04	NA	0.52	0.34	0.25	0.96	
B	01409500	Batsto River at Batsto	5	--	--	--	NA	0.43	--	0.22	0.82	10
			10	--	--	--	NA	0.58	--	0.65	0.75	
			15	--	--	--	0.41	0.84	--	0.89	0.65	
			20	--	--	--	NA	0.54	--	0.62	0.58	
	01410000	Oswego River at Harrisville	5	--	--	--	NA	<0.01	--	0.17	0.99	
			10	--	--	--	0.57	0.09	--	0.34	0.99	
			15	--	--	--	0.56	0.35	--	0.53	0.98	
			20	--	--	--	NA	0.76	--	0.65	0.94	
C	[5]01384500	Ringwood Creek near Wanaque	5	<0.01	<0.01	<0.01	0.04	<0.01	0.26	<0.01	0.98	10
			10	0.13	0.87	0.21	0.14	0.66	0.99	0.27	0.99	
			15	0.12	0.01	0.45	0.01	0.17	0.43	0.59	1.00	
	01386000	West Brook near Wanaque	5	0.01	0.02	0.19	0.80	0.40	0.55	0.01	1.00	
			10	0.07	0.70	0.67	0.67	0.58	0.77	0.61	0.97	
			15	0.30	0.54	0.74	0.79	0.51	0.79	0.63	0.95	
			20	0.36	0.88	0.50	0.87	0.73	0.94	0.65	0.71	
D	01466500	Mcdonalds Branch in Lebanon State Forest	5	--	--	--	NA	0.03	0.00	--	0.98	20
			10	--	--	--	NA	0.12	0.00	--	0.90	
			15	--	--	--	NA	0.12	0.00	--	0.90	
			20	--	--	--	NA	0.37	0.03	--	0.97	

[1] A list of the indices used for determining minimum periods of record is given in table 4.

[2] Stream classes are statistically similar groupings of streams based on a cluster analysis of selected ecologically relevent hydrologic streamflow statistics and are described in Henriksen and others (2006).

[3] The minimum number of years for a baseline period is defined here as the least number of years for which the null hypothesis was not rejected for all hydrologic indices used in the analysis.

[4] There are no hydrologic indices in this analysis which describe the frequency or duration of average flow or the rate of change of high or low flow.

[5]Comparison of differences in index value distribution was not performed for a 20-year increment because a 10-year increment was determined to be sufficient as the minimum number of years for the baseline period.

Table 8. Preliminary baseline periods for 85 streamflow-gaging stations in New Jersey and supporting data.

[Data were obtained from U.S. Geological Survey (USGS) annual data reports for given years and from information provided by staff of the New Jersey Water Science Center; NA, no substantial or known human activity occurred during the continuous period of record that could be used to define a baseline period; SB, South Branch; NB, North Branch]

USGS station identifier	Station name	Complete period of record[1,2]	Type of alteration to the basin or stream	Period of alteration	Preliminary baseline period[1,2]
01379000	Passaic River near Millington, NJ	1903–2005	Regulation	1980–2005	1903–1979
01379500	Passaic River near Chatham, NJ	1903–1911, 1938–2005	Diversions and effluent	1971–2005	1938–1970
01379773	Green Pond Brook at Picatinny Arsenal, NJ	1983–2005	NA	NA	1983–2005
01380500	Rockaway River Above Reservoir at Boonton, NJ	1937–2005	NA	NA	1937–2005
01381500	Whippany River at Morristown, NJ	1921–2005	Stormwater management	1971–2005	1921–1970
01383500	Wanaque River at Awosting, NJ	1919–2005	Diversions	1969–2005	1919–1968
01384000	Wanaque River at Monks, NJ	1934–1985	NA	NA	1934–1985
01384500	Ringwood Creek near Wanaque, NJ	1934–1979, 1985–2005	NA	NA	1934–2004
01385000	Cupsaw Brook near Wanaque, NJ	1934–1958	NA	NA	1934–1958
01386000	West Brook near Wanaque, NJ	1934–1978	NA	NA	1934–1978
01386500	Blue Mine Brook near Wanaque, NJ	1934–1958	NA	NA	1934–1958
01387000	Wanaque River at Wanaque, NJ	1912–1914, 1918–2005	Regulation and effluent	1929–2005	1918–1928
01387450	Mahwah River near Suffern, NY	1958–1995, 2005	NA	NA	1958–1995
01387500	Ramapo River near Mahwah, NJ	1902–1906, 1923–2005	Ground–water withdrawals	1979–2005	1923–1979
01388000	Ramapo River at Pompton Lakes, NJ	1921–2005	Diversions	1953–2005	1921–1953
01390500	Saddle River at Ridgewood, NJ	1954–1977, 1979–2005	Ground–water withdrawals	1965–2005	1954–1964
01391000	Hohokus Brook at Ho–Ho–Kus, NJ	1954–1973, 1978–1996, 2003–2005	Effluent	1974–2005	1954–1973
01391500	Saddle River at Lodi, NJ	1923–2005	Regulation, diversion, and ground–water withdrawal	1961–2005	1923–1965
01392000	Weasel Brook at Clifton, NJ	1937–1962	Regulation and stormwater management	1952–1962	1937–1951
01392210	Third River at Passaic, NJ	1977–1997	NA	NA	1977–1997
01392500	Second River at Belleville, NJ	1937–1964	NA	NA	1937–1964
01396000	Robinsons Branch at Rahway, NJ	1939–1996	Diversions	1939–1969	1970–1996
01396500	South Branch Raritan River near High Bridge, NJ	1918–2005	Regulation and development	1971–2005	1918–1970
01396580	Spruce Run at Glen Gardner, NJ	1978–1988, 1991–2005	NA	NA	1978–2005
01396660	Mulhockaway Creek at Van Syckel, NJ	1977–2005	NA	NA	1977–2005
01397000	SB Raritan River at Stanton, NJ	1903–1905, 1919–2005	Regulation and diversion	1964–2005	1919–1963
01397500	Walnut Brook near Flemington, NJ	1936–1961	NA	NA	1936–1961
01398000	Neshanic River at Reaville, NJ	1930–2005	NA	NA	1930–2004
01398045	Back Brook Tributary near Ringoes, NJ	1977–1988	NA	NA	1977–1988
01398107	Holland Brook at Readington, NJ	1978–1996	NA	NA	1978–1996

Table 8. Preliminary baseline periods for 85 streamflow-gaging stations in New Jersey and supporting data.—Continued

[Data were obtained from U.S. Geological Survey (USGS) annual data reports for given years and from information provided by staff of the New Jersey Water Science Center; NA, no substantial or known human activity occurred during the continuous period of record that could be used to define a baseline period; SB, South Branch; NB, North Branch]

USGS station identifier	Station name	Complete period of record[1,2]	Type of alteration to the basin or stream	Period of alteration	Preliminary baseline period[1,2]
01398500	NB Raritan River near Far Hills, NJ	1921–2005	NA	NA	1921–2005
01399190	Lamington (Black) River at Succasunna, NJ	1976–1987	NA	NA	1976–1987
01399200	Lamington (Black) River near Ironia, NJ	1975–1987	NA	NA	1975–1987
01399500	Lamington (Black) River near Pottersville, NJ	1921–2005	NA	NA	1921–2004
01399510	Upper Cold Brook near Pottersville, NJ	1972–1996	Regulation	1972–1981	1982–1996
01399525	Axle Brook near Pottersville, NJ	1977–1988	NA	NA	1977–1988
01399670	South Branch Rockaway Creek at Whitehouse Station, NJ	1977–2005	NA	NA	1977–2005
01400000	North Branch Raritan River near Raritan, NJ	1923–2005	NA	NA	1923–2004
01400350	Macs Brook at Somerville, NJ	1982–1996	Regulation and stormwater management[3]	NA	1982–1992
01400500	Raritan River at Manville, NJ	1903–1907, 1921–2005	Regulation and diversion	1965–2005	1921–1964
01400730	Millstone River at Plainsboro, NJ	1964–1975, 1987–1989	NA	NA	1964–1975
01401000	Stony Brook at Princeton, NJ	1953–2005	Effluent	1981–2005	1953–1980
01401500	Millstone River near Kingston, NJ	1933–1949	NA	NA	1933–1949
01401650	Pike Run at Belle Mead, NJ	1979–2005	Development[3]	1979–2005	1979–2005
01402000	Millstone River at Blackwells Mills, NJ	1921–2005	Sewage effluent	1961–2005	1921–1960
01402600	Royce Brook Tributary near Belle Mead, NJ	1966–1975, 1980–1996	Regulation	1981–1996	1966–1980
01403060	Raritan River Below Calco Dam at Bound Brook, NJ	1903–1909, 1945–2005	Regulation	1964–2005	1902–1963
01403400	Green Brook at Seeley Mills, NJ	1978–2005	NA	NA	1979–2005
01403535	East Branch Stony Brook at Best Lake at Watchung, NJ	1980–2000	NA	NA	1980–2000
01403540	Stony Brook at Watchung, NJ	1974–2005	Channel alteration	1992–2005	1974–1991
01405300	Matchaponix Brook at Spotswood, NJ	1957–1967	NA	NA	1957–1967
01408000	Manasquan River at Squankum, NJ	1931–2005	Regulation	1990–2005	1931–1989
01408120	North Branch Metedeconk River near Lakewood, NJ	1972–2005	NA	NA	1972–2005
01408500	Toms River near Toms River, NJ	1928–2005	Diversion and Regulation	1967–2005	1928–1966
01409000	Cedar Creek at Lanoka Harbor, NJ	1932–1958, 1969–1971, 2003–2005	NA[4]	NA	1932–1958
01409095	Oyster Creek near Brookville, NJ	1965–1985	NA	NA	1965–1985
01409280	Westecunk Creek at Stafford Forge, NJ	1973–1988, 2003–2005	NA	NA	1973–1988
01409400	Mullica River near Batsto, NJ	1957–2005	NA	NA	1957–2005
01409500	Batsto River at Batsto, NJ	1927–2005	NA	NA	1927–2005
01409810	West Branch Wading River near Jenkins, NJ	1974–1996, 2006–2005	NA	NA	1974–2005

Table 8. Preliminary baseline periods for 85 streamflow-gaging stations in New Jersey and supporting data.—Continued

[Data were obtained from U.S. Geological Survey (USGS) annual data reports for given years and from information provided by staff of the New Jersey Water Science Center; NA, no substantial or known human activity occurred during the continuous period of record that could be used to define a baseline period; SB, South Branch; NB, North Branch]

USGS station identifier	Station name	Complete period of record[1,2]	Type of alteration to the basin or stream	Period of alteration	Preliminary baseline period[1,2]
01410000	Oswego River at Harrisville, NJ	1930–2005	NA	NA	1930–2005
01410150	East Branch Bass River near New Gretna, NJ	1978–2005	NA	NA	1978–2005
01411000	Great Egg Harbor River at Folsom, NJ	1925–2005	NA	NA	1925–2005
01411300	Tuckahoe River at Head of River, NJ	1969–2005	NA	NA	1969–2005
01411456	Little Ease Run near Clayton, NJ	1987–2005	NA	NA	1987–2005
01411500	Maurice River at Norma, NJ	1932–2005	NA	NA	1932–2005
01412000	Menantico Creek near Millville, NJ	1931–1985	NA[5]	NA	1931–1957
01412800	Cohansey River at Seeley, NJ	1977–1988, 2003–2005	NA	NA	1977–1988
01437500	Neversink River at Godeffroy, NY	1937–2005	Regulation	1954–2005	1937–1953
01440000	Flat Brook near Flatbrookville, NJ	1923–2005	NA	NA	1923–2005
01443500	Paulins Kill at Blairstown, NJ	1921–2005	NA	NA	1921–2005
01445000	Pequest River at Huntsville, NJ	1939–1962	NA	NA	1939–1962
01445500	Pequest River at Pequest, NJ	1921–2005	Channel alteration	1959–2005	1921–1958
01446000	Beaver Brook near Belvidere, NJ	1922–1961	NA	NA	1922–1961
01456000	Musconetcong River near Hackettstown, NJ	1921–1973	NA	NA	1921–1973
01457000	Musconetcong River near Bloomsbury, NJ	1903–1907, 1921–2005	NA	NA	1903–2005
01464000	Assunpink Creek at Trenton, NJ	1923–2005	Diversion	1954–2005	1923–1954
01464500	Crosswicks Creek at Extonville, NJ	1940–2005	NA	NA	1940–2005
01465850	South Branch Rancocas Creek at Vincentown, NJ	1961–1975	NA	NA	1961–1975
01466000	Middle Branch Mt Misery Brook In Lebanon State Forest, NJ	1952–1964	NA	NA	1952–1964
01466500	Mcdonalds Branch in Lebanon State Forest, NJ	1953–2005	NA	NA	1953–2005
01467000	North Branch Rancocas Creek at Pemberton, NJ	1921–2005	NA	NA	1921–2005
01467081	South Branch Pennsauken Creek at Cherry Hill, NJ	1967–2005	NA	NA	1967–2005
01475000	Mantua Creek at Pitman, NJ	1940–1976, 2003–2005	NA	NA	1940–1976
01477120	Raccoon Creek near Swedesboro, NJ	1966–2005	NA	NA	1966–2005

[1]Period of record ends at the last complete year of streamflow data.

[2]Indicates water year, which is the 12-month period beginning October 1 and ending September 30 and is named for the year in which it ends.

[3]The entire period of record was affected by this human activity.

[4] No substantial known human activity during the longest portion of the continuous period of record (1932-1958).

[5] No substantial known human activity during the longest portion of the continuous period of record (1931-1957).

Table 9. Estimated percentages of impervious surface and correction factors for drainage basins of selected streamflow-gaging stations in New Jersey.

[--, no analysis]

USGS station identifier	Impervious surface from 1986 land-use coverage (in percent)	Impervious surface for 1986 estimated by regression (in percent)	Correction factor for 1986[1]	Impervious surface from 1995/97 land-use coverage (in percent)	Impervious surface for 1996[2] estimated by regression (in percent)	Correction factor for 1996[3]	Final correction factor[4]
01379000	8.7	8.7	1.0	9.2	9.4	1.0	1.0
01379500	11.1	10.6	1.0	12.1	11.6	1.0	1.0
01379773	2.7	5.9	0.5	2.8	6.3	0.4	0.5
01380500	8.6	10.0	0.9	9.5	10.9	0.9	0.9
01381500	14.6	16	0.9	15.8	16.8	0.9	0.9
01383500	5.3	4.2	1.3	5.6	4.6	1.2	1.2
01384000	3.7	4.4	0.8	3.9	4.6	0.9	0.8
01384500	1.3	5.7	0.2	1.6	5.6	0.3	0.3
01385000	5.4	6.2	0.9	5.4	6.0	0.9	0.9
01386000	3.2	5	0.6	3.6	5.1	0.7	0.7
01386500	1.0	8.6	0.1	1.0	8.4	0.1	0.1
01387000	3.3	5.5	0.6	3.6	5.7	0.6	0.6
01387450	--	--	--	--	--	--	--
01387500	18.4	7	2.6	20.8	9.9	2.1	2.4
01388000	11.0	5.4	5.4	5.4	5.4	5.4	5.4
01390500	16.0	16.4	1.0	16.8	16.3	1.0	1.0
01391000	22.1	20.7	1.1	23.4	21.7	1.1	1.1
01391500	25.3	23.7	1.1	26.1	24.2	1.1	1.1
01392000	41.6	39.9	1.0	41.5	40.8	1.0	1.0
01392210	34.6	42.1	0.8	34.6	41.9	0.8	0.8
01392500	39.9	44.6	0.9	40.1	44.9	0.9	0.9
01396000	25.1	2.9	8.7	26.0	3.5	7.4	8.0
01396500	5.8	6.4	0.9	6.6	7.1	0.9	0.9
01396580	2.9	3.7	0.8	3.3	4.1	0.8	0.8
01396660	3.8	2.9	1.3	4.7	3.5	1.4	1.3
01397000	4.9	5	1.0	5.6	5.7	1.0	1.0
01397500	2.8	8.7	0.3	3.2	9.4	0.3	0.3
01398000	3.7	4	0.9	4.8	5.1	0.9	0.9
01398045	1.5	2.2	0.7	1.6	2.4	0.7	0.7
01398107	4.5	3.8	1.2	5.3	4.5	1.2	1.2
01398500	4.6	6.6	0.7	5.2	7.4	0.7	0.7
01399190	5.3	4.3	1.2	5.6	4.7	1.2	1.2
01399200	12.4	11.8	1.0	13.2	13.4	1.0	1.0
01399500	6.6	6.9	1.0	7.1	7.9	0.9	0.9
01399510	2.4	3.0	0.8	2.6	3.6	0.7	0.8
01399525	0.9	3	0.3	1.2	4.8	0.3	0.3
01399670	6.5	4.6	1.4	7.6	5.5	1.4	1.4
01400000	5.4	5	1.1	6.2	5.9	1.0	1.1
01400350	14.8	11.8	1.3	25.9	13.1	2.0	1.6
01400500	5.5	5.5	1.0	6.3	6.5	1.0	1.0
01400730	6.9	8.8	0.8	8.3	9.3	0.9	0.8
01401000	4.4	6	0.7	4.7	6.9	0.7	0.7
01401500	7.5	8.7	0.9	9.0	10.1	0.9	0.9
01401650	7.6	6	1.3	7.6	7.9	1.0	1.1
01402000	5.4	8.6	0.6	5.4	10.0	0.5	0.6

Table 9. Estimated percentages of impervious surface and correction factors for drainage basins of selected streamflow-gaging stations in New Jersey.—Continued

[--, no analysis]

USGS station identifier	Impervious surface from 1986 land-use coverage (in percent)	Impervious surface for 1986 estimated by regression (in percent)	Correction factor for 1986[1]	Impervious surface from 1995/97 land-use coverage (in percent)	Impervious surface for 1996[2] estimated by regression (in percent)	Correction factor for 1996[3]	Final correction factor[4]
01402600	34.3	6.2	5.5	38.8	6.8	5.7	5.6
01403060	--	--	--	--	--	--	--
01403400	12.5	20.3	0.6	13.3	21.1	0.6	0.6
01403535	10.4	10.6	1.0	11.1	13.2	0.8	0.9
01403540	11.3	9.4	1.2	12.6	9.9	1.3	1.2
01405300	11.2	10.3	1.1	13.5	12.8	1.1	1.1
01408000	7.9	8.9	0.9	9.7	10.9	0.9	0.9
01408120	10.0	8.2	1.2	11.3	10.4	1.1	1.2
01408500	3.9	5.9	0.7	4.7	7.1	0.7	0.7
01409000	1.3	3.6	0.3	1.5	4.3	0.3	0.3
01409095	0.3	2.5	0.1	0.4	3.0	0.1	0.1
01409280	0.1	2.2	0.1	0.1	2.9	0.0	0.0
01409400	1.4	4	0.4	1.5	4.5	0.3	0.3
01409500	0.9	1.8	0.5	1.1	1.9	0.6	0.5
01409810	0.2	0.8	0.2	0.2	0.7	0.2	0.2
01410000	0.1	1.7	0.1	0.1	2.1	0.1	0.1
01410150	0.5	0.7	0.7	0.5	0.7	0.7	0.7
01411000	7.1	7.6	0.9	8.7	9.3	0.9	0.9
01411300	0.6	1.4	0.5	0.7	1.7	0.4	0.4
01411456	4.9	12.5	0.4	5.4	14.3	0.4	0.4
01411500	4.9	6.3	0.8	5.6	6.9	0.8	0.8
01412000	6.4	8.2	0.8	7.0	8.4	0.8	0.8
01412800	2.0	2.6	0.8	2.3	2.7	0.9	0.8
01437500	--	--	--	--	--	--	--
01440000	0.5	0.9	0.5	0.5	1	0.5	0.5
01443500	2.7	3.2	0.8	3.0	3.5	0.9	0.9
01445000	2.7	3.6	0.8	3.0	4	0.8	0.8
01445500	2.3	2.8	0.8	2.6	3.2	0.8	0.8
01446000	1.8	1.6	1.1	2.0	1.8	1.1	1.1
01456000	5.8	8.9	0.6	6.3	9.3	0.7	0.7
01457000	4.9	7	0.7	5.4	7.5	0.7	0.7
01464000	13.5	13.7	1.0	14.9	14.7	1.0	1.0
01464500	4.3	3.9	1.1	4.5	3.8	1.2	1.1
01465850	2.1	2.7	0.8	2.2	2.7	0.8	0.8
01466000	0.2	13.7	0.0	0.0	14.7	0.0	0.0
01466500	0.0	0.7	0.0	0.0	0.6	0.0	0.0
01467000	2.6	4.9	0.5	2.5	4.9	0.5	0.5
01467081	35.6	22.8	1.6	39.6	24.1	1.6	1.6
01475000	13.4	18.5	0.7	18.3	21.3	0.9	0.8
01477120	3.1	3.6	0.9	4.0	4.9	0.8	0.8

[1]Correction factor is determined by dividing the percentage impervious surface from the 1986 land-use coverage by the percentage impervious surface for 1986 estimated by regression.

[2]Estimated by linear interpolation between the population density estimate for 1990 and for 2000.

[3]Correction factor is determined by dividing the percentage impervious surface from the 1995/97 land-use coverage by the percentage impervious surface for 1995 estimated by regression.

[4]Correction factor is determined by averaging the correction factor for 1986 and the correction factor for 1996.

Table 10. Years in which estimated impervious surface in the drainage basins of selected streamflow-gaging stations in New Jersey exceeded 10 percent or 20 percent of the drainage basin area, or had increased by 15 percent.

[%, percent; --, did not exceed indicated percentage]

USGS station identifier	Available period of record[1]	Year in which impervious surface exceeded 10%	Year in which impervious surface exceeded 20%	Year in which impervious surface had increased by 15%[2]
01379000	1903–2005	--	--	--
01379500	1903–1911, 1938–2005	1966	--	--
01379773	1983–2005	--	--	--
01380500	1937–2005	1996	--	--
01381500	1921–2005	1952	--	--
01383500	1919–2005	--	--	--
01384000	1934–1985	--	--	--
01384500	1934–1979, 1985–2005	--	--	--
01385000	1934–1958	--	--	--
01386000	1934–1978	--	--	--
01386500	1934–1958	--	--	--
01387000	1912–1914, 1918–2005	--	--	--
01387450	1958–1995, 2005	--	--	--
01387500	1902–1906, 1923–2005	1964	1993	[3]1981
01388000	1921–2005	1966	--	--
01390500	1954–1977, 1979–2005	--	--	--
01391000	1954–1973, 1978–1996, 2003–2005	1947	1965	--
01391500	1923–2005	1937	1957	[4]1955
01392000	1937–1962	Before 1930	Before 1930	--
01392210	1977–1997	Before 1930	Before 1930	--
01392500	1937–1964	Before 1930	Before 1930	--
01396000	1939–1996	1963	1986	1987
01396500	1918–2005	--	--	--
01396580	1978–1988, 1991–2005	--	--	--
01396660	1977–2005	--	--	--
01397000	1903–1905, 1919–2005	--	--	--
01397500	1936–1961	--	--	--
01398000	1930–2005	--	--	--
01398045	1977–1988	--	--	--
01398107	1978–1996	--	--	--
01398500	1921–2005	--	--	--
01399190	1976–1987	--	--	--
01399200	1975–1987	1971	--	--
01399500	1921–2005	--	--	--
01399510	1972–1996	--	--	--
01399525	1977–1988	--	--	--
01399670	1977–2005	--	--	--
01400000	1923–2005	--	--	--
01400350	1982–1996	1957	1991	--
01400500	1903–1907, 1921–2005	--	--	--
01400730	1964–1975, 1987–1989	--	--	--
01401000	1953–2005	--	--	--
01401500	1933–1949	--	--	--
01401650	1979–2005	1999	--	--
01402000	1921–2005	--	--	--
01402600	1966–1975, 1980–1996	1958	1973	1982

Table 10. Years in which estimated impervious surface in the drainage basins of selected streamflow-gaging stations in New Jersey exceeded 10 percent or 20 percent of the drainage basin area, or had increased by 15 percent.—Continued

[%, percent; --, did not exceed indicated percentage]

USGS station identifier	Available period of record[1]	Year in which impervious surface exceeded 10%	Year in which impervious surface exceeded 20%	Year in which impervious surface had increased by 15%[2]
01403060	1903–1909, 1945–2005	--	--	--
01403400	1978–2005	1957	--	--
01403535	1980–2000	--	--	--
01403540	1974–2005	1968	--	--
01405300	1957–1967	1983	--	--
01408000	1931–2005	1997	--	--
01408120	1972–2005	1989	--	--
01408500	1928–2005	--	--	--
01409000	1932–1958, 1969–1971, 2003–2005	--	--	--
01409095	1965–1985	--	--	--
01409280	1973–1988, 2003–2005	--	--	--
01409400	1957–2005	--	--	--
01409500	1927–2005	--	--	--
01409810	1974–1996, 2006–2005	--	--	--
01410000	1930–2005	--	--	--
01410150	1978–2005	--	--	--
01411000	1925–2005	--	--	--
01411300	1969–2005	--	--	--
01411456	1987–2005	--	--	--
01411500	1932–2005	--	--	--
01412000	1931–1985	--	--	--
01412800	1977–1988, 2003–2005	--	--	--
01437500	1937–2005	--	--	--
01440000	1923–2005	--	--	--
01443500	1921–2005	--	--	--
01445000	1939–1962	--	--	--
01445500	1921–2005	--	--	--
01446000	1922–1961	--	--	--
01456000	1921–1973	--	--	--
01457000	1903–1907, 1921–2005	--	--	--
01464000	1923–2005	--	1997	--
01464500	1940–2005	--	--	--
01465850	1961–1975	--	--	--
01466000	1952–1964	--	--	--
01466500	1953–2005	--	--	--
01467000	1921–2005	--	--	--
01467081	1967–2005	1950	1960	[5]After 2005
01475000	1940–1976, 2003–2005	1972	--	--
01477120	1966–2005	--	--	--

[1]From the value of estimated impervious surface at the beginning of the continuous period of record, in water years.

[2]Indicates water year, which is the 12-month period beginning October 1 and ending September 30 and is named for the year in which it ends.

[3]Least-square regression used to estimate 15-percent change in impervious surface since 1923; $IS = 8*10^{-21}e^{024(Y)}$, $R^2 = 0.97$.

[4]Least-squares regression used to estimate 15-percent change in impervious surface since 1923 using estimated values from 1930-1970; $IS = .492*(Y) - 943.3$, $R^2 = 0.97$.

[5]Least-square regression used to estimate 15-percent change in impervious surface since 1967 using estimated values from 1970-2000; $IS = 0.26*(Y) - 481.2$, $R^2 = 0.97$.

Table 11. Estimated population density in drainage basins of 83 selected streamflow-gaging stations in New Jersey, by decade.

[--, no analysis]

USGS station identifier	Mean population density (per square mile)[1] for the year:							
	1930	1940	1950	1960	1970	1980	1990	2000
01379000	244	285	359	507	648	647	693	774
01379500	253	311	407	648	847	826	870	1,004
01379773	70	53	97	228	417	437	431	478
01380500	237	254	326	521	738	784	801	934
01381500	585	636	773	1,036	1,450	1,396	1,414	1,541
01383500	24	31	46	109	216	284	298	339
01384000	25	32	47	111	229	298	311	339
01384500	37	35	62	149	370	449	387	411
01385000	39	38	65	152	371	449	455	434
01386000	29	33	52	119	270	342	364	364
01386500	166	169	222	384	621	672	654	645
01387000	46	49	74	155	315	389	406	414
01387450	--	--	--	--	--	--	--	--
01387500	130	143	180	232	416	468	554	932
01388000	172	201	293	361	1,034	1,042	720	1,292
01390500	241	330	439	831	1,479	1,455	1,450	1,423
01391000	499	610	800	1,542	2,046	1,975	1,993	2,202
01391500	618	800	1,237	2,018	2,742	2,543	2,325	2,603
01392000	4,054	4,223	5,577	7,111	7,164	6,468	6,239	7,069
01392210	5,971	6,212	7,329	7,959	8,264	7,514	7,154	7,218
01392500	8,559	8,603	9,614	9,669	9,601	9,069	8,696	9,303
01396000	48	54	63	72	97	176	211	252
01396500	64	73	96	150	287	428	499	561
01396580	76	79	101	133	179	219	278	291
01396660	48	54	63	72	97	176	211	252
01397000	76	85	102	140	224	321	384	437
01397500	244	285	359	507	648	647	693	774
01398000	63	69	85	119	171	201	330	392
01398045	42	43	53	69	90	121	151	156
01398107	59	61	86	130	165	232	289	343
01398500	122	125	167	247	385	478	500	590
01399190	24	31	46	102	216	284	318	339
01399200	188	212	288	504	795	937	984	1,227
01399500	93	107	144	243	399	488	532	641
01399510	36	39	46	65	114	171	217	272
01399525	52	61	61	88	98	94	268	390
01399670	96	113	139	178	213	267	363	426
01400000	85	94	121	183	273	322	385	464
01400350	103	152	253	485	929	897	999	1,160
01400500	107	116	149	207	297	358	434	513
01400730	305	305	360	395	521	624	715	729
01401000	156	167	234	333	410	421	455	557
01401500	223	233	304	383	504	593	722	850

Table 11. Estimated population density in drainage basins of 83 selected streamflow-gaging stations in New Jersey, by decade.—Continued

[--, no analysis]

USGS station identifier	Mean population density (per square mile)[1] for the year:							
	1930	1940	1950	1960	1970	1980	1990	2000
01401650	45	53	75	136	201	337	505	674
01402000	187	199	262	360	507	581	714	840
01402600	42	48	71	138	201	347	525	500
01403060	136	147	193	268	381	446	543	641
01403400	557	635	863	1,685	2,098	1,985	1,893	2,132
01403535	149	190	299	544	781	869	840	1,293
01403540	118	158	247	447	653	731	733	814
01405300	265	289	357	420	617	708	890	1,173
01408000	141	158	201	279	485	575	770	939
01408120	62	77	118	194	390	508	705	907
01408500	34	38	60	108	233	377	470	566
01409000	8	9	12	27	59	181	282	318
01409095	13	14	17	29	65	127	183	209
01409280	13	15	16	21	44	109	162	207
01409400	53	57	67	93	138	240	302	322
01409500	9	10	16	21	30	92	112	116
01409810	8	11	13	17	19	32	33	27
01410000	12	13	14	17	24	82	113	141
01410150	9	8	9	9	11	20	25	26
01411000	138	140	165	259	349	497	625	796
01411300	29	29	30	36	43	63	91	99
01411456	307	311	385	646	810	974	1,073	1,316
01411500	142	149	194	280	349	435	487	530
01412000	235	262	335	432	529	611	635	647
01412800	59	61	119	144	159	166	168	178
01437500	--	--	--	--	--	--	--	--
01440000	13	14	16	21	27	34	41	46
01443500	73	77	86	116	150	205	223	244
01445000	46	51	68	114	163	232	260	284
01445500	41	43	52	76	108	165	200	231
01446000	33	37	40	47	62	85	103	114
01456000	83	93	127	230	470	682	702	744
01457000	88	98	125	198	371	507	531	583
01464000	512	559	685	891	1,060	1,082	1,200	1,310
01464500	36	43	180	305	347	267	268	255
01465850	25	29	40	67	98	167	187	180
01466000	512	559	685	891	1,060	1,083	1,200	1,310
01466500	10	14	16	20	21	24	22	15
01467000	23	28	98	192	239	330	356	350
01467081	277	291	412	1,015	1,841	2,159	2,363	2,542
01475000	279	283	344	581	1,015	1,434	1,892	2,180
01477120	100	100	123	154	176	218	268	404

[1]Mean population density was estimated for each drainage basin using historic census data for municipalities in New Jersey (U.S. Census Bureau, 2007).

Table 12. Description of data for selected streamflow-gaging stations and selected index stations in New Jersey sorted by stream type, used to develop double-mass curves.

[--, no analysis]

USGS station identifier	Station name	Continuous period of record	Associated index station	Index station period of record selected for analysis	Number of years in double-mass curve dataset	Was double-mass analysis performed?
Stream class A						
01379000	Passaic River near Millington	1903–2005	01440000	1924–2005	81	Yes
			01443500	1921–2005	84	Yes
01379500	Passaic River near Chatham	1903–1911, 1938–2005	01440000	1938–2005	67	Yes
			01443500	1938–2005	67	Yes
01380500	Rockaway River Above Reservoir at Boonton	1937–2005	01440000	1937–2005	68	Yes
			01443500	1937–2005	68	Yes
01384000	Wanaque River at Monks	1934–1985	01440000	1934–1985	51	Yes
			01443500	1934–1985	51	Yes
01387000	Wanaque River at Wanaque	1912–1914, 1918–2005	01440000	1924–2005	81	Yes
			01443500	1921–2005	84	Yes
01387500	Ramapo River near Mahwah	1902–1906, 1923–2005	01440000	1924–2005	81	Yes
			01443500	1923–2005	82	Yes
01388000	Ramapo River at Pompton Lakes	1921–2005	01440000	1924–2005	81	Yes
			01443500	1921–2005	84	Yes
01391500	Saddle River at Lodi	1923–2005	01440000	1923–2005	82	Yes
			01443500	1923–2005	82	Yes
01396500	South Branch Raritan River near High Bridge	1918–2005	01440000	1924–2005	81	Yes
			01443500	1924–2005	81	Yes
01397000	South Branch Raritan River at Stanton	1903–1905, 1919–2005	01440000	1924–2005	81	Yes
			01443500	1924–2005	81	Yes
01398000	Neshanic River at Reaville	1930–2005	01440000	1930–2005	75	Yes
			01443500	1930–2005	75	Yes
01400000	North Branch Raritan River near Raritan, NJ	1923–2005	01443500	1924–2005	81	Yes
01400500	Raritan River at Manville	1903–1907, 1921–2005	01440000	1924–2005	81	Yes
			01443500	1921–2005	84	Yes
01400730	Millstone River at Plainsboro	1964–1975, 1987–1989	01440000	1964–1975	11	Yes
			01443500	1964–1975	11	Yes
01401000	Stony Brook at Princeton	1953–2005	01440000	1953–2005	52	Yes
			01443500	1953–2005	52	Yes
01401500	Millstone River near Kingston	1933–1949	01440000	1933–1949	16	Yes
			01443500	1933–1949	16	Yes
01402000	Millstone River at Blackwells Mills	1921–2005	01440000	1924–2005	81	Yes
			01443500	1921–2005	84	Yes

Table 12. Description of data for selected streamflow-gaging stations and selected index stations in New Jersey sorted by stream type, used to develop double-mass curves.—Continued

[--, no analysis]

USGS station identifier	Station name	Continuous period of record	Associated index station	Index station period of record selected for analysis	Number of years in double-mass curve dataset	Was double-mass analysis performed?
Stream class A—Continued						
01403060	Raritan River Below Calco Dam at Bound Brook	1903–1909, 1945–2005	01440000	1945–2005	60	Yes
			01443500	1945–2005	60	Yes
01405300	Matchaponix Brook at Spotswood	1957–1967	01440000	1957–2005	48	Yes
			01443500	1957–2005	48	Yes
01408000	Manasquan River at Squankum	1931–2005	01440000	1931–2005	74	Yes
			01443500	1931–2005	74	Yes
01408120	North Branch Metedeconk River near Lakewood	1972–2005	01440000	1972–2005	33	Yes
			01443500	1972–2005	33	Yes
01437500	Neversink River at Godeffroy, NY	1937–2005	--	--	--	No
01440000	Flat Brook near Flatbrookville	1923–2005	01440000	1924–2005	81	Yes
			01443500	1924–2005	81	Yes
01443500	Paulins Kill at Blairstown	1921–2005	01440000	1924–2005	81	Yes
01464000	Assunpink Creek at Trenton	1923–2005	01440000	1924–2005	81	Yes
			01443500	1924–2005	81	Yes
01464500	Crosswicks Creek at Extonville	1940–2005	01440000	1940–2005	65	Yes
			01443500	1940–2005	65	Yes
Stream class B						
01408500	Toms River near Toms River	1928–2005	01409500	1928–2005	77	Yes
			01410000	1930–2005	75	Yes
01409000	Cedar Creek at Lanoka Harbor	1932–1958, 1969–1971, 2003–2005	01409500	1932–1958	26	Yes
			01410000	1932–1958	26	Yes
01409400	Mullica River near Batsto	1957–2005	01409500	1957–2005	48	Yes
			01410000	1957–2005	48	Yes
01409500	Batsto River at Batsto, NJ	1927–2005	01410000	1930–2005	75	Yes
01409810	West Branch Wading River near Jenkins	1974–1996, 2004–2005	01409500	1974–1996	22	Yes
			01410000	1974–1996	22	Yes
01410000	Oswego River at Harrisville	1930–2005	01409500	1930–2005	75	Yes
01411000	Great Egg Harbor River at Folsom	1925–2005	01409500	1927–2005	78	Yes
			01410000	1930–2005	75	Yes
01411500	Maurice River at Norma	1932–2005	01409500	1932–2005	73	Yes
			01410000	1932–2005	73	Yes

Table 12. Description of data for selected streamflow-gaging stations and selected index stations in New Jersey sorted by stream type, used to develop double-mass curves.—Continued

[--, no analysis]

USGS station identifier	Station name	Continuous period of record	Associated index station	Index station period of record selected for analysis	Number of years in double-mass curve dataset	Was double-mass analysis performed?
		Stream class B—Continued				
01445500	Pequest River at Pequest	1921–2005	01409500	1927–2005	78	Yes
			01410000	1930–2005	75	Yes
01456000	Musconetcong River near Hackettstown	1921–1973	01409500	1927–1973	46	Yes
			01410000	1930–1973	43	Yes
01457000	Musconetcong River near Bloomsbury	1903–1907, 1921–2005	01409500	1927–2005	78	Yes
			01410000	1930–2005	75	Yes
01465850	South Branch Rancocas Creek at Vincentown	1961–1975	01409500	1961–1975	14	Yes
			01410000	1961–1975	14	Yes
01467000	North Branch Rancocas Creek at Pemberton	1921–2005	01409500	1927–2005	78	Yes
			01410000	1930–2005	75	Yes
		Stream class C				
01381500	Whippany River at Morristown	1921–2005	01384500	1934–2005	71	Yes
			01386000	1935–1978	43	Yes
01383500	Wanaque River at Awosting	1919–2005	01384500	1934–2005	71	Yes
			01386000	1935–1978	43	Yes
01384500	Ringwood Creek near Wanaque, NJ	1934–1979, 1985–2005	01386000	1934–1978	44	Yes
01386000	West Brook near Wanaque	1934–1978	01384500	1934–1978	44	Yes
01387450	Mahwah River near Suffern, NY	1958–1995, 2005	--	--	--	No
01390500	Saddle River at Ridgewood	1954–1977, 1979–2005	01384500	1954–2005	49	Yes
			01386000	1954–1977	23	Yes
01391000	Hohokus Brook at Ho-Ho-Kus	1954–1973, 1978–1996, 2003–2005	01384500	1954–1996	37	Yes
			01386000	1954–1973	19	Yes
01392210	Third River at Passaic	1977–1997	01384500	1977–1997	20	Yes
			01386000	1977–1978	1	No
01392500	Second River at Belleville	1937–1964	01384500	1937–1964	27	Yes
			01386000	1937–1964	27	Yes
01396580	Spruce Run at Glen Gardner	1978–1988, 1991–2005	01384500	1978–2005	25	Yes
			01386000	1978	0	No
01396660	Mulhockaway Creek at Van Syckel	1977–2005	01384500	1977–2005	28	Yes
			01386000	1977–1978	1	No
01398500	North Branch Raritan River near Far Hills	1921–2005	01384500	1934–2005	71	Yes
			01386000	1935–1978	43	Yes

Table 12. Description of data for selected streamflow-gaging stations and selected index stations in New Jersey sorted by stream type, used to develop double-mass curves.—Continued

[--, no analysis]

USGS station identifier	Station name	Continuous period of record	Associated index station	Index station period of record selected for analysis	Number of years in double-mass curve dataset	Was double-mass analysis performed?
		Stream class C—Continued				
01399500	Lamington (Black) River near Pottersville	1921–2005	01384500	1934–2005	71	Yes
			01386000	1935–1978	43	Yes
01399670	South Branch Rockaway Creek at Whitehouse Station	1977–2005	01384500	1977–2005	28	Yes
			01386000	1977–1978	1	No
01411300	Tuckahoe River at Head of River	1969–2005	01384500	1969–2005	36	Yes
			01386000	1969–1978	9	No
01412800	Cohansey River at Seeley	1977–1988, 2003–2005	01384500	1977–1988	11	Yes
			01386000	1977–1978	1	No
01445000	Pequest River at Huntsville	1939–1962	01384500	1939–1962	23	Yes
			01386000	1939–1962	23	Yes
01446000	Beaver Brook near Belvidere	1922–1961	01384500	1934–1961	27	Yes
			01386000	1935–1961	26	Yes
01467081	South Branch Pennsauken Creek at Cherry Hill	1967–2005	01384500	1967–2005	38	Yes
			01386000	1967–1978	11	Yes
01477120	Raccoon Creek near Swedesboro	1966–2005	01384500	1966–2005	39	Yes
			01386000	1966–1978	12	Yes
		Stream class D				
01379773	Green Pond Brook at Picatinny Arsenal	1983–2005	01466500	1983–2005	22	Yes
01385000	Cupsaw Brook near Wanaque	1934–1958	01466500	1953–1958	5	No
01386500	Blue Mine Brook near Wanaque	1934–1958	01466500	1953–1958	5	No
01392000	Weasel Brook at Clifton	1937–1962	01466500	1953–1962	9	No
01396000	Robinsons Branch at Rahway	1939–1996	01466500	1953–1996	43	Yes
01397500	Walnut Brook near Flemington	1936–1961	01466500	1953–1961	8	No
01398045	Back Brook Tributary near Ringoes	1977–1988	01466500	1977–1988	11	Yes
01398107	Holland Brook at Readington	1978–1996	01466500	1978–1996	18	Yes
01399190	Lamington (Black) River at Succasunna	1976–1987	01466500	1976–1987	11	Yes

Table 12. Description of data for selected streamflow-gaging stations and selected index stations in New Jersey sorted by stream type, used to develop double-mass curves.—Continued

[--, no analysis]

USGS station identifier	Station name	Continuous period of record	Associated index station	Index station period of record selected for analysis	Number of years in double-mass curve dataset	Was double-mass analysis performed?
		Stream class D—Continued				
01399200	Lamington (Black) River near Ironia	1975–1987	01466500	1975–1987	12	Yes
01399510	Upper Cold Brook near Pottersville	1972–1996	01466500	1972–1996	24	Yes
01399525	Axle Brook near Pottersville	1977–1988	01466500	1977–1988	11	Yes
01400350	Macs Brook at Somerville	1982–1996	01466500	1982–1996	14	Yes
01401650	Pike Run at Belle Mead	1979–2005	01466500	1979–2005	26	Yes
01402600	Royce Brook Tributary near Belle Mead	1966–1975, 1980–1996	01466500	1966–1996	25	Yes
01403400	Green Brook at Seeley Mills	1978–2005	01466500	1978–2005	27	Yes
01403535	East Branch Stony Brook at Best Lake at Watchung	1980–2000	01466500	1980–2000	20	Yes
01403540	Stony Brook at Watchung	1974–2005	01466500	1974–2005	31	Yes
01409095	Oyster Creek near Brookville	1965–1985	01466500	1965–1985	20	Yes
01409280	Westecunk Creek at Stafford Forge	1973–1988, 2003–2005	01466500	1973–1988	15	Yes
01410150	East Branch Bass River near New Gretna	1978–2005	01466500	1978–2005	27	Yes
01411456	Little Ease Run near Clayton	1987–2005	01466500	1987–2005	18	Yes
01412000	Menantico Creek near Millville	1931–1985	01466500	1953–1985	32	Yes
01466000	Middle Branch Mt Misery Brook in Lebanon State Forest	1952–1964	01466500	1953–1964	11	Yes
01466500	Mcdonalds Branch in Lebanon State Forest, NJ	1953–2005	--	--	--	No
01475000	Mantua Creek at Pitman	1940–1976, 2003–2005	01466500	1953–1976	23	Yes

Table 13. Selected results of analysis of covariance conducted on double-mass curves for 85 streamflow-gaging stations and selected index streamflow-gaging stations on the same stream type in New Jersey.

[No BP identified, no significant breakpoints were detected on the double-mass curve; --, not applicable; No BP considered, no significant breakpoints were considered for further analysis; No analysis, double-mass analysis was not performed; <, less than]

USGS station identifier	Period of record[1]	Stream class	Breakpoint year	Index station	Flow type	F-value	p-value	Is F-value the maximum for the F-test dataset?
01379000	1903–2005	A	1927	01440000	Base flow	21.625	<0.0001	Yes
			1950	01440000	Base flow	5.896	0.0174	No
			1950	01443500	Base flow	11.293	0.0012	Yes
01379500	1903–1911, 1938–2005	A	1941	01440000	Base flow	9.605	0.0029	Yes
			1941	01443500	Base flow	9.305	0.0033	Yes
			1956	01440000	Runoff	5.961	0.0173	Yes
			1956	01443500	Runoff	9.949	0.0024	Yes
			1964	01443500	Runoff	4.987	0.0289	No
01379773	1983–2005	D	1995	01466500	Runoff	5.530	0.0290	Yes
01380500	1937–2005	A	1941	01440000	Base flow	7.691	0.0072	Yes
			1941	01443500	Base flow	5.734	0.0195	Yes
			1959	01443500	Runoff	12.797	0.0007	Yes
			1989	01440000	Base flow	4.937	0.0297	No
			1992	01443500	Base flow	4.264	0.0429	No
01381500	1921–2005	C	1971	01384500	Runoff	5.090	0.0270	No
			1971	01386000	Runoff	4.490	0.0400	Yes
			1974	01384500	Runoff	6.130	0.0160	Yes
01383500	1919–2005	C	1945	01386000	Base flow	9.601	0.0033	Yes
			1978	01384500	Base flow	5.828	0.0186	Yes
			1989	01384500	Runoff	6.920	0.0107	Yes
01384000	1935–1985	A	1939	01440000	Base flow	7.661	0.0079	Yes
			1939	01440000	Runoff	7.487	0.0086	Yes
			1950	01440000	Runoff	4.682	0.0353	No
			1950	01443500	Runoff	9.059	0.0041	Yes
			1954	01440000	Base flow	4.421	0.0406	No
			1962	01443500	Runoff	7.642	0.0080	No
01384500	1934–2005	C	1946	01386000	Base flow	8.018	0.0068	Yes
			1953	01386000	Runoff	7.635	0.0082	Yes
01385000	1936–1958	D	No BP identified	--	--	--	--	--
01386000	1935–1978	C	1946	01384500	Base flow	6.152	0.0168	Yes
			1952	01384500	Runoff	7.888	0.0073	Yes
01386500	1935–1958	D	No Analysis[2]	01466500	--	--	--	--
01387000	1911–1914, 1918–2005	A	1927	01440000	Runoff	12.355	0.0007	Yes
			1928	01440000	Base flow	24.870	<0.0001	No
			1929	01443500	Base flow	15.647	0.0002	No
			1932	01440000	Base flow	27.432	<0.0001	Yes
			1932	01443500	Base flow	35.450	<0.0001	Yes
			1932	01443500	Runoff	14.171	0.0003	Yes
			1939	01443500	Base flow	13.645	0.0004	No
			1950	01440000	Base flow	4.537	0.0362	No
			1952	01443500	Base flow	4.481	0.0373	No
			1983	01443500	Base flow	4.026	0.0481	No
01387450	1958–1995	C	No BP identified	--	--	--	--	--
01387500	1903–1906, 1923–2005	A	1957	01443500	Runoff	9.651	0.0026	Yes
			1966	01440000	Base flow	5.060	0.0272	No
			1981	01443500	Base flow	13.105	0.0005	Yes
			1989	01440000	Base flow	13.507	0.0004	Yes
01388000	1921–2005	A	1927	01440000	Base flow	18.038	<0.0001	Yes

Table 13. Selected results of analysis of covariance conducted on double-mass curves for 85 streamflow-gaging stations and selected index streamflow-gaging stations on the same stream type in New Jersey.—Continued

[No BP identified, no significant breakpoints were detected on the double-mass curve; --, not applicable; No BP considered, no significant breakpoints were considered for further analysis; No analysis, double-mass analysis was not performed; <, less than]

USGS station identifier	Period of record[1]	Stream class	Breakpoint year	Index station	Flow type	F-value	p-value	Is F-value the maximum for the F-test dataset?
			1933	01440000	Runoff	4.836	0.0308	Yes
			1953	01440000	Base flow	8.638	0.0043	No
			1961	01440000	Base flow	10.926	0.0014	No
			1966	01443500	Base flow	16.624	0.0001	No
			1969	01443500	Base flow	17.817	<0.0001	Yes
			1992	01443500	Runoff	4.096	0.0462	Yes
01390500	1954–2005	C	1968	01386000	Runoff	4.618	0.0419	Yes
01391000	1954–2005	C	1959	01386000	Base flow	6.609	0.0182	Yes
			1962	01384500	Base flow	4.704	0.0374	No
			1966	01386000	Runoff	6.011	0.0235	No
			1970	01386000	Runoff	10.428	0.0042	Yes
			1973	01384500	Base flow	6.148	0.0184	No
01391500	1923–2005	A	1956	01440000	Runoff	19.577	<0.0001	Yes
			1963	01440000	Base flow	4.626	0.0345	No
			1964	01443500	Base flow	4.955	0.0288	No
			1965	01440000	Runoff	13.814	0.0004	No
			1969	01443500	Base flow	8.623	0.0043	Yes
			1970	01440000	Base flow	8.952	0.0037	Yes
01392000	1936–1962	D	No BP considered	--	--	--	--	--
01392210	1976–1997	C	1986	01384500	Base flow	6.497	0.0232	Yes
01392500	1936–1964	C	1956	01386000	Runoff	4.392	0.0460	Yes
01396000	1939–1999	D	1971	01466500	Base flow	4.220	0.0460	No
			1973	01466500	Runoff	8.070	0.0070	Yes
			1981	01466500	Base flow	10.920	0.0020	Yes
01396500	1918–2005	A	1925	01443500	Base flow	14.501	0.0003	Yes
			1927	01440000	Base flow	13.920	0.0004	Yes
			1930	01443500	Base flow	12.307	0.0007	No
			1956	01440000	Runoff	5.133	0.0262	Yes
			1956	01443500	Runoff	7.646	0.0070	Yes
			1962	01440000	Runoff	3.963	0.0499	No
			1970	01443500	Runoff	4.354	0.0400	No
			1987	01443500	Base flow	4.518	0.0366	No
			1989	01440000	Base flow	5.608	0.0203	No
01396580	1977–1988, 1991–2005	C	1987	01384500	Base flow	6.614	0.0192	Yes
01396660	1976–2005	C	No BP identified	--	--	--	--	--
01397000	1903–1905, 1919–2005	A	1926	01443500	Base flow	12.563	0.0007	Yes
			1927	01440000	Base flow	15.316	0.0002	Yes
			1927	01440000	Runoff	7.685	0.0069	Yes
01397500	1935–1961	D	No Analysis[2]	01466500	--	--	--	--
01398000	1930–2005	A	1956	01440000	Runoff	7.138	0.0093	Yes
			1956	01443500	Runoff	12.057	0.0009	Yes
			1962	01443500	Runoff	11.367	0.0012	No
			1966	01440000	Runoff	4.132	0.0457	No
01398045	1977–1988	D	1982	01466500	Base flow	7.661	0.0199	Yes
01398107	1979–1996	D	1985	01466500	Base flow	5.269	0.0347	Yes
01398500	1921–2005	C	1945	01384500	Runoff	5.940	0.0176	Yes
			1945	01386000	Runoff	4.254	0.0450	Yes
			1950	01386000	Base flow	16.993	0.0002	Yes

Table 13. Selected results of analysis of covariance conducted on double-mass curves for 85 streamflow-gaging stations and selected index streamflow-gaging stations on the same stream type in New Jersey.—Continued

[No BP identified, no significant breakpoints were detected on the double-mass curve; --, not applicable; No BP considered, no significant breakpoints were considered for further analysis; No analysis, double-mass analysis was not performed; <, less than]

USGS station identifier	Period of record[1]	Stream class	Breakpoint year	Index station	Flow type	F-value	p-value	Is F-value the maximum for the F-test dataset?
			1952	01384500	Runoff	4.025	0.0491	No
01399190	1977–1987	D	none	--	--	--	--	--
01399200	1976–1987	D	none	--	--	--	--	--
01399500	1921–2005	C	1945	01384500	Runoff	6.754	0.0116	Yes
			1950	01386000	Base flow	14.422	0.0004	Yes
			1951	01384500	Runoff	4.406	0.0398	No
01399510	1972–1996	D	1976	01466500	Runoff	6.549	0.0175	Yes
			1979	01466500	Runoff	4.284	0.0499	No
			1981	01466500	Base flow	24.716	<0.0001	Yes
01399525	1978–1988	D	No BP identified	--	--	--	--	--
01399670	1976–2005	C	No BP identified	--	--	--	--	--
01400000	1923–2005	A	1962	01440000	Runoff	5.270	0.0243	Yes
			1962	01443500	Runoff	10.663	0.0016	Yes
			1975	01440000	Base flow	3.996	0.0490	Yes
01400350	1982–1995	D	No BP identified	--	--	--	--	--
01400500	1903–1907, 1921–2005	A	1927	01440000	Base flow	12.873	0.0006	Yes
			1927	01440000	Runoff	6.399	0.0134	Yes
			1956	01443500	Runoff	4.257	0.0422	Yes
			1975	01440000	Base flow	4.421	0.0386	No
			1975	01443500	Base flow	5.064	0.0271	Yes
01400730	1964–1975	A	1969	01443500	Base flow	7.028	0.0200	No
			1970	01440000	Base flow	9.581	0.0085	Yes
			1971	01443500	Base flow	14.631	0.0021	Yes
01401000	1953–2005	A	1957	01440000	Base flow	5.126	0.0279	Yes
			1957	01440000	Runoff	4.609	0.0367	Yes
			1957	01443500	Base flow	7.117	0.0103	Yes
			1957	01443500	Runoff	8.730	0.0048	Yes
			1959	01440000	Base flow	4.663	0.0357	No
			1960	01443500	Runoff	4.065	0.0492	No
01401500	1934–1949	A	1939	01440000	Runoff	5.188	0.0378	Yes
01401650	1979–2005	D	1995	01466500	Runoff	4.339	0.0485	Yes
01402000	1921–2005	A	1927	01440000	Base flow	13.947	0.0004	Yes
			1927	01440000	Runoff	4.836	0.0308	Yes
			1942	01443500	Base flow	13.080	0.0005	Yes
			1958	01440000	Runoff	4.104	0.0461	No
			1958	01443500	Runoff	10.854	0.0015	Yes
			1961	01443500	Runoff	9.572	0.0027	No
01402600	1966–1975, 1980–1996	D	1980	01466500	Runoff	5.070	0.0330	Yes
			1980	01466500	Base flow	6.430	0.0180	Yes
			1985	01466500	Base flow	5.660	0.0250	No
01403060	1903–1909, 1945–2004	A	1956	01440000	Runoff	9.500	0.0031	Yes
			1956	01443500	Runoff	12.056	0.0010	Yes
			1962	01440000	Runoff	4.697	0.0343	No
			1967	01443500	Base flow	4.550	0.0371	No
			1979	01443500	Base flow	5.461	0.0229	No
			1980	01443500	Base flow	7.488	0.0082	No
			1981	01443500	Runoff			No
			1990	01440000	Base flow	5.715	0.0200	Yes

Table 13. Selected results of analysis of covariance conducted on double-mass curves for 85 streamflow-gaging stations and selected index streamflow-gaging stations on the same stream type in New Jersey.—Continued

[No BP identified, no significant breakpoints were detected on the double-mass curve; --, not applicable; No BP considered, no significant breakpoints were considered for further analysis; No analysis, double-mass analysis was not performed; <, less than]

USGS station identifier	Period of record[1]	Stream class	Breakpoint year	Index station	Flow type	F-value	p-value	Is F-value the maximum for the F-test dataset?
01403400	1978–2005	D	1985	01466500	Base flow	5.652	0.0257	Yes
01403535	1979–2000	D	1995	01466500	Runoff	7.636	0.0124	Yes
01403540	1974–2005	D	1981	01466500	Base flow	19.221	0.0001	Yes
			1995	01466500	Runoff	4.593	0.0406	Yes
01405300	1957–1967	A	No BP identified	--	--	--	--	--
01408000	1931–2005	A	1956	01440000	Runoff	4.644	0.0345	Yes
			1956	01443500	Runoff	7.170	0.0092	Yes
			1982	01443500	Base flow	12.143	0.0008	Yes
			1989	01440000	Base flow	9.299	0.0032	Yes
01408120	1972–2005	A	1976	01443500	Base flow	6.500	0.0160	Yes
			1976	01440000	Base flow	5.050	0.0006	Yes
			1977	01443500	Runoff	4.410	0.0440	Yes
			1977	01440000	Runoff	6.760	0.0140	Yes
01408500	1928–2005	B	1934	01410000	Base flow	5.518	0.0215	Yes
			1942	01410000	Runoff	6.932	0.0103	Yes
			1959	01409500	Base flow	6.641	0.0119	Yes
			1963	01409500	Runoff	22.542	<0.0001	Yes
01409000	1931–1958, 1969–1971, 2003–2005	B	1941	01410000	Runoff	5.454	0.0266	No
			1958	01409500	Base flow	7.276	0.0115	Yes
			1958	01410000	Runoff	10.430	0.0031	Yes
			1970	01409500	Runoff	11.189	0.0023	Yes
01409095	1966–1985	D	No BP identified	--	--	--	--	--
01409280	1974–1988	D	1980	01466500	Base flow	6.442	0.0219	Yes
01409400	1956–2005	B	1962	01409500	Base flow	22.940	<0.0001	Yes
			1963	01409500	Runoff	23.684	<0.0001	Yes
			1995	01409500	Base flow	4.300	0.0437	No
01409500	1927–2005	B	1962	01410000	Runoff	6.656	0.0119	No
			1968	01410000	Runoff	10.321	0.0020	Yes
			1994	01410000	Runoff	4.067	0.0474	No
01409810	1974–1996	B	No BP identified	--	--	--	--	--
01410000	1930–2005	B	1959	01409500	Base flow	4.769	0.0322	Yes
			1963	01409500	Runoff	12.303	0.0008	Yes
01410150	1977–2005	D	1988	01466500	Base flow	15.910	0.0005	No
			1993	01466500	Runoff	4.5856	0.0422	No
			1995	01466500	Base flow	22.717	<0.0001	Yes
			1995	01466500	Runoff	5.335	0.0294	Yes
01411000	1924–2005	B	1931	01409500	Base flow	4.337	0.0407	Yes
			1970	01409500	Runoff	8.818	0.0040	Yes
01411300	1969–2005	C	1976	01384500	Base flow	5.830	0.0223	Yes
			1978	01384500	Runoff	7.152	0.0122	Yes
			1979	01384500	Base flow	4.219	0.0491	No
01411456	1989–2005	D	1995	01466500	Runoff	7.847	0.0134	Yes
01411500	1932–2005	B	1963	01409500	Runoff	4.305	0.0416	Yes
01412000	1930–1985	D	No BP identified	--	--	--	--	--
01412800	1978–1988	C	No BP identified	--	--	--	--	--
01437500	1937–2005	A	No BP identified	--	--	--	--	--
01440000	1924–2005	A	1959	01443500	Runoff	4.582	0.0354	Yes
01443500	1921–2005	A	No BP considered	--	--	--	--	--

Table 13. Selected results of analysis of covariance conducted on double-mass curves for 85 streamflow-gaging stations and selected index streamflow-gaging stations on the same stream type in New Jersey.—Continued

[No BP identified, no significant breakpoints were detected on the double-mass curve; --, not applicable; No BP considered, no significant breakpoints were considered for further analysis; No analysis, double-mass analysis was not performed; <, less than]

USGS station identifier	Period of record[1]	Stream class	Breakpoint year	Index station	Flow type	F-value	p-value	Is F-value the maximum for the F-test dataset?
01445000	1939–1962	C	No BP identified	--	--	--	--	--
01445500	1921–2005	B	1962	01409500	Runoff	4.245	0.0428	No
			1972	01409500	Runoff	9.054	0.0036	Yes
01446000	1922–1961	C	1939	01386000	Runoff	5.034	0.0329	Yes
			1951	01384500	Runoff	12.518	0.0014	Yes
			1951	01386000	Runoff	4.727	0.0383	No
01456000	1921–1972	B	No BP considered	--	--	--	--	--
01457000	1903–1907, 1921–2005	B	1972	01409500	Runoff	8.457	0.0048	Yes
01464000	1923–2005	A	1956	01440000	Runoff	5.095	0.0267	Yes
			1956	01443500	Runoff	10.852	0.0015	Yes
			1961	01443500	Runoff	9.792	0.0024	No
01464500	1939–2005	A	1956	01440000	Runoff	4.381	0.0404	Yes
			1956	01443500	Runoff	6.386	0.0140	Yes
01465850	1962–1975	B						No
01466000	1953–1964	D	1958	01466500	Runoff	5.528	0.0352	Yes
01466500	1953–2005	D	No BP considered	--	--	--	--	--
01467000	1921–2005	B	1932	01409500	Runoff	9.990	0.0023	Yes
01467081	1967–2005	C	1978	01384500	Runoff	15.447	0.0004	Yes
01475000	1940–1976, 2003–2005	D	No BP considered	--	--	--	--	--
01477120	1965–2005	D	No BP identified	--	--	--	--	--

[1]Indicates water year, which is the 12-month period beginning October 1 and ending September 30 and is named for the year in which it ends.

[2]Analysis was not performed because the period of record of the station and the period of record for the index station for this stream type had less than 10 years of overlap which resulted in less than ten data points for the double-mass curve; this dataset was considered too short for double-mass analysis.

near Bloomsbury (01457000), when related to index station 01410000 (Oswego River at Harrisville), had a significant breakpoint in 1973 when cumulative annual runoff data from 1930 to 1951 were not considered.

The station at South Branch Pennsauken Creek at Cherry Hill (01467081), when related to the index station at Ringwood Creek near Wanaque (01384500), had a breakpoint initially rated as very strong in 1978. There is a gap in the record at station 01384500 from 1978 to 1986, and change in the double-mass slope apparently occurred during those years. Year 1978 was designated as the breakpoint year for the runoff curve for this station, but the strength of the breakpoint was downgraded to moderate because the breakpoint appearance, breakpoint prominence, and slope ratio could not be determined accurately for the period with missing data.

Final Baseline Period Determination

The final baseline periods for all 85 stations, which were determined by using a combination of historical gage information on the streamflow-gaging station, land-use analysis, and double-mass analysis of annual runoff and base-flow data are listed in table 15. The steps used to combine the results and determine the baseline period are shown in figure 5. Of 85 stations evaluated, 41 stations had baseline periods that consisted of fewer years than the continuous period of record. Baseline periods of record were reduced primarily by analysis of historical changes in the drainage basin, changes in historical land use, or double-mass analysis. For example, the station at Manasquan River at Squankum (01408000) has a period of record from 1931 to 2005. Based on historical analysis alone, the baseline period ended in 1989 as a result of expansion of the Manasquan Reservoir in 1990. Statistically significant breakpoints were detected for 1956 on the runoff double-mass curve and for 1982 and 1989 on the base-flow double-mass curve, and it was estimated that 10 percent of the drainage basin was impervious surface in 1997. Since 1956 is the earliest year for which a baseline-period threshold was exceeded and did not compromise the minimum period of record established for stream class A, the baseline period was defined as 1931 to 1956.

For 10 stations, the baseline period was limited in years by change in land use; for 14, by results of double mass analysis; and for 17, by evaluation of historical basin and stream information. Of the 14 stations with a baseline period limited by double-mass analysis, 13 were limited by breakpoints in

Table 14. Evaluation of breakpoints in double-mass analysis of base-flow and runoff data for selected streamflow-gaging stations in New Jersey.

[BA, numerical score of breakpoint appearance; BP, numerical score of breakpoint prominence; SR, numerical score of slope ratio; BR, numerical score of breakpoint rating = BP/BA+SR/BA]

USGS station identifier	Year of breakpoint	Index station used for double-mass curve	Flow type	Slope ratio at BP	Breakpoint Interpretation Scores				Breakpoint strength
					BP	BA	SR	BR	
01379500	1956	01440000	Runoff	0.84	4	3	2	20	Moderate
	1964	01443500	Runoff	0.79	3	3	2	15	Moderate
01379773	1995	01466500	Base flow	0.62	4	5	3	32	Very strong
01380500	1959	01443500	Runoff	0.80	4	2	2	16	Moderate
	1989	01440000	Base flow	1.11	3	3	2	15	Moderate
01381500	1971	01384500	Runoff	0.72	3	3	2	15	Moderate
	1971	01386000	Runoff	0.73	3	3	2	15	Moderate
	1974	01384500	Runoff	0.73	3	3	2	15	Moderate
01383500	1978	01384500	Base flow	0.86	4	4	2	24	Strong
	1989	01384500	Runoff	1.21	4	2	2	16	Moderate
01387000	1927	01440000	Runoff	2.30	4	3	4	28	Strong
	1928	01440000	Base flow	3.31	3	4	4	24	Strong
	1929	01443500	Base flow	3.66	3	3	4	21	Moderate
	1932	01443500	Runoff	1.82	4	3	4	28	Strong
	1932	01440000	Base flow	3.00	4	4	4	32	Very strong
	1932	01443500	Base flow	3.40	4	4	4	32	Very strong
	1939	01443500	Base flow	2.44	3	3	4	21	Moderate
	1950	01440000	Base flow	1.39	3	4	3	21	Moderate
	1952	01443500	Base flow	1.49	3	4	3	21	Moderate
	1983	01443500	Base flow	1.48	3	3	3	18	Moderate
01391500	1957	01443500	Runoff	0.71	4	4	2	24	Strong
	1965	01440000	Runoff	0.81	3	3	2	15	Moderate
01392210	1986	01384500	Base flow	1.70	2	4	4	16	Moderate
01396000	1971	01466500	Base flow	0.45	3	5	4	27	Strong
	1973	01466500	Runoff	0.63	4	3	3	24	Strong
01398000	1962	01443500	Runoff	0.72	3	3	2	15	Moderate
	1966	01440000	Runoff	0.78	3	3	2	15	Moderate
01398045	1982	01466500	Base flow	0.81	3	3	2	15	Moderate
01398500	1950	01386000	Base flow	1.20	4	2	2	16	Moderate
01399500	1950	01386000	Base flow	1.18	4	2	2	16	Moderate
01399510	1981	01466500	Base flow	0.70	4	4	2	24	Strong
01400000	1962	01440000	Runoff	0.86	4	2	2	16	Moderate
	1962	01443500	Runoff	0.79	4	4	2	24	Strong
01400500	1927	01440000	Runoff	1.14	4	2	2	16	Moderate
01400730	1969	01443500	Base flow	1.38	3	4	3	21	Moderate
	1970	01440000	Base flow	1.20	4	2	2	16	Moderate
	1971	01443500	Base flow	1.28	3	3	2	15	Moderate
01401500	1939	01440000	Runoff	0.83	4	2	2	16	Moderate
01401650	1995	01466500	Runoff	0.65	4	5	3	32	Very strong

Table 14. Evaluation of breakpoints in double-mass analysis of base-flow and runoff data for selected streamflow-gaging stations in New Jersey.—Continued

[BA, numerical score of breakpoint appearance; BP, numerical score of breakpoint prominence; SR, numerical score of slope ratio; BR, numerical score of breakpoint rating = BP/BA+SR/BA]

USGS station identifier	Year of breakpoint	Index station used for double-mass curve	Flow type	Slope ratio at BP	Breakpoint Interpretation Scores				Breakpoint strength
					BP	BA	SR	BR	
01402000	1960	01443500	Runoff	0.78	3	4	2	18	Moderate
01402600	1980	01466500	Runoff	0.67	4	4	3	28	Strong
	1980	01466500	Base flow	0.67	4	3	3	24	Strong
01403060	1956	01443500	Runoff	0.74	4	3	2	20	Moderate
	1962	01440000	Runoff	0.85	3	3	2	15	Moderate
	1981	01443500	Runoff	1.31	3	3	3	18	Moderate
01403540	1981	01466500	Base flow	0.76	4	2	2	16	Moderate
	1995	01466500	Runoff	0.72	4	3	2	20	Moderate
01408000	1956	01443500	Runoff	0.76	3	3	2	15	Moderate
	1982	01443500	Base flow	1.25	4	2	2	16	Moderate
	1989	01440000	Base flow	1.24	4	2	2	16	Moderate
01408500	1963	01409500	Runoff	0.76	4	3	2	20	Moderate
01408120	1976	0143500	Base flow	0.98	4	4	0	16	Moderate
	1977	01435000	Runoff	0.87	4	2	2	16	Moderate
	1977	01440000	Runoff	0.80	4	2	2	16	Moderate
01409000	1941	01410000	Runoff	0.77	4	5	2	28	Strong
	1958	01410000	Runoff	2.98	4	5	5	40	Very strong
01410150	1993	01466500	Runoff	0.58	3	5	3	24	Strong
	1995	01466500	Base flow	0.79	4	2	2	16	Moderate
	1995	01466500	Runoff	0.65	3	4	3	21	Moderate
01411000	1970	01409500	Runoff	0.81	4	2	2	16	Moderate
01411456	1995	01466500	Runoff	0.65	4	5	3	32	Very strong
01445500	1962	01409500	Runoff	0.76	3	4	2	18	Moderate
	1972	01409500	Runoff	0.68	4	5	3	32	Very strong
01446000	1951	01386000	Runoff	1.11	3	4	2	18	Moderate
	1951	01384500	Runoff	1.32	4	5	3	32	Very strong
01457000	1972	01409500	Runoff	0.66	4	5	3	32	Very strong
	1973	01410000	Runoff	0.70	3	5	2	21	Moderate
01464000	1956	01440000	Runoff	0.77	4	2	2	16	Moderate
	1961	01443500	Runoff	0.77	3	5	2	21	Moderate
01464500	1956	01440000	Runoff	0.66	3	4	3	21	Moderate
	1956	01443500	Runoff	0.57	4	5	3	32	Very strong
	1979	01443500	Runoff	1.33	3	5	3	24	Strong
01467081[1]	1978	01384500	Runoff	0.65	4	5	3	32	Moderate

[1]Breakpoint most likely occurred between the years of 1978 and 1986, but exact year could not be determined owing to missing data for the index station.

Table 15. Final baseline period and quality ranking and supporting data for 85 selected streamflow-gaging stations in New Jersey.

[None during selected record, indicates that although years were identified that meet the specifications defined by the column heading, these years did not occur during the preliminary period of record. None identified, indicates that no years were identified that meet the specifications defined by the column heading.]

USGS station identifier	Available period of record[1]	Preliminary baseline period[2]	Year when impervious surface exceeded criteria[3]	Years during which breakpoints were identified[4]	Final baseline period	Baseline period quality ranking[5]
01379000	1903–2005	1903–1979	None identified	None identified	1921–1979	Excellent
01379500	1903–1911, 1938–2005	1938–1970	1966	1956, 1964	1938–1964	Excellent
01379773	1983–2005	1983–2005	None identified	1995	1983–2005	Fair
01380500	1937–2005	1937–2005	1996	1959, 1989	1937–1959	Excellent
01381500	1921–2005	1921–1970	1952	None during selected record	1921–1952	Excellent
01383500	1919–2005	1919–1968	None identified	None during selected record	1919–1968	Excellent
01384000	1934–1985	1934–1985	None identified	None identified	1934–1985	Excellent
01384500	1934–1979, 1985–2005	1934–2004	None identified	None identified	1934–2005	Excellent
01385000	1934–1958	1934–1958	None identified	None identified	1934–1958	Excellent
01386000	1934–1978	1934–1978	None identified	None identified	1934–1978	Excellent
01386500	1934–1958	1934–1958	None identified	None identified	1934–1958	Excellent
01387000	1912–1914, 1918–2005	1918–1928	None identified	1927–1928	1918–1928	Poor
01387450	1958–1995, 2005	1958–1995	None identified	None identified	1958–1995	Excellent
01387500	1902–1906, 1923–2005	1923–1979	1964	None identified	1923–1964	Excellent
01388000	1921–2005	1921–1953	None during selected record	None identified	1921–1953	Excellent
01390500	1954–1977, 1979–2005	1954–1964	None identified	None identified	1954–1964	Excellent
01391000	1954–1973, 1978–1996, 2003–2005	1954–1973	1947	None identified	1954–1965	Good
01391500	1923–2005	1923–1965	1937	1957, 1965	1923–1957	Good
01392000	1937–1962	1937–1951	None during selected record	None identified	1937–1950	Poor
01392210	1977–1997	1977–1997	None during selected record	1986	1977–1986	Poor
01392500	1937–1964	1937–1964	None during selected record	None identified	1937–1964	Fair
01396000	1939–1996	1970–1996	1986	1971–1973	[6]1973–1996	Poor
01396500	1918–2005	1918–1970	None identified	None identified	1918–1970	Excellent
01396580	1978–1988, 1991–2005	1978–2005	None identified	None identified	1978–2005	Excellent
01396660	1977–2005	1977–2005	None identified	None identified	1977–2005	Excellent
01397000	1903–1905, 1919–2005	1919–1963	None identified	None identified	1919–1963	Excellent
01397500	1936–1961	1936–1961	None identified	None identified	1936–1961	Excellent
01398000	1930–2005	1930–2004	None identified	1962–1966	1930–1962	Excellent
01398045	1977–1988	1977–1988	None identified	1982	1977–1988	Poor
01398107	1978–1996	1978–1996	None identified	None identified	1978–1996	Poor
01398500	1921–2005	1921–2005	None identified	None identified	1921–2005	Excellent
01399190	1976–1987	1976–1987	None identified	None identified	1976–1987	Poor
01399200	1975–1987	1975–1987	None during selected record	None identified	1975–1987	Poor
01399500	1921–2005	1921–2004	None identified	1950	1921–1950	Excellent
01399510	1972–1996	1982–1996	None identified	None during selected record	1982–1996	Poor

Table 15. Final baseline period and quality ranking and supporting data for 85 selected streamflow-gaging stations in New Jersey.—Continued

[None during selected record, indicates that although years were identified that meet the specifications defined by the column heading, these years did not occur during the preliminary period of record. None identified, indicates that no years were identified that meet the specifications defined by the column heading.]

USGS station identifier	Available period of record[1]	Preliminary baseline period[2]	Year when impervious surface exceeded criteria[3]	Years during which breakpoints were identified[4]	Final baseline period	Baseline period quality ranking[5]
01399525	1977–1988	1977–1988	None identified	None identified	1977–1988	Poor
01399670	1977–2005	1977–2005	None identified	None identified	1977–2005	Excellent
01400000	1923–2005	1923–2004	None identified	1962	1923–1962	Excellent
01400350	1982–1996	1982–1992	1991	None identified	1982–1992	Poor
01400500	1903–1907, 1921–2005	1921–1964	None identified	1927	1921–1963	Good
01400730	1964–1975, 1987–1989	1964–1975	None identified	1969–1971	1964–1975	Poor
01401000	1953–2005	1953–1980	None identified	None identified	1953–1980	Excellent
01401500	1933–1949	1933–1949	None identified	1939	1933–1949	Poor
01401650	1979–2005	1979–2005	1999	1995	1980–1999	Fair
01402000	1921–2005	1921–1960	None identified	1960	1921–1960	Excellent
01402600	1966–1975, 1980–1996	1966–1980	1973	1980	1966–1980	Poor
01403060	1903–1909, 1945–2005	1902–1963	None identified	1956, 1963	1945–1963	Poor
01403400	1978–2005	1979–2005	None during selected record	None identified	1979–2005	Good
01403535	1980–2000	1980–2000	None identified	None identified	1980–2000	Excellent
01403540	1974–2005	1974–1991	None during selected record	1981	1974–1991	Poor
01405300	1957–1967	1957–1967	None during selected record	None identified	1957–1967	Poor
01408000	1931–2005	1931–1989	None during selected record	1956	1931–1956	Excellent
01408120	1972–2005	1972–2005	1989	1976–1977	1972–2004	Fair
01408500	1928–2005	1928–1966	None identified	1963	1928–1963	Excellent
01409000	1932–1958, 1969–1971, 2003–2005	1932–1958	None identified	1941	1932–1956	Fair
01409095	1965–1985	1965–1985	None identified	None identified	1966–1985	Excellent
01409280	1973–1988, 2003–2005	1973–1988	None identified	None identified	1973–1988	Poor
01409400	1957–2005	1957–2005	None identified	None identified	1957–2005	Excellent
01409500	1927–2005	1927–2005	None identified	None identified	1927–2005	Excellent
01409810	1974–1996, 2006–2005	1974–2005	None identified	None identified	1974–1996	Excellent
01410000	1930–2005	1930–2005	None identified	None identified	1930–2005	Excellent
01410150	1978–2005	1978–2005	None identified	1993–1995	1978–2005	Fair
01411000	1925–2005	1925–2005	None identified	1970	1925–1970	Excellent
01411300	1969–2005	1969–2005	None identified	None identified	1969–2005	Excellent
01411456	1987–2005	1987–2005	None identified	1995	1987–2005	Poor
01411500	1932–2005	1932–2005	None identified	None identified	1932–2005	Excellent
01412000	1931–1985	1931–1957	None identified	None identified	1931–1957	Excellent
01412800	1977–1988, 2003–2005	1977–1988	None identified	None identified	1977–1988	Excellent
01437500	1937–2005	1937–1953	None identified	None identified	1937–1953	Poor
01440000	1923–2005	1923–2005	None identified	None identified	1923–2005	Excellent

Table 15. Final baseline period and quality ranking and supporting data for 85 selected streamflow-gaging stations in New Jersey.—Continued

[None during selected record, indicates that although years were identified that meet the specifications defined by the column heading, these years did not occur during the preliminary period of record. None identified, indicates that no years were identified that meet the specifications defined by the column heading.]

USGS station identifier	Available period of record[1]	Preliminary baseline period[2]	Year when impervious surface exceeded criteria[3]	Years during which breakpoints were identified[4]	Final baseline period	Baseline period quality ranking[5]
01443500	1921–2005	1921–2005	None identified	None identified	1921–2005	Excellent
01445000	1939–1962	1939–1962	None identified	None identified	1939–1962	Excellent
01445500	1921–2005	1921–1958	None identified	None during selected record	1921–1958	Excellent
01446000	1922–1961	1922–1961	None identified	1951	1922–1951	Excellent
01456000	1921–1973	1921–1973	None identified	None identified	1921–1973	Excellent
01457000	1903–1907, 1921–2005	1903–2005	None identified	1972–1973	1921–1972	Excellent
01464000	1923–2005	1923–1954	None identified	None during selected record	1923–1956	Excellent
01464500	1940–2005	1940–2005	None identified	1956, 1979	1940–1979	Fair
01465850	1961–1975	1961–1975	None identified	None identified	1961–1975	Excellent
01466000	1952–1964	1952–1964	None identified	None identified	1952–1964	Poor
01466500	1953–2005	1953–2005	None identified	None identified	1953–2005	Excellent
01467000	1921–2005	1921–2005	None identified	None identified	1921–2005	Excellent
01467081	1967–2005	1967–2005	None during selected record	1978	1967–1978	Fair
01475000	1940–1976, 2003–2005	1940–1976	1972	None identified	1940–1972	Excellent
01477120	1966–2005	1966–2005	None identified	None identified	1966–2005	Excellent

[1]Indicates water year, which is the 12-month period beginning October 1 and ending September 30 and is named for the year in which it ends.

[2]The preliminary baseline period of record is the continuous time period that remained after eliminating years that are clearly not baseline on the basis of historical basin information and the years that fall outside the impervious-surface thresholds (less than 10 percent, greater than 10 percent and less than 20 percent, greater than 20 percent and less than 15 percent change, and greater than 20 percent and greater than 15 percent change).

[3]The criteria for noting an exceedance in the estimated percent of impervious surface in the drainage basin were greater than 10 percent impervious surface unless otherwise noted.

[4]Selected breakpoint years were those that were statistically significant and determined to be “weak,” “strong,” or “very strong” based on visual interpretation.

[5]This ranking is a measure of the quality of the baseline period and is determined by the number of years, the estimated changes in impervious surface in the drainage basin, and the number and severity of breakpoints in the double-mass curve.

the runoff double-mass curve. The baseline periods of four stations were ended when a threshold was reached after the minimum number of years was achieved. No stations had final baseline periods that crossed three or more thresholds, one station had final baseline periods that crossed two thresholds, and three stations had baselines that crossed one threshold.

Periods of record for several stations were not reduced, although some years in the record did not appear, based on one or more criteria, to be baseline because deleting those years would decrease the record to less than the minimum period of record for the given stream class. A “poor” quality rating was assigned to the baseline period of such stations. The “poor” rated stations, for the purposes of this study, however, are considered the optimal period of record, given the years of continuous streamflow-data available.

Most baseline periods were considered “good” (64 percent); however, final baseline periods of 20 stations were considered “poor” because they contained fewer than the minimum number of years for its stream class. Of those 20 stations, 12 had total periods of record shorter than the required number of years; 6 had baseline periods limited because of historical information; and 4 had baseline periods limited by breakpoints in double-mass curves.

Assumptions and Limitations of Methods Used to Determine Baseline Periods

Several assumptions were made when determining minimum periods of record for stream classes and baseline periods of record. Relations between impervious surface and population were based on recent data and extrapolated to historical periods. Additionally, the evaluation of double-mass curves included visual assessment of breakpoints, which is subjective by nature.

Historical Land Use/Land Cover

Historical land use was analyzed to determine a period of record at each station during which urbanization was minimal or unchanging. Urbanization is directly responsible for increases in impervious surface, which leads to increases in stormwater runoff, decreases in base flow, and increases in ground-water withdrawals and surface-water diversions for consumptive purposes (Arnold and Gibbons, 1996; Konrad, 2003; Konrad and Booth, 2002). Previous studies have found that impervious surface levels of 10 to 20 percent cause moderate impairment of hydrologic processes in the basin and greater than 20 percent cause severe impairment (Kennen and Ayers, 2002; Brun and Band, 2000). Therefore, changes resulting from urbanization can compromise the ecological integrity of a stream.

Information on impervious surface was digitally available from the 1995/97 GIS land-use/land-cover coverage (New Jersey Department of Environmental Protection, 2000). In this coverage, Level II land-use information was available for both 1995/97 and 1986, and the percentage of impervious surface for 1986 was estimated on the basis of the relation between land use and impervious surface in the 1995/97 coverage. Following the method of Stankowski (1972), a regression model was developed to relate the mean population density of 570 municipalities in New Jersey to the mean percentage of impervious surface, which was based on digital information from the 1995/97 GIS coverage. The assumption was made that this relation, which reflects more recent patterns of urbanization, would hold constant over time despite changes in building and road-construction patterns. There could be bias in this assumption, however, as a result of changes in patterns of urban development and their relation to impervious surface over the course of the 20th century. For example, the average floor area of new houses has increased from 983 square feet in 1950 to about 2,266 square feet in 2000, whereas average family size decreased over the past 60 years (Diamond and Moezzi, 2004). The results may be that the percentage of impervious surface for earlier years was overestimated, which could explain why Stankowski’s 1972 estimate of impervious surface was generally lower than those calculated in this study (fig. 3).

Estimates of the percentage of impervious surface in drainage basins were based on the relation between impervious surface and population density for municipalities, which have different community structures. The difference between the percentage of impervious surface estimated using the regression (equation 2) and the percentage of impervious surface from the 1995/97 GIS coverage for 570 municipalities in New Jersey is shown in figure 6. There is increasing variability in impervious surface for a given population density as population density increases. Also, a linear regression using these two variables results in a slope that is less than 1. The slope, r^2, and standard error of the relation between percentage of impervious surface estimated using a regression model and percentage of impervious surface estimated using GIS data are 0.87, 0.84, and 5.5, respectively. A plot of the percentage of impervious surface for 85 drainage basins based on the 1995/97 GIS land-use coverage and the percentage of impervious surface for 1996 estimated using the regression model is shown in figure 7. For comparison purposes, an error bar was set at 5.5 units, the standard error of the relation between the two variables for municipalities (shown in figure 7), above and below a one-to-one line. Outliers at higher percentages of impervious surface, most of which are below the one to one line appear to be more extreme than those at lower percentages, indicating that some drainage basins may contain a relatively high proportion of areas of non-residential impervious surface (such as industrial, commercial, military, or transportation areas). This would result in a lower estimate of impervious surface from the regression model as a result of lower population density, but in reality the percentage of impervious surface would be greater because of the non-residential land uses. The correction factor (Equation 3) was used to compensate for this variability.

Estimates of historical impervious-surface values are subject to error from several sources, including the relation between population density and impervious surface, incomplete and inaccurate population data, and additional error from the assumption of uniform percentages of Level II land use (and, therefore, impervious surface) throughout the drainage basin where part of the drainage basin lies outside of New Jersey. For the purposes of the baseline study, however, the estimates were considered adequate for determining the period of record with the least degree of human alteration. This is because the change in impervious surface over time was considered more important than the accuracy of the percentage of impervious surface at any point in time. A more in-depth study of historical land-use practices may consider a detailed history of urbanization and other types of development, including historical changes in Level II land use, cultural and socioeconomic factors of development, and changes in agricultural activity in the drainage basin.

The history of agriculture in New Jersey indicates, in general, a decrease in agricultural land use and an increase in urban land use. By 1870, about 3 million of the 4.8 million acres in New Jersey were agricultural. Agriculture in the early 20th century gradually changed from poultry, dairy, and livestock to row crops and nursery products. As urbanization increased, agricultural activity decreased. Agriculture accounted for 36.5 percent of land area in 1930, 37 percent in 1950, 22 percent in 1970, and 17 percent in 1996. Agricultural land may be sold to developers or may be abandoned and undergo natural forest succession. Forested land accounted for 30 percent of New Jersey in 1880, and 32 percent by 1995, according to the 1995/97 land-use coverage (New Jersey Department of Environmental Protection, 2000). Thus there has not been a substantial net loss of forested land in New Jersey in more than 100 years, and urban land use is expanding mostly at the cost of agricultural land use. The transition from agricultural land use to re-forested land use or urban land use is not well defined for the historical time frame of this study, and the historical effects of agricultural land use on hydrology in the basin would have been difficult to predict; therefore, agricultural land use was not considered in the baseline period investigation.

Double-Mass Curves

The objective of using double-mass analysis was to improve the quality of baseline periods of record by excluding years in which substantial changes in streamflow patterns occurred but were not identified through the evaluation of historical records or population and impervious-surface data. Changes in the slope of the double-mass curve (breakpoints) are assumed to represent changes in streamflow characteristics at the test station that are independent of annual changes in local climate and are the result of changes in land use, regulation, diversion, or other human activity in the basin. In this investigation, an assumption was made that the years before the breakpoint were more representative of baseline conditions than the years after the breakpoint. Therefore, a continuous series of years that met baseline criteria, occurred prior to a breakpoint that was rated moderate or greater, and exceeded the minimum period of record was considered to be the baseline period for that station. In some basins, the early years may not be the best choice of baseline period, especially in areas where stormwater management has been improved, or where former agricultural areas have reverted to forest. Stormwater management, including implementation of retention ponds and catchment basins, can regulate the amount of runoff from precipitation that enters the stream after an event. This may serve to offset the assumed increases in runoff and decreases in base flow that would occur as a result of increases in impervious surface and decreases in native vegetation. Forest canopy and leaf litter from native vegetation help to attenuate runoff by increasing evapotranspiration and reducing runoff. These assumptions reflect the partially subjective nature of determining baseline periods, regardless of the methods and criteria used.

Slope ratios of double-mass curves for the 85 sites are shown as box plots in figure 8. A one-sided t-test was conducted to determine whether the slope ratios for runoff double-mass curves are less then those of base-flow double-mass curves. Results showed this to be the case ($t = 3.60$ with 71 degrees of freedom, probability is greater than 0.999). Additionally, the probability of base-flow slope ratios being greater than 1.0 is 0.98. and the probability of runoff slope ratios being less than 1.0 is 0.85. This indicates a trend of increasing runoff and decreasing base flow after a breakpoint, which is consistent with the effects on urbanization of streamflow, where an increase in urbanization can cause an increase in cumulative annual runoff and a decrease in cumulative annual base flow as a result of increases in impervious surface and increases in ground-water and surface-water withdrawals, as was observed by Watson and others (2005) for selected streamflow-gaging stations in New Jersey. Watson and others (2005) also found that urbanization is more strongly related to increasing high-flow values than to decreasing low-flow values.

The abruptness of a breakpoint was an indication of the rate of change in basin dynamics that caused the breakpoint. It is assumed that long-term changes in land use, primarily increases in urbanization or other development, would cause gradual changes in runoff and base-flow patterns, and a curve rather than a sharp bend would be evident in the double-mass curve. A limitation of the analysis of covariance of double-mass curves is that statistically significant breakpoints did not always occur in the same year when a station was tested against two different index stations. Of 45 stations that are classified as stream classes A, B, or C with breakpoints considered for analysis, 19 had breakpoints for the same type of flow (base flow or runoff) that occurred in the same year and

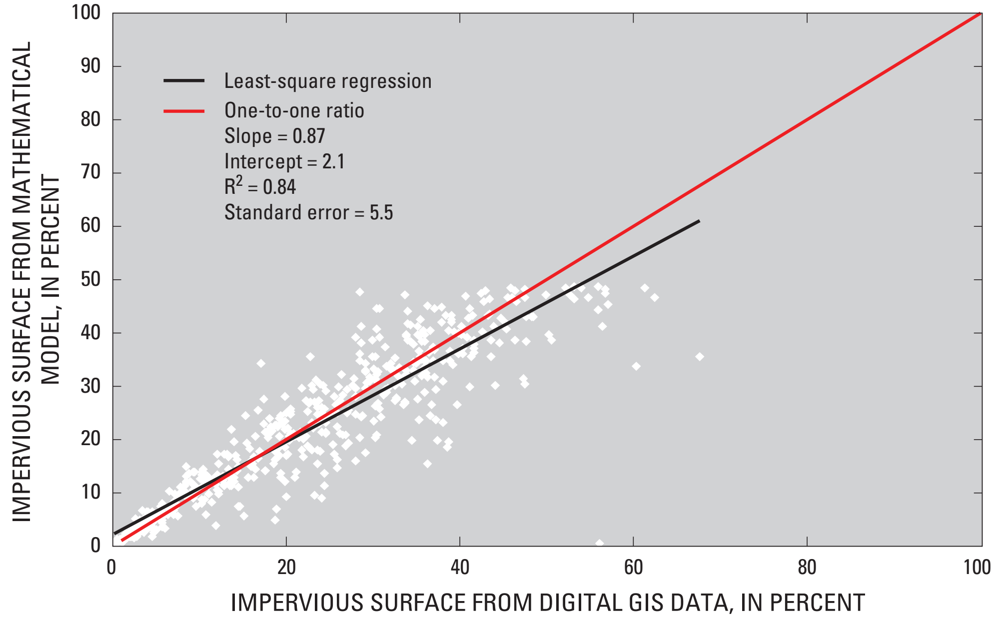


Figure 6. Relation of impervious surface determined from digital geographic information system (GIS) data for 570 municipalities for the years 1995-1997[1] to impervious surface determined from a mathematical model used to estimate impervious surface using population density for the year 1996. (Spatial impervious surface information, municipality boundaries, and census data[2] for municipalities were used to derive the relation of percentage of impervious surface and population density data for each municipality.)

[1]Impervious surface data were derived from a digital geographic information system coverage of land use in New Jersey for 1995-1997 (New Jersey Department of Environmental Protection, 2000).

[2]Municipality and population density information are from historic U.S. Census Bureau information for the years 1930-2000 (U.S. Census Bureau, 2007).

6 other stations had breakpoints for the same type of flow that occurred within 3 years of each other. For these stations, of which a total of 55 breakpoints were identified for the same flow type that occurred during the same or similar year when tested against both index stations, only 19 breakpoints (among 11 stations) were considered moderate or stronger. One possible explanation is that one or both of the index stations used in the double-mass curve may not have been appropriate for the test station. It was assumed for this investigation, however, that double-mass curves of index stations and test stations of the same stream class should be linear without breakpoints in the absence of hydrologic changes in the test station basin, even though stream class is based solely on similarities and differences in selected hydrologic indices, not on hydrogeology, precipitation, soil type, or other physical factors that can affect streamflow.

Poor correlation between the test station and index station could hinder detection of the breakpoint using the analysis of covariance test. Although index stations were compared to test sites of the same stream class, the comparison does not ensure that the sites are hydrologically similar. A difference in precipitation patterns between geographically distant sites could produce poorly correlated double-mass curves in which line segments would have substantial scatter and breakpoints would be difficult to detect. For example, a test station and index station that are the same stream class but are located in different climate zones could receive substantially different precipitation amounts.

Given the assumptions and observations mentioned above, double-mass analysis alone could not be used to identify baseline periods. The method, as used in this investigation, combines objective, statistically based screening with subjective observation and analysis. The double-mass analysis results were used only to reduce the number of years considered as baseline while maintaining a minimum period of record or to assign a qualitative ranking to the baseline period.

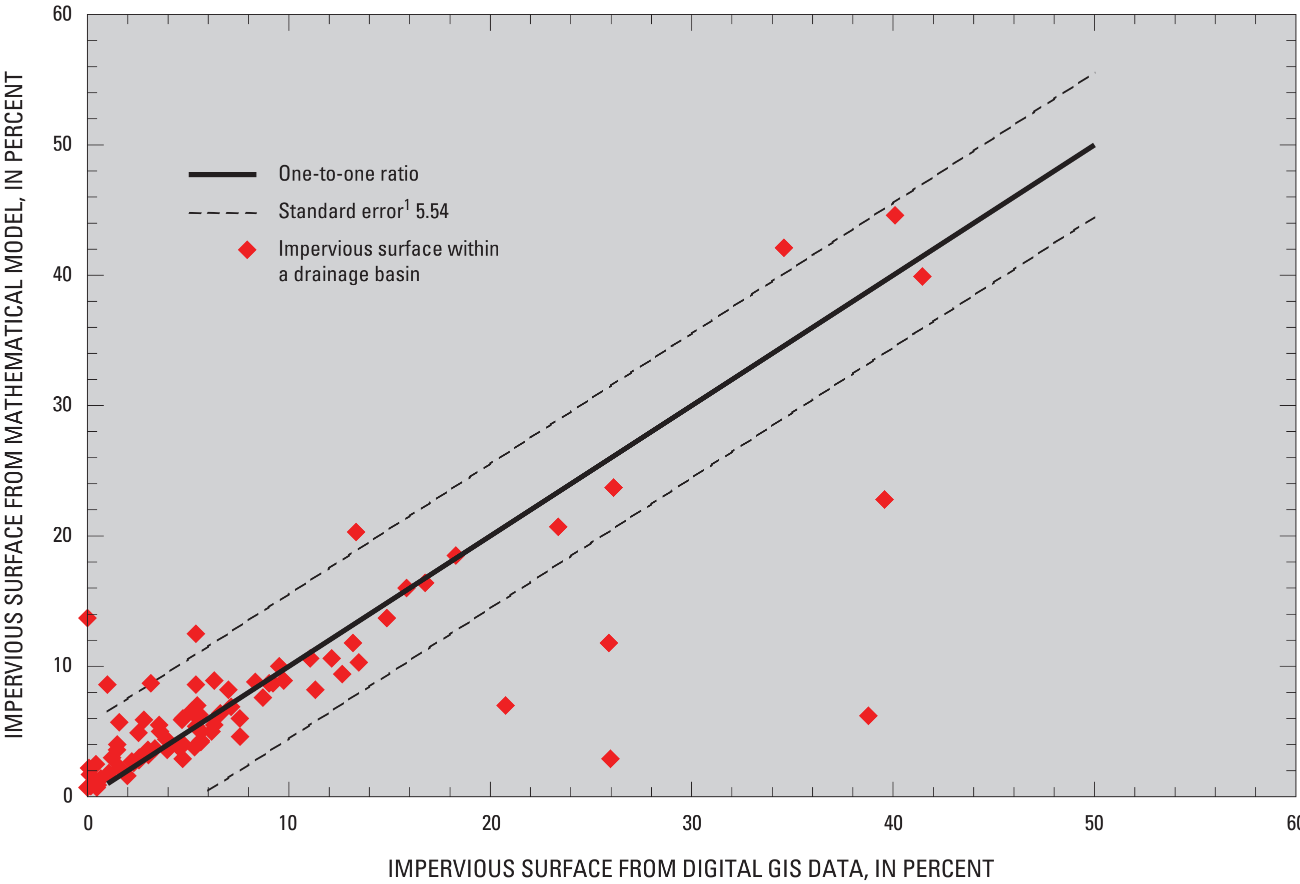


Figure 7. Relation of impervious surface determined from digital geographic information system (GIS) data for 85 drainage basins for the years 1995-1997 to impervious surface determined from mathematical model based on population density for the year 1996, for the same 85 drainage basins in New Jersey. (Spatial impervious surface information[2] and drainage basin boundaries[3] were used to derive the percentage of impervious surface for each drainage basin. Spatial census block data[4] and drainage basin boundaries were used to derive the population density for each drainage basin.)

[1]Standard error is from least-squares regression for the relation between the percentage of impervious surface for drainage basins determined from GIS information (1995-1997) and from a mathematical model, and in this graph is set about the one-to-one line.

[2]Impervious surface data were derived from a digital geographic information system coverage of land use in New Jersey for1995-1997 (New Jersey Department of Environmental Protection, 2000).

[3]A geographic information systems coverage of drainage basins for 85 surface-water gaging stations was developed from drainage basin delineations using a 30-meter-grid digital elevation model coverage of New Jersey.

[4]Population density information for drainage basins was derived from a digital geographic information system coverage of spatial census block information for the years 1930-2000, using historic information from the U.S. Census Bureau (U.S. Census Bureau, 2007).

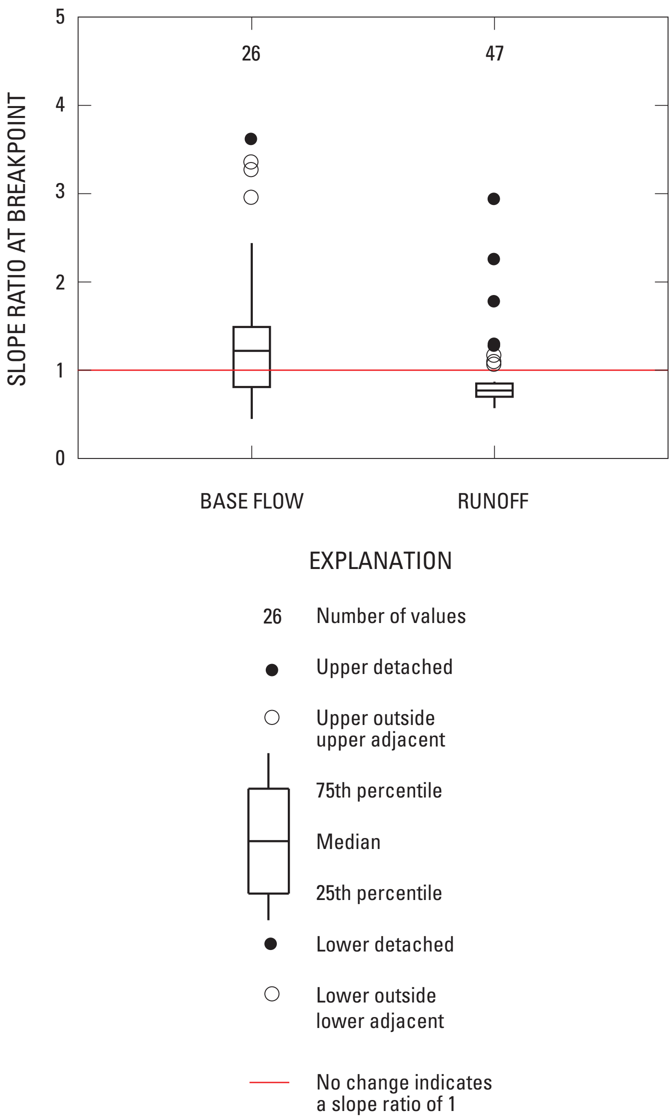


Figure 8. Boxplot showing slope ratios at selected statistically significant breakpoints on the double-mass curve for test stations and index stations.

(Slope ratios are the ratio of cumulative annual flow at the test station divided by cumulative annual flow at the index station at selected breakpoint years. Slope ratios greater than 1 indicate an increase in slope at the test station and values less than 1 indicate a decrease in slope at the test station. "No change" line indicates a slope of 1.0)

Summary and Conclusions

Characteristics of streamflow, which can be represented by environmentally relevant hydrologic indices (ERHIs), are known to affect the integrity of aquatic ecological systems. Many of these indices have been identified in previous research. The aspects of the flow regime considered when determining the indices include magnitude, duration, frequency, and rate of change, and the timing from the daily hydrograph.

Continuous daily streamflow data from 85 automated streamflow-gaging stations in New Jersey were used to compute hydrologic indices. To compute the hydrologic indices, an optimum baseline period of record for each station was determined from the available record of continuous daily streamflow data that reflects a period when the streamflow was the least altered by human activity.

The minimum number of years for a baseline period was determined by testing the null hypothesis of no difference among ERHIs calculated for sequential periods of 5, 10, 15, and 20 years by using the Kruskall-Wallis test. If the years considered for baseline status after analysis of historical streamflow information amounted to less than that minimum period, which varies among the four stream classes, the baseline period was rated "poor."

Urbanization and population growth in New Jersey has increased substantially over the past century, but rates of development vary among basins. Therefore, the baseline period as defined in this investigation may vary in quality. Each baseline period was ranked as "excellent," "good," "fair," or "poor," the rank denotes stability of the period of record selected for baseline status with respect to changes in the basin that affect streamflow characteristics.

Years during which stations had substantial regulation, large diversions of flow, major ground-water or surface-water withdrawals from the drainage basins, or extensive urbanization were excluded from baseline periods. This information was gathered from documented streamflow-gaging station data and information from the USGS News Jersey Water Science Center staff. Additional methods were used to supplement analysis for years when no known historical changes in the stream reach had occurred, or minor activity had occurred, but the best period of record could not be selected from the streamflow-gaging station data alone. Land use in the drainage basin and changes in annual runoff and base flow were estimated for the selected stations in order to improve the baseline period.

Historic trends in urbanization were evaluated using population data and the relation between population growth and impervious surface. Impervious surface was used as an indictor for the baseline period because it has a direct effect on rates of runoff and base flow, and increases in impervious surface are related to other effects of urbanization, including increased ground-water and surface-water withdrawals for consumption. Impervious surface and other specific land-use information, in general, were not available for years prior to 1986; therefore, population density was used to estimate impervious surface for those years. Variability in the estimates probably was the result of differences in population growth and development, such as construction of industrial or commercial development, which may or may not include residential areas.

Changes in trends of annual runoff and base flow were determined by using analysis of covariance of double-mass curves. Double-mass curves consist of a plot of cumulative data, in this case cumulative annual runoff and base flow, between the test station (x-axis) and index station (y-axis). Changes in annual runoff or base flow depicted on this curve were assumed to result from changes in the test station and not from periodic climate variation or changes in the annual streamflow characteristics at the index station. It was assumed that changes in annual runoff or base flow at the test station resulted from a change in annual streamflow characteristics and that the earlier period of record (before the suspected change occurred) was better suited for a baseline period. Statistically significant breakpoints on the double-mass curve for the period of record were evaluated using analysis of covariance to test the null hypothesis of no difference between the slope of the regression line before and the slope after the breakpoint. In addition, breakpoints were visually evaluated for strength and magnitude. A numerical rating system then was used to give each breakpoint an overall rating of “very strong,” “strong,” “moderate,” or “weak.”

Results from all three baseline determination criteria then were used to select the final baseline period. Index values for all 171 indices were calculated for the baseline period and presented on the USGS World Wide Web site at *http://(website construction in progress).gov.*

Hydrologic indices can be used in regulatory planning to establish streamflow standards that encompass ecological integrity as a management goal in riverine resources. Indices calculated from daily streamflow data from a period when human activities in the drainage basin were minimal, a time when the local aquatic ecological system was functioning in a relatively more natural state, can be used to establish more comprehensive streamflow standards and requirements than are currently available.

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Appendix 1

Appendix 1. Determination of preliminary baseline period for selected stream reaches in New Jersey (in water years) based on streamflow-gaging station history from published USGS annual data reports (1930-2005), and oral and written communications from USGS staff at the New Jersey Water Science Center.

[A water year is the 12-month period beginning October 1 and ending September 30 and is named for the year in which it ends. SB, South Branch; NB, North Branch]

Station number	Station name	Comments	Years of record
01379000	Passaic River near Millington, NJ	Regulation since 1979 reduces flood peaks and augments low flow. Period of record before regulation selected as preliminary baseline period.	1903-1979
01379500	Passaic River near Chatham, NJ	Diversions from Osborn Pond for municipal supply during water years 1903-79 and substantial sewage discharge into stream since 1970. Period of record before 1970 selected as preliminary baseline period.	1938-1970
01379773	Green Pond Brook at Picatinny Arsenal, NJ	Some minor regulation by Lake Denmark and Green Pond, but full period of record selected as baseline period.	1983-2005
01380500	Rockaway River above Reservoir at Boonton, NJ	Flow has been regulated by Splitrock Reservoir and diversions have been made from Taylortown Reservoir since the start of the period of record. Substantial ground-water diversion in the basin has been steadily increasing with development and increases in population in the drainage basin. Sewage-treatment-plant outfall to the stream above the gage was discontinued in 1960.	1937-1960
01381500	Whippany River at Morristown, NJ	Early on in the period of record, storm sewers entering the river in Morristown caused sharp rises in stage during runoff events and diurnal patterns in low flows due to sewage effluent. After route I-287 was built in 1970, magnitude and frequency of peak flows increased noticeably. Period of record before 1970 selected as preliminary baseline period.	1921-1970
01383500	Wanaque River at Awosting, NJ	Water has been diverted into the basin from the Upper Greenwood Lake for municipal supply since 1968. Period before 1968 selected as preliminary baseline period.	1969-2004
01384000	Wanaque River at Monks, NJ	Minor regulation by Greenwood Lake. Water has been diverted into the basin from the Upper Greenwood Lake for municipal supply since 1968, period of record before diversion was selected as preliminary baseline period.	1934-1985
01384500	Ringwood Creek near Wanaque, NJ	Minor regulation by Ringwood Mill Pond, Sterling Forest Lakes, and several smaller retention basins upstream from the station. Entire period of record selected as baseline period.	1934-2004
01385000	Cupsaw Brook near Wanaque, NJ	Minor regulation by Cupsaw Lake and Sheppard Pond. Entire period of record selected as preliminary baseline period.	1934-1958
01386000	West Brook near Wanaque, NJ	Entire period of record selected as preliminary baseline period.	1934-1978
01386500	Blue Mine Brook near Wanaque, NJ	Entire period of record selected as preliminary baseline period.	1934-1958
01387000	Wanaque River at Wanaque, NJ	Substantial regulation since 1928. Sewage effluent also enters stream at multiple locations throughout the basin, which affects low flows. Period of record before 1928 selected as preliminary baseline period.	1918-1928

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Station number	Station name	Comments	Years of record
01387450	Mahwah River near Suffern, NY	Minor and occasional regulation from unknown sources. Entire period of record selected as preliminary baseline period.	1958-1995
01387500	Ramapo River near Mahwah, NJ	Since 1979, flow substantially affected by pumping from ground-water wells in areas of the drainage basin for municipal supply. Period of record before 1979 selected as preliminary baseline period.	1923-1979
01388000	Ramapo River at Pompton Lakes, NJ	Water diverted since 1953 for municipal supply to Wanaque Reservoir. Additional diversions to Oradell Reservoir since 1985. Period of record before 1953 selected as preliminary baseline period.	1921-1953
01390500	Saddle River at Ridgewood, NJ	Flow affected by ground-water withdrawals in the drainage basin since 1964. Period of record before 1964 selected as preliminary baseline period.	1954-1964
01391000	Hohokus Brook at Ho-Ho-Kus, NJ	In 1980, there was expansion of a sewage-treament plant contributing substantial effluent to the stream which causes diurnal fluctuation at medium and low flow. No data were available for 1974 to 1977. Therefore, to obtain a continuous period of record, the period before 1974 was selected as the baseline period.	1954-1973
01391500	Saddle River at Lodi, NJ	Regulation since 1965 reduces flood peaks and augments low flow. Diversion upstream from station for municipal supply and ground-water withdrawal also affect flow, but specific year of influence is hard to identify. Period of record before 1965 was selected for preliminary baseline period.	1923-1965
01392000	Weasel Brook at Clifton, NJ	Regulation and inflow from Garden State Parkway stormwater management occurred since 1950. Period of record before 1950 was selected for preliminary baseline period.	1937-1950
01392210	Third River at Passaic, NJ	Minor regulation from upstream ponds. Entire period of record selected as preliminary baseline period.	1977-1997
01392500	Second River at Belleville, NJ	Entire period of record selected as preliminary baseline period.	1937-1964
01396000	Robinsons Branch at Rahway, NJ	Diversions from Robinsons Branch continued until 1970 when water supply was available from another location. Period of record after 1970 was selected as preliminary baseline period.	1970-1996
01396500	South Branch Raritan River near High Bridge, NJ	Golf courses in the area contribute to regulation since around 1970. Period of record before 1970 selected as preliminary baseline period.	1918-1970
01396580	Spruce Run at Glen Gardner, NJ	Minor regulation from unknown sources upstream. Entire period of record selected as preliminary baseline period.	1978-2005

Appendix 1. Determination of preliminary baseline period for selected stream reaches in New Jersey (in water years) based on streamflow-gaging station history from published USGS annual data reports (1930-2005), and oral and written communications from USGS staff at the New Jersey Water Science Center.—Continued

[A water year is the 12-month period beginning October 1 and ending September 30 and is named for the year in which it ends. SB, South Branch; NB, North Branch]

Station number	Station name	Comments	Years of record
01396660	Mulhockaway Creek at Van Syckel, NJ	Entire period of record selected as preliminary baseline period.	1977-2004
01397000	SB Raritan River at Stanton, NJ	Regulation from Spruce Run reservoir since 1963. Diversions to reservoir pumping station since 1966. Period of record before 1963 selected as preliminary baseline period.	1919-1963
01397500	Walnut Brook near Flemington, NJ	Entire period of record selected as preliminary baseline period.	1936-1961
01398000	Neshanic River at Reaville, NJ	Minor regulation from irrigation pumpage and gradual substantial development over the period. No other substantial change in anthropogenic alteration of the stream or drainage basin could be determined; therefore, the entire period of record was selected as preliminary baseline period.	1930-2004
01398045	Back Brook Tributary near Ringoes, NJ	Entire period of record selected as preliminary baseline period.	1977-1988
01398107	Holland Brook at Readington, NJ	Entire period of record selected as preliminary baseline period.	1978-1996
01398500	NB Raritan River near Far Hills, NJ	Occasional regulation and diversion affects streamflow. No other substantial change from human alteration of the stream or drainage basin could be determined; therefore, the entire period of record was selected as preliminary baseline period.	1921-2004
01399190	Lamington (Black) River at Succasunna, NJ	Entire period of record selected as preliminary baseline period.	1976-1987
01399200	Lamington (Black) River near Ironia, NJ	Ground-water withdrawal for municipal supply occurred upstream from gaging station throughout period of record. No other substantial change from human alteration of the stream or drainage basin could be determined; therefore, the entire period of record was selected as baseline period.	1975-1987
01399500	Lamington (Black) River near Pottersville, NJ	Entire period of record selected as preliminary baseline period.	1921-2004
01399510	Upper Cold Brook near Pottersville, NJ	Regulation by Pottersville Reservoir occurred until 1982 when the dam was demolished. Period of record after 1982 was selected for preliminary baseline period.	1982-1996
01399525	Axle Brook near Pottersville, NJ	Entire period of record selected as preliminary baseline period.	1977-1988
01399670	South Branch Rockaway Creek at Whitehouse Station, NJ	Releases from Round Valley Reservoir have affected stream during the entire period of record. The entire period of record was selected as preliminary baseline period.	1977-2005

Appendix 1. Determination of preliminary baseline period for selected stream reaches in New Jersey (in water years) based on streamflow-gaging station history from published USGS annual data reports (1930-2005), and oral and written communications from USGS staff at the New Jersey Water Science Center.—Continued

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Station number	Station name	Comments	Years of record
01400000	North Branch Raritan River near Raritan, NJ	Intermittent releases from Round Valley Reservoir have affected stream during the entire period of record. The entire period of record was selected as preliminary baseline period.	1923-2004
01400350	Macs Brook at Somerville, NJ	Expansion of commercial development in the drainage basin occurred in 1992. Streamflow was affected by stormwater management (regulation by detention ponds). Period of record before 1992 was selected as preliminary baseline period.	1982-1992
01400500	Raritan River at Manville, NJ	Regulation from Spruce Run Reservoir has occurred since 1963. Diversions to Round Valley Reservoir and other locations have occurred since 1966. After 1986, some diversions stopped.	1921-1964
01400730	Millstone River at Plainsboro, NJ	Minor diversion for irrigation occurred throughout the period. Entire period of record selected as preliminary baseline period.	1964-1975
01401000	Stony Brook at Princeton, NJ	Sewage effluent is substantial during periods of increased development. A period of accelerated increase in effluent is thought to have occurred around 1980. Period of record before 1980 was selected as preliminary baseline period.	1953-1980
01401500	Millstone River near Kingston, NJ	During the entire period of record there were limited diversions to and inflow from Delaware and Raritan Canal, slight regulation at upstream lake, and diurnal fluctuations at low flow at a gristmill above the station. The entire period of record was selected as preliminary baseline period.	1933-1949
01401650	Pike Run at Belle Mead, NJ	Substantial development in the basin occurred gradually throughout the period of record. The entire period of record was selected as preliminary baseline period.	1980-2005
01402000	Millstone River at Blackwells Mills, NJ	During the entire period of record, there was inflow from and losses to the Delaware and Raritan Canal, and minor regulation from Carnegie Lake and other smaller reservoirs. Sewage effluent increased dramatically following development after around 1960. Period of record before 1960 was selected as preliminary baseline period.	1921-1960
01402600	Royce Brook Tributary near Belle Mead, NJ	Regulation from stormwater detention basins upstream from the station has occurred since 1980. Period of record before 1980 was selected as preliminary baseline period.	1966-1980
01403060	Raritan River below Calco Dam at Bound Brook, NJ	Regulated by Spruce Run and Round Valley Reservoirs since 1963. Diversions have been made 1.2 miles upstream from station for municipal supply throughout the period of record. Period of record before 1963 was selected as preliminary baseline period.	1902-1963
01403400	Green Brook at Seeley Mills, NJ	A dam upstream from the station has been a source of regulation throughout the period of record. The entire period of record was selected as preliminary baseline period.	1979-2005

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Station number	Station name	Comments	Years of record
01403535	East Branch Stony Brook at Best Lake at Watchung, NJ	A dam upstream from the station has been a source of regulation throughout the period of record. The entire period of record was selected as preliminary baseline period.	1980-2000
01403540	Stony Brook at Watchung, NJ	Channel enlarged and modified in 1991. Right wall of channel was replaced in 1997. Period before 1991 was selected as preliminary baseline period.	1974-1991
01405300	Matchaponix Brook at Spotswood, NJ	Flow past the station is affected by pumpage from well fields for nearby industrial use. The time period and rate of increases of this pumpage could not be determined. The entire period of record was selected as preliminary baseline period.	1957-1967
01408000	Manasquan River at Squankum, NJ	Regulation from Manasquan Reservoir has occurred since 1990 when the reservoir was constructed. Period before 1990 was selected as preliminary baseline period.	1931-1989
01408120	North Branch Metedeconk River near Lakewood, NJ	Entire period of record selected as preliminary baseline period.	1972-2004
01408500	Toms River near Toms River, NJ	Diversion and regulation for industrial use occurred from 1966-1990. Currently, additional minor regulation occurs from an unknown source. Period of record before 1966 was selected as preliminary baseline period.	1928-1966
01409000	Cedar Creek at Lanoka Harbor, NJ	Regulation from cranberry operations upstream had ceased at some point after 1958 (exact date unknown) with the creation of Double Trouble State Park. Cranberry operations have continued on a very minor scale since 1995 for preliminary re-enactment purposes. Period of record before 1958 was selected as preliminary baseline period because it is the longest continuous period available.	1932-1958
01409095	Oyster Creek near Brookville, NJ	Minor regulation from cranberry bogs. Entire period of record selected as preliminary baseline period.	1965-1985
01409280	Westecunk Creek at Stafford Forge, NJ	Minor regulation from upstream dam. Entire period of record selected as preliminary baseline period.	1973-1988
01409400	Mullica River near Batsto, NJ	Minor regulation from upstream cranberry bogs and Atison Lake. Diversions from Sleeper Branch enter upstream from the station. No substantial change from human alteration of the stream or drainage basin could be determined from documented or known information. Therefore, the entire period of record was selected as preliminary baseline period.	1957-2005

Appendix 1. Determination of preliminary baseline period for selected stream reaches in New Jersey (in water years) based on streamflow-gaging station history from published USGS annual data reports (1930-2005), and oral and written communications from USGS staff at the New Jersey Water Science Center.—Continued

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Station number	Station name	Comments	Years of record
01409500	Batsto River at Batsto, NJ	Regulation from sluice gates prior to 1954 and after 1959. No substantial change from human alteration of the stream or drainage basin could be determined based on documented or known information; therefore, the entire period of record was selected as preliminary baseline period.	1927-2005
01409810	West Branch Wading River near Jenkins, NJ	Minor regulation from cranberry bogs and small ponds. Entire period of record selected as baseline period.	1974-2005
01410000	Oswego River at Harrisville, NJ	Regulation from Harrisville Pond and cranberry bogs. Low flows also are reduced by outflow of ground water to nearby drainage basins. No years could be excluded from the baseline period as a result of reviewing historical data.	1930-2004
01410150	East Branch Bass River near New Gretna, NJ	Minor regulation by Lake Absegami. Entire period of record selected as preliminary baseline period.	1978-2005
01411000	Great Egg Harbor River at Folsom, NJ	Entire period of record selected as preliminary baseline period.	1925-2005
01411300	Tuckahoe River at Head of River, NJ	Minor regulation from upstream ponds. Entire period of record selected as preliminary baseline period.	1969-2004
01411456	Little Ease Run near Clayton, NJ	Entire period of record selected as preliminary baseline period.	1987-2005
01411500	Maurice River at Norma, NJ	Entire period of record selected as preliminary baseline period.	1932-2004
01412000	Menantico Creek near Millville, NJ	Minor regulation from unknown source. Earlier period of record selected as preliminary baseline period.	1931-1957
01412800	Cohansey River at Seeley, NJ	Minor regulation from lakes and irrigation. Entire period of record selected as preliminary baseline period.	1977-1988
01437500	Neversink River at Godeffroy, NY	Prior to 1949, minor diurnal fluctuations at low flow caused by power plant. Regulation from Neversink Reservoir has occurred since 1954. Currently, flow is diverted for municipal supply. Period of record before 1954 was selected as preliminary baseline period.	1937-1953
01440000	Flat Brook near Flatbrookville, NJ	Minor regulation from upstream ponds. Entire period of record selected as preliminary baseline period.	1923-2005
01443500	Paulins Kill at Blairstown, NJ	Minor regulation by Swartswood Lake and other ponds. Minor and temporary fluctuations by unknown source. Entire period of record selected as preliminary baseline period.	1921-2004
01445000	Pequest River at Huntsville, NJ	Entire period of record selected as preliminary baseline period.	1939-1962

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Station number	Station name	Comments	Years of record
01445500	Pequest River at Pequest, NJ	Channel was dredged and realigned from 1958 to 1960 which has altered peak discharges ever since. Period of record before 1958 was selected as preliminary baseline period.	1921-1958
01446000	Beaver Brook near Belvidere, NJ	Entire period of record selected as preliminary baseline period.	1922-1961
01456000	Musconetcong River near Hackettstown, NJ	Minor regulation by Lake Hopatcong and other small lakes. Entire period of record was selected as preliminary baseline period.	1921-1973
01457000	Musconetcong River near Bloomsbury, NJ	Minor regulation by Lake Hopatcong. Entire period of record was selected as preliminary baseline period.	1903-2004
01464000	Assunpink Creek at Trenton, NJ	Since 1954, diverted flow (municipal supply) from outside the basin is returned to the stream about 2 miles upstream from the gage. Period before 1954 was selected as preliminary baseline period.	1923-1954
01464500	Crosswicks Creek at Extonville, NJ	Minor regulation by upstream ponds. Entire period of record selected as preliminary baseline period.	1940-2005
01465850	South Branch Rancocas Creek at Vincentown, NJ	Minor regulation by upstream ponds. Entire period of record selected as preliminary baseline period.	1961-1975
01466000	Middle Branch Mt Misery Brook in Lebanon State Forest, NJ	Entire period of record selected as preliminary baseline period.	1952-1964
01466500	Mcdonalds Branch in Lebanon State Forest, NJ	Entire period of record selected as preliminary baseline period.	1953-2004
01467000	North Branch Rancocas Creek at Pemberton, NJ	Minor regulation by ponds. Flow is diverted for water supply upstream from station. The entire period of record was selected as preliminary baseline period.	1921-2004
01467081	South Branch Pennsauken Creek at Cherry Hill, NJ	Diurnal fluctuations occur at low flow owing to sewage effluent. Effect of effluent has increased gradually during the period of record. No years could be excluded from the preliminary baseline period on the basis of historical information.	1967-2004
01475000	Mantua Creek at Pitman, NJ	Minor regulation by Wadsworth Dam. Entire period of record selected as preliminary baseline period.	1940-1976
01477120	Raccoon Creek near Swedesboro, NJ	Minor regulation from irrigation. Entire period of record selected as preliminary baseline period.	1966-2005

For additional information, write to:
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