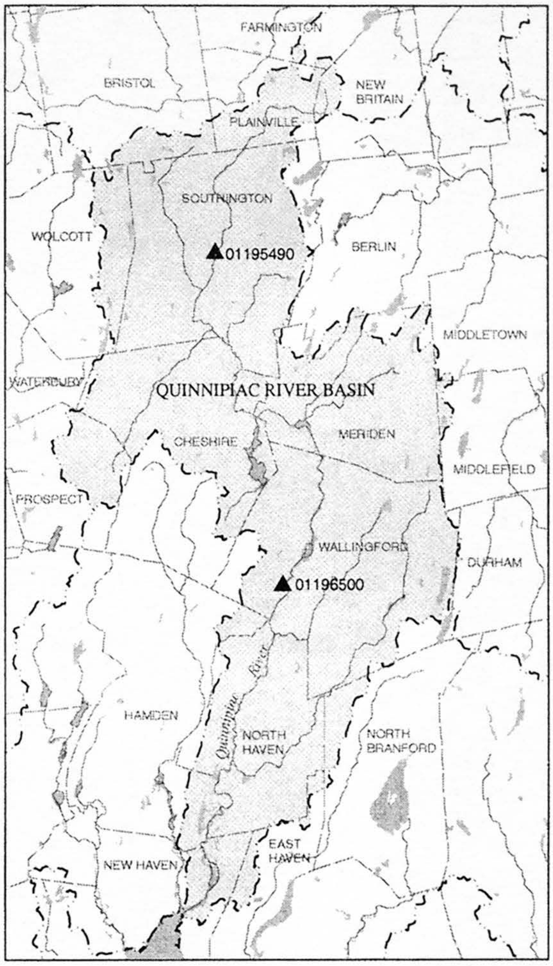
Streamflow in the Quinnipiac River Basin, Connecticut—Statistics and Trends, 1931–2000

Water-Resources Investigations Report 02-4217



Prepared in cooperation with the
Connecticut Department of Environmental Protection

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

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

Streamflow in the Quinnipiac River Basin, Connecticut—Statistics and Trends, 1931–2000

By Elizabeth A. Ahearn

Water-Resources Investigations Report 02-4217

Prepared in cooperation with the
Connecticut Department of Environmental Protection

East Hartford, Connecticut
2002

U.S. DEPARTMENT OF THE INTERIOR
GALE A. NORTON, Secretary

U.S. GEOLOGICAL SURVEY
Charles G. Groat, Director

For additional information write to:

District Chief
U.S. Geological Survey
101 Pitkin Street
East Hartford, CT 06108
http://ct.water.usgs.gov

Copies of this report can be purchased from:

U.S. Geological Survey
Branch of Information Services
Box 25286, Federal Center
Denver, CO 80225

CONTENTS

FIGURES

FIGURES—Continued

TABLES

CONVERSION FACTORS

Multiply	By	To obtain
inch (in.)	25.4	millimeter
mile (mi)	1.609	kilometer
square mile (mi^2)	2.590	square kilometer
cubic foot per second (ft^3/s)	0.02832	cubic meter per second
million gallons per day (Mgal/d)	0.04381	cubic meter per second

Streamflow in the Quinnipiac River Basin, Connecticut—Statistics and Trends, 1931–2000

by Elizabeth A. Ahearn

ABSTRACT

Streamflow statistics were updated for two U.S. Geological Survey continuous record streamflow-gaging stations on the Quinnipiac River (01196500—Wallingford and 01195490—Southington). The streamflow record from the Wallingford station was analyzed to determine trends in streamflow quantity from October 1930 to September 2000. Trends were analyzed using the non-parametric Mann-Kendall test and magnitudes estimated for selected percentiles of streamflow, ranging from the 0^{th} (annual minimum) to 100^{th} (annual maximum) percentile. Trend tests were performed on various time periods (30-, 40-, 50-, 55-, 60-, 65- to 70-year periods), all ending in 2000, except for two periods (1931–1960 and 1941–1971) that were studied as 30-year reference periods.

The two most prevalent trends were increases in the annual minimum and annual maximum streamflow during the period 1931–00. The annual minimum streamflow increased by an average of 0.44 cubic feet per second per year ($ft^3/s/yr$), and the annual maximum streamflow increased by an average of 17 $ft^3/s/yr$. Increasing streamflows were detected predominantly in the lower half of the flow distribution (0^{th} to 50^{th} percentile) and in the annual maximum (100^{th} percentile) streamflow for periods 1931–00, 1941–00, and 1951–00. During 1961–00, the pattern changed—increasing streamflows were detected in the middle to upper half of the flow distribution (30^{th} to 100^{th} percentile). No trends were detected during 1971–00.

Trend analyses of precipitation (data from 1930 to 2000) and wastewater discharge (data from 1985 to 2001) provide some evidence about the effects these factors have on streamflow trends. Changes in rainfall intensity and, to a lesser extent, increases in residential and commercial development and expansion of storm drainage systems are probable causes for increases in the annual maximum streamflow. No evidence was found to indicate that a precipitation trend is causing the increase in the annual minimum to annual median streamflow. Upward trends in wastewater discharge from municipal (Meriden, Cheshire and Southington) wastewater-treatment facilities were detected during 1985–01. Statistical evidence suggests that the wastewater-discharge trend increased at a rate consistent with the annual minimum streamflow trend during 1985–01 and that the increases in the annual minimum streamflow appear to be caused by increases in wastewater discharges.

Flow regulation appears to have an effect on streamflow trends, particularly on base flows (annual minimum daily mean streamflow) from 1932 to 1939 when exceptionally low flows were recorded at a time of average to above-average precipitation. Droughts during the early 1930's, early 1940's, and 1960's, and above-average precipitation during the 1970's indicate that the magnitude of the streamflow trends (annual minimum to annual median) particularly for 1931–00 may, in part, be a result of the relation between precipitation variability and the time periods analyzed. The highest number of streamflow trends were detected during 1931–00, 1941–00 and 1961–00, coincident with the beginning of multi-year droughts. Flow regulation during the early period of record (1930's) appears to be the predominant reason for the trend magnitude in the annual minimum streamflow from 1931 to 2000.

INTRODUCTION

The Quinnipiac River is an important resource for economic development, industry, agriculture, water supply, and biological diversity in south-central Connecticut. Despite the river's abundant flow, water demands periodically are greater than minimum streamflow. Water scarcity caused by an over-allocation of the resource and (or) drought poses a challenge to all water users. Three tributaries (Sodom Brook, segments of Misery Brook, and Harbor Brook) and the upper Quinnipiac main stem headwaters are listed in the Draft 2002 Connecticut Waterbodies Not Meeting Water Quality Standards (Impaired Water List), pursuant to Sections 303(d) and 305(b) of the Federal Clean Water Act, prepared by the Connecticut Department of Environmental Protection (DEP) for the U.S. Environmental Protection Agency (USEPA) (Connecticut Department of Environmental Protection, written commun., 2002). Flow alteration was a criterion used in designating these waterbodies as impaired. Low streamflows call attention to the seriousness of limited supplies, and degradation of the resource has widespread implications. Federal, State, and local agencies are concerned that declining streamflows are degrading the ecological health of the river. As demands for and uses of water increase, consideration is directed to the effects of human influences on ecological health of the river, and the balance between streamflow needed for fish and wildlife habitat integrity and water use. The stream habitat and stream ecosystem are affected by changes to the natural flow regime.

The natural flow of the Quinnipiac River has been altered by numerous flow diversions resulting in a complex, modified river system. This complexity is evident during low-flow periods when diversions may cause some stream reaches to dry up, whereas other reaches may gain flow from treated wastewater discharge. Flow-regulation patterns in the basin affect the tributaries and main stem in different ways (Quinnipiac River Watershed Partnership, 2000). Streamflow is decreasing (low flow) in the tributaries and in the headwaters where water primarily is withdrawn. A large percentage of water that is diverted from the tributaries eventually is returned as wastewater to the main stem of the Quinnipiac River, thereby increasing flows on the main stem.

In response to the water allocation and streamflow concerns in the basin, the U.S. Geological Survey (USGS) began a cooperative study with the Connecticut DEP in 2000 to (1) compute current streamflow statistics from two continuous-record streamflow-gaging stations (Wallingford 01196500 and Southington 01195490) that can be used for water-resource planning, management, and regulatory activities; and (2) analyze historical streamflow data for trends to document any long-term (30 years or greater) flow changes. Streamflow records from the two gaging stations in the Quinnipiac River Basin and results of streamflow-trend analysis for the Wallingford gaging station provide data to improve the understanding of past and current streamflow conditions in the basin.

Purpose and Scope

This report presents streamflow statistics of duration, frequency, and quantity of annual, monthly, maximum, and minimum streamflow for two gaging stations in the Quinnipiac River Basin. Streamflow statistics are presented in tabular and graphical form to characterize the basin's water resources and estimate flows needed for water supply and allocation. The report also presents trends in streamflow for 1931–00 at the Wallingford gaging station. Statistical techniques used to perform the trend analysis and compute the basin characteristics that affect streamflow processes are presented to provide perspective on the detected trends. In addition, the report briefly describes how and to what extent climatic and human influences affect streamflow characteristics.

Streamflow records were retrieved from the USGS National Water Information System (NWIS) accessed on the World Wide Web at URL http://waterdata.usgs.gov/nwis. All analyses were based on historical average daily discharge records from two continuous-record streamflow-gaging stations operated by the USGS on the main stem of the Quinnipiac River. Records from the downstream station (Wallingford–01196500) began in October 1930, and records from the upstream station (Southington–01195400) began in November 1987. In this report, all time periods are expressed in water years[1].

---

[1]A water year is the 12-month period October 1 through September 30 and is designated by the calendar year in which it ends; thus, the year from October 1, 1930 through September 30, 1931 is called the 1931 water year.

Previous Studies

Streamflow duration and frequency statistics were compiled in a water-resources inventory of the Quinnipiac River Basin by Mazzaferro and others (1979) for the Wallingford gaging station for the period 1931–60. In the early 1980's, Cervione (1982) and Weiss (1983) summarized low- and high-flow frequency statistics for rivers in the State with appreciable record length. Low- and high-flow frequency statistics for the Quinnipiac River at Wallingford gaging station are included in these two studies. The later studies benefited from longer records and supersede the statistics in the earlier report by Mazzaferro and others. Monthly, annual, and period of record streamflow statistics and a limited number of duration statistics are published annually by the USGS in the Water-Resources Data series.

Description of Basin

The Quinnipiac River Basin is in south-central Connecticut and drains an area of about 166 mi^2 (fig. 1). The Quinnipiac River originates in the town of New Britain and flows southward for approximately 38 mi through the towns of Plainville, Southington, Cheshire, Meriden, Wallingford, North Haven, and New Haven to Long Island Sound. The lower 9 mi of the Quinnipiac River are affected by tides from Long Island Sound. Major tributaries are the Eightmile River, Tenmile River, Misery Brook, Broad Brook, Harbor Brook, Sodom Brook, Wharton Brook, and Muddy River. Subregional basins of the major tributaries range from 5 to 22 mi^2. Land use is predominantly forest, agriculture, and residential in the upper basin and predominantly densely developed urban and industrial in the lower basin.

The USGS operates two continuous-record streamflow-gaging stations on the Quinnipiac River—at Wallingford (station 01196500) and at Southington (station 01195490). The Wallingford station was established in October 1930 and has a drainage area of 115 mi^2, which is approximately 70 percent of the basin. The Southington station was established in November 1987 and has a drainage area of 17.4 mi^2, which is 10 percent of the basin.

An assessment of water diversions in 2000 identified 103 consumptive water withdrawals, with a combined maximum withdrawal capacity of 120.3 Mgal/d, and 19 wastewater discharges, with a combined maximum daily discharge of 44.6 Mgal/d (Quinnipiac River Watershed Partnership, 2000).

Acknowledgments

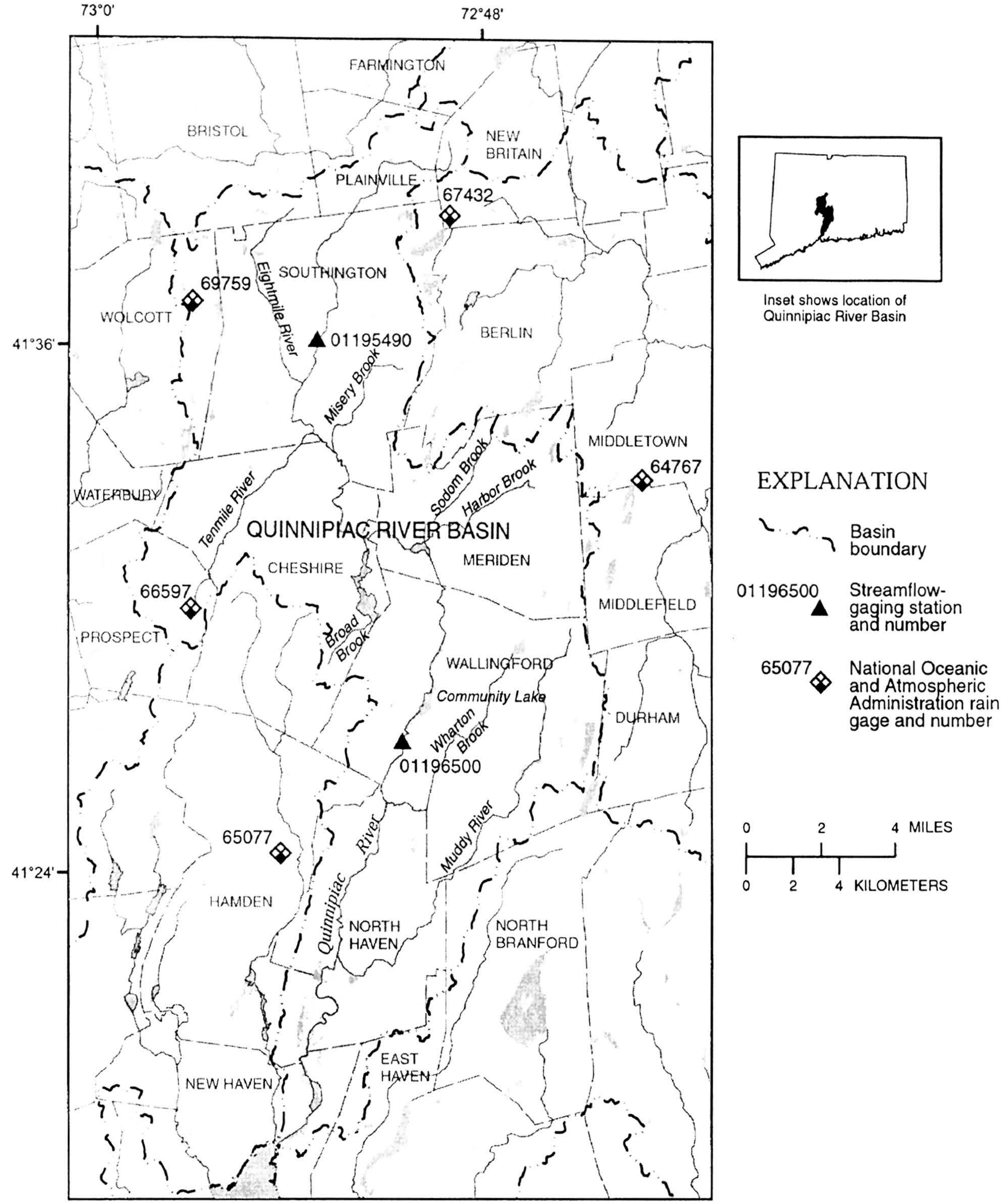
Charles Fredette of the Connecticut DEP, and Glenn A. Hodgkins and Phillip J. Zarriello of the USGS provided valuable technical insight and review of the report. Barbara Korzendorfer, USGS, provided assistance in editorial review and report production.

STREAMFLOW STATISTICS

Statistical analysis of hydrologic data is important in understanding streamflow variability, estimating future water supplies, and establishing new policies and regulations for managing water resources. Some of the most commonly used streamflow statistics include flow duration, flow frequency (recurrence of a given flow), averages, and percentiles of daily flows. Flow duration characterizes past streamflow by ranking the distribution of flows over the analyzed period of record. Flow-frequency estimates the probability of a given streamflow occurring in the future. Averages and percentiles describe the central tendency and distribution of streamflow data.

The Wallingford gaging station (01196500; fig. 1) had a mean annual flow of 217 ft^3/s (140 Mgal/d), a historical minimum daily mean flow of 9.0 ft^3/s (5.8 Mgal/d) recorded on November 2, 1930, and a historical maximum daily mean flow of 7,210 ft^3/s (4,660 Mgal/d) recorded on June 6, 1982. The monthly median streamflow ranged from a low of 79.2 ft^3/s (51.2 Mgal/d) in August to a high of 294 ft^3/s (190 Mgal/d) in March.

The Southington gaging station (01195490; fig. 1) had a mean annual flow of 34.2 ft^3/s (22.1 Mgal/d), a historical minimum daily mean flow of 3.8 ft^3/s (2.5 Mgal/d) recorded on August 20, 1999, and a historical maximum daily mean flow of 810 ft^3/s (523 Mgal/d) recorded on October 21, 1999. The monthly median streamflow ranged from a low of 11.7 ft^3/s (7.56 Mgal/d) in September to a high of 38.4 ft^3/s (24.8 Mgal/d) in April.



Base from U.S. Geological Survey digital line graph (1988)

Figure 1. Location of the Quinnipiac River Basin, south-central Connecticut, and data-collection points.

Flow-Duration Statistics

Annual and monthly flow-duration statistics were calculated for the Wallingford and Southington gaging stations (table 1; figs. 2 and 3). Flow-duration statistics represent the percentage of time specified streamflows were equaled or exceeded over the analysis period. For example, the daily flows at the Wallingford gaging station were greater than or equal to 85.9 ft^3/s 50 percent of the time (table 1) in October during the period 1931–00. Because flow-durations statistics are performed on the rank position of a flow value, the chronology of the flows is concealed. No indication is given of the date on which the flows occurred. Flow-duration statistics are estimated by arranging (by month) all the daily mean streamflows for the given time period in ascending order without regard to the sequence of the occurrence. The data then are grouped into class intervals by ascending order and the probabilities of specified streamflow being equaled or exceeded are computed. Flow-duration statistics were estimated by using the DVSTAT Computation computer program in the USGS National Water Information System following USGS standard methods for estimating flow duration (Searcy, 1959) at gaging stations. The duration analysis provides values for exceedance percentages based on the class limits and the percentage of all days in which a class limit was equaled or exceeded.

For the Wallingford gaging station, the wettest and driest water years on record (fig. 2A) show a wide range in the percentage of time specified streamflows were equaled or exceeded in a single year. During the wettest year on record (water year 1984), streamflow was equal to or greater than 259 ft^3/s (167 Mgal/d) 50 percent of the time; during the driest year (water year 1966), streamflow was equal to or greater than 56.3 ft^3/s (36.4 Mgal/d) 50 percent of the time. From the long-term average (1931-00) at the Wallingford gaging station, streamflow was equal to or greater than 152 ft^3/s (98.2 Mgal/d) 50 percent of the time.

The driest and wettest years are defined as water years with the overall greatest number of minimum and maximum flow durations in a water year. During water year 1966 (driest water year), the 10- to 90-percent flow duration ranged from 26 to 168 ft^3/s and were the lowest flows for that duration range in 70 years. During water year 1984 (wettest water year), the 20- to 80-percent flow duration ranged from 138 to 473 ft^3/s and were the highest flows for that duration range in 70 years. Although water year 1931 had the lowest daily mean streamflow (9.0 ft^3/s) recorded at the Wallingford gaging station, water year 1966 was the driest water year because of the extent and severity of the low flows. The minimum daily mean streamflow in water year 1966 at the Wallingford gaging station was 14.0 ft^3/s.

Because of the relatively short record of the Southington gaging station (12 years), compared to the Wallingford station, the minimum and maximum flow durations for each duration grouping in the period of record (1988–00) are used to emphasize the variation in durations (fig. 3A). At the minimum limit, streamflow was equal to or greater than 15 ft^3/s (9.7 Mgal/d) 50 percent of the time in a single year (water year 1999). At the maximum limit, streamflow was equal to or greater than 33 ft^3/s (21 Mgal/d) 50 percent of the time in a single year (water year 1990). From the 12-year average (1988–00) at the Southington gaging station, streamflow was equal to or greater than 25.1 ft^3/s (16.2 Mgal/d) 50 percent of the time.

Generally, flow-duration statistics apply to the period of record for which the data were analyzed. Where the period of record used to compute the statistics is sufficiently long, flow-duration statistics can be used as an indicator of probable future flows (Searcy, 1959); however, if diversions, return flows, or climatic factors affecting flow are expected to change substantially, flow-duration statistics cannot be used to indicate probable future flows with statistical certainty.

Low-Flow Frequency Statistics

Frequency analysis can be used to obtain the probability that specific streamflow will be equaled or exceeded. The major application of low-flow frequency analysis is for setting flow standards associated with diversion permits and for prediction purposes in water-resources planning. Two commonly used indices of low flow are the 7-day, 10-year low flow, (7Q10), the lowest streamflow for a period of 7 consecutive days that is expected to occur once in a 10-year period, and the 30-day, 2-year low flow, (30Q2), the lowest streamflow for a period of 30 consecutive days that is expected to occur once every other year. The most widely used low-flow frequency statistic in Connecticut is the 7Q10 flow, which is used by many State and local agencies and by the USEPA to regulate wastewater discharges to streams. The Connecticut DEP adopted as State policy the 7Q10 statistic as a minimum flow event for which water-quality standards are expected to be met (Connecticut Department of Environmental Protection, 1997).

Table 1. Annual and monthly flow duration, Quinnipiac River at Wallingford, Conn. (01196500), 1931–2000 and Quinnipiac River at Southington, Conn. (01195490), 1988–2000

Duration (in percent)	Streamflow, in cubic feet per second												
	October	November	December	January	February	March	April	May	June	July	August	September	Annual
	U.S. Geological Survey station 01196500, Quinnipiac River at Wallingford												
99	22.7	30.8	42.9	50.0	62.3	105	97.4	71.8	53.0	30.1	19.6	25.6	34.7
98	35.3	39.7	49.8	61.6	70.8	115	107	82.2	57.0	36.1	26.8	33.7	40.7
97	39.7	43.8	55.7	67.1	82.0	123	115	87.3	61.0	40.6	33.2	35.5	44.1
96	41.0	47.1	60.6	71.9	89.5	130	123	92.3	63.7	43.2	35.3	37.2	47.5
95	42.4	50.3	64.7	76.2	92.5	137	129	95.6	66.3	45.6	37.4	38.9	50.0
90	48.3	63.3	76.5	91.3	107	164	152	111	75.9	53.9	44.1	44.3	60.9
85	52.4	71.9	87.6	104	119	186	169	124	83.5	59.4	50.3	48.5	70.3
80	56.6	78.0	99.2	116	130	203	184	135	90.2	64.2	55.3	52.1	79.4
75	60.7	84.0	110	126	144	218	200	148	96.3	68.5	59.4	55.8	88.7
70	64.8	92.2	122	136	157	233	215	161	102	72.9	63.4	59.4	98.4
65	69.5	101	133	146	170	246	230	172	108	77.4	67.2	63.0	110
60	74.3	111	147	156	184	260	245	184	114	81.9	71.1	67.3	122
55	79.6	122	160	170	199	276	261	196	121	87.5	75.2	71.8	136
50	85.9	134	173	184	215	295	280	207	129	93.1	79.5	76.4	152
45	92.3	148	187	199	234	317	299	220	138	98.6	83.9	81.6	169
40	100	163	202	215	253	342	321	233	147	104	89.7	86.9	188
35	109	180	222	232	272	370	346	250	159	111	96.1	93.3	208
30	121	199	245	257	295	400	373	268	173	120	104	101	232
25	137	222	273	288	322	439	411	292	192	132	113	110	258
20	164	250	307	331	358	488	455	322	215	147	130	124	297
15	200	297	355	384	408	551	520	358	251	166	152	145	347
10	249	368	439	487	482	661	628	413	311	195	190	184	424
5	360	533	601	724	643	969	842	521	431	266	260	277	587
2	576	760	888	1,140	957	1,320	1,240	702	694	410	408	510	904
1	843	896	1,220	1,460	1,270	1,730	1,530	962	1,070	535	637	822	1,210

Table 1. Annual and monthly flow duration, Quinnipiac River at Wallingford, Conn. (01196500), 1931–2000 and Quinnipiac River at Southington, Conn. (01195490), 1988–2000—Continued

Duration (in percent)	Streamflow, in cubic feet per second												
	October	November	December	January	February	March	April	May	June	July	August	September	Annual
						U.S. Geological Survey station 01195490, Quinnipiac River at Southington							
99	5.30	8.70	8.00	11.2	12.9	15.6	16.8	13.6	7.30	5.00	4.00	4.10	4.80
98	5.50	9.00	8.30	11.6	13.8	16.2	18.2	14.4	7.90	5.20	4.10	4.30	5.50
97	5.70	9.20	8.70	12.0	15.3	16.9	19.3	15.1	8.40	5.60	4.30	4.50	6.20
96	6.00	9.40	9.10	12.4	16.2	17.7	20.2	15.5	8.70	5.90	4.50	4.90	6.80
95	6.36	9.62	9.60	12.8	17.1	19.4	20.7	15.9	9.06	6.16	4.63	5.15	7.35
90	7.22	11.4	13.5	14.7	19.2	25.2	22.7	18.1	10.8	7.34	5.34	6.25	9.42
85	7.76	12.5	15.5	16.5	20.8	27.5	24.2	19.3	12.3	8.15	6.52	7.12	11.6
80	8.50	13.4	17.4	18.2	22.7	29.0	25.9	20.7	13.1	8.85	7.81	7.80	13.3
75	9.50	14.7	19.0	19.8	24.1	30.5	27.8	22.4	13.9	9.75	8.77	8.51	15.0
70	11.1	17.2	20.4	21.5	25.5	31.9	29.7	24.2	14.6	11.1	9.75	9.12	16.8
65	12.5	19.8	21.5	23.9	26.8	33.4	31.6	25.8	15.6	12.1	10.9	9.61	18.8
60	13.7	21.3	22.7	25.9	28.4	34.8	33.5	27.6	16.7	13.0	11.8	10.2	20.8
55	14.8	23.2	24.0	27.7	30.2	36.1	35.9	29.5	17.9	13.9	12.6	11.0	22.9
50	15.8	24.9	25.3	29.2	32.1	37.5	38.4	31.4	19.2	14.9	13.4	11.7	25.1
45	17.6	26.8	26.7	31.0	34.2	39.0	40.8	33.2	20.6	16.0	14.2	12.5	27.4
40	19.4	29.1	28.5	33.1	36.2	40.8	43.2	35.3	22.3	17.1	15.1	13.5	29.8
35	21.3	31.7	30.8	35.4	38.2	42.9	46.1	37.6	24.4	18.3	16.0	15.0	32.7
30	24.1	35.6	33.6	37.9	40.6	46.1	49.2	41.0	26.6	20.1	17.7	16.4	35.7
25	27.3	40.5	37.3	41.8	44.5	51.5	52.7	45.8	29.3	22.5	19.7	18.2	39.5
20	32.5	44.8	42.7	47.3	48.3	58.6	58.5	52.1	33.5	24.9	23.3	21.2	44.6
15	39.0	51.6	50.3	56.6	55.3	71.5	63.4	61.4	40.5	29.1	28.4	24.7	52.2
10	48.3	66.2	63.4	69.1	63.5	92.2	73.3	74.6	50.5	36.4	37.6	31.5	64.6
5	81.5	97.2	90.2	106	85.7	151	98.0	102	74.7	66.4	64.7	49.5	91.8
2	179	136	121	193	104	184	133	187	95.2	98.7	140	106	154
1	276	172	153	223	125	199	250	258	186	144	234	166	200

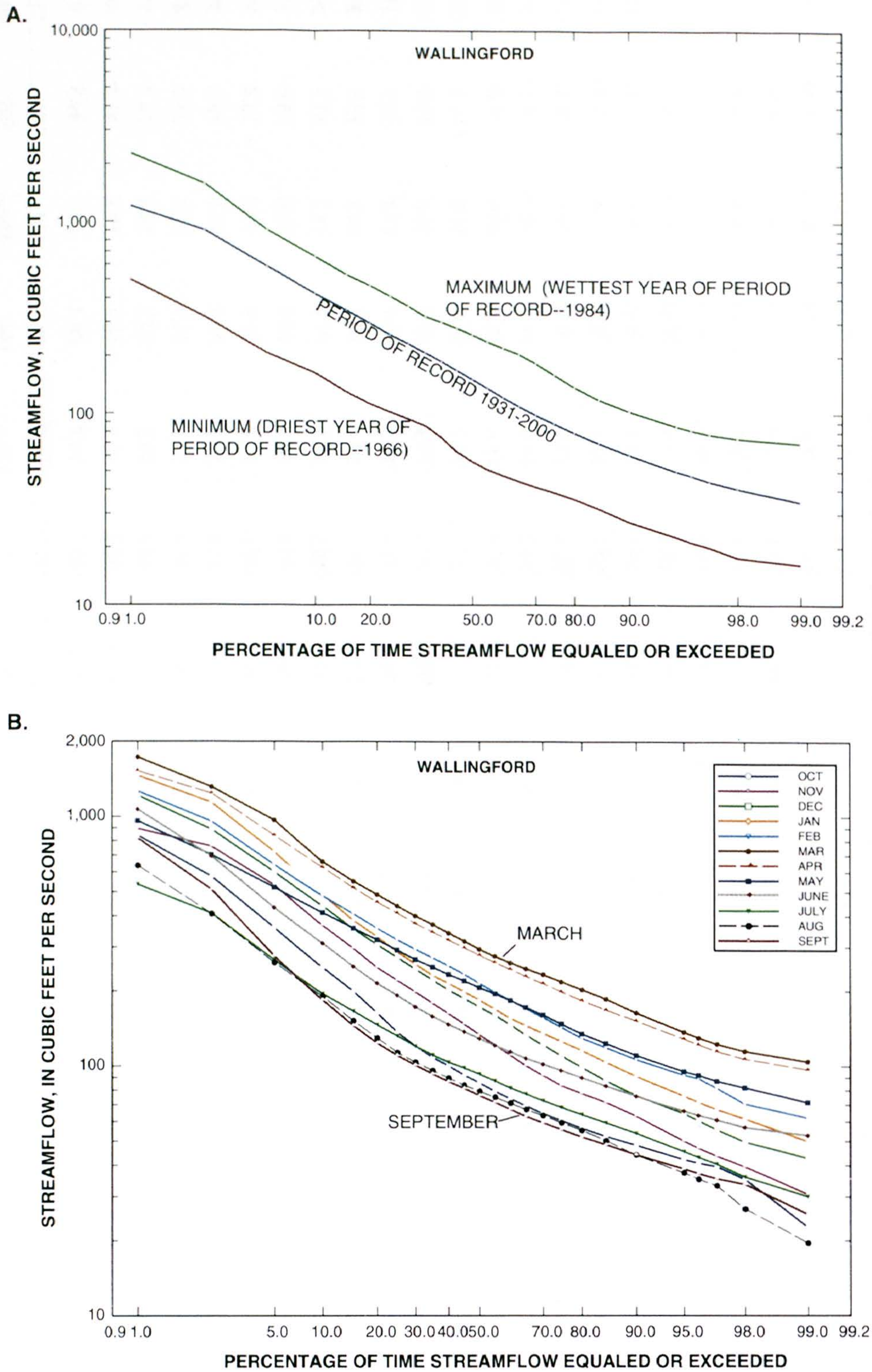


Figure 2. Minimum, maximum, and period of record flow-duration curves (A), and monthly flow-duration curves (B) at Quinnipiac River at Wallingford, Conn. (01196500), 1931–2000.

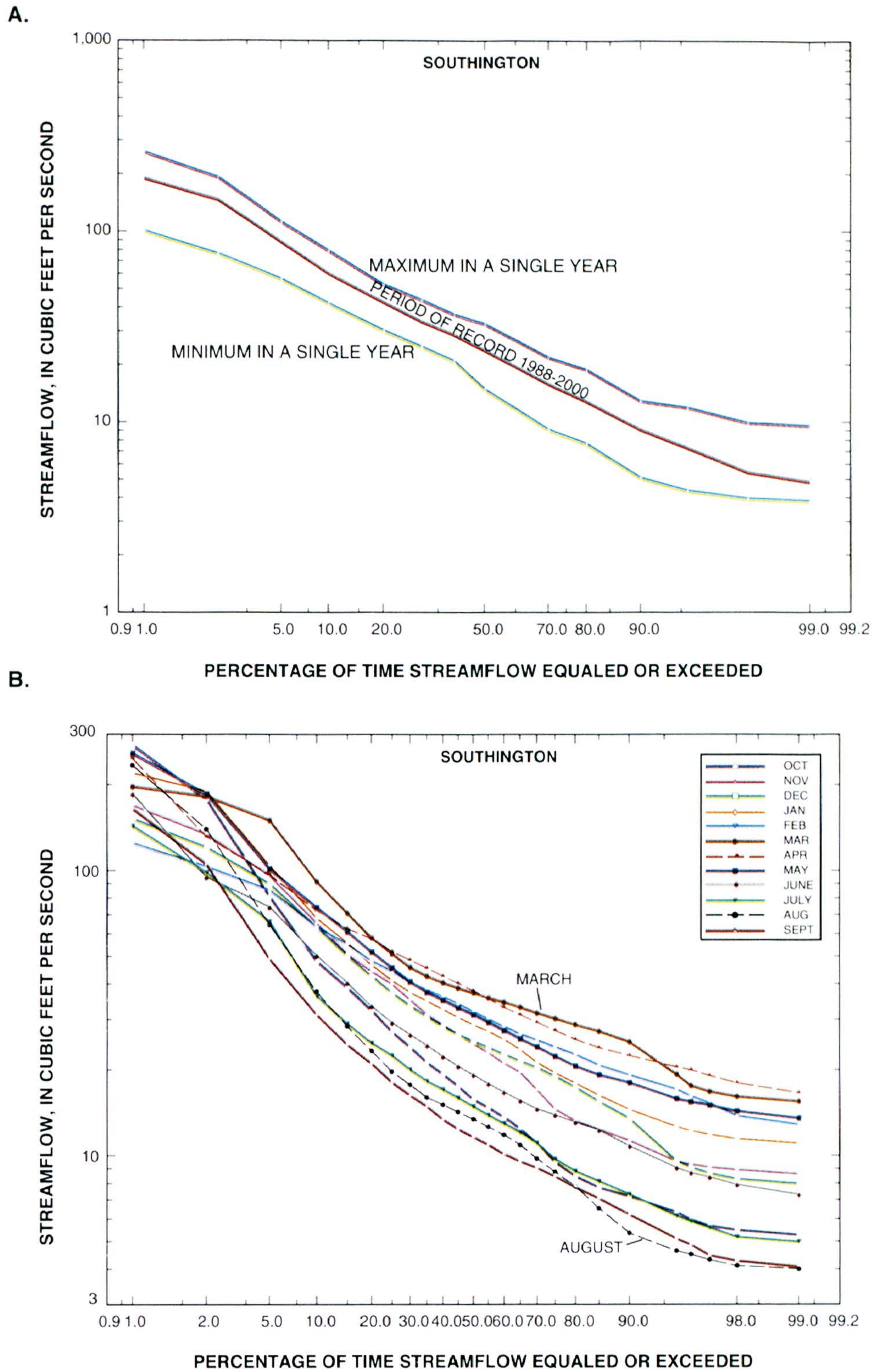


Figure 3. Minimum, maximum, and period of record flow-duration curves (A), and monthly flow-duration curves (B) at Quinnipiac River at Southington, Conn. (01195490), 1988–2000.

The 7Q10 computed for the period of record (1931–00 Wallingford; 1988–00 Southington) is 33.4 ft^3/s (21.6 Mgal/d) for the Wallingford gaging station and 4.32 ft^3/s (2.79 Mgal/d) for the Southington gaging station (table 2; fig. 4). The 30Q2 computed for the period of record is 61.8 ft^3/s (39.9 Mgal/d) for the Wallingford gaging station and 9.01 ft^3/s (5.82 Mgal/d) for the Southington gaging station (table 2; fig. 4). Stated in terms of probability (1 divided by the recurrence interval), the 7-day annual minimum streamflow at the Wallingford gaging station has a 10-percent chance in any year of being less than 33.4 ft^3/s (21.6 Mgal/d); the 30-day annual minimum streamflow at the Wallingford gaging station has a 2-percent chance in any year of being less than 61.8 ft^3/s (39.9 Mgal/d).

Frequency statistics relate magnitude of a given streamflow to recurrence interval. The recurrence interval is the average length of time, usually stated in years, between the exceedance of particular streamflow magnitudes. Low-flow frequency statistics are computed from a series of annual minimum flows and can be computed for any combination of days of minimum flows.

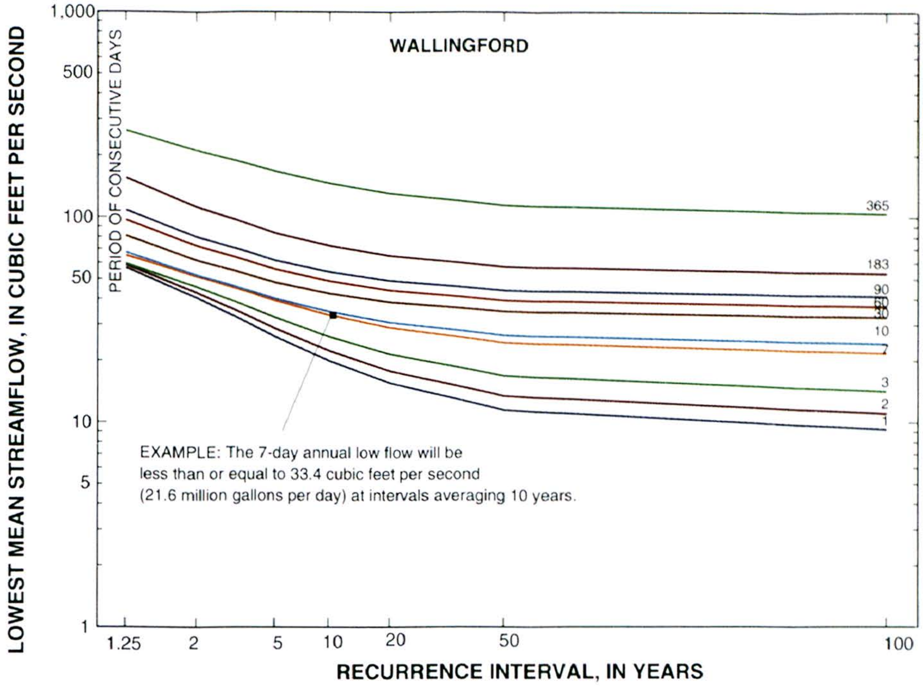
Low-flow frequency statistics for Wallingford and Southington gaging stations (table 2; fig. 4) were calculated with the USGS computer program SWSTAT (Lumb and others, U.S. Geological Survey, written commun., 1994) for minimum 1-day flows and the minimum average daily flow for n-days, where n equals 2, 3, 7, 10, 30, 60, 90, 120, 183, and 365 consecutive days for each year of record. The n-day low flows were fitted to a log-Pearson Type III distribution curve to calculate recurrence frequencies.

Table 2. Annual lowest mean flows for indicated periods of consecutive days and indicated recurrence intervals, Quinnipiac River at Wallingford, Conn. (01196500), 1931–2000 and Quinnipiac River at Southington, Conn. (01195490), 1988–2000

[--, low-flow frequency estimates beyond a 20-year recurrence interval are considered unreliable and were not calculated]

Period of consecutive days	Annual lowest mean flows (in cubic feet per second) for indicated recurrence intervals (in years)						
	1.25	2	5	10	20	50	100
U.S. Geological Survey station 01196500, Quinnipiac River at Wallingford, April 1, 1932 to March 31, 2000							
1	56.6	40.6	26.2	20.0	15.6	11.5	9.2
2	58.5	42.9	28.7	22.4	17.8	13.5	11.0
3	59.4	45.8	32.5	26.2	21.6	16.9	14.2
7	64.9	51.5	39.2	33.4	29.0	24.5	21.8
10	67.4	52.5	40.2	34.8	30.7	26.7	24.2
30	81.2	61.8	48.1	42.6	38.6	34.8	32.6
60	96.9	72.7	55.7	48.9	44.1	39.4	36.7
90	108	80.5	61.7	54.2	49.1	44.1	41.2
183	155	112	83.8	72.6	64.9	57.5	53.2
365	264	212	167	147	131	114	104
U.S. Geological Survey station 01195490, Quinnipiac River at Southington, April 1, 1989 to March 31, 2000							
1	8.64	6.36	4.72	4.06	3.59	--	--
2	8.77	6.41	4.76	4.09	3.63	--	--
3	8.90	6.47	4.81	4.15	3.69	--	--
7	9.43	6.83	5.03	4.32	3.82	--	--
10	9.98	7.14	5.18	4.41	3.87	--	--
30	13.28	9.01	6.26	5.23	4.52	--	--
60	16.1	11.2	7.89	6.61	5.73	--	--
90	20.0	13.9	9.76	8.19	7.10	--	--
183	27.6	19.9	15.3	13.7	12.6	--	--
365	39.9	32.8	26.7	24.0	21.9	--	--

A.



B.

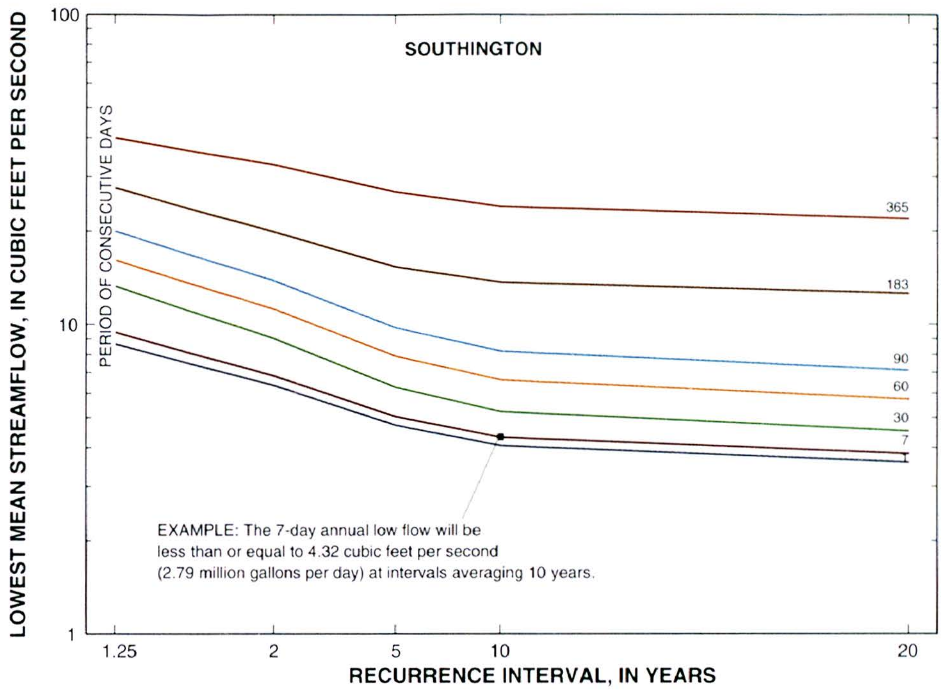


Figure 4. Low-flow frequency curves, Quinnipiac River at Wallingford, Conn. (01196500), 1931–2000 (A) and Quinnipiac River at Southington, Conn. (01195490), 1988–2000 (B).

The reliability of low-flow frequency statistics is related closely to the length of record used to compute the frequency statistics. At least 10 years of record are needed to determine the statistics (7Q10) with reasonable confidence (Ries, 2000). The results from the low-frequency analysis can be used as an indication of probability that certain flow events will occur in the future, assuming the human influences on streamflow are expected to remain unchanged. The low-flow frequency statistics for both the Wallingford and Southington gaging stations should not be used to predict future flows because of the changing flow regulation during the period of record affecting natural streamflow. The frequency statistics presented in table 2 reflect the overall period of record that includes past flow regulation at the Wallingford and Southington gaging stations. Because the Southington gaging station has a relatively short record (12 years), compared to the Wallingford gaging station, the maximum low-flow frequency estimated at the Southington gaging station is 20 years. Low-flow frequency estimates beyond a 20-year recurrence interval at the Southington gaging station are considered unreliable and, therefore, were not calculated.

When streamflows are altered by diversions, reservoirs, and wastewater discharges, the natural 7Q10 flow cannot be estimated from a frequency analysis of streamflow data. For rivers that are altered largely by regulation, the 7Q10 low flow can be computed from a regional regression equation. Low streamflows (such as the 7Q10) are highly dependent on the geologic characteristics of the basin (Thomas, 1966). The regression equation developed by Cervione (1982) for estimating the 7Q10 in Connecticut is based on the percentage of the basin underlain by coarse-grained deposits. The 7Q10 computed from the regression equation is 30.2 ft^3/s (19.5 Mgal/d) for the Wallingford gaging station and 6.21 ft^3/s (4.01 Mgal/d) for the Southington gaging station. The estimated 7Q10 value for Wallingford from the regression equation is 10 percent less than the 7Q10 calculated from the station data. The estimated 7Q10 value for Southington from the regression equation is 30 percent greater than the 7Q10 calculated from the station data.

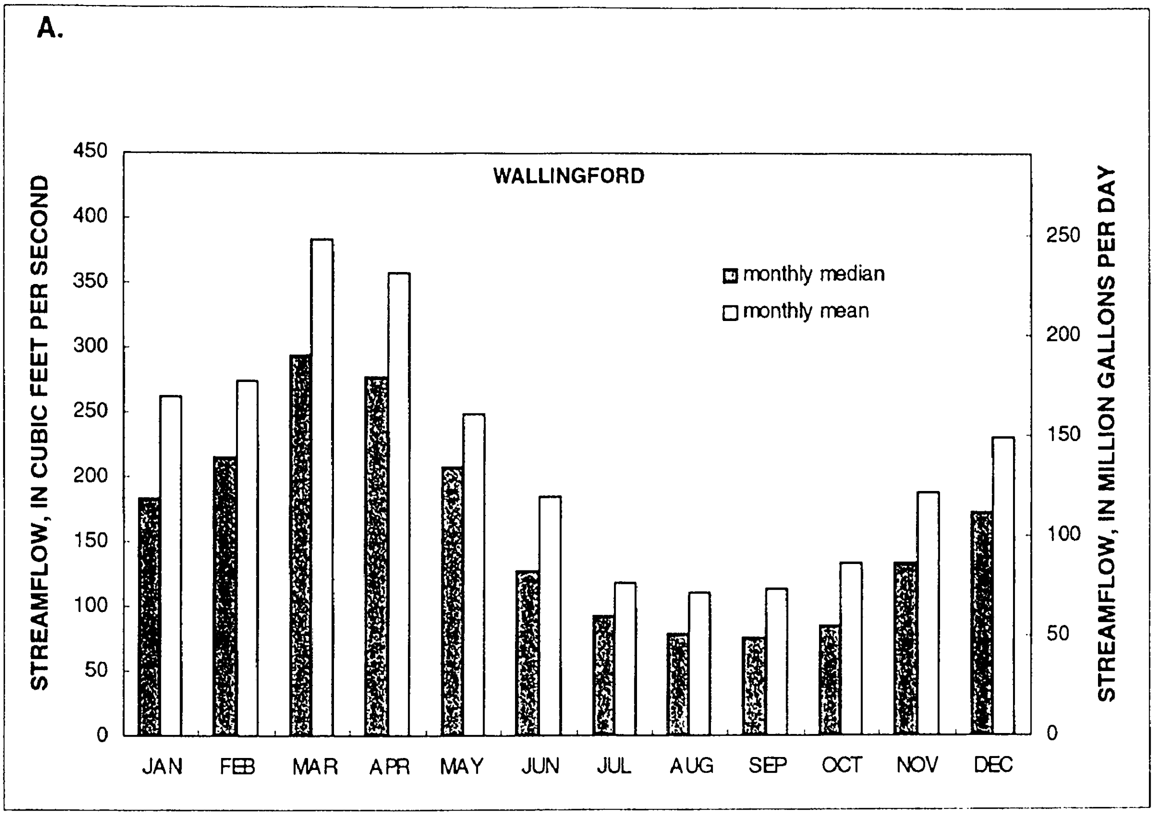
Monthly Mean and Monthly Median Streamflow

Monthly mean and monthly median streamflow (figs. 5A and 5B) were calculated from the daily mean streamflow for the Wallingford gaging station for the years 1931–00 and for the Southington gaging station for the years 1988–00. Mean streamflow shows a maximum in March at the Wallingford gaging station of 383 ft^3/s (247 Mgal/d) and at the Southington gaging station of 50.1 ft^3/s (32.4 Mgal/d) in response to precipitation, snowmelt, and soil-moisture content. Increasing evaporation and transpiration during the growing season contribute to a minimum mean flow at the Wallingford gaging station of 110 ft^3/s (71.1 Mgal/d) in August and at the Southington gaging station of 19.1 ft^3/s (12.3 Mgal/d) in September. Mean streamflow generally is much larger than the median streamflow because very large streamflow values often associated with storm events affect the mean appreciably more than the median.

Boxplots (figs. 6A and 6B) illustrate the central tendency and variability in monthly streamflow, and provide a graphical representation of distribution and range of the data. The top and bottom of the box represent the 75th and 25th percentiles, respectively, and bracket the central 50 percent of the flow data for a given month. The centerline splitting the box represents the median (50th percentile) and is defined as the median of all the daily discharges during the period of record for that month. The lines drawn from the ends of the box extend to the 10th and 90th percentiles of the data. Streamflows that are less than the 10th and greater than the 90th percentiles define and emphasize the extreme values. The largest 10 percent (for example, major flood events) and smallest 10 percent (for example, droughts) of the streamflow data values are not shown.

From the boxplots (figs. 6A and 6B), it can be seen that August and September have similar flow characteristics at each station, as indicated by almost identical percentiles used to define the boxplots. From 25 to 75 percent of the observed streamflows in August and September range from about 60 to 110 ft^3/s (39 to 71 Mgal/d) at the Wallingford gaging station, and from about 9.0 to 18 ft^3/s (5.8 to 12 Mgal/d) at the Southington gaging station.

Monthly streamflow percentiles used to create the boxplots (10-, 25-, 50-, 75-, 90-percentiles) and monthly minimum, maximum, and mean streamflows are listed in table 3. The 10th percentile indicates that 90 percent of the streamflow equals or exceeds this value for a given month. Conversely, the 90th percentile indicates that 10 percent of the streamflow equals or exceeds this value for a given month. These descriptive statistics summarize information about the distribution of streamflow in a given month for the period of record. The percentiles are reciprocals of flow durations.



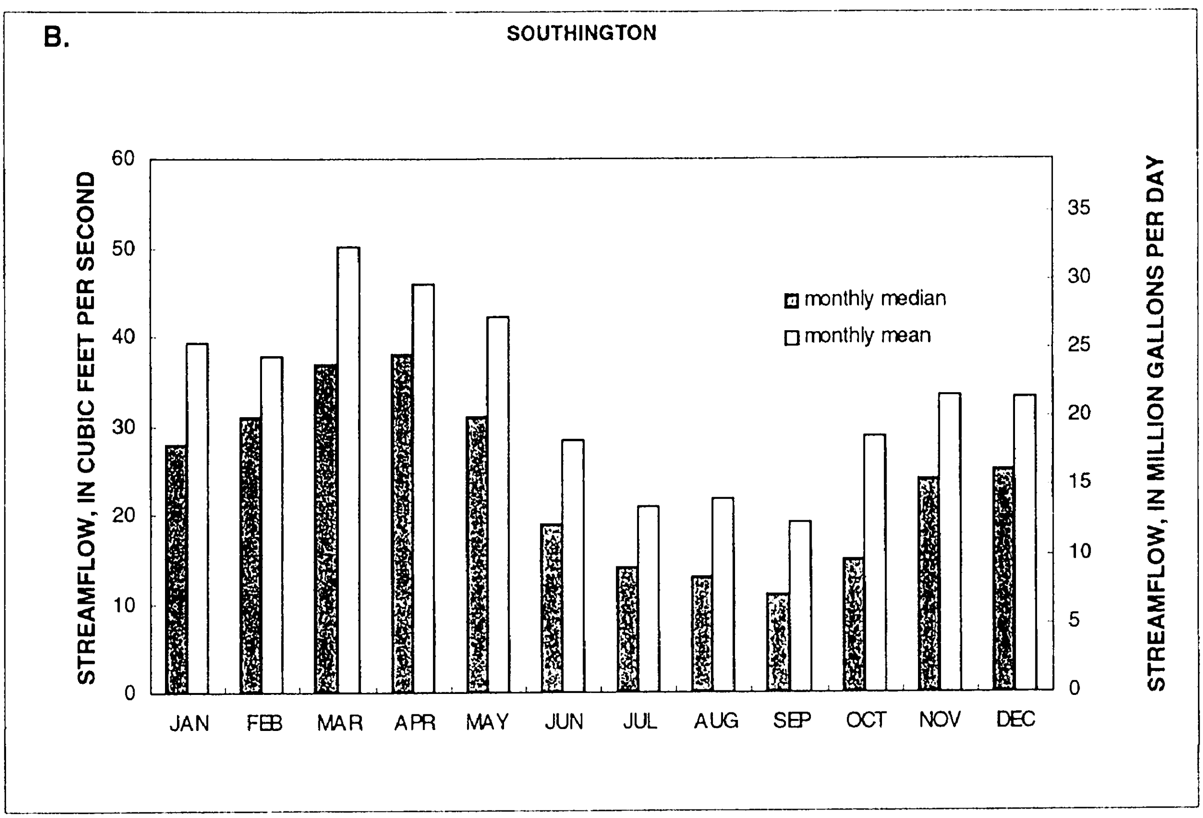


Figure 5. Monthly median and monthly mean streamflow, Quinnipiac River at Wallingford, Conn. (01196500), 1931–2000 (A), and Quinnipiac River at Southington, Conn. (01195490), 1988–2000 (B).

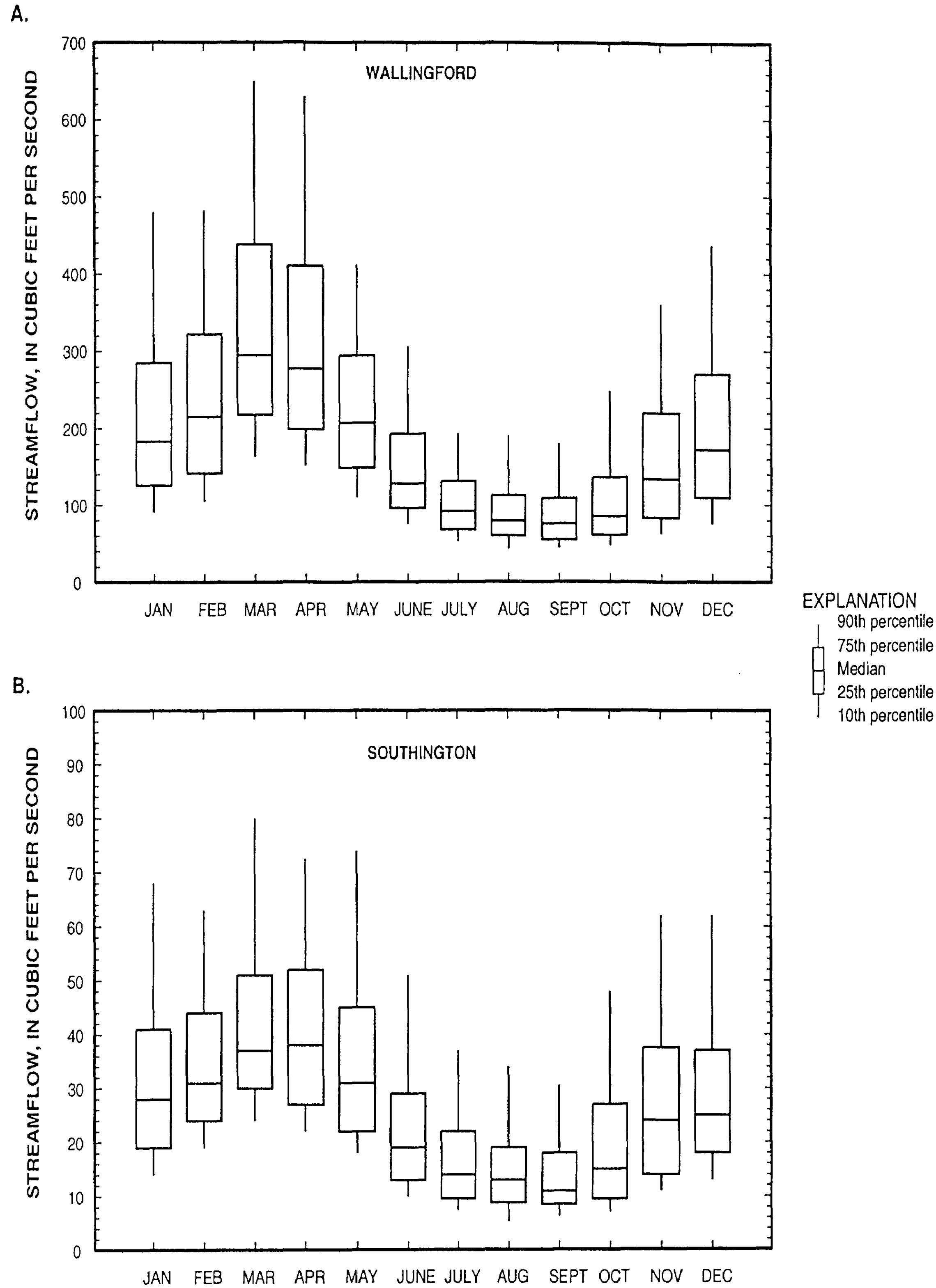


Figure 6. Monthly streamflow, Quinnipiac River at Wallingford, Conn. (01196500), 1931–2000 (A) and Quinnipiac River at Southington, Conn. (01195490), 1988–2000 (B)

Table 3. Monthly streamflow in percentiles, Quinnipiac River at Wallingford, Conn. (01196500), 1931–2000 and Quinnipiac River at Southington, Conn. (01195490), 1988–2000

[Percentiles were determined from daily mean flows using SPLUS software]

Month	Maximum (daily mean)	90th-percentile	75th-percentile	50th-percentile (median)	25th-percentile	10th-percentile	Minimum (daily mean)	Daily mean
U.S. Geological Survey station 01196500, Quinnipiac River at Wallingford, water years 1931–2000								
January	4,100	480	285	183	126	91	37	261
February	3,290	481	322	215	142	105	36	273
March	2,800	651	438	295	218	164	80	383
April	3,360	630	410	277	199	152	80	358
May	3,300	411	294	207	149	110	27	248
June	7,210	306	193	128	96	76	40	185
July	1,610	193	131	92	68	53	16	118
August	3,160	190	112	79	60	43	13	110
September	3,770	180	109	76	55	44	12	114
October	3,350	250	136	85	61	48	10	134
November	2,080	361	220	134	83.8	63	9	188
December	2,620	437	270	172	110	76	17	230
U.S. Geological Survey station 01195490, Quinnipiac River at Southington, water years 1988–2000								
January	374	67.8	41	28	19	14	7.7	39.4
February	251	62.3	44	31	24	19	12	37.9
March	348	90	51	37	30	24.2	15	50.1
April	360	72.1	52	38	27	22	15	45.9
May	313	73.8	45	31	22	18	12	42.1
June	724	51	29	19	13	10	6.5	28.4
July	230	36.6	22	14	9.6	7.4	4.7	20.9
August	283	35.8	19	13	8.9	5.3	3.8	21.8
September	704	30.1	18	11	8.5	6.3	3.9	19.1
October	810	47.9	27	15	9.5	7.1	5.1	28.9
November	289	62	37.3	24	14	11	7.9	33.3
December	227	61.6	37	25	18.5	13	7.7	33.2

August Median Streamflow

The August median flow, also called the aquatic base flow (ABF), is a streamflow statistic used by many Federal and State regulators as the minimum streamflow required for maintaining aquatic habitat in New England streams. The U.S. Fish and Wildlife Service (USFWS) recommends computing the aquatic base flow as the median of all the August monthly means (U.S. Fish and Wildlife Service, 1981). Alternatively, Charles Ritzi and Associates (1987) computed the ABF as the median of the August daily mean flow. From a time-series plot (fig. 7) of August median flows from 1931 to 2000 at the Wallingford gaging station, it can be seen that the medians differ considerably from year to year. The August median flow ranged from a low of 25 ft^3/s (16 Mgal/d) in water year 1966 to a high of 218 ft^3/s (141 Mgal/d) in water year 1938. The extremes in 1966 and 1938 August median streamflows reflect the end of multi-year drought period and a hurricane, respectively. The LOWESS smooth curve illustrates the general trends in the August median flow that have taken place since 1931. The smooth line shows the August median flow dipped to the lowest point in 70 years during the multi-year drought in the 1960's.

The computed August median flow (table 4) may not be the appropriate flow for maintaining aquatic habitat as recommended by the USFWS because of the extent of regulation affecting streamflows. The USFWS states that the ABF should be determined from unregulated streamflow. The September median flow is shown to illustrate the similarity of the monthly averages during late summer when low-flow conditions are present. September flows are less than August flows.

Table 4. Monthly median streamflows for August and September, Quinnipiac River at Wallingford, Conn. (01196500), 1931–2000 and Quinnipiac River at Southington, Conn. (01195490), 1988–2000

[All values in cubic feet per second. USFWS, U.S. Fish and Wildlife Service]

U.S. Geological Survey station	Computed from	August median	September median
Quinnipiac River at Wallingford (01196500)	Daily means	79.0	76.0
	Monthly means (USFWS)	90.1	89.1
Quinnipiac River at Southington (01195490)	Daily means	13.0	11.0
	Monthly means (USFWS)	20.7	12.4

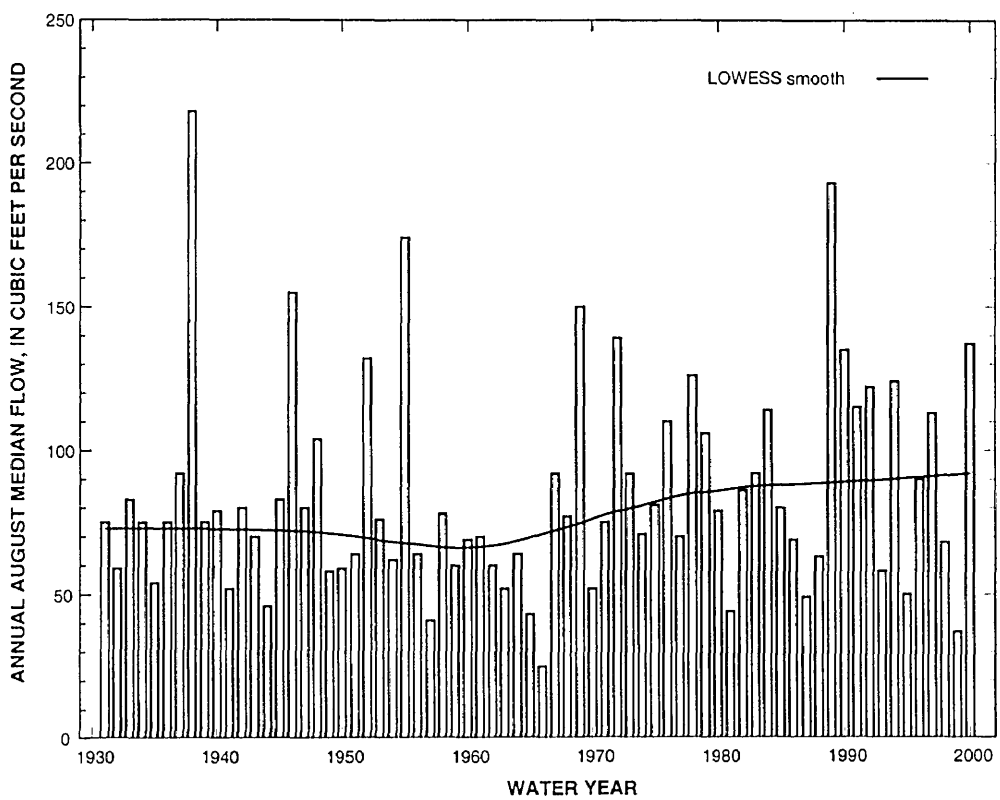


Figure 7. Trends in annual August median streamflow, Quinnipiac River at Wallingford, Conn. (01196500), 1931–2000.

STREAMFLOW TREND ANALYSIS AT THE WALLINGFORD GAGING STATION

Statistical procedures were used to detect trends in the streamflow data and to evaluate how streamflow has changed over the entire streamflow range (annual minimum to annual maximum). Long-term streamflow records at the Wallingford streamflow-gaging station were examined for trends during the period 1931–00. Streamflow records at the Southington streamflow-gaging station were not examined for trends because of the uncertainty of trend analysis on short periods (less than 30 years) of streamflow records.

Trend Detection Methods

The approach to assess trends was based on an approach used by Lins and Slack (1999) to assess national streamflow trends. Although the statistical methods are similar, the national study evaluated trends in streamflow in climate-sensitive streams with drainage basins with limited anthropogenic (human-caused) influences. Streamflow trends in the Quinnipiac River could be caused by flow diversions, wastewater discharges, flow regulation by dams and reservoirs, ground-water pumping, basin transfers, changes in land use and population, and climatic variability.

Because of the large differences in streamflow characteristics between months and seasons, streamflow data were subdivided into 14 indices to represent different streamflow distributions. Streamflow from the same indices are compared and evaluated for trends over time. The indices are based on a range of percentiles from high to low flows. The range of percentiles evaluated for trends includes the annual maximum (100^{th}-), 90^{th}-, 80^{th}-, 70^{th}-, 60^{th}-, annual median (50^{th}-), 40^{th}-, 30^{th}-, 20^{th}-, 10^{th}-, 5^{th}-, 2^{nd}-, 1^{st}-, and annual minimum (0^{th}-) percentiles. The annual maximum and minimum percentiles represent the highest daily mean and lowest daily mean streamflow in a water year, respectively.

Different time periods were evaluated to provide information on how characteristics of streamflow trends are affected by the length of record and to provide insight into regulation and natural variation of streamflow. Trend analyses were performed on time periods that were not heavily affected by droughts, which may bias the trend results. Trend tests were performed for 30-, 40-, 50-, 55-, 60-, 65- to 70-year periods, all ending in water year 2000, except for two 30-year periods (1931–1960 and 1941–1970) that were studied as reference periods.

A time-series plot of the annual minimum and maximum streamflow bracketing the annual mean and median flows was used to make preliminary inferences concerning streamflow over time (fig. 8). Statewide, multi-year droughts occurred from July 1929 to December 1932, from September 1940 to April 1945, and from August 1961 to November 1971 (Weiss, 1991). Scatterplots of streamflow percentiles were created and visually inspected for trends. To determine if the observed trends resulted from a chance arrangement of the data rather than from an actual change in streamflow, a statistical test (Mann-Kendall test) was performed. The underlying test is for correlation between two variables (streamflow and time). The correlation coefficient Kendall's tau was used to measure the strength of association between streamflow and time. The Mann-Kendall test is a nonparametric trend test (Helsel and Hirsch, 1992) and uses a rank-based procedure that tests for one-directional (monotonic) changes over time. The test examines whether streamflow is increasing or decreasing monotonically with time.

Three statistical parameters—Kendall's tau, p-value, and Sen slope—are used to summarize the results of the trend analysis. Kendall's tau ranges from –1 to +1 and measures the strength of the trend. The strength of the trend increases as the value approaches its upper or lower limits; values less than 0 indicate an upward trend, and values greater than 0 indicate a downward trend. If there is no correlation between streamflow and time, Kendall's tau equals 0.

The second statistical parameter used to summarize the trend results is the p-value. The p-value measures the attained significance level of the statistical test (correlation) and is defined as the probability that a detected trend could have arisen by chance rather than from an actual change in streamflow. The p-value does not indicate the size or importance of a trend (for example, magnitude of the streamflow trend); rather, it indicates whether the Kendall's tau value has any significance. For this study, a p-value of 0.05 was selected as the critical attained significance level of the test. Where the p-value is less than or equal to 0.05, there is a less than or equal to 5-percent chance that the indicated significant trend actually is due to chance rather than from an actual change in streamflow, and the trend is than considered 95-percent reliable or "believable." The p-value can be statistically significant and the trend inconsequential at the same time.

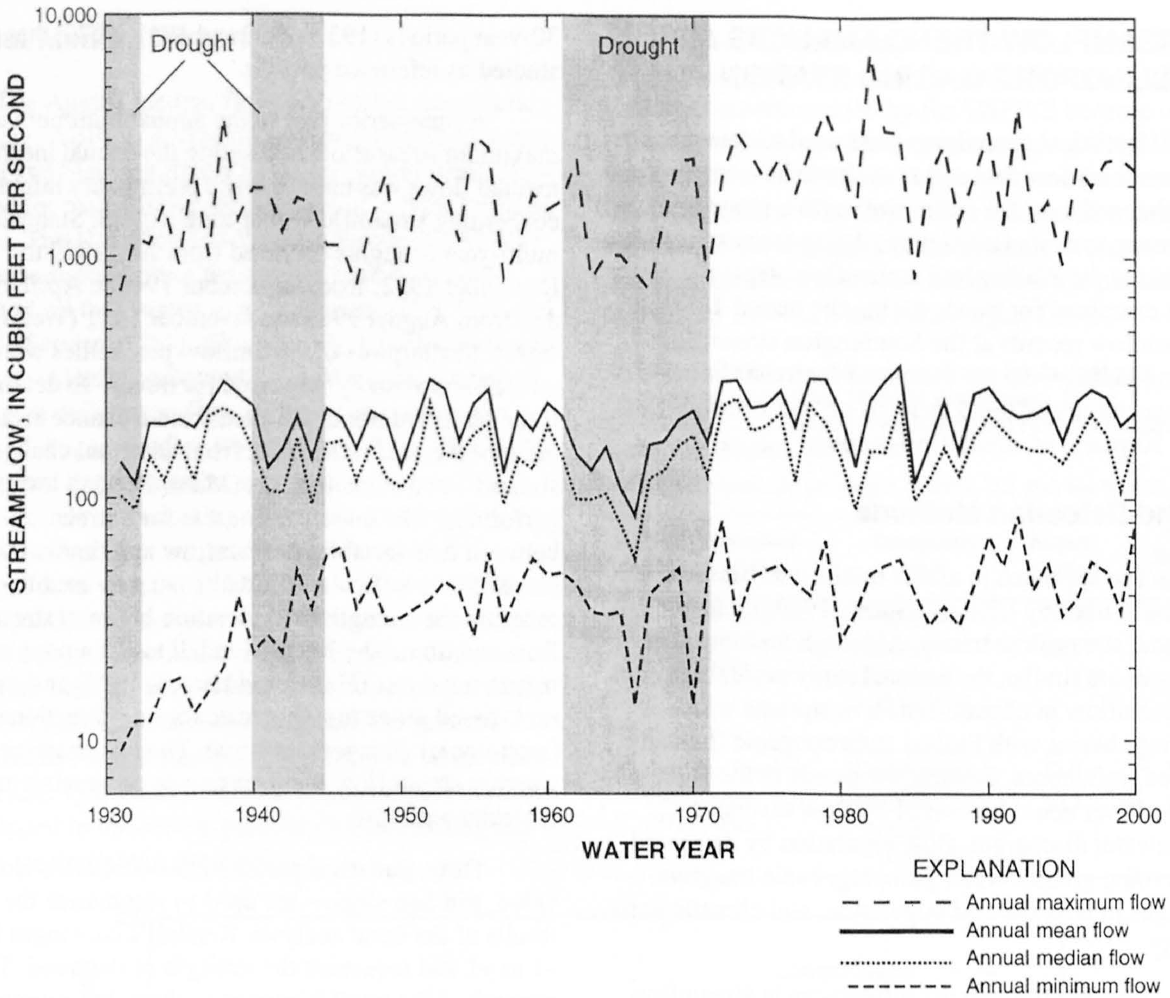


Figure 8. Annual maximum, mean, median, and minimum streamflow, Quinnipiac River at Wallingford, Conn. (01196500), 1931–2000. Shaded areas represent statewide, multi-year droughts.

To illustrate central patterns in streamflow data as a function of time, a smooth line is added to the scatterplots of streamflow for the range of percentiles analyzed for trends. The smoothing procedure used is LOWESS, locally weighted scatterplot smoothing (Cleveland, 1979). The smooth line is derived by the pattern of the data and indicates trend directions over the time. A smoothing factor is used to control the fit of the curve to the data and ranges from 0 to 1. Smaller smoothing factors result in less smoothing of the curve to the data. A smoothing factor of 0.5 was used for the final fit.

The Seasonal Kendall Slope Estimator (Sen slope) is used to estimate the magnitude of the trend. The Sen slope for streamflow is expressed as a change in streamflow per year, in cubic feet per second. Although the relation between streamflow and time usually is nonlinear, a linear function is used to represent the trend magnitude. The actual trend magnitude may differ significantly from the trend magnitude estimated from the Sen slope; particularly where anomalies are near the beginning or the end of the period of record (Lins and Slack, 1999). The procedure for computing the Sen slope is described by Smith and others (1982).

Trend analyses were performed on records of precipitation and wastewater discharge to evaluate whether these factors affected trends in streamflow. The Mann-Kendall test was applied to monthly precipitation and wastewater discharge records to determine the presence or absence of a trend in individual months and seasons. A variation of the Mann-Kendall test, known as the seasonal Kendall test, was used to test for overall trends. The seasonal Kendall test statistic is determined by calculating the Mann-Kendall test statistic for each month or season and combining the individual test statistics into a single test statistic. The single test statistic represents the overall trend. Where seasons consistently show the same trend pattern, trend results can be more significant by combining the individual test statistics into one overall test statistic. The Mann-Kendall test statistic can incorporate an upward trend in one season and a downward trend in another season that cancel each other, resulting in a seasonal Kendall test statistic that indicates no overall trend.

Trends in Streamflow

Trend test results, by percentile and by period of record, are summarized in table 5. Complete trend-analysis results for streamflow are shown in appendix 1. Many similarities in trends are found across time periods, across percentiles, and with respect to direction. Increasing streamflows were detected predominantly in the lower half of the flow distribution (annual minimum to annual median) and the extreme upper half of the flow distribution (annual maximum flow), except during 1961–00, when upward trends were detected in only the upper half of the flow distribution. No decreasing flow trends were detected in any time periods or percentiles. Another important characteristic is that most trends represent only modest increases in streamflow.

The most statistically significant trend detected (highest Kendall's tau value and lowest p-value) is an upward trend in the annual minimum (daily mean) streamflow at the Wallingford gaging station. The annual minimum streamflow (0^{th} percentile) increased by an average of 0.44 ft^3/s per year from 1931 to 2000 (fig. 9). A LOWESS smooth line also shows an upward trend in the annual minimum flow since 1931 (fig. 9). The smooth line begins at its lowest point during the 70-year period, which coincides with the lowest streamflow on record for the Quinnipiac River, then rapidly rises from 1931 until the early 1950's. From the early 1950's to 2000, the smooth line, which illustrates the relation between streamflow and time, continues to rise at a more gradual rate.

Table 5. Trends for selected percentiles of streamflow between the annual minimum and annual maximum streamflows, Quinnipiac River at Wallingford, Conn. (01196500), 1931–2000

[Kendall's tau values range from -1 to 1; values less than 0 indicate an upward trend, and values greater than 0 indicate a downward trend; ; p-value, attained significance level of the trend test; p-values in bold and shaded lines are at the attained significance level of less than or equal to 0.05; median is the median value for the percentile; Sen slope is the change in streamflow per year, in cubic feet per second; <, less than]

Percentile	Kendall's tau	p-value	Median	Sen slope
		1931–2000 (drought 1929–32)		
0 percentile (annual minimum daily mean)	0.357	**<0.001**	40.0	0.436
1^{st} percentile	.281	**<.001**	46.3	.331
2^{nd} percentile	.253	**.002**	50.2	.313
5^{th} percentile	.201	**.014**	55.9	.263
10^{th} percentile	.171	**.037**	65.0	.235
20^{th} percentile	.151	.066	82.8	.250
30^{th} percentile	.153	.062	102	.358
40^{th} percentile	.145	.077	125	.444
50^{th} percentile (median)	.151	.066	156	.533
100^{th} percentile (annual maximum daily mean)	.253	**.002**	1,780	16.8
		1935–2000		
0 percentile (annual minimum daily mean)	.280	**<.001**	41.0	.333
1^{st} percentile	.194	**.021**	46.8	.201
2^{nd} percentile	.176	**.037**	50.9	.204
100^{th} percentile (annual maximum daily mean)	.215	**.011**	1,860	15.7

Table 5. Trends for selected percentiles of streamflow between the annual minimum and annual maximum streamflows, Quinnipiac River at Wallingford, Conn. (01196500), 1931–2000—Continued

[Kendall's tau values range from -1 to 1; values less than 0 indicate an upward trend, and values greater than 0 indicate a downward trend; ; p-value, attained significance level of the trend test; p-values in bold and shaded lines are at the attained significance level of less than or equal to 0.05; median is the median value for the percentile; Sen slope is the change in streamflow per year, in cubic feet per second; <, less than]

Percentile	Kendall's tau	p-value	Median	Sen slope
	1941–2000 (drought 1940–45)			
0 percentile (annual minimum daily mean)	0.167	0.060	43.0	0.202
5th percentile	.159	.073	57.2	.250
10th percentile	.193	**.030**	65.0	.314
20th percentile	.200	**.024**	81.9	.391
30th percentile	.214	**.016**	100	.530
40th percentile	.189	**.034**	123	.650
50th percentile (median)	.179	**.044**	158	.772
90th percentile	.156	.078	418	1.84
100th percentile (annual maximum daily mean)	.241	**.007**	1,860	18.5
	1945–2000			
30th percentile	.158	.086	105	.441
100th percentile (annual maximum daily mean)	0.247	**0.007**	1,980	20.8
	1951–2000			
1st percentile	.179	.068	48.3	.233
2nd percentile	.181	.064	52.2	.272
5th percentile	.162	.099	59.1	.289
30th percentile	.166	.091	105	.512
100th percentile (annual maximum daily mean)	.168	.086	2,100	16.8
	1961–2000 (drought 1961–69)			
30th percentile	.222	**.045**	109	.912
40th percentile	.203	.067	132	1.18
50th percentile (median)	.219	**.048**	160	1.53
60th percentile	.227	**.040**	194	1.71
70th percentile	.212	.056	232	1.85
80th percentile	.221	**.046**	285	2.53
90th percentile	.245	**.027**	414	4.42
	1971–2000			
No trends detected				

Although the annual minimum flow trend was the most statistically significant trend, it was not as significant in the shorter time periods. The annual minimum streamflow increased by an average of 0.44 ft^3/s per year from 1931 to 2000 (p-value less than 0.001 and Kendall's tau of 0.357) as compared to 0.20 ft^3/s per year from 1941–00 (p-value of 0.060 and Kendall's tau of 0.167). Exceptionally low streamflows were recorded through the 1930's that largely affect the magnitude of the annual minimum streamflow trend. The unusually low flows of the 1930's are an anomaly for the period of record. After the drought of July 1929 to December 1932 (recurrence interval of more than 25 years), the annual minimum streamflow remained exceptionally low through 1938. The low streamflows during that time period probably are caused by the extensive flow regulation. No trends were detected in the annual minimum streamflow for the 30- or 40-year periods (1961–00 and 1971–00) at the Wallingford gaging station.

The second most statistically significant trend detected is an upward trend in the annual maximum streamflow (fig. 10). Upward trends also were detected in the annual median streamflow (fig. 11). The annual maximum (100^{th} percentile) streamflow increased by an average of 16.8 ft^3/s per year, and annual median (50^{th} percentile) streamflow increased by an average of 0.53 ft^3/s per year during 1931–00. Statistically significant upward trends in the annual maximum daily mean streamflow were detected during the 60- and 70-year periods. The increasing streamflow trend was detected at the 90^{th} percentile (high flow) but not the 100^{th} percentile during the 40-year period; the trend was nearly significant (p-value = 0.086) during the 50-year period. No trends were detected in the annual maximum streamflow during 1971–00. Land-cover changes from pervious to impervious surface, expansion of the storm-drainage systems, and increases in rainfall intensity probably result in increases in annual maximum streamflow.

Statistically significant upward trends in the annual median streamflow (50^{th} percentile) were detected during 1941–00 and 1961–00. The upward trend in the annual median streamflow nearly was significant (p-value = 0.066) during 1931–00. No trends were detected in the annual median streamflow in the non-drought beginning time periods (1935–00, 1945–00, 1951–00 and 1971–00). Severe droughts at the beginning of the time period analyzed probably can result in the detection of an increase in streamflow. The LOWESS smooth line of the annual median streamflow pattern begins at its lowest point, which coincides with the 1930's drought, then gradually rises until the early 1950's and dips during the 1960's drought (fig. 11). The smooth line rises from 1960 to 1980, then gradually falls from approximately 1982 until 2000.

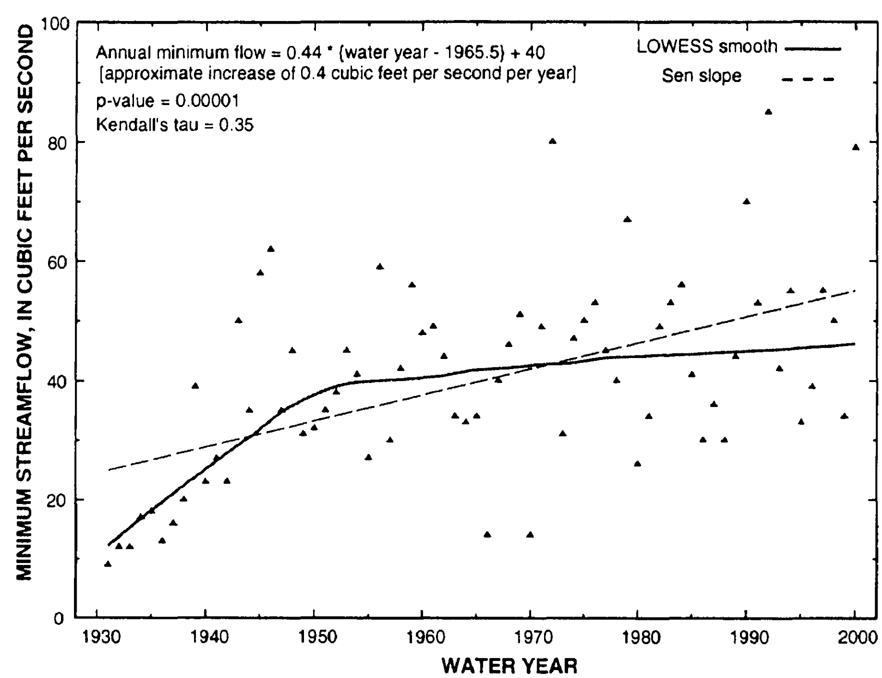


Figure 9. Trends in annual minimum streamflow, Quinnipiac River at Wallingford, Conn. (01196500), 1931–2000.

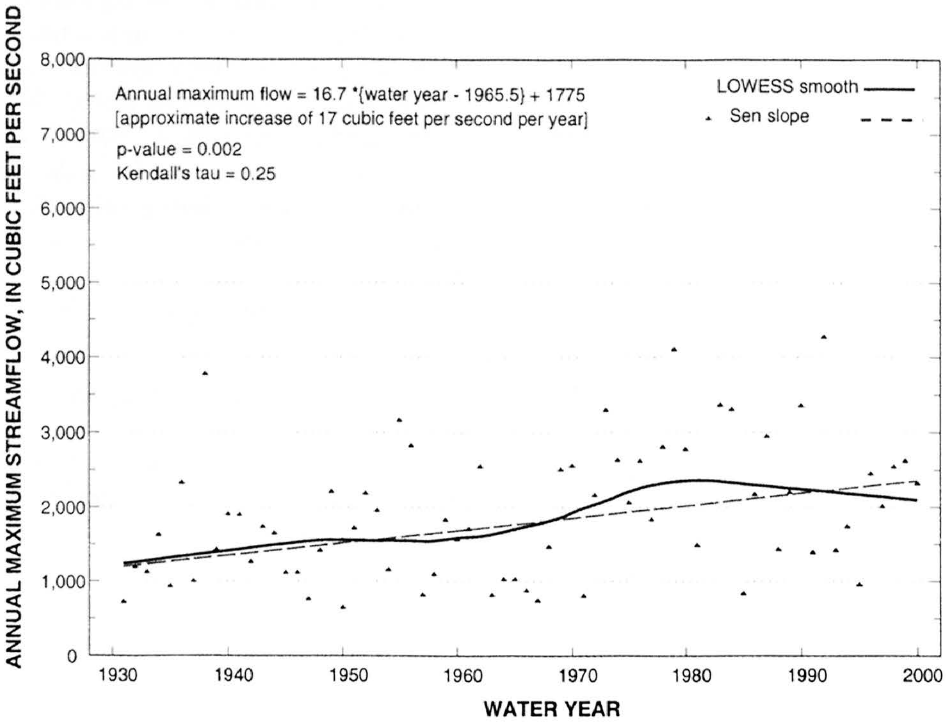


Figure 10. Trends in annual maximum streamflow, Quinnipiac River at Wallingford, Conn. (01196500), 1931–2000.

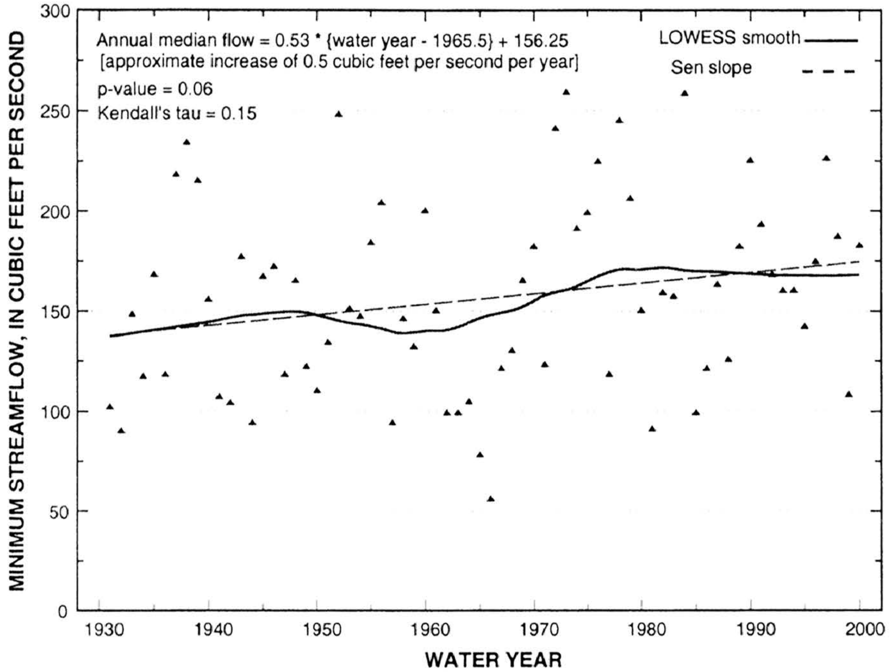


Figure 11. Trends in annual median streamflow, Quinnipiac River at Wallingford, Conn. (01196500), 1931–2000.

The highest number of statistically significant trends (p-value <= 0.05) over all the percentiles is seen during the 60- and 70-year periods (1941–00 and 1931–00). A high number of trends also is evident during the 40-year period (1961–00) and 50-year period (1951–00). No statistically significant trends were detected during the most recent 30-year period (1971–00). For the 60- and 70-year periods (1941–00 and 1931–00), trends are detected in the low to middle range (0^{th} to 50^{th} percentile) and the uppermost percentile (100^{th} percentile). The trend pattern changes from the lower half to the upper half of the streamflow-percentile distribution during the most recent 40-year period (1961–00). Statistically significant trends (p-value <= 0.05 and Kendall's tau value > 0.2) are detected in the middle to upper percentile range (30^{th} to 90^{th} percentile) during 1961–00. No statistically significant trends were detected in the 60^{th} to 90^{th} percentiles for the periods analyzed, except during 1961–00.

Trend-analysis results are sensitive to the extreme climatic anomalies near the beginning and the end of the record. Statewide droughts, from July 1929 to December 1932, from September 1940 to April 1945, and from August 1961 to November 1971 (Weiss, 1991), can affect the trend-analysis results for the 70-, 60-, and 40-year periods (1931–00, 1941–00, and 1961–00). Because the results are sensitive to extreme climatic anomalies early or late in the analysis period, a second series of trend analyses were performed on non-drought beginning periods: 1935–00, 1945–00, 1951–00, and 1971–00.

Fewer increasing streamflow trends were detected across the non-drought beginning time periods than in the drought beginning time periods. Also, the magnitude of the trends was much lower and the attained significance of the statistical test was higher for the non-drought beginning periods. For example, the magnitude of the trend at the 30^{th} percentile is higher and the attained significance of the trend test is more significant for the time periods beginning in a drought (1941–00—Kendall's tau of 0.214 and p-value equal to 0.016; 1961–00—Kendall's tau of 0.222 and p-value equal to 0.045) than the time period not beginning in a drought (1951–00—Kendall's tau of 0.166 and p-value = 0.091). A number of trends were detected with an attained significance level slightly greater than 0.05 (0.06 to 0.1) in the lower half and extreme upper range of the flow distribution, and across time periods (droughts and non-drought beginnings). Trends may be possible at significance levels greater than 0.05.

The trend-analysis results only reflect streamflow patterns detected at the Wallingford streamflow-gaging station. The station is approximately 14 mi from Long Island Sound and receives runoff and ground water from 70 percent of the basin. The accuracy of transferring flow characteristics or trend results upstream or downstream from the station was not evaluated for this study. Diversions, return flows, other regulation and natural changes in streamflow need to be interpreted before flow characteristics can be transferred to another location on the river.

Factors That Affect Trends in Streamflow

Factors that may affect streamflow trends include (1) climatic variability, such as precipitation, and (2) human influences, such as wastewater discharges, streamflow diversions, interbasins transfers, consumptive uses, and land-cover changes, such as urbanization. Generally, streamflow diversions, out-of-basin transfers, and consumptive uses decrease low streamflow. Urbanization may cause an increase in runoff and flooding and a decrease in low streamflow. Relations between streamflow trends and trends in precipitation and municipal wastewater discharges were examined to determine the effects of precipitation and wastewater discharge on streamflow. Analyses of the effects of human influences other than wastewater discharges are not included in this study.

Precipitation

Precipitation data were analyzed to evaluate whether streamflow trends on the Quinnipiac River might be related to precipitation. Regional precipitation data were retrieved from the National Oceanic and Atmospheric Administration (NOAA), National Climatic Data Center database for the period 1930–00 (data accessed on November 26, 2001 on the World Wide Web at URL http://lwf.ncdc.noaa.gov/oa/climate/climatedata.html). A precipitation dataset, both spatial and temporal, was compiled from five rain gages in south-central Connecticut (fig. 1; appendix 2). Four different precipitation indices were evaluated for trends: monthly total, annual total, annual median, and annual mean. Monthly precipitation data from five rain gages were averaged within each year to produce annual mean and annual median values, and summed each year to produce annual totals. When monthly data for one or more of the five rain gages were missing, the monthly average was based on the number of rain gages with data. A time-series plot of total annual precipitation as the arithmetic average of the five rain gages is shown in figure 12. Monthly precipitation totals were compiled by averaging data from two rain gages (NOAA station numbers 65077 and 64767) with nearly complete record. These two rain gages used to analyze monthly precipitation trends are missing less than 1 percent of the rainfall data for the time period analyzed. A Kendall tau test was performed to detect trends in precipitation.

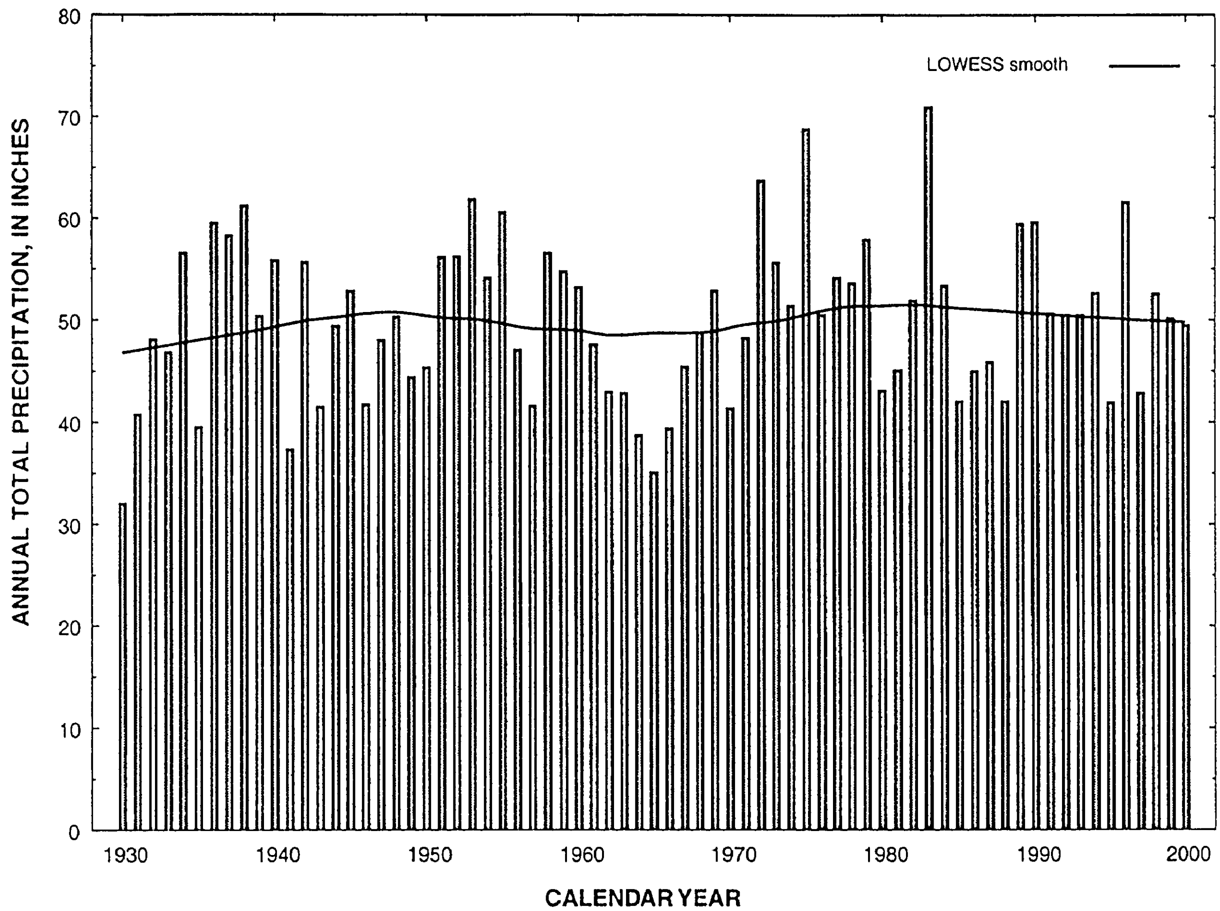


Figure 12. Annual total precipitation for five rain gages in and near the Quinnipiac River Basin, Conn., and LOWESS smooth line, 1930–2000.

The trend-analysis results on precipitation indicated that no significant trends are present at the 95-percent significance level (p-value <= 0.05). The monthly precipitation total, annual precipitation total, and annual average (median and mean) precipitation totals show no statistical evidence of upward or downward trends during 1930–00. From this analysis, no evidence is available to indicate that precipitation may be causing the increase in the annual minimum flow at the Wallingford gaging station.

A national research study on precipitation trends indicates that extreme precipitation events, such as the 1-day rainfall intensity for coastal areas, are increasing (Karl and Knight, 1998). The magnitude of the maximum streamflow is a function of rainfall intensity. An increase in rainfall intensity as indicated in the national study of extreme precipitation events lends support to an upward trend detected in the annual maximum streamflow from 1931 to 2000.

Wastewater Discharges

Wastewater discharges can augment streamflow. Of the 19 permitted wastewater discharges in the basin, 12 are upstream from the Wallingford gaging station with a combined maximum flow of 25 Mgal/d (38.7 ft^3/s). Three of the 12 permitted discharges are municipal wastewater-treatment facilities in Meriden, Cheshire, and Southington. Collectively, these three municipal wastewater-treatment facilities account for 92 percent of the permitted discharges (upstream from the Wallingford gaging station) into the Quinnipiac River with a combined maximum daily flow of 22.9 Mgal/d (35.5 ft^3/s) and an average daily flow of 15.8 Mgal/d (24.5 ft^3/s). The combined wastewater discharges above the Wallingford streamflow-gaging station represent about 33 percent of the monthly median streamflow in August at the station. Data from the three municipal wastewater-treatment facilities were analyzed for trends because of the large percentage of streamflow that these permitted discharges represent. The other nine permitted wastewater discharges (upstream from the Wallingford gaging station) that make up the remaining 8 percent of permitted discharges have a combined maximum daily flow of 2.1 Mgal/d (3.2 ft^3/s) and were not included in the trend analysis.

To further understand the trend in annual minimum streamflow, the annual minimum streamflow was plotted for the Southington and Wallingford stations for coincident time periods (fig. 13). (The Southington station is upstream from the three municipal wastewater-treatment facilities.) Streamflow at the Southington station is regulated by 15 industrial and public-water diversions with a combined maximum daily withdrawal of 13.2 Mgal/d, and 4 permitted surface-water discharges with a combined maximum daily flow of 0.732 Mgal/d (Quinnipiac River Watershed Partnership, 2000). The Southington station would be expected to yield higher natural flows during low-flow conditions than the Wallingford station because the percentage of coarse-grained deposits (as percent of total drainage area) is higher at Southington than at Wallingford. A comparison of annual minimum streamflow at the two stations since 1988 shows that for the annual minimum streamflow, the yield per square mile of basin generally is lower at Southington than at Wallingford. Wastewater discharge may be increasing the annual minimum streamflow at the Wallingford station, and diversions may be reducing the annual minimum flow at Southington.

Wastewater records were obtained from each town's Water Pollution Control Department. Records were available in electronic form from 1985 to 2001 (17 years) for Meriden and Cheshire and from 1983 to 2001 (19 years) for Southington. Monthly total discharge data were available from the Meriden and Southington facilities; daily average discharge was available for the Cheshire facility. A boxplot of wastewater discharge from the Meriden wastewater-treatment facility shows monthly and seasonal variability in the wastewater discharge data (fig. 14). A Kendall tau statistical analysis was used to detect statistically significant trends in monthly wastewater discharges. A p-value less than or equal to 0.05 was selected to indicate the presence of a statistically significant trend.

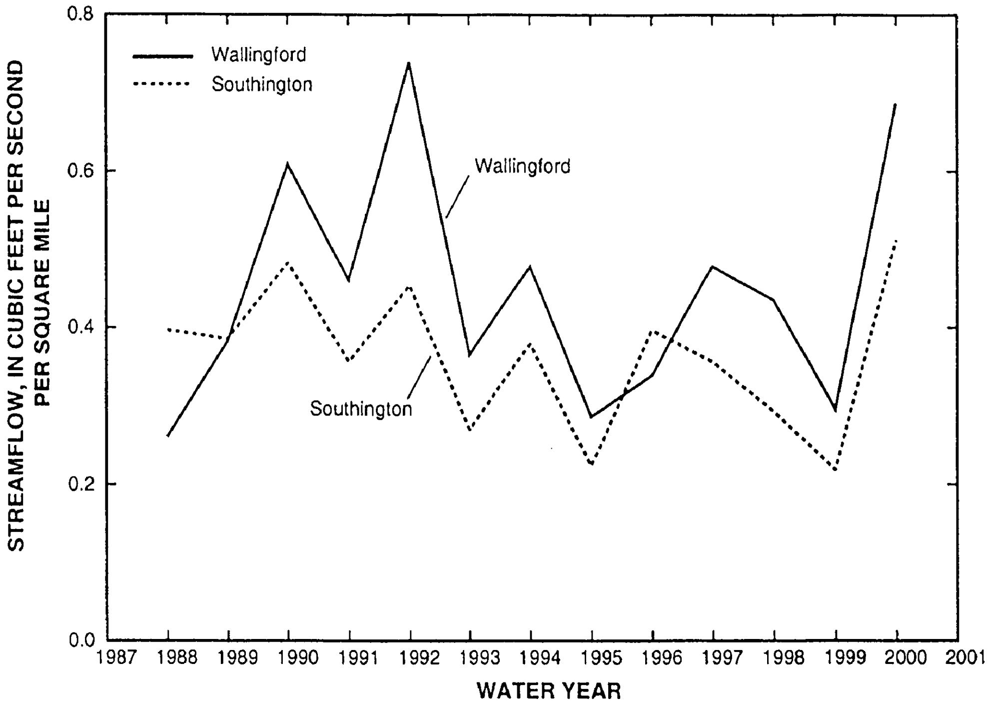


Figure 13. Annual minimum streamflow at two U.S. Geological Survey streamflow-gaging stations (Quinnipiac River at Wallingford, Conn.—01196500 and Quinnipiac River at Southington, Conn.—01195400), 1988–2000. [Wallingford station has 39 percent coarse-grained deposits, and Southington has 51 percent coarse-grained deposits.]

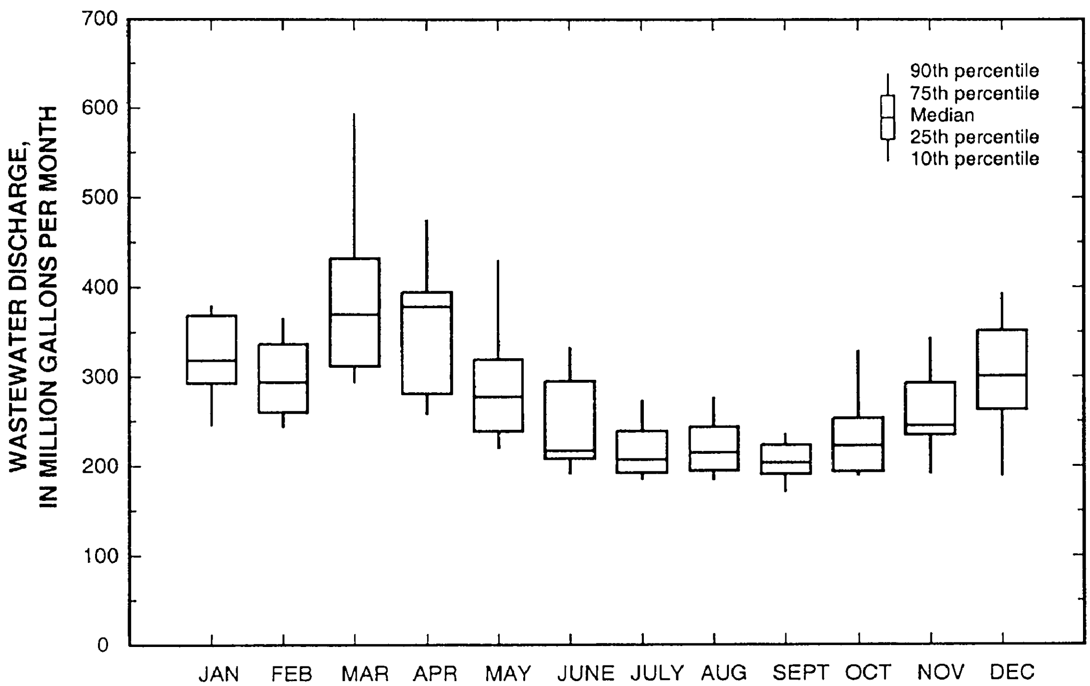


Figure 14. Monthly total permitted wastewater discharges into the Quinnipiac River from the wastewater-treatment facility in Meriden, Conn., 1985–2001.

Selected trends in wastewater discharges are summarized in table 6. Complete trend-analysis results for wastewater discharge are shown in appendix 3. Upward trends were detected at all three municipal wastewater-treatment facilities (fig. 15). The overall upward trends were 2.23 Mgal/month/year (about 2 ft^3/s) at Meriden; 1.18 Mgal/month/year (about 1.2 ft^3/s) at Southington; and an average 0.04 Mgal/d/year (about 1 ft^3/s) at Cheshire. Trend-analysis results by month for Meriden showed statistically significant trends in February and March. No trends were detected in summer or early fall during low-flow conditions. Trend-analysis results by month for Cheshire showed statistically significant trends in all months except December and August. Trend-analysis results for Southington showed statistically significant trends in January, February, and March.

The population of the Meriden, Cheshire, and Southington has increased by about 9.3 percent between 1980 (115,785) and 2000 (126,515), and by 148 percent between 1930 (50,981) and 2000 (126,515) (data accessed on April 19, 2002, on the World Wide Web at URLs http://www.sots.state.ct.us/RegisterManual/SectionVII/Population1900.htm and http://www.sots.state.ct.us/RegisterManual/SectionVII/Population1970.htm). Population increases in urban and suburban areas generally cause increases in water use, water consumption, and wastewater. In recent years, many water-conservation practices (such as modern plumbing fixtures and educational programs related to conservation) were implemented to reduce the volume of wastewater generated; however, the wastewater data (fig. 15) and trend-analysis results indicate that wastewater discharge increased from 1985 to 2000. A trend analysis of water use and consumption was beyond the scope of this study.

Table 6. Trends in permitted wastewater discharges at selected wastewater-treatment facilities, Quinnipiac River Basin, Conn.

[Kendall's tau values range from -1 to 1; values less than 0 indicate an upward trend, and values greater than 0 indicate a downward trend; p-value, attained significance level of the trend test; p-values in bold and shaded lines are at the attained significance level of less than or equal to 0.05; median is the median value for the percentile; Sen slope is the change in wastewater discharge per year; <, less than]

Trend	Kendall's tau	P-value	Median	Sen slope
Meriden wastewater-treatment facility (1985–01; units are total million gallons per month)				
Overall trend (seasonal Kendall)	0.178	**0.040**	264	2.23
February	.456	**.012**	294	6.86
March	.529	**.003**	370	11.7
Cheshire wastewater-treatment facility (1985–01; units are average million gallons per day)				
Overall trend (seasonal Kendall)	.477	**<.001**	1.93	.046
January	.684	**<.001**	2.18	.065
February	.691	**<.001**	1.99	.075
March	.603	**<.001**	2.15	.080
April	.485	**.007**	2.23	.086
May	.441	**.015**	1.99	.054
June	.463	**.010**	1.85	.055
July	.485	**.007**	1.65	.038
August	.353	.052	1.72	.027
September	.463	**.010**	1.77	.031
October	.382	**.036**	1.84	.035
November	.375	**.039**	1.91	.030
Southington wastewater-treatment facility (1983–01; units are total million gallons per month)				
Overall trend (seasonal Kendall)	.205	**<.001**	117	1.18
January	.368	**.030**	124	2.73
February	.380	**.025**	113	1.76
March	.555	**.001**	141	2.99

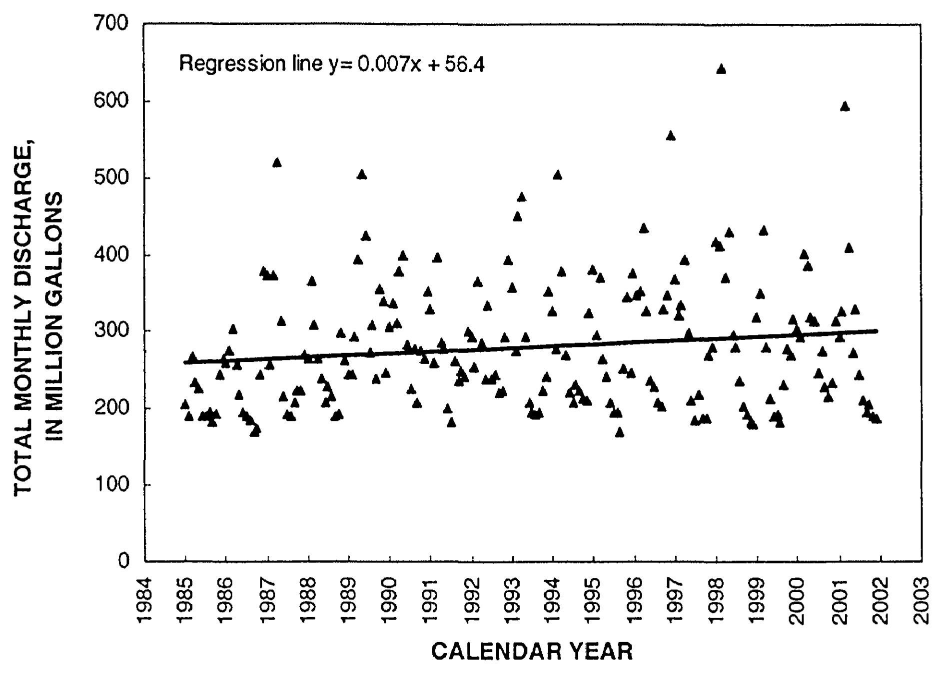


Figure 15. Trends in wastewater discharges to the Quinnipiac River from the wastewater-treatment facility in Meriden, Conn., 1985–2001.

From the wastewater-discharge trend analysis, evidence indicates that wastewater discharge may be increasing streamflow at the Wallingford gaging station. Both the LOWESS line of the annual minimum streamflows and Sen slope of annual minimum streamflows are consistent with an increase in wastewater discharges. The combined daily average wastewater discharge from the three facilities increased by about 4 ft^3/s (2.5 Mgal/d) during 1985–01. Because the Sen slope from 1931 to 2000 is affected by the unusually low flows in the 1930's, the Sen slope from 1941 to 2000 is used to interpret the relation between trends in wastewater discharge and the annual minimum streamflow. The LOWESS line shows an increase in the annual minimum flow of about 2 ft^3/s (1.3 Mgal/d) and the Sen slope (from 1941 to 2000) shows an increase in the annual minimum flow of about 3 ft^3/s (1.9 Mgal/d) at the gaging station during 1985–00.

An increase in the quantity of wastewater discharge may not necessarily cause an increase in downstream flow, particularly on a regulated river or where the distance between the release point and study point is considerable (miles). Other factors affecting low flow, such as water withdrawals and land-use changes, were not evaluated and cannot confirm or refute the possibility that increases in the annual minimum streamflow primarily are related to the increases in wastewater discharges. The storage capacity of the channel reach between the wastewater-treatment facilities and the gaging station, particularly the Community Lake reach, has not been analyzed and can be an important factor in controlling low-streamflow characteristics. Additional investigation on water withdrawals, land-use changes, and the storage capacity of the channel reach would be necessary to better understand the effects of wastewater discharges on streamflow trends.

SUMMARY

The Quinnipiac River is an important resource in south-central Connecticut. In response to water allocation and streamflow concerns in the basin, the USGS, in cooperation with the Connecticut DEP, began a study in 2000 to compute current streamflow statistics and analyze historical streamflow data for trends to document long-term changes. Streamflow statistics for two continuous-record streamflow-gaging stations on the Quinnipiac River (Wallingford—01196500 and Southington—01195490) were updated using standard USGS methods and computer software to estimate statistics for flow duration, low-flow frequency, annual average streamflow, and monthly average streamflow. The flow statistics were estimated from an analysis of the historical streamflow record. Because the streamflow is affected by diversions, wastewater discharges, reservoirs, ground-water pumping, basin transfers, and changes in land use and population, the streamflow statistics reflect regulated flow and not the natural flow of the river.

Low-flow frequency estimates from station data varied by 10 percent at Wallingford and by 30 percent at Southington from the low-flow frequency estimates from a regression equation. The 7Q10 for Wallingford from the regression equation is 10-percent less than the 7Q10 calculated from the station data, indicating that regulation (release of wastewater discharges) may be increasing the flow at Wallingford. The 7Q10 for Southington from the regression equation is 30-percent greater than the 7Q10 value calculated from the station data, indicating that diversions may be reducing flow at Southington.

Streamflow trends were evaluated at the long-term gaging station in Wallingford using the non-parametric Mann-Kendall test. Trends were computed for a range of percentiles of streamflow, from the annual minimum to annual maximum, and for a range of time periods, from 30 to 70 years. Trend results indicate that the annual minimum and annual maximum streamflow increased by 0.44 ft^3/s and 17 ft^3/s per year, respectively, for the Wallingford gaging station during the period of record (1931–00). The highest percentage of trends were detected in the 40-, 60- and 70-year periods (1961–00, 1941–00 and 1931–00, respectively). Increases in the annual maximum streamflow were common during all time periods, except during 1971–00, when no streamflow trends were detected. No downward trends were detected for any time periods or percentiles. Significant streamflow trends were common in the lower half of the flow distribution ranging from the annual minimum to annual median (0^{th} to 50^{th} percentile) for periods longer than 40 years. During 1961–00, streamflow trends were detected in the middle to upper half of the flow distribution (30^{th} to 90^{th} percentile).

Records of precipitation and wastewater discharges were analyzed to provide insight into streamflow trends. Trend-analysis results of precipitation from rain gages in and near the basin indicate no trends in annual or monthly precipitation totals during 1930–00. The trend-analysis results for precipitation could not directly lend support to an upward trend in the annual minimum streamflow. A national research study on precipitation trends indicate increases in the rainfall intensity for Connecticut in the 20^{th} century. Increases in rainfall intensity lends support to an upward trend in the annual maximum streamflow. Increases in residential and commercial development and expansion of storm-drainage systems may be causes of an upward trend in the annual maximum streamflow.

Wastewater discharges can constitute a substantial percentage of streamflow in August and September during low-flow conditions and during periodic droughts. A trend analysis of wastewater discharges for municipal wastewater-treatment facilities in Meriden, Cheshire, and Southington indicates an increase in wastewater discharge at each municipal wastewater-treatment facility during 1985–01. Results of the trend analyses provide evidence that wastewater discharge is increasing at a rate consistent with the annual minimum streamflow trend. Wastewater discharge increased by about 4 ft^3/s and the annual minimum streamflow at the gaging station in Wallingford increased by approximately 2-3 ft^3/s.

Analyses of precipitation and wastewater discharge provide general insight to what extent these trends have on the streamflow. Abnormally low flows were recorded from 1932 to 1938 when annual precipitation totals were normal to above-normal. Graphical evidence suggests that regulation affected streamflow in the early period of record (1930's). Conversely, the recurrence of droughts in the early period (1930's, 1940's and 1960's) and above-normal precipitation in the 1970's indicates that the upward trends in streamflow (annual minimum to annual median) may, in part,

be a result of climatic variability. The magnitude of the trend in the annual minimum streamflow from 1931 to 2000 at the Wallingford gaging station appears to reflect both regulation and periodic droughts in the early record. The extent that regulation and droughts affect the magnitude of the trends could not be determined readily and was outside the scope of the study. Wastewater discharges appear to be affecting some streamflow trends. Increases in both the wastewater discharges and the annual minimum streamflow seem to indicate that the annual minimum streamflow at the Wallingford gaging station has been augmented by upstream wastewater discharges.

The streamflow statistics and trend-analysis results presented here provide a limited understanding and assessment of the water quantity in the Quinnipiac River; however, many uncertainties are associated with factors causing streamflow trends. A watershed-simulation model could, for example, provide valuable information about the effects of the withdrawals and discharges on streamflow. Both natural effects and human influences that affect streamflow trends need further investigation to understand the effects of regulation and climate on the Quinnipiac River.

REFERENCES CITED

Cervione, M.A., Jr., 1982, A method for estimating the 7-day, 10-year low flow of streams in Connecticut: Connecticut Water Resources Bulletin 34, p. 17 p.

Cleveland, W.S., 1979, Robust locally weighted regression and smoothing scatterplots: Journal of American Statistical Association, v. 74, no. 368, p. 829–836.

Connecticut Department of Environmental Protection, 1997, Connecticut water quality standards and criteria: Hartford, Conn., Inland Water Resources Division, Connecticut Department of Environmental Protection, 46 p.

Helsel, D.R., and Hirsch, R.M., 1992, Statistical methods in water resources: Studies in Environmental Science 49, New York, Elsevier Science Publishers, 529 p.

Karl, T.R., and Knight, R.W., 1998, Secular trends of precipitation amount, frequency, and intensity in the USA: Bulletin of the American Meteorological Society, v. 79, p. 231–241.

Lins, H.F., and Slack, J.R., 1999, Streamflow trends in the United States: Geophysical Research Letters, v. 26, no. 2, p. 227–230.

Mazzaferro, D.L., Handman, E.H., and Thomas, M.P., 1979, Water resources inventory of Connecticut, part 8, Quinnipiac River Basin: Connecticut Water Resources Bulletin 27, 88 p.

Quinnipiac River Watershed Partnership, 2000, Preliminary assessment of water withdrawals and streamflows in the Quinnipiac River watershed: Hartford, Conn., Quinnipiac River Watershed Partnership Work Group Report, July 2000, Hartford, Conn., 37 p.

Ries, K.G., III, 2000, Methods for estimating low-flow statistics for Massachusetts Streams: U.S. Geological Survey Water-Supply Paper 00-4135, p. 7–9.

Ritzi, Charles, and Associates, 1987, Computation of USFWS aquatic base flow for regulated streams: Winthrop, Maine, 15 p.

Searcy, J.K., 1959, Flow-duration curves, Manual of hydrology—Part 2, Low-flow techniques: U.S. Geological Survey Water-Supply Paper 1542-A, 33 p.

Smith, R.A., Hirsch, R.N., and Slack, J.R., 1982, A study of trends in total phosphorus at NASQAN stations: U.S. Geological Survey Water-Supply Paper 2190, 34 p.

Thomas, M.P., 1966, Effect of glacial geology upon the time distribution of streamflow in eastern and southern Connecticut: U.S. Geological Survey Professional Paper 550-B, p. B209–B212.

U.S. Fish and Wildlife Service, 1981, Interim regional policy for New England streamflow recommendations: Concord, N.H.,U.S. Fish and Wildlife Service, Region 1, 3 p.

Weiss, L.A., 1983, Evaluation and design of a streamflow-data network for Connecticut: Connecticut Water Resources Bulletin 36, 30 p.

———1991, Connecticut floods and droughts, with a section on "water management" by C.J. Hughes, *in* Paulson, R.W., Chase, E.B., Roberts, R.S., and Moody, D.W. (compilers), National Water Summary 1988-89—Hydrologic events and floods and droughts: U.S. Geological Survey Water-Supply Paper 2375, p. 215–222.

APPENDIXES

Appendix 1. Trend results of selected percentiles of streamflow between the annual minimum and annual maximum, Quinnipiac River at Wallingford, Conn., 1931–2000

[Kendall's tau values range from -1 to 1; values less than 0 indicate an upward trend, and values greater than 0 indicate a downward trend p-value, attained significance level of the trend test; p-values in bold and shaded lines are at the attained significance level of less than or equal to 0.05; median is the median value for the percentile; Sen slope is the change in streamflow per year, in cubic feet per second; <, less than]

Percentile	Kendall's tau	p-value	Median	Sen slope
	1931–2000 (drought 1929–32)			
0 percentile (annual minimum daily mean)	0.357	**<0.001**	40.0	0.436
1st percentile	.281	**<.001**	46.3	.331
2nd percentile	.253	**.002**	50.2	.313
5th percentile	.201	**.014**	55.9	.263
10th percentile	.171	**.037**	65.0	.235
20th percentile	.151	.066	82.8	.250
30th percentile	.153	.062	102	.358
40th percentile	.145	.077	125	.444
50th percentile (median)	.151	.066	156	.533
60th percentile	.127	.121	192	.518
70th percentile	.093	.256	232	.467
80th percentile	.098	.232	292	.583
90th percentile	.133	.105	417	1.21
100th percentile (annual maximum daily mean)	.253	**.002**	1,780	16.8
	1935–2000			
0 percentile (annual minimum daily mean)	.280	**<.001**	41.0	.333
1st percentile	.194	**.021**	46.8	.201
2nd percentile	.176	**.037**	50.9	.204
5th percentile	.136	.107	58.0	.200
10th percentile	.138	.104	65.7	.200
20th percentile	.117	.165	84.3	.205
30th percentile	.117	.168	103	.286
40th percentile	.094	.268	129	.338
50th percentile (median)	.092	.276	160	.333
60th percentile	.073	.388	195	.300
70th percentile	.044	.607	236	.238
80th percentile	.051	.550	299	.324
90th percentile	.103	.223	419	1.02
100th percentile (annual maximum daily mean)	.215	**.011**	1,860	15.7

Appendix 1. Trend results of selected percentiles of streamflow between the annual minimum and annual maximum, Quinnipiac River at Wallingford, Conn., 1931–2000—Continued

[Kendall's tau values range from -1 to 1; values less than 0 indicate an upward trend, and values greater than 0 indicate a downward trend p-value, attained significance level of the trend test; p-values in bold and shaded lines are at the attained significance level of less than or equal to 0.05; median is the median value for the percentile; Sen slope is the change in streamflow per year, in cubic feet per second; <, less than]

Percentile	Kendall's tau	p-value	Median	Sen slope
		1941–2000 (drought 1940–45)		
0 percentile (annual minimum daily mean)	0.167	0.060	43.0	0.202
1st percentile	.145	.102	47.3	.166
2nd percentile	.145	.104	51.3	.199
5th percentile	.159	.073	57.2	.250
10th percentile	.193	**.030**	65.0	.314
20th percentile	.200	**.024**	81.9	.391
30th percentile	.214	**.016**	100	.530
40th percentile	.189	**.034**	123	.650
50th percentile (median)	.179	**.044**	158	.772
60th percentile	.145	.102	194	.716
70th percentile	.118	.185	232	.709
80th percentile	.124	.162	294	.882
90th percentile	.156	.078	418	1.84
100th percentile (annual maximum daily mean)	.241	**.007**	1,860	18.5
		1945–2000		
0 percentile (annual minimum daily mean)	.125	.174	44.0	.167
1st percentile	.114	.216	48.3	.139
2nd percentile	.105	.258	52.2	.176
5th percentile	.110	.235	59.1	.188
10th percentile	.136	.140	66.7	.262
20th percentile	.142	.125	84.3	.323
30th percentile	.158	.086	105	.441
40th percentile	.136	.140	128	.532
50th percentile (median)	.133	.149	160	.619
60th percentile	.083	.369	195	.368
70th percentile	.045	.631	237	.273
80th percentile	.061	.511	298	.413
90th percentile	.107	.246	426	1.34
100th percentile (annual maximum daily mean)	.247	**.007**	1,980	20.8

Appendix 1. Trend results of selected percentiles of streamflow between the annual minimum and annual maximum, Quinnipiac River at Wallingford, Conn., 1931–2000—Continued

[Kendall's tau values range from -1 to 1; values less than 0 indicate an upward trend, and values greater than 0 indicate a downward trend p-value, attained significance level of the trend test; p-values in bold and shaded lines are at the attained significance level of less than or equal to 0.05; median is the median value for the percentile; Sen slope is the change in streamflow per year, in cubic feet per second; <, less than]

Percentile	Kendall's tau	p-value	Median	Sen slope
		1951–2000		
0 percentile (annual minimum daily mean)	0.158	0.106	44.0	0.227
1st percentile	.179	.068	48.3	.233
2nd percentile	.181	.064	52.2	.272
5th percentile	.162	.099	59.1	.289
10th percentile	.149	.130	66.7	.329
20th percentile	.145	.139	84.3	.375
30th percentile	.166	.091	105	.512
40th percentile	.130	.186	128	.593
50th percentile (median)	.122	.213	160	.670
60th percentile	.087	.380	194	.524
70th percentile	.044	.657	237	.321
80th percentile	.056	.569	298	.436
90th percentile	.091	.353	433	1.31
100th percentile (annual maximum daily mean)	.168	.086	2,100	16.8
		1961–2000 (drought 1961–69)		
0 percentile (annual minimum daily mean)	.176	.113	44.5	.306
1st percentile	.144	.196	49.4	.278
2nd percentile	.121	.278	53.9	.256
5th percentile	.124	.263	60.5	.302
10th percentile	.142	.200	67.5	.444
20th percentile	.153	.169	85.8	.500
30th percentile	.222	**.045**	109	.912
40th percentile	.203	.067	132	1.18
50th percentile (median)	.219	**.048**	160	1.53
60th percentile	.227	**.040**	194	1.71
70th percentile	.212	.056	232	1.85
80th percentile	.221	**.046**	285	2.53
90th percentile	.245	**.027**	414	4.42
100th percentile (annual maximum daily mean)	.179	.105	2,180	22.7

Appendix 1. Trend results of selected percentiles of streamflow between the annual minimum and annual maximum, Quinnipiac River at Wallingford, Conn., 1931–2000—Continued

[Kendall's tau values range from -1 to 1; values less than 0 indicate an upward trend, and values greater than 0 indicate a downward trend p-value, attained significance level of the trend test; p-values in bold and shaded lines are at the attained significance level of less than or equal to 0.05; median is the median value for the percentile; Sen slope is the change in streamflow per year, in cubic feet per second; <, less than]

Percentile	Kendall's tau	p-value	Median	Sen slope
1971–2000				
0 percentile (annual minimum daily mean)	0.039	0.775	48.0	0.111
1st percentile	-.103	.432	52.1	-.272
2nd percentile	-.140	.284	57.0	-.358
5th percentile	-.133	.309	65.3	-.362
10th percentile	-.133	.309	75.7	-.375
20th percentile	-.138	.292	90.0	-.583
30th percentile	-.506	.708	112	-.300
40th percentile	-.074	.580	138	-.486
50th percentile (median)	-.078	.556	171	-.857
60th percentile	-.110	.402	205	-.862
70th percentile	-.092	.486	248	-.777
80th percentile	-.030	.830	312	-.800
90th percentile	-.021	.887	452	-.545
100th percentile (annual maximum daily mean)	-.051	.708	2,380	-8.18
1931–1960				
0 percentile (annual minimum daily mean)	.566	**<.001**	33.5	1.29
1st percentile	.368	**.005**	42.0	.920
2nd percentile	.278	**.032**	45.1	.760
5th percentile	.184	.158	52.5	.385
10th percentile	.076	.568	61.7	.118
20th percentile	.253	.858	81.0	<.001
30th percentile	.064	.630	98.5	.350
40th percentile	.097	.464	120	.667
50th percentile (median)	.113	.392	148	1.07
60th percentile	.154	.239	183	1.50
70th percentile	.166	.205	231	1.77
80th percentile	.191	.144	298	2.24
90th percentile	.182	.164	417	2.71
100th percentile (annual maximum daily mean)	.101	.443	1,490	12.5

Appendix 1. Trend results of selected percentiles of streamflow between the annual minimum and annual maximum, Quinnipiac River at Wallingford, Conn., 1931–2000—Continued

[Kendall's tau values range from -1 to 1; values less than 0 indicate an upward trend, and values greater than 0 indicate a downward trend p-value, attained significance level of the trend test; p-values in bold and shaded lines are at the attained significance level of less than or equal to 0.05; median is the median value for the percentile; Sen slope is the change in streamflow per year, in cubic feet per second; <, less than]

Percentile	Kendall's tau	p-value	Median	Sen slope
		1941–1970		
0 percentile (annual minimum daily mean)	-0.005	0.986	39.0	<0.001
1st percentile	-.140	.284	42.8	-.263
2nd percentile	-.129	.326	45.6	-.222
5th percentile	-.087	.509	51.6	-.133
10th percentile	-.021	.886	60.7	-.077
20th percentile	-.007	.972	75.9	<.001
30th percentile	.009	.957	90.8	.087
40th percentile	-.021	.887	116	-.174
50th percentile (median)	-.064	.630	133	-.364
60th percentile	-.090	.498	170	-.859
70th percentile	-.094	.475	211	-.975
80th percentile	-.076	.568	263	-1.36
90th percentile	-.113	.392	366	-2.26
100th percentile (annual maximum daily mean)	-.030	.830	1,510	-1.67

Appendix 2. Trend results of annual and monthly precipitation data for selected stations in Connecticut, 1930–2000

[Regional precipitation data from National Oceanic and Atmospheric Administration (NOAA), National Climatic Data Center (data accessed on November 26, 2001 on the World Wide Web at URL http://lwf.ncdc.noaa.gov/oa/climate/climatedata.html). Kendall's tau values range from -1 to 1; values less than 0 indicate an upward trend, and values greater than 0 indicate a downward trend; p-value, attained significance level of the trend test; p-values in bold are at the attained significance level of less than or equal to 0.05; median is the median value for the percentile; Sen slope is the change in wastewater discharge per year; <, less than]

	Kendall's tau	P-value	Median	Sen slope
Annual precipitation (NOAA station numbers 65077, 64767, 67432, 69759, and 66597)				
Annual total	0.047	0.568	50.4	0.028
Annual median	.024	.784	3.80	.001
Annual mean	.031	.732	4.16	.002
Monthly total precipitation (NOAA station numbers 65077 and 64767)				
January	-.048	.588	3.34	-.010
February	-.021	.813	3.10	-.002
March	-.036	.690	4.14	-.006
April	-.025	.779	4.12	-.004
May	-.045	.610	4.07	-.008
June	-.088	.316	3.20	-.014
July	.099	.262	3.85	.016
August	.018	.837	3.48	.003
September	.082	.350	3.56	.014
October	.158	.073	3.38	.026
November	-.020	.828	4.48	-.006
December	-.039	.663	4.27	-.006

Appendix 3. Trend results of wastewater-discharge data from municipal wastewater-treatment facilities in Meriden, Cheshire, and Southington, Conn., 1985–2001

[Kendall's tau values range from -1 to 1; values less than 0 indicate an upward trend, and values greater than 0 indicate a downward trend; p-value, attained significance level of the trend test; p-values in bold and shaded lines are at the attained significance level of less than or equal to 0.05; median is the median value for the percentile; Sen slope is the percent change of median wastewater discharge per year; <, less than]

Trend	Kendall's tau	p-value	Median	Sen slope
Meriden wastewater-treatment facility (1985–01; units are total million gallons per month)				
Overall trend (seasonal Kendall)	0.178	**0.040**	264	2.23
January	.309	.091	318	6.53
February	.456	**.012**	294	6.86
March	.529	**.003**	370	11.7
April	.191	.303	378	4.41
May	.140	.458	278	2.60
June	.265	.149	217	2.74
July	.265	.149	207	1.48
August	.044	.837	215	.612
September	.118	.536	204	.775
October	.044	.837	223	.303
November	-.132	.484	245	-1.08
December	-.088	.650	301	-3.20
Cheshire wastewater-treatment facility (1985–01; units are average million gallons per day)				
Overall trend (seasonal Kendall)	.477	**<.001**	1.93	.046
January	.684	**<.001**	2.18	.065
February	.691	**<.001**	1.99	.075
March	.603	**<.001**	2.15	.080
April	.485	**.007**	2.23	.086
May	.441	**.015**	1.99	.054
June	.463	**.010**	1.85	.055
July	.485	**.007**	1.65	.038
August	.353	.052	1.72	.027
September	.463	**.010**	1.77	.031
October	.382	**.036**	1.84	.035
November	.375	**.039**	1.91	.030
December	.294	.108	1.98	.029

Appendix 3. Trend results of wastewater-discharge data from municipal wastewater-treatment facilities in Meriden, Cheshire, and Southington, Conn., 1985–2001—Continued

[Kendall's tau values range from -1 to 1; values less than 0 indicate an upward trend, and values greater than 0 indicate a downward trend; p-value, attained significance level of the trend test; p-values in bold and shaded lines are at the attained significance level of less than or equal to 0.05; median is the median value for the percentile; Sen slope is the percent change of median wastewater discharge per year; <, less than]

Trend	Kendall's tau	p-value	Median	Sen slope
Southington wastewater-treatment facility (1983–01; units are total million gallons per month)				
Overall trend (seasonal Kendall)	0.205	**<0.001**	117	1.18
January	.368	**.030**	124	2.73
February	.380	**.025**	113	1.76
March	.555	**.001**	141	2.99
April	.088	.624	152	.985
May	.076	.674	131	.508
June	.193	.263	116	1.33
July	.310	.069	113	1.17
August	.228	.184	107	1.18
September	.041	.834	104	.242
October	.076	.675	105	.591
November	.146	.401	104	.834
December	-.006	1.00	119	-.044