

Summary of Water Quality Trends in the Connecticut River, 1968–1998

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Abstract.—The Connecticut River has a long history of water quality impairment. From the 1800s to the late 1960s, untreated or minimally treated waste discharges from population centers and industries have caused serious water quality problems. Trend analysis of selected water quality data in Connecticut from 1968 to 1998, collected by the U.S. Geological Survey in cooperation with the Connecticut Department of Environmental Protection, shows that water quality has improved, benefiting aquatic plants and animals, recreation, and the esthetics of the river. Many of the trends detected—including downward trends in total phosphorus, total nitrogen, and indicator bacteria, and upward trends in pH and dissolved oxygen—can be attributed primarily to improvements in wastewater treatment following the Federal Clean Water Act of 1972. Some uncertainty remains in evaluating the environmental significance of trends in dissolved oxygen, pH, and other constituents with diurnal fluctuations caused by plant metabolism. Downward trends in sulfate concentrations likely are attributable to reductions in sulfur dioxide emissions mandated by the Clean Air Act of 1970 and amendments made in 1990. Upward trends in chloride concentrations illustrate some effects of increasing urbanization and nonpoint-source pollution. Current (2003) and future water quality challenges for the Connecticut River include reducing nitrogen loads from point and nonpoint sources, reducing bacteria and other contaminant concentrations in urban stormwater runoff, and separating stormwater and sanitary sewers at some locations to prevent combined-sewer overflows.

Introduction

The Connecticut River basin, with its rich natural resources, has attracted people since precolonial times. European settlers and associated industries came to the region in the early 1600s. The region was favored for its plentiful waters, which were used for agriculture, industrial processing, navigation, and waste disposal. By 1897, the problem of pollution of Connecticut's waterways was recognized by the Connecticut General Assembly. A commission was formed to investigate sewage-disposal practices because the quantity of raw sewage being discharged into some streams had become unbearable (Hupfer 1965). By the 1930s, after the creation of the State Water Resources Commission, wastewater discharges to the Connecticut part of the basin had reached 154,000 m³/d. About 35% of this wastewater had some form of primary treat-

ment, and a number of facilities, including one in Hartford, were under construction. The reported municipal wastewater discharge to the Massachusetts part of the basin was about 112,000 m³/d; only about 5% of this discharge received any form of treatment (New England Regional Planning Commission 1937). By 1962, 95 municipalities in four states were discharging wastewater to the Connecticut River Basin; of these, 41 provided primary treatment and 26 provided secondary treatment. Water samples collected in Agawam, Massachusetts, during September 1963, contained concentrations of fecal coliform bacteria as high as 550,000 colonies/100 mL. Industrial discharges of untreated wastes from paper, chemical, metal, plating, dyeing, and other industries were recognized as a serious problem (U.S. Department of Health, Education and Welfare 1963). These industrial discharges included pollutants that contributed to high biological oxygen demand (BOD), causing reduced concentrations of dissolved oxygen in the Connecticut River. Concentrations of

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dissolved oxygen in an area below the Holyoke Dam in Massachusetts were nearly zero during the drought of 1966 and less than 2 mg/L in 1971 (EPA 2000).

In 1965–1972, the original Connecticut River Ecological Study was conducted to evaluate the ecological effects of the construction and operation of the Connecticut Yankee Haddam Neck nuclear power station (Merriman and Thorpe 1976 and Part 1 of this volume). This study provided only limited information on water quality, but collected a great deal of information on the ecology of the Connecticut River, and provides a baseline for current comparisons.

A number of initiatives, including the Connecticut Clean Water Act of 1967 (State of Connecticut 1967) and the Federal Water Pollution Control Act of 1972, have led to improvements in the water quality of the Connecticut River in Connecticut. There, the water quality currently (2003) is classified using standards adopted in 2002. The upper part of the Connecticut River between the Massachusetts border and just below the confluence with the Farmington River (the nontidal section of the river in Connecticut) is classified as C/B. The tidal section of the river (from the segment described above to Middle Haddam) is classified as SC/SB. The last reach from Middle Haddam to Long Island Sound is classified as SB. These classifications are subsequently defined.

The goal for water quality in the Connecticut River is to achieve standards for class B, or SB in coastal areas. Class B waters are designated for habitat for fish and other aquatic life and wildlife, recreation, navigation, and industrial and agricultural water supply. Class SB has a similar designated use to class B, except it includes habitat for marine fish and commercial harvesting of shellfish. Criteria for attainment of class B includes factors such as good esthetics, dissolved oxygen concentrations not less than 5 mg/L, and bacteria levels within established ranges.¹ Criteria for class B limit the color and amount of sludge, oils/grease, suspended solids, silt and sand deposits, turbidity, pH, allowable temperature increase, and concentrations of chemical constituents (CTDEP 2002). Classes

C/B, or SC/SB indicate that the waters currently are not meeting class B criteria for one or more reasons (CTDEP 2002), but the established goal for water quality is B or SB conditions.

The U.S. Geological Survey (USGS) has been collecting water quality samples in the Connecticut River since passage of the state and federal Clean Water Acts. An expanded cooperative effort between the USGS and the Connecticut Department of Environmental Protection (CTDEP) began in 1973 and has continued to the present. Water quality data also have been collected as part of various federal initiatives, including the National Stream Accounting Network (NASQAN) (Ficke and Hawkinson 1975) and the National Water-Quality Assessment (NAWQA) program (Gilliom et al. 1995).

This paper summarizes selected water quality trends and constituent loads in the main stem of the Connecticut River. Information has been summarized from analyses of trends in water quality in Connecticut during 1969–1988 (Trench 2000), 1989–1998 (Colombo and Trench 2002), and Trench and Vecchia (2002). Information on loads in phosphorus and nitrogen has been summarized from Trench (2000) and Mullaney et al. (2002). Most of the information summarized herein postdates the Connecticut River Ecological Study (Merriman and Thorpe and Part 1 of this volume 1976).

Study Area

The five water quality monitoring stations discussed herein are on the Connecticut River in Connecticut (Figure 1; Table 1). Four of the stations are in tidally affected sections of the Connecticut River (all but 01184000, Thompsonville); therefore, no streamflow data are available. Water quality sampling frequency at these stations has varied from monthly during the earlier part of the sampling record to eight or six times per year at some stations in the latter part of the record.

The monitoring station on the Connecticut River at Thompsonville is the farthest downstream station that is unaffected by tidal conditions. The Thompsonville station is near the Connecticut border with Massachusetts, just downstream from Springfield. Annual mean flow of the river at this station during water years 1928–2001 was 476 m³/s (Morrison et al. 2002). During 1968–2001, the highest annual peak flow was measured on 31

¹ Current standards based on enterococci concentration data. An older standard for fecal coliform has been referenced in this paper (CTDEP 1996) because the collection of primarily fecal coliform data during the time period described in this paper.

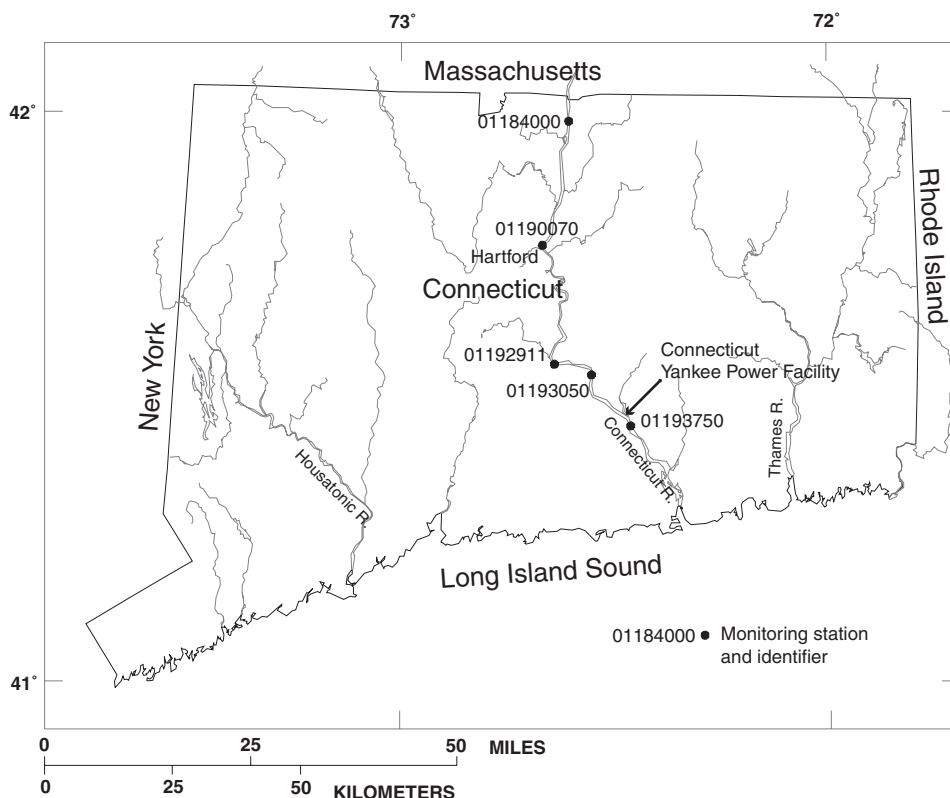


FIGURE 1. Selected monitoring stations on the Connecticut River, Connecticut, 1960s–1990s.

May 1984 (5,270 m³/s), and the lowest mean daily flow was measured on 2 September 1968 (29.7 m³/s). The average flow at this station during the Connecticut River Ecological Study (Merriman and Thorpe 1976 and Part 1 of this volume) for water years 1965–1972 was 411 m³/s. Monthly flow statistics are shown in Figure 2.

The only station located downstream from the Connecticut Yankee nuclear power facility is the East Haddam station (01193750). The stations at Middle Haddam and Middletown are downstream of the Hartford Connecticut metropolitan area.

Methods

The nonparametric seasonal Kendall test was used to analyze trends in selected water quality constituents in two statewide studies (Trench 1996; Colombo and Trench 2002). The seasonal Kendall test can be applied to actual constituent concentrations or to constituent concentrations that have been adjusted for streamflow-related variability. In the seasonal Kendall test, the trends are assumed to be monotonic for the period of analysis. The use of the seasonal Kendall test for analysis

TABLE 1. Water-quality monitoring stations on the Connecticut River, Connecticut, 1960s–present.

Water-quality monitoring station	U.S. Geological Survey identifier	Drainage area (km ²)	Period of sampling
Connecticut River at Thompsonville, Connecticut	01184000	25,019	1966–present
Connecticut River at Hartford, Connecticut	01190070	27,161	1976–present
Connecticut River at Middletown, Connecticut	01192911	28,151	1974–1991
Connecticut River at Middle Haddam, Connecticut	01193050	28,223	1966–present
Connecticut River at East Haddam, Connecticut	01193750	28,728	1968–present

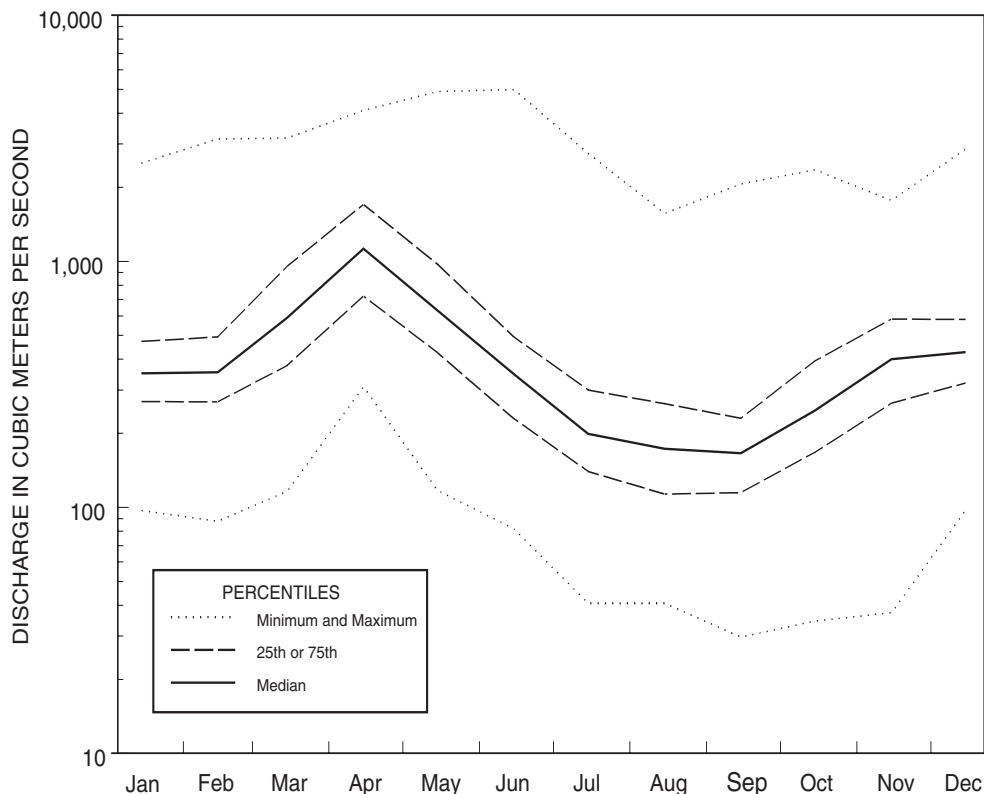


FIGURE 2. Monthly flow statistics Connecticut River at Thompsonville, Connecticut (01184000), 1968–2001.

of trends in water quality is described by Hirsch et al. (1982), Smith et al. (1982), Schertz (1990), and Schertz et al. (1991).

Trench and Vecchia (2002) used a time-series analysis of river discharge and concentration at five water quality monitoring stations in Connecticut to understand and remove the effects of annual and seasonal variability to produce flow-adjusted concentration data. Variation in the data set that could not be explained by annual and seasonal variability was filtered using a periodic autoregressive moving average (PARMA) model. The application of this method to streamflow was described by Vecchia (1985) and for concentration by Vecchia (2000). The time-series method was used to identify linear trends and step trends, and also to understand both long-term (10 years or more) and short-term (1–2 years) water quality trends. Step trends were used to evaluate periods where changes or biases in analytical methods may have affected measured constituent concentrations (Trench and Vecchia 2002). Results were used to design

optimum sampling schedules for trend detection at specific stations.

Annual loads of total phosphorus and total nitrogen were estimated for the Connecticut River at Thompsonville as part of two regional studies (Trench 2000; Mullaney et al. 2002). Loads were estimated using a log-linear regression model that incorporates algorithms to deal with censored water quality data and to account for retransformation bias. The regression models relate the natural log of load to flow, time, and seasonal variability (Cohn et al. 1989, 1992).

Trends in Selected Water-Quality Constituents

Phosphorus

Total phosphorus concentrations in the Connecticut River at Thompsonville have been decreasing steadily since 1969 (Figure 3). Concentrations of total phosphorus at Thompsonville have decreased

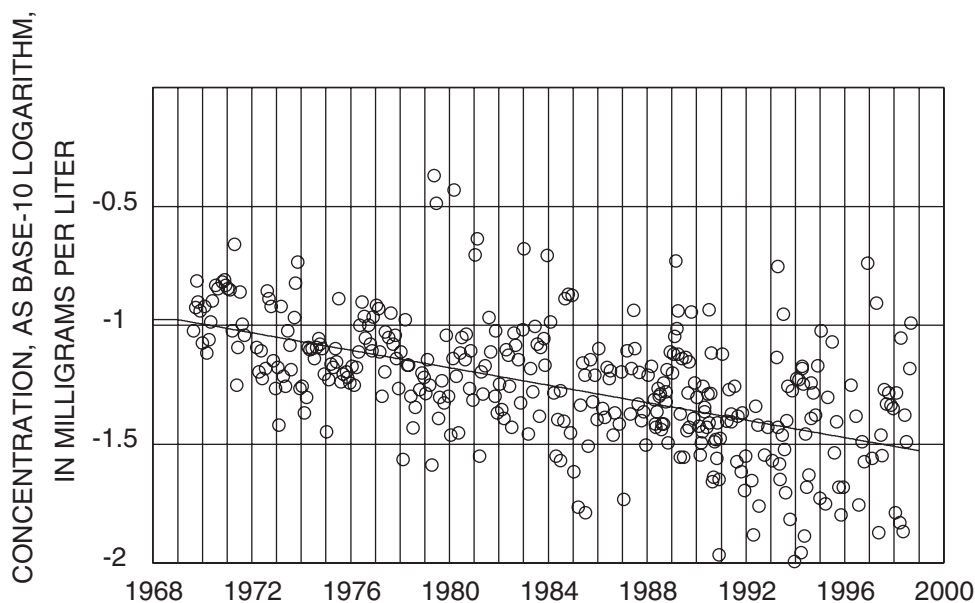


FIGURE 3. Trends in flow-adjusted concentrations of total phosphorus, Connecticut River at Thompsonville, Connecticut, 1969–1998 (from Trench and Vecchia [2002]: Figure 12A).

from an average of 0.15 mg/L in the late 1960s to about 0.05 mg/L in 2001. Trench and Vecchia (2002) report a decline in median total phosphorus concentrations at this station of 4.1% per year. The load of total phosphorus at Thompsonville has decreased from about 1.5 million kg/year in the early 1970s to less than 0.7 million kg/year during the mid-1990s (Figure 4) (Trench 2000). Significant downward trends in total phosphorus concentrations (not flow adjusted) also were reported at the four tidally affected Connecticut River monitoring stations during 1975–1988 and 1981–1988 (Trench 1996) (Table 2).

Nitrogen

Trends in nitrogen concentrations in the Connecticut River have varied during 1971–1998 (Figure 5) at the Thompsonville station. Total nitrogen increased during 1975–1988 and began to decline thereafter (Trench and Vecchia 2002). Colombo and Trench (2002) report no significant trends in total nitrogen at Thompsonville and three other stations for 1992–1998. Annual loads of total nitrogen calculated for the Connecticut River at Thompsonville ranged from about 7 million kg in 1995 (a dry year) to more than 18 million kg in 1984 (Figure 6).

Analysis of data from 1975 to 1988 for the Connecticut River at Thompsonville and some downstream stations indicated that significant upward trends were present in concentrations of total organic nitrogen, nitrite-plus-nitrate nitrogen, and dissolved ammonia nitrogen. Downward trends in the concentrations of dissolved ammonia nitrogen were detected for three stations on the Connecticut River for 1989–1998 (Colombo and Trench 2002).

Indicator Bacteria

Downward trends in concentrations of fecal coliform and fecal streptococcus bacteria (Table 2) were detected at some Connecticut River stations for the periods between 1975 and 1988 (Trench 1996). Trends in fecal coliform and enterococcus bacteria were analyzed during 1989–1998 (Colombo and Trench 2002). Concentrations of these indicator bacteria showed downward trends during 1975–1988 and 1981–1988 (Table 2). No significant trends were detected during 1989–1998.

Median and maximum measured concentrations of fecal coliform bacteria generally decreased in the Connecticut River at Thompsonville by an order of magnitude from 1970 to the mid-1980s

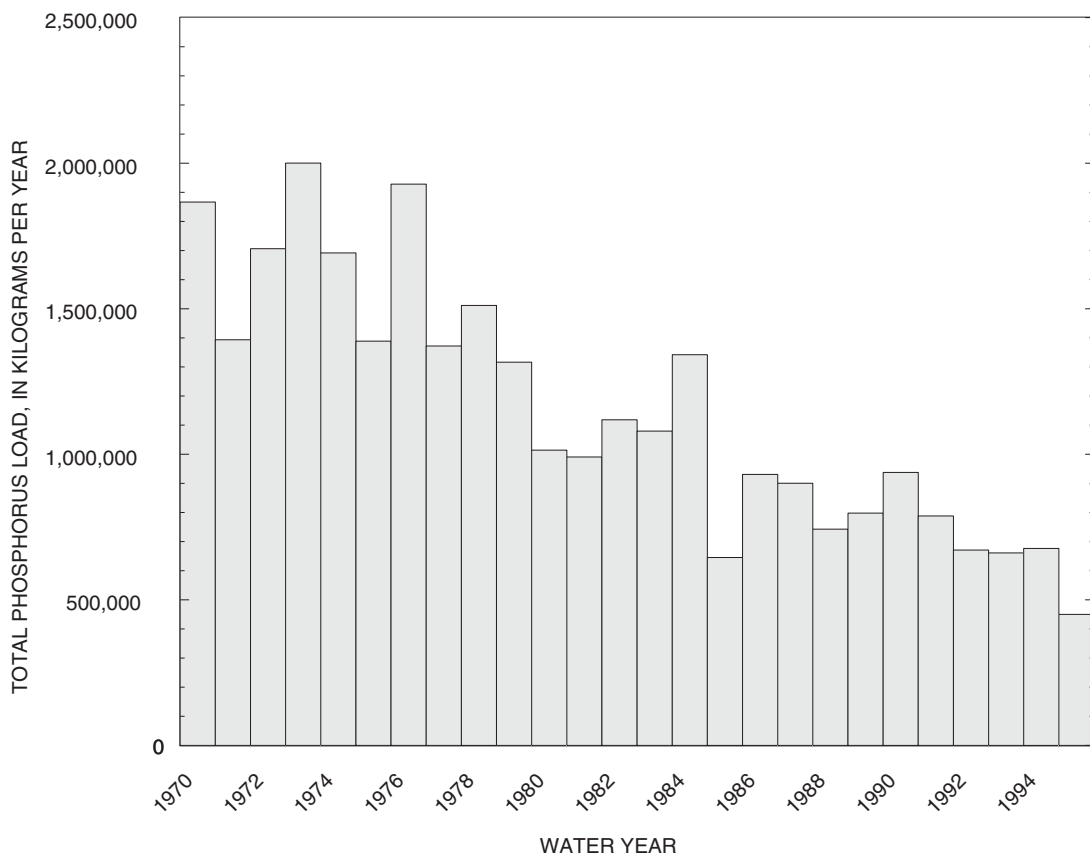


FIGURE 4. Annual loads of total phosphorus, Connecticut River at Thompsonville, Connecticut, water years 1970–1995 (from Trench [2000]: Figure 17).

TABLE 2. Summary of selected water-quality trends reported for monitoring stations on the Connecticut River, Connecticut, 1968–1998. (Data compiled from Trench [2002], Colombo and Trench [2002], Trench [1996]; *, insufficient data for trend analysis)

U.S. Geological Survey identifier	Total phosphorus		Total nitrogen		Fecal coliform		Chloride	
	Trend	Period	Trend	Period	Trend	Period	Trend	Period
01184000	–	1969–1998	–	1971–1975	–	1975–1988	–	1968–1973
			+	1976–1982			+	1974–1998
			–	1988–1998				
01190070	–	1981–1988	*		–	1981–1988	+	1981–1988
01192911	–	1975–1988	+	1975–1988	–	1981–1988	+	1975–1988
01193050	–	1975–1988	+	1975–1988		no significant trends	+	1981–1988
01193750	–	1975–1988	+	1975–1988		no significant trends		no significant trends

+ indicates upward trend.

– indicates downward trend.

Table 2. Continued

U.S. Geological Survey identifier	Sulfate		pH		Dissolved Oxygen	
	Trend	Period	Trend	Period	Trend	Period
01184000	-	1968–1976	+	1969–1988	+	1969–1988
	+	1977–1981				
	-	1988–1998				
01190070	-	1989–1998	+	1981–1988	+	1981–1988
01192911	*	*	+	1975–1988		no significant trends
01193050	-	1969–1998	+	1969–1988	+	1969–1988
01193750	*		+	1975–1998		no significant trends

(Figure 7). The number of years with more than 50% of the samples higher than the state standard (400 colonies/100 mL in greater than 10% of samples) has decreased with time (CTDEP 1996).

No significant trends in indicator bacteria were reported for the Connecticut River at East Haddam, Connecticut, during 1975–1998. Annual maximum concentrations and many annual median concentrations of fecal coliform have exceeded the state standard throughout the period of record (Figure 8).

Inorganic Compounds

Upward trends in chloride concentrations have been detected at all four Connecticut River monitoring stations (Table 2). Upward trends in chloride concentrations may be attributable to nonpoint sources, including deicing chemicals.

Sulfate concentrations have declined in the Connecticut River during the past 30 years (Figure 9). Significant trends in flow-adjusted concentrations of sulfate were detected at the

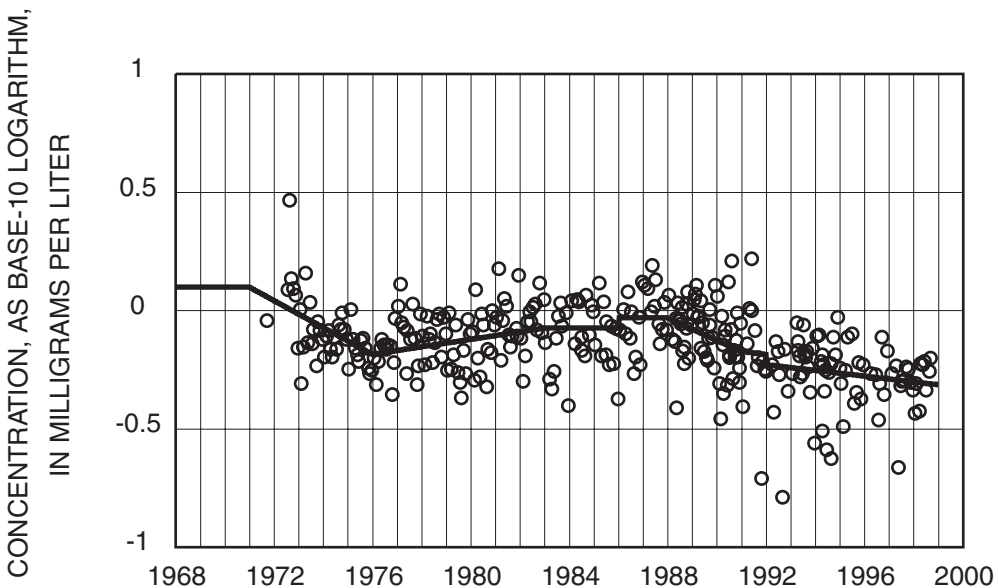


FIGURE 5. Trends in flow-adjusted concentrations of total nitrogen, Connecticut River at Thompsonville, Connecticut, 1971–1998 (from Trench and Vecchia [2002]; Figure 11A).

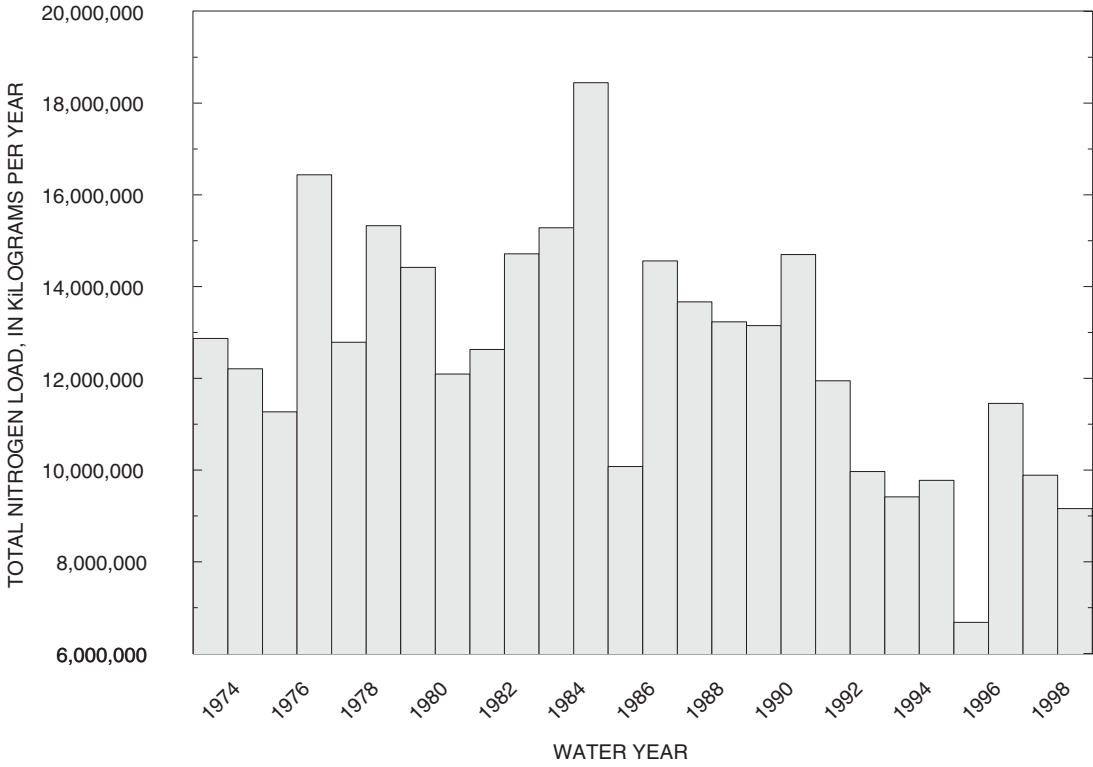


FIGURE 6. Annual loads of total nitrogen, Connecticut River at Thompsonville, Connecticut, water years 1973–1998.

Connecticut River at Thompsonville for samples collected from 1968 to 1998 (Trench 2002) (Figure 9). Downward trends were present during 1968–1976 and 1988–1998. Upward trends were detected for sulfate concentration data collected during 1983–1989 (step trend possibly related to analytical methods) and 1977–1981. Downward trends in sulfate concentrations have been detected for the monitoring stations at Hartford and at Middletown (Table 2). Colombo and Trench (2002) reported downward trends in sulfate from 1989 to 1998 as a regional trend in Connecticut.

Dissolved Oxygen and pH

Upward trends in the concentration of dissolved oxygen were detected for the Connecticut River from the late 1960s to the late 1980s. Upward trends in flow-adjusted dissolved oxygen concentrations were detected in data from 1969 to 1988 at Thompsonville (Trench 1996) (Table 2). Signifi-

cant upward trends were reported for Hartford during 1981–1988 and for Middle Haddam (Table 2) during 1969–1988. No significant trends in dissolved oxygen concentrations were detected in data for East Haddam. No significant trends in dissolved oxygen concentrations were detected for Connecticut River stations during 1989–1998 (Colombo and Trench 2002). Trends in concentrations of dissolved oxygen may be attributed primarily to improvements in wastewater-treatment practices and a reduction in the discharge of oxygen-demanding effluent; however, trends detected prior to 1974 may have resulted because of changes in sampling methods (Trench 1996). The trend also was detected in basins with no point-source discharges. Dissolved oxygen concentrations with time for the Middle Haddam station are shown in Figure 10.

Upward trends in pH were detected at all five stations during various periods from 1969 to 1988 (Table 2). Significant upward trends in pH also were detected for Thompsonville and East Haddam

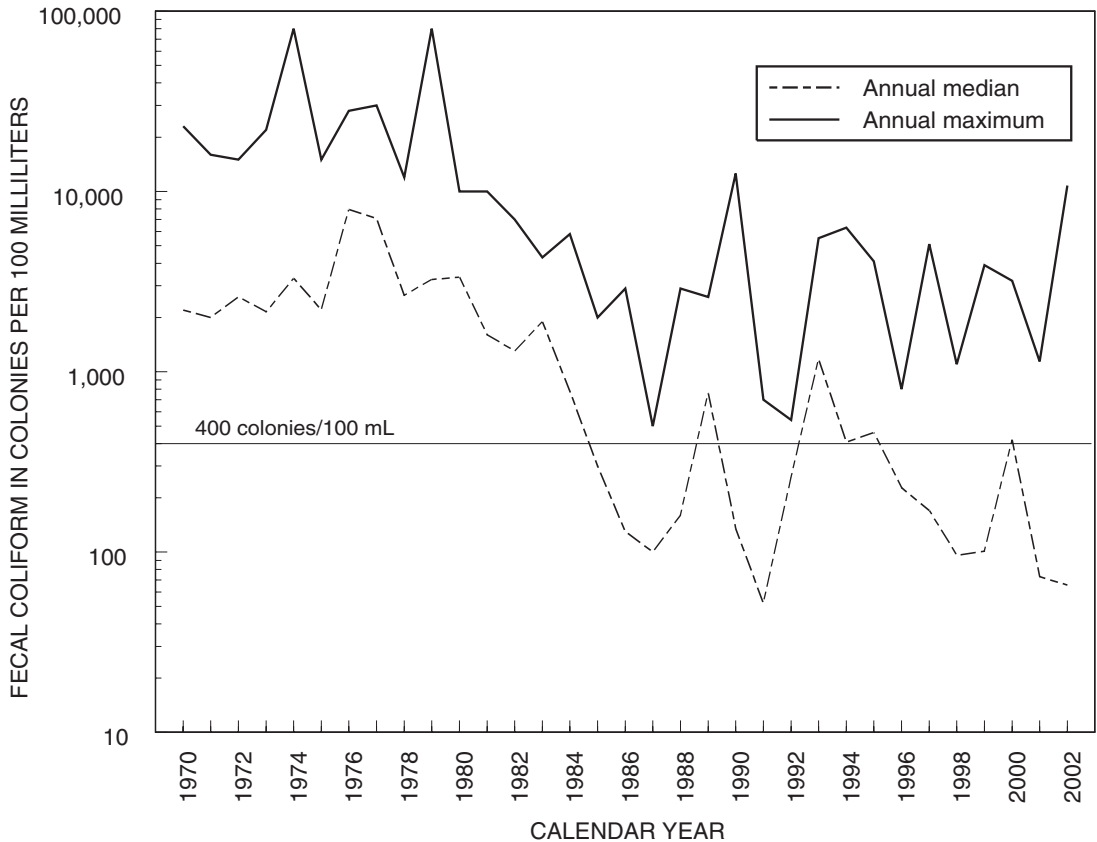


FIGURE 7. Annual maximum and annual median measured fecal coliform concentrations, Connecticut River at Thompsonville, Connecticut, 1970–2002.

during 1989–1998. Trends in pH also are likely related to improvements in wastewater treatment, including improved treatment of industrial waste, and to improvements in the treatment of ammonia at municipal wastewater-treatment facilities (Trench 1996).

An additional complexity in evaluating detected trends in dissolved oxygen concentrations, pH, and temperature results from the diurnal fluctuations that typically occur instream during the growing season. In addition to the seasonal variability that is accounted for in the seasonal Kendall test, the time of day can affect the measured value. There has been a tendency, for example, towards collecting samples later in the day during the latter part of the record. This change in sampling time complicates the interpretation of environmental trends because pH, temperature, and dissolved oxygen may increase during the day during the growing season.

Discussion

The original Connecticut River Ecological Study was begun during a period that, based on historical observations, likely represents the most degraded water quality conditions for the Connecticut River. Many positive changes in water quality began during this study period and have continued to the present. The data from the Connecticut River Ecological Study provide a baseline of the aquatic habitat that existed on the lower river prior to the implementation of management action.

Water quality trend analysis for the main stem of the Connecticut River in Connecticut during 1968–1998 shows substantial improvement in the concentrations of many water quality constituents; therefore, improvement in the support of aquatic life, esthetics, and the use of the river for recreation. Many of these improvements can be

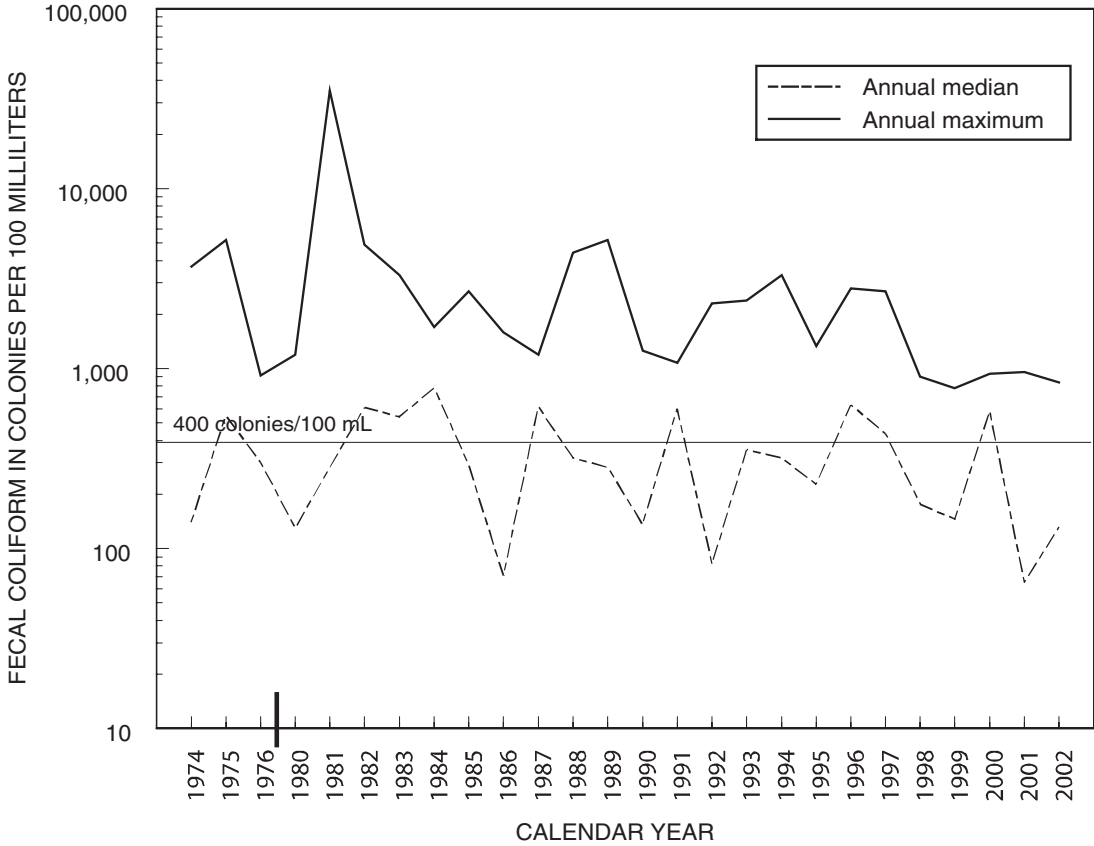


FIGURE 8. Annual median and annual maximum measured fecal coliform concentrations, Connecticut River at East Haddam, Connecticut, 1974–2002.

attributed to the successful management actions following the Connecticut Clean Water Act of 1967 and the Federal Water Pollution Control Act of 1972.

Downward trends in the concentrations of total phosphorus primarily are due to improvements in municipal wastewater treatment and to a reduction in the use of phosphate detergents since the 1970s (Litke 1999). These improvements also could be caused in small part by the loss of agricultural land and by the implementation of Best Management Practices (BMPs) on some farms.

Downward trends in total nitrogen since 1988 at Thompsonville are most likely the result of improved nitrogen removal at municipal wastewater-treatment facilities, but could relate to changes in land use (i.e., agricultural to residential or forest). Reductions in nitrogen concentrations in the Connecticut River are likely

not related to atmospheric sources because wet deposition of nitrogen oxides in precipitation has remained relatively unchanged since the 1980s (Driscoll et al. 2001). Additional reductions in nitrogen load are mandated by the Long Island Sound Total Maximum Daily Load (TMDL) calculation, which is designed to improve dissolved oxygen conditions in Long Island Sound (NYDEC/CTDEP 2000). A reduction in nitrogen load of 58.5% by 2014 has been mandated by this TMDL; the reduction has been allocated between municipal wastewater discharges and nonpoint contributions of nitrogen. This amounts to a reduction of 1.7 million kg/year for the Connecticut part of the Connecticut River basin (NYDEC/CTDEP 2000).

Concentrations of indicator bacteria have decreased in the Connecticut River at four of the monitoring stations upstream from East Haddam (Table 3); yet, concentrations in samples fre-

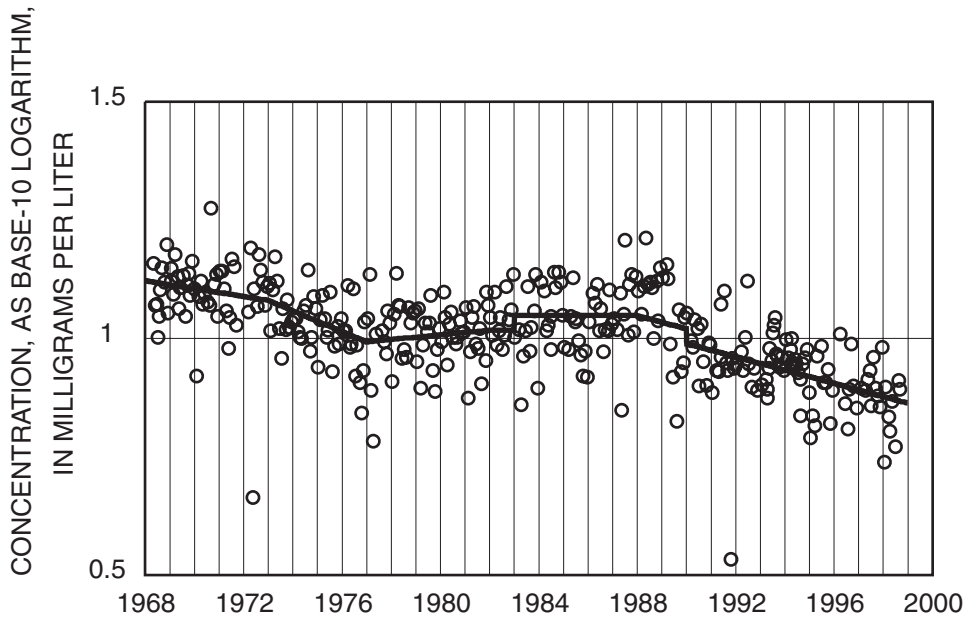


FIGURE 9. Trends in flow-adjusted concentrations of sulfate, Connecticut River at Thompsonville, Connecticut, 1968–1998 (from Trench and Vecchia [2002]: Figure 10A)

quently exceeded water quality standards for class B waters. The reductions noted in these concentrations likely result because of wastewater-treatment improvements in the watershed during the past 30 years. The continued presence of elevated bacteria concentrations may be attributable to combined sewer overflows that still are present in Connecticut and Massachusetts and to nonpoint stormwater runoff.

The upward trends in chloride concentration may be indicative of the effects of the increasing nonpoint runoff of road-deicing chemicals from the expansion of impervious areas through new land development during the last 30 years.

Upward trends in pH and dissolved oxygen are primarily attributed to improvements in wastewater-treatment, both municipal and industrial. Trend analyses for these constituents and for other measurements, such as temperature (not studied), are complicated by the large diurnal fluctuations in values coupled with an apparent trend in sample collection time. A possible bias in dissolved oxygen concentrations was discussed by Trench (1996).

Trends in sulfate concentrations are consistent with declines in sulfate concentration in precipitation that have been linked to reductions in

sulfur dioxide emissions from power plants in the northeast (Driscoll et al. 2001). Sulfur dioxide emissions were highest during 1973 and began to decline thereafter (EPA 2003). The Title IV Amendments to the Clean Air Act of 1990 have accelerated the downward trend in emissions beginning in 1995. The importance of this trend to aquatic life in the Connecticut River is uncertain; however, reductions in emissions of sulfur dioxide may be a partial cause for the upward trends that were detected in pH, and ultimately may improve the quality of habitat in acid-sensitive lakes and headwater streams in parts of the Connecticut River basin.

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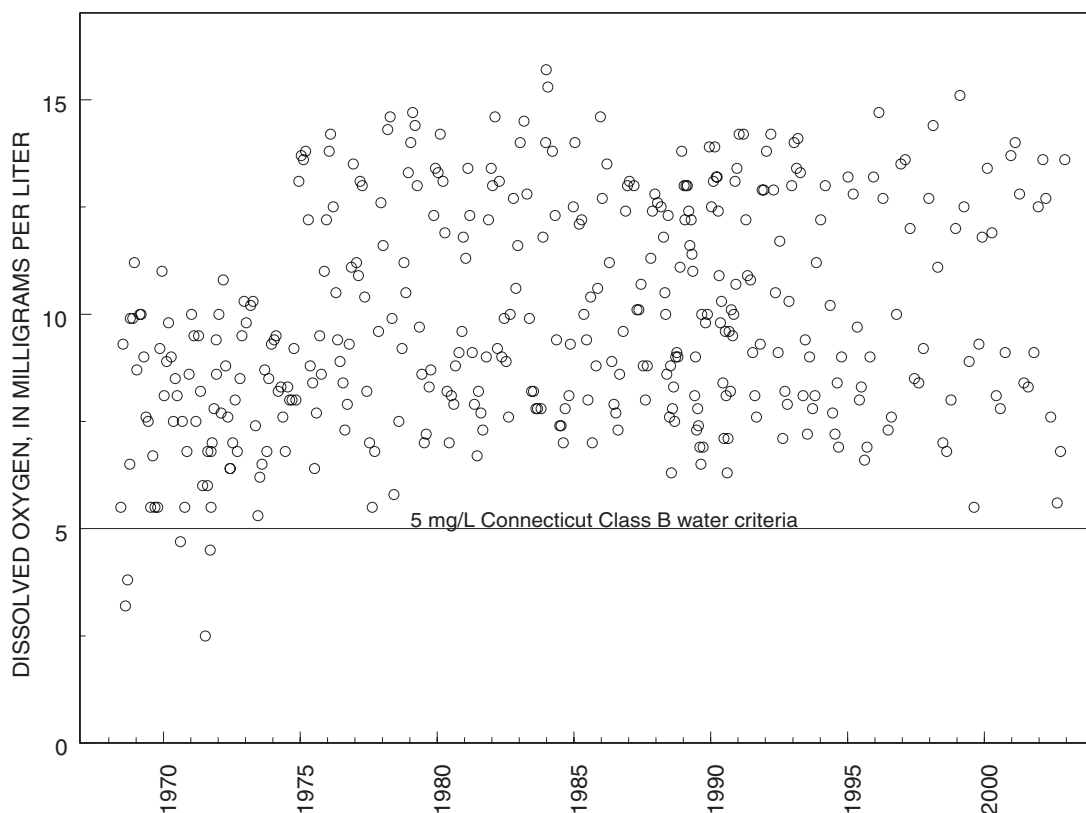


FIGURE 10. Concentrations of dissolved oxygen at the Connecticut River at Middle Haddam, Connecticut, 1968–2002.

TABLE 3. Significant trends (95% confidence level) in colonies of indicator bacteria in the Connecticut River in Connecticut, 1975–1988. (Data from Trench [1996]; values in percent per year; negative sign denotes downward trend; na, not analyzed or insufficient data; ns, no significant trend; F, flow adjusted; *, significant at 90% confidence level)

Water-quality monitoring station	1975–1988		1981–1988	
	Fecal coliform	Fecal streptococcus	Fecal coliform	Fecal streptococcus
Connecticut River at Thompsonville Connecticut 01184000	-28.6 F	-18.1 F	-37.5	-34.7 F
Connecticut River at Hartford Connecticut 01190070	na	-14.9	-29.0	-35.3
Connecticut River at Middletown Connecticut 01192911	-3.9*	ns	-17.6	-16.8
Connecticut River at Middle Haddam Connecticut 01193050	ns	ns	ns	-16.9*
Connecticut River at East Haddam Connecticut 01193750	ns	ns	ns	ns

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