Regional

Report

Regional Progress in Water Quality

Analysis of Water Quality Data from 1976 to 2002 for the Major Rivers in the Twin Cities

June 2004

Metropolitan Council

Metropolitan Council

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The water quality data that were used in this report were sampled by the staff of the Water Quality Section of MCES and analyzed by the Laboratory Services Section of MCES.

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EXECUTIVE SUMMARY

This report focuses on an analysis of river water quality data from 1976 to 2002 for four monitoring sites: the Minnesota River at Jordan, the Mississippi River at Anoka, the St. Croix River at Stillwater, and the Mississippi River at Red Wing. The first three sites represent the approximate points where each of the three major rivers enter the Twin Cities Metropolitan Area (TCMA) and the fourth site represents the combined flow of these rivers as it leaves the TCMA. Ten water quality variables were selected for an analysis of the typical values for each site, the data variability, patterns relating to river flow or season, and long-term trends. These ten variables relate to issues of major concern for the rivers such as nutrients, sediment, bacteria, and dissolved oxygen. In addition, the concentration data were combined with flow data to calculate mass loads for four of these variables to allow a more direct comparison of incoming and outgoing water quality.

The Minnesota River at Jordan exhibited significant decreasing trends in concentration for fecal coliform bacteria, NO_x, BOD5, TKN, and NH_4 (abbreviations for water quality variables are defined on page 5 in the main body of the report). The trend test also indicated decreasing trends for TP, TSS, and turbidity, but a closer examination of these data indicated that concentrations of these variables decreased from 1976 to about 1993 and increased afterwards. The Mississippi River at Anoka had decreasing trends for BOD5, NH_4, TP, TSS, and turbidity and an increasing trend for NO_x. A decreasing trend was also indicated for TKN, but this decrease came after a period of increase. The St. Croix River at Stillwater showed decreasing trends for fecal coliform bacteria, BOD5, TKN, NH_4, TSS, and turbidity and increasing trends for DO and NO_x. The Mississippi River at Red Wing showed decreasing trends for fecal coliform bacteria, BOD5, TKN, NH_4, and TP and increasing trends for chl-a and NO_x.

This report found that the largest trends in these rivers have occurred for NH_4, BOD5, and fecal coliform bacteria. The NH_4 concentrations for all four sites decreased more than 70%. Assuming an exponential decrease, this translates into a decrease of more than 4.5% per year. Fecal coliform bacteria trends were significant at three of the four sites, with decreases between 64% and 71%. BOD5 decreased more than 50% at three of four sites; a reduction of more than 2.6% per year assuming an exponential decrease. While there were significant trends for other water quality variables, the magnitude of the trends were relatively small. For example, NO_x trends at three of the four sites showed changes of 20% or less over the study period. This translates into a change of less than 1% per year.

The decreasing trends for NH_4 and BOD5 are probably due, in large part, to improvements in point source controls that occurred over the period from 1976 to 2002. Trends for TKN, fecal coliform, and NO_x are also likely influenced by changes in point source controls although probably to a lesser degree than NH_4 and BOD5. In contrast, the trends in TSS and turbidity are most likely due to changes in nonpoint source loading because loading of TSS and turbidity is clearly dominated by nonpoint sources. Trends in TP appear to reflect a mixture of point and nonpoint influences. In the Minnesota River, the TP trend appears to be mostly influenced by nonpoint sources. Meanwhile, the decreasing trends for TP in the Mississippi River at Anoka and at Red Wing may reflect lower point source loading of phosphorus.

Pollutant mass loads entering and leaving the TCMA are strongly dependent upon flow volume, which may vary considerably from year to year due to climatic differences. The mean relative contributions of the three major rivers to the total incoming water volume are reasonably comparable, with 25 – 30% of the flow coming from each of the Minnesota River and the St. Croix River and a slightly larger volume 40 – 45% coming from the Mississippi River.

Although the volume contributions of water coming from the three main rivers are somewhat comparable, the mass load of NO_x is largely dominated by the contribution of the Minnesota River, which contributes, on average, about 75% of the overall incoming load. The Mississippi River at Anoka contributes about 20% of the total incoming load, while the St. Croix River only contributes about 5% of the load. The total incoming mass load of NO_x is very close to the outgoing mass load of NO_x at Red Wing, except for the drought years of 1987-1989 when the outgoing mass load is higher than the incoming load. Given the contribution of both point and nonpoint sources within the TCMA, the overall comparability of incoming and outgoing loads suggests that there is a significant loss of NO_x occurring in the TCMA, possibly as a result of natural denitrification in the river system.

The mean relative contribution of TKN from the Mississippi River at Anoka is 44%, which is similar to its water volume contribution. At 39%, the TKN contribution from the Minnesota River is somewhat higher than its water contribution. The TKN contribution from the St. Croix River to incoming TKN load is 17%, which is slightly lower than its water contribution. The outgoing mass load of TKN at Red Wing has been higher than the total incoming load for every year from 1980-2001 and the difference is commonly 20 – 25%. However, since 1993, the difference between the combined incoming load and the outgoing load appears to have decreased, possibly as a result of the reduction in ammonium discharged from WWTPs.

The incoming mass load of TP is dominated by the Minnesota River at Jordan, contributing 53% of the total load on average. The Mississippi River at Anoka contributes 36% and the St. Croix River at Stillwater contributes 11%. The difference between the outgoing TP load and the combined incoming TP load has apparently decreased since 1994. On average, the outgoing load of TP was 750 metric tonnes higher than the combined incoming load from 1980 through 1993. From 1994 through 2001, the outgoing load of TP exceeded the incoming load by only 140 metric tonnes. Given the contribution of phosphorus from both point and non point sources within the TCMA, the overall comparability of incoming and outgoing TP loads suggest that there is a significant loss of TP occurring in the TCMA, probably as a result of the sedimentation of particulate associated phosphorus.

The Minnesota River at Jordan, the Mississippi River at Anoka, and the St. Croix River at Stillwater contributed about 75%, 20%, and 5% of the TSS load, respectively. The relative TSS contributions from the three incoming rivers are nearly identical to the contributions for NO_x; however, the fate of these two pollutants are quite different because TSS is particulate and thus subject to settling. The outgoing load of TSS was lower than the total incoming load of TSS for nearly every year from 1980 – 2001, indicating that the TCMA is a net sink for TSS. The results indicate that in a typical year, about 425,000 tonnes of TSS are deposited somewhere in the river system or floodplain within the TCMA.

Based upon a comparison of incoming and outgoing 10-year median loads of NO_x, TKN, TP, and TSS, the Council's benchmark water quality goal for the TCMA is being met. However, this goal is likely being met in large part due to sedimentation of solids and particulate associated nitrogen and phosphorus. In the future, additional analysis is planned to further quantify the importance of sedimentation as well as other sources and sinks of pollutants within the TCMA. With this additional information, it may be possible to consider the adverse impact of excessive sedimentation on the health of the TCMA river system in future water quality goals for the region.

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INTRODUCTION

The Metropolitan Council and its predecessor organizations have a long-standing commitment to protect and improve the water quality of the Twin Cities Metropolitan Area (TCMA). This commitment began in 1938 when the Minneapolis/St. Paul Sanitary District began operation of the Metropolitan Wastewater Treatment Plant (WWTP), formerly known as the Pig's Eye Plant, in direct response to the acute public health problem that the Mississippi River had become (EPA 2000). This commitment continues today and is demonstrated by the Council's regional development framework, which establishes a policy that the Council will work with local and regional partners to conserve, protect, and enhance the region's vital natural resources. The Council's efforts also include long-term monitoring programs that routinely check the water quality of the region's rivers, streams, and lakes. The Council's river monitoring program originated in the 1920s through predecessor organizations and continues to this day, although it has evolved significantly to reflect changing needs and water quality issues.

This report focuses on an analysis of river water quality data from 1976 to 2002 for four monitoring sites: the Minnesota River at Jordan, the Mississippi River at Anoka, the St. Croix River at Stillwater, and the Mississippi River at Red Wing. The first three sites represent the approximate points where each of the three major rivers enter the TCMA and the fourth site represents the combined flow of these rivers as it leaves the TCMA. Ten water quality variables were selected for an analysis of the typical values for each site, the data variability, patterns relating to river flow or season, and long-term trends. These ten variables relate to issues of major concern for the rivers such as nutrients, sediment, bacteria, and dissolved oxygen. In addition, the concentration data were combined with flow data to calculate mass loads for four of these variables to allow a more direct comparison of incoming and outgoing water quality. Some of the questions that this report aims to answer are as follows:

- What has been the typical water quality of the three major rivers in the recent past?
- Are there major differences in water quality between the rivers?
- Are there patterns in the water quality data of these rivers?
- What are some of the main factors affecting patterns in water quality data?
- Has the water quality of the rivers become better or worse over the period from 1976 to 2002?
- Is the water quality leaving the TCMA better or worse than when it enters?

Study Area

The Twin Cities Metropolitan Area comprises seven counties in Minnesota that center on the cities of Minneapolis and St. Paul: Anoka, Carver, Dakota, Hennepin, Scott, Ramsey, and Washington (Figure 1). This region also encompasses the confluence of three large rivers: the Mississippi, the Minnesota, and the St. Croix. The Minnesota River Watershed covers an area of 17,000 square miles across south and southwestern Minnesota and small portions of South Dakota and Iowa. This area is characterized by gently rolling hills to nearly level fields with highly productive soils. Land use in the Minnesota River Watershed is predominantly agricultural with about 73% of the land in cropland (Ploetz 1997). The Mississippi River Watershed above the confluence with the Minnesota River covers an area of 19,900 square miles across much of central and north central Minnesota. This watershed has a more balanced mixture of land use than the Minnesota River Watershed with only about 21% of the land in cropland and about 37% of the land in forest. The St. Croix River Watershed covers an area of 7,720 square-miles along eastern Minnesota and western Wisconsin. It is predominantly forested with about 50% of its land covered by forests, 15% covered by grassland or hay pasture, and another 15% covered by agricultural crops. The TCMA covers an area of 2,970 square miles and is comprised of a mixture of land use with about 40% in agricultural crop production and 32% in urban development (Metropolitan Council unpublished data).

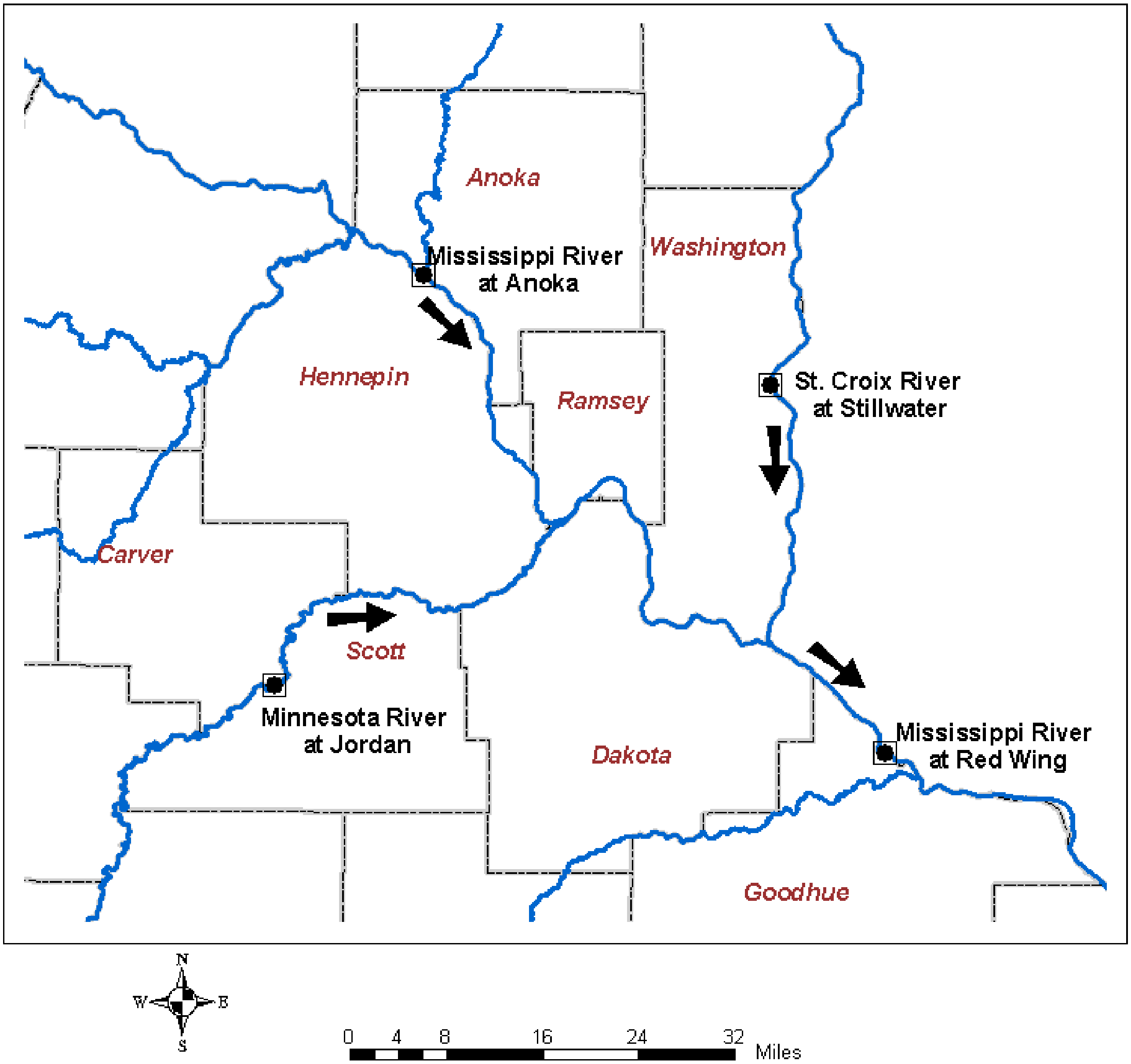

Figure 1: Map showing Metropolitan Council river monitoring sites used in this analysis. The arrows indicate the direction of river flow.

METHODS

Water Quality Data

The Council has an extensive river monitoring network with data collected from 70 sites on the three major rivers (Figure 1), although only 19 of these are part of the Council's routine river monitoring program. The rest of these sites fall under a number of different programs and special projects that are described elsewhere (Metropolitan Council 2002). This report focuses on analysis of data collected from just four sites in the routine river monitoring program: the Minnesota River at Jordan (MI0394 - Jordan), the Mississippi River at Anoka (UM8716 - Anoka), the St. Croix River at Stillwater (SC0233 - Stillwater) and the Mississippi River at Red Wing (UM7966 – Red Wing). These four sites were selected because they represent the approximate entry and exit points for the region's major rivers. The primary purpose of the routine river monitoring program is to assess potential water quality impacts to the rivers from the discharge of treated wastewater from the Council's wastewater treatment facilities, although the data are also amenable to trend analysis and the calculation of pollutant mass loads. The routine river monitoring program involves manual collection of samples (grab samples), which are then submitted to the Council's laboratory for analysis of 32 conventional water quality parameters.

Water quality samples are collected using a vertical Van Dorn sampler, a stainless steel sampler, or a polypropylene sampler from one meter below the surface. The sampler is rinsed with water from the site before sample collection, and then the sample is poured into a laboratory-cleaned sample container, placed in a cooler on ice, and transported to the Council's laboratory located at 2400 Childs Road in St. Paul for processing and analysis. The Council's laboratory uses analytical procedures that are based on methods approved by the EPA, ASTM, or APHA, and it is certified under the State of Minnesota's laboratory certification program.

The frequency of chemical analysis varies by analyte. Most water quality variables included in this report are sampled and analyzed on a biweekly basis. While the roots of this program date back to the 1920s, only data collected from 1976 through 2002 are used in this report because prior to 1976 the water quality records for the four sites are not complete. In addition to routine grab sampling, the Jordan site is also monitored under the Council's nonpoint source program, which includes event-based composite samples as well as additional grab samples. The data from this program, which began in 1989, was included in the pollutant load estimation procedures, but not in the trend analysis procedure. The water quality variables included in the trend analysis are as listed below.

- Total Ammonium Nitrogen (NH_4 as N)
- Total, 5-day Biochemical Oxygen Demand (BOD5)
- Total Chlorophyll *a* (chl-a)
- Dissolved Oxygen (DO)
- Fecal Coliform Bacteria
- Nitrate plus Nitrite Nitrogen (NO_x as N)
- Total Kjeldahl Nitrogen (TKN as N)
- Total Phosphorus (TP as P)
- Total Suspended Solids (TSS)
- Turbidity

Of these water quality parameters, loads were calculated for NO_x, TKN, TP, and TSS. All water quality data were obtained from the Council's Environmental Information Management System.

Flow Data

Jordan is the only site that has a flow gauge located on-site - USGS station number 05330000. Daily flow estimates for the other three sites were developed by using nearby USGS gauging stations or a combination of stations. Flow at the Anoka site was estimated by subtracting flow for the Rum River at St. Francis (Station No. 05286000) from the flow at the site located on the Mississippi River near the Coon Rapids Dam (Station No. 05288500). Flow at Stillwater was estimated by multiplying the flow measured at St. Croix Falls (Station No. 05340500) by 1.1. This correction factor was determined after examining flow for the Apple River, which is the only significant tributary entering the St. Croix River between St. Croix Falls and Stillwater. Flow at Red Wing was estimated to be approximately equal to the flow measured on the Mississippi River at Prescott, Wisconsin (Station No. 5344500). Flow data between January 1976 and December 2001 for these stations were obtained from the USGS National Water Information System in October 2003. Because flow data for only the first nine months of 2002 were available at this time, 2002 was excluded from the loading analysis.

Statistical Methods

Handling Values Less than the Reporting Limit

Water quality measurements may occasionally be below the reporting limits of the analytical methods used by the Council's laboratory. In cases such as this, the results are reported by the laboratory as less than the reporting limit (LRL). For example, the LRL for NH_4 is <0.01 mg/L. For the water quality parameters in this study, the frequency of LRL data is generally small except for NH_4 (Table 1). When LRL results do occur, a value of one-half of the LRL was substituted for the result. In addition, one of the criteria used in selecting statistical methods for this analysis was its lack of sensitivity to moderate data censoring and skewed data. Some caution should be used in interpreting the results of this analysis for parameters where the level of censoring exceeds 5%.

Table 1
Frequency of Occurrence of Values Less than Reporting Limit

Parameter	Minnesota River at Jordan	Mississippi River at Anoka	St. Croix River at Stillwater	Mississippi River at Red Wing
Ammonium	30%	33%	36%	15%
BOD, 5-Day	3%	5%	14%	4%
Chlorophyll-a	0%	0%	3%	1%
Dissolved Oxygen	0%	0%	0%	0%
Fecal Coliform	1%	0%	1%	3%
Nitrate plus Nitrite	2%	3%	5%	0%
Total Kjeldahl Nitrogen	0%	1%	4%	0%
Total Phosphorus	0%	2%	5%	0%
Total Suspended Solids	0%	1%	5%	2%
Turbidity	0%	0%	0%	0%

Exploratory Analysis

Prior to trend analysis and load estimation, several exploratory analysis techniques were employed to characterize the data and examine the distribution of the data to aid in the subsequent analyses. The techniques included graphical analyses, summary statistical measures, and formal statistical tests such as the Shapiro-Francia test for normal distribution of the data. In addition, the effects of flow and season on concentration were evaluated using one-way analysis of variance (ANOVA) on flow categorized into ten percentile groups and month number as a surrogate for season. The results of this analysis provide an estimate of the relative influence of flow and month upon concentration. The strength of the effects of season and flow were determined by looking at the ratio of variability between groups of data classified by month or flow and the total variability. This effect ratio varies from zero to one with higher values indicating a stronger correlation between water quality and the explanatory variables of flow or month. Basic descriptive statistics were tabulated using Microsoft Excel 97, the normality test was performed using ChemStat version 5.0, and the one-way ANOVA was performed using SPSS version 10.0.

Trend Analysis

Trend analysis was performed using the seasonal Kendall Tau test ($p \leq 0.05$), which is a seasonal modification of the Mann-Kendall nonparametric test for monotonic trends (Hirsch et al. 1982; Hirsch et al. 1991; Helsel and Hirsch 1992). This modification performs an independent Mann-Kendall test for trend on the data for each season and then combines these results into a single result. This test is commonly used for trend analysis of river and stream water quality data because it avoids the assumption of a normal probability distribution, which is typically not valid for these data. It is also relatively robust even in the presence of a moderate number of values below the detection limit, up to approximately five percent of the sample population (Hirsch et al. 1982; Schertz et al. 1991). This test does not adjust for serial correlation, which may lead to a tendency to over predict the existence of trends when significant serial correlation exists.

Trend analysis was performed on concentration data. The effects of flow on concentration were removed prior to trend analysis by using a locally-weighted scatterplot smoothing (LOWESS) procedure, which is a robust, nonparametric curve-fitting procedure (Cleveland 1979). The trend analysis is performed on the residuals from the LOWESS fit of concentration to flow. The smoothing parameter for the LOWESS procedure was set to 0.6 (the range is from 0.0 to 1.0) because a sensitivity analysis indicated that this value provided a good fit of the relationship without resulting in several localized minima and maxima. Because the flow concentration relationship was found to be seasonally variable, a separate model was developed for each month. With about 25 years of data, and typical biweekly sampling frequency, each curve was fitted to about 50 observations. For display purposes, a fixed value was added to all of the flow-adjusted residuals for each variable at each site so that the median of the flow-adjusted data was equal to the median of the unadjusted data.

The data were edited using Microsoft Excel 97 and imported into SAS version 8.0 for Unix to perform the LOWESS fit. The residuals were then output to a text file that was edited and imported into ChemStat version 5.0 for a seasonal Kendall Tau test. The LOWESS fit was performed on all available data, but the trend analysis only used the residual from the grab sample located closest to the 15th day of each month. The trend magnitude was determined by performing a second LOWESS fit of the residuals to time. The advantage of this approach over other common techniques to estimate trend magnitude (e.g., Sen’s Slope Estimator) is that this technique makes no assumptions about the shape of the trend line.

Load Estimation

The simplest method for calculating pollutant mass load for a river or stream is to multiply the concentration by flow. Because a continuous daily flow record exists, the flow part of this equation is well known. However, it is not practical to have continuous daily water quality measurements for most water quality variables. Instead, the most common approach, and the approach used in this study, is to try to estimate the mean concentration of a pollutant over a longer period of time, such as the mean annual concentration, based on a relatively small sample size. This is not always straight-forward because water quality concentrations are highly variable, and these variations are not completely random; instead, they often vary with several factors such as time, season, and flow.

An interactive analysis program known as FLUX was used to account for the effect of these factors in developing unbiased estimates of mean annual pollutant concentrations and then to calculate annual mass loads. FLUX is one of a suite of three programs developed for the US Army Corp of Engineers to assess the eutrophication impacts of nutrient loading to reservoirs (Walker 1996). FLUX provides six different techniques for calculating mass loads: a simple arithmetic average, two ratio methods, and three regression methods. The user selects one of these six calculation techniques to develop a model of pollutant concentration from the sample record, and then applies this model to the entire flow record to calculate total mass load and associated error statistics. An option to stratify the data into groups based on flow, date, or season is also included, and is usually an important means of controlling for potential bias. FLUX also provides a series of tabular and graphic outputs that serve as diagnostic tools to assess the quality of the load calculation.

The selection of calculation method and the data stratification scheme varied by site and by water quality variable (Appendix B). The calculation methods used in this analysis were limited to flow ratio estimators (method 2 and 3 in FLUX) and regression methods (method 4 and 5 in FLUX). Method 1 (direct mean load) and method 6 (regression applied to daily flows) were considered generally inappropriate for this analysis and were not used. Three main criteria were used to evaluate the quality of the mass load estimates for this study: 1) the independence of the model residuals versus time, flow, and season, 2) the agreement between the mean flow for the sample dates and the total flow record within the limits of the uncertainty of the data, and 3) the agreement of the mass load results among the six different calculation techniques. In addition, some weight was given to using a consistent calculation method and stratification scheme for a given variable at a given site.

RESULTS

Summary Statistics

Based on daily flow data, the smallest of these rivers is the Minnesota River at Jordan with a median flow of 3200 cubic feet per second (cfs), followed closely by the St. Croix River at Stillwater (3810 cfs), and then Mississippi River at Anoka (6990 cfs). The Mississippi River at Red Wing (median flow = 16200 cfs) combines the flow from all three of the other sites. In terms of water quality of the three incoming rivers, the St. Croix River has the lowest levels of pollution, followed by Mississippi River, and then the Minnesota River (Table 2).

Exploratory data analysis revealed that these data do not follow a normal probability distribution. Data for all water quality variables and all sites were positively skewed, meaning that in a histogram most of the data are clustered around a relatively low value and that the frequency of occurrence decreases slowly as the value increases, with a few very high values. A normal probability distribution would follow a symmetrical, bell-shaped curve and have a skewness coefficient close to zero. Highly skewed data have a skewness coefficient greater than about 1.5. Most of the parameters at most of the sites in this study have skewness coefficients that exceed 1.5 (Table 2). Dissolved oxygen is the only water quality variable that has a low skewness coefficient at all sites. A Shapiro-Francia test performed on a subset of the data confirmed that nearly all of the water quality variables do not follow a normal probability distribution and using a log transformation did not ensure a normal probability distribution in most cases.

This result is important because many statistical tests and techniques (i.e., parametric statistics) rely on the assumption of normality. The skewness of the water quality data is further demonstrated by the fact that the mean and median values are quite different for most water quality variables. Frequently the mean in a data set is heavily influenced by the presence of a few extreme values. Because the data are not normally distributed, the median is a better measure of the central tendency. Furthermore, parametric statistical tests are probably not valid for these data. Therefore, nonparametric statistical techniques were used for subsequent analysis, as these tests do not assume the data follow any particular probability distribution.

Table 2
Summary Statistics for River Water Quality Data (1976-2002)

Parameter	Lower Quartile	Upper Quartile	Median	Mean	Standard Deviation	Coefficient of Variation	Skewness
Minnesota River at Jordan							
Flow on Sampling Days (cfs)	1,770	12,800	5,510	8,990	10,200	1.14	2.41
Ammonium (mg/L)	0.01	0.13	0.05	0.12	0.19	1.56	3.24
Total 5-Day BOD (mg/L)	2.1	5.0	3.1	3.9	2.8	0.71	2.14
Chlorophyll-a (mg/L)	0.013	0.089	0.035	0.063	0.072	1.14	2.00
Dissolved Oxygen (mg/L)	7.9	11.6	9.8	9.9	2.4	0.24	0.37
Fecal Coliform (#/100ml)	20	230	70	307	914	2.97	8.28
Nitrate plus Nitrite (mg/L)	2.48	6.92	4.43	4.90	3.36	0.69	0.80
Total Kjeldahl Nitrogen (mg/L)	1.09	1.70	1.35	1.44	0.67	0.47	4.73
Total Phosphorus (mg/L)	0.17	0.35	0.23	0.28	0.20	0.70	3.75
Total Suspended Solids (mg/L)	47	186	97	141	156	1.11	3.49
Turbidity (NTU)	14	43	26	36	38	1.06	3.50
St. Croix River at Stillwater							
Flow on Sampling Days (cfs)	2,730	6,630	3,890	5,680	5,120	0.90	3.09
Ammonium (mg/L)	0.01	0.10	0.05	0.08	0.12	1.47	5.44
Total 5-Day BOD (mg/L)	1.2	2.8	1.9	2.2	1.5	0.69	2.12
Chlorophyll-a (mg/L)	0.003	0.021	0.009	0.014	0.013	0.97	1.28
Dissolved Oxygen (mg/L)	8.3	11.3	9.7	9.9	1.9	0.19	0.36
Fecal Coliform (#/100ml)	14	56	30	62	158	2.54	13.81
Nitrate plus Nitrite (mg/L)	0.16	0.48	0.27	0.36	0.36	1.00	6.06
Total Kjeldahl Nitrogen (mg/L)	0.36	0.76	0.59	0.59	0.30	0.51	0.92
Total Phosphorus (mg/L)	0.030	0.070	0.050	0.058	0.055	0.95	4.79
Total Suspended Solids (mg/L)	4.0	12.0	8.0	8.5	6.3	0.74	1.65
Turbidity (NTU)	3.2	5.0	4.0	4.4	1.9	0.44	3.13
Mississippi River at Anoka							
Flow on Sampling Days (cfs)	4,430	12,100	7,110	9,390	7,470	0.80	2.27
Ammonium (mg/L)	0.01	0.13	0.05	0.11	0.18	1.66	6.61
Total 5-Day BOD (mg/L)	1.7	3.6	2.6	2.9	1.9	0.65	2.51
Chlorophyll-a (mg/L)	0.010	0.037	0.022	0.028	0.024	0.85	1.52
Dissolved Oxygen (mg/L)	8.2	12.1	9.9	10.1	2.3	0.23	0.13
Fecal Coliform (#/100ml)	30	174	75	182	489	2.68	11.72
Nitrate plus Nitrite (mg/L)	0.30	1.04	0.61	0.80	0.74	0.93	2.23
Total Kjeldahl Nitrogen (mg/L)	0.67	1.12	0.85	0.92	0.38	0.41	1.18
Total Phosphorus (mg/L)	0.06	0.14	0.09	0.12	0.10	0.84	3.84
Total Suspended Solids (mg/L)	6	25	15	18	16	0.89	2.68
Turbidity (NTU)	3.5	8.1	5.6	6.6	7.3	1.09	17.96
Mississippi River at Red Wing							
Flow on Sampling Days (cfs)	9,820	29,800	16,800	22,900	18,200	0.79	1.72
Ammonium (mg/L)	0.04	0.35	0.13	0.26	0.35	1.35	3.16
Total 5-Day BOD (mg/L)	2.0	4.3	2.9	3.4	2.1	0.62	1.73
Chlorophyll-a (mg/L)	0.011	0.045	0.029	0.033	0.030	0.88	1.87
Dissolved Oxygen (mg/L)	7.8	11.8	9.7	9.9	2.3	0.23	0.27
Fecal Coliform (#/100ml)	10	100	37	134	375	2.80	9.05
Nitrate plus Nitrite (mg/L)	0.85	2.21	1.42	1.73	1.24	0.71	1.51
Total Kjeldahl Nitrogen (mg/L)	0.87	1.45	1.12	1.19	0.43	0.36	0.79
Total Phosphorus (mg/L)	0.13	0.21	0.17	0.19	0.18	0.97	20.14
Total Suspended Solids (mg/L)	7	43	26	29	23	0.80	1.01
Turbidity (NTU)	6	17	11	12	8	0.67	1.35

* Shaded entries indicate significant spread in the data (CV > 1.2) or significantly skewed distributions (skewness > 1.5).

Exploratory data analysis also revealed that two of the water quality variables in this study had unusually high variability, or spread, in the data for all sites. The coefficient of variation (CV) is a relative expression of the standard deviation, and it is calculated as the standard deviation divided by the mean. The CVs for NH_4 and fecal coliform were greater than 1.2 for all four sites, indicating significant variability in the data. This variability can lead to analytical problems as well as difficulties in graphical display. Therefore, the NH_4 and fecal coliform data were log transformed prior to trend analysis. The reverse transformation was applied to the trend using a simplified bias correction factor (Gilbert 1987).

Correlation and Patterns

The strength of season as an explanatory variable was greater than that of flow for most parameters and sites (Figure 2 and 3). The seasonal effect ratio was highest for DO with ratios from 0.53 to 0.72. Most (~90%) of the water quality variables and sites had seasonal effect ratios of 0.50 or less, which can be interpreted to mean that season accounted for 50% or less of the observed variability in the data. The flow effect ratios were smaller, with flow having the strongest effect on TSS at Red Wing (effect ratio = 0.37) and NO_x at Jordan (effect ratio = 0.35). Most (~90%) of the water quality variables and sites had flow effect ratios less than 0.27. However, one should note that season and flow are weakly correlated; therefore, the results of the flow and seasonal ANOVA cannot be considered additive. These results are merely an indication of the relative strength of the influence of flow and season on concentration.

An analysis of scatterplots reveal that the relationships indicated by the ANOVA results follow several different patterns. For example, NO_x concentrations in the Minnesota River at Jordan shows an increase with increasing flow (Figure 4). There is also a weak seasonal response in NO_x at this site, but it can be explained by the seasonal pattern in flow. By contrast, TSS concentrations at this site show a more complicated pattern (Figure 5). TSS increases with increasing flow up to a flow of about 15,000 cfs, above which concentrations begin to decline. The decrease in TSS concentration at high flows corresponds with the occurrence of out-of-bank flow, which occurs around 17000 cfs at Jordan. In addition, there are two distinctly different subpopulations of TSS at low flow for this site. For example, in winter (Dec – Feb), the TSS concentration at 1000 cfs is typically around 10 mg/L, whereas during the rest of the year, the TSS concentration is more typically around 60 mg/L for the same flow. Other water quality variables exhibit a strong seasonal pattern with little effect from flow. For example, dissolved oxygen concentrations at Red Wing have a distinct seasonal minimum in late summer and a seasonal maximum in winter (Figure 6), while TSS at the same site follows a nearly opposite pattern (Figure 7).

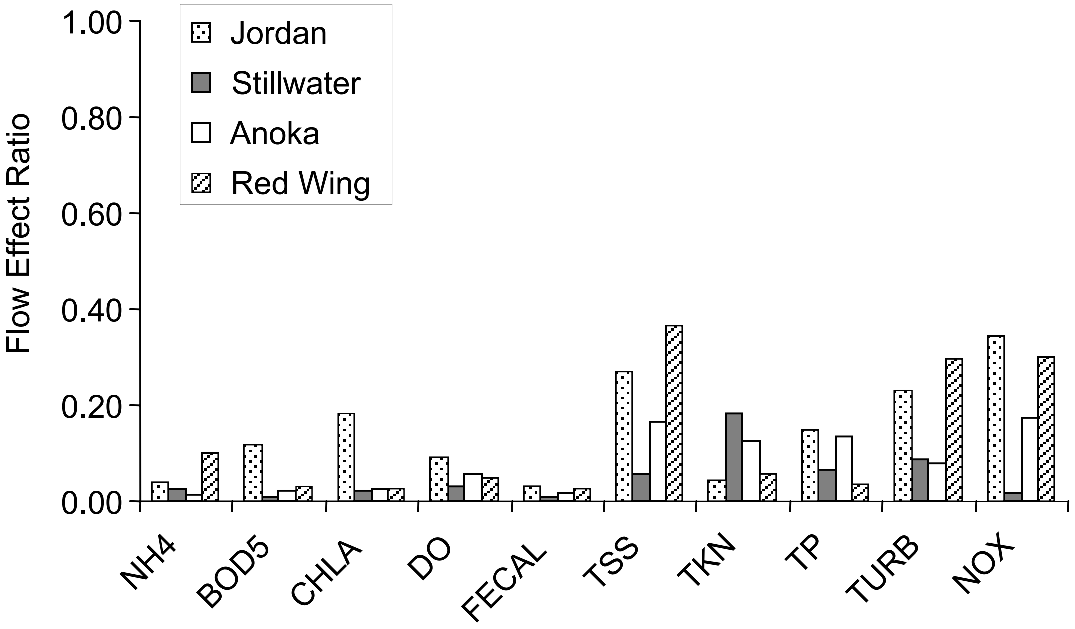

Figure 2: The relative influence of flow upon concentrations of select water quality variables at four sites on the Minnesota, Mississippi, and St. Croix Rivers. The relatively low values indicate that flow has only a weak effect on concentration.

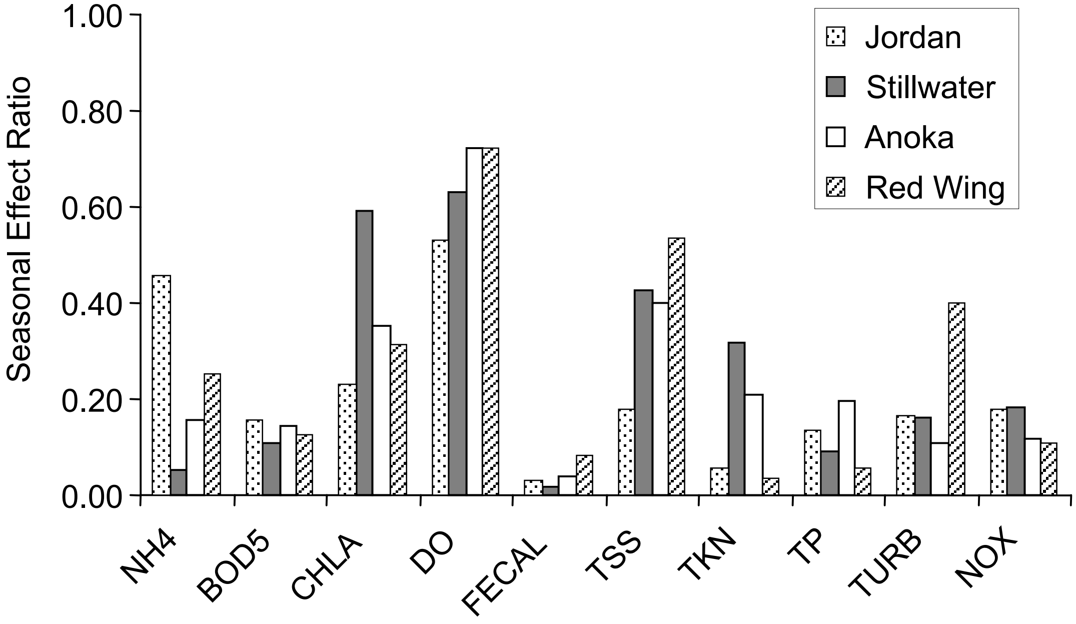

Figure 3: The relative influence of season upon concentrations of select water quality variables at four sites on the Minnesota, Mississippi, and St. Croix Rivers. The relatively high values for some variables indicate a strong seasonal influence on concentration.

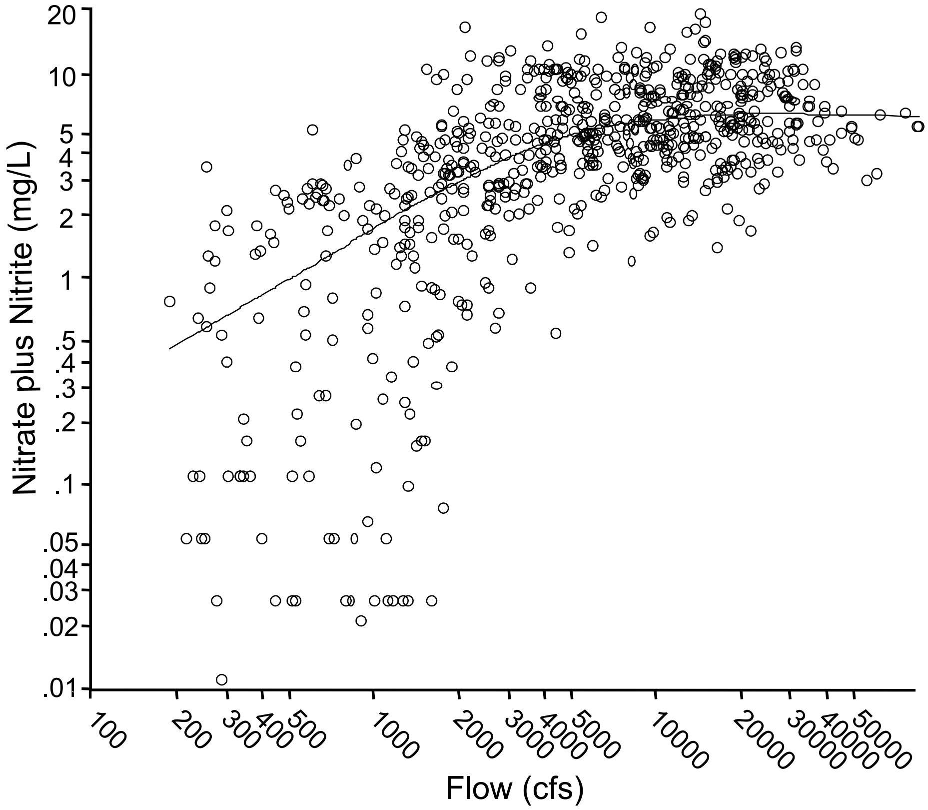

Figure 4: Nitrate plus nitrite concentrations for the Minnesota River at Jordan increase with flow.

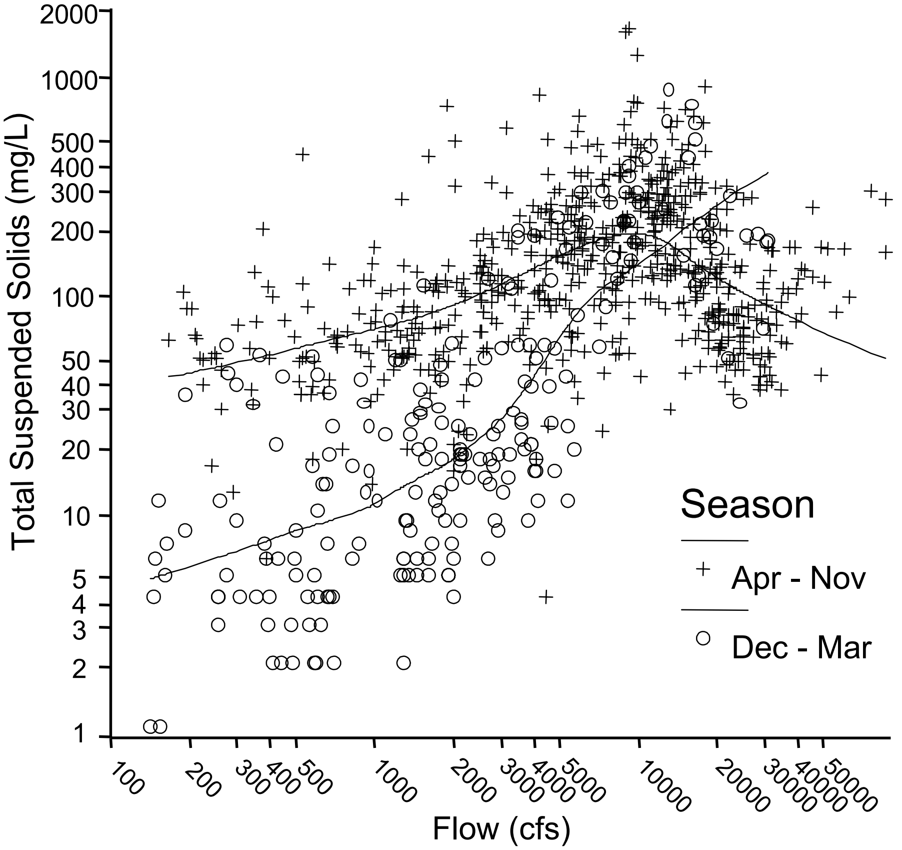

Figure 5: Total suspended solids concentrations for the Minnesota River at Jordan show a complex relationship with flow and season.

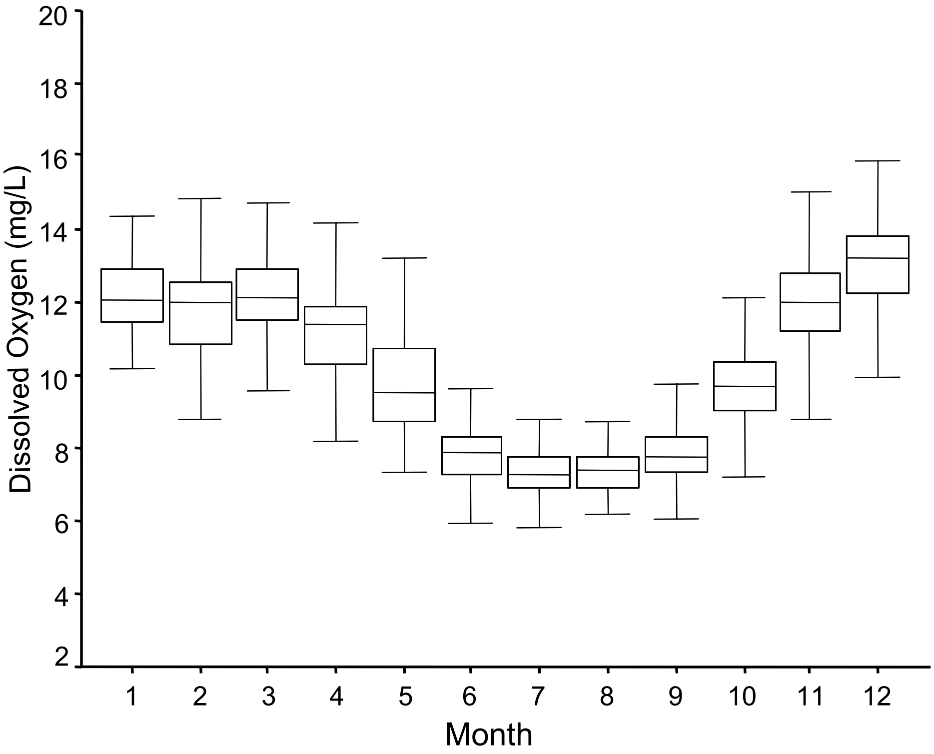

Figure 6: Dissolved oxygen for the Mississippi River at Red Wing shows a strong seasonal pattern with a winter maximum and late summer minimum.

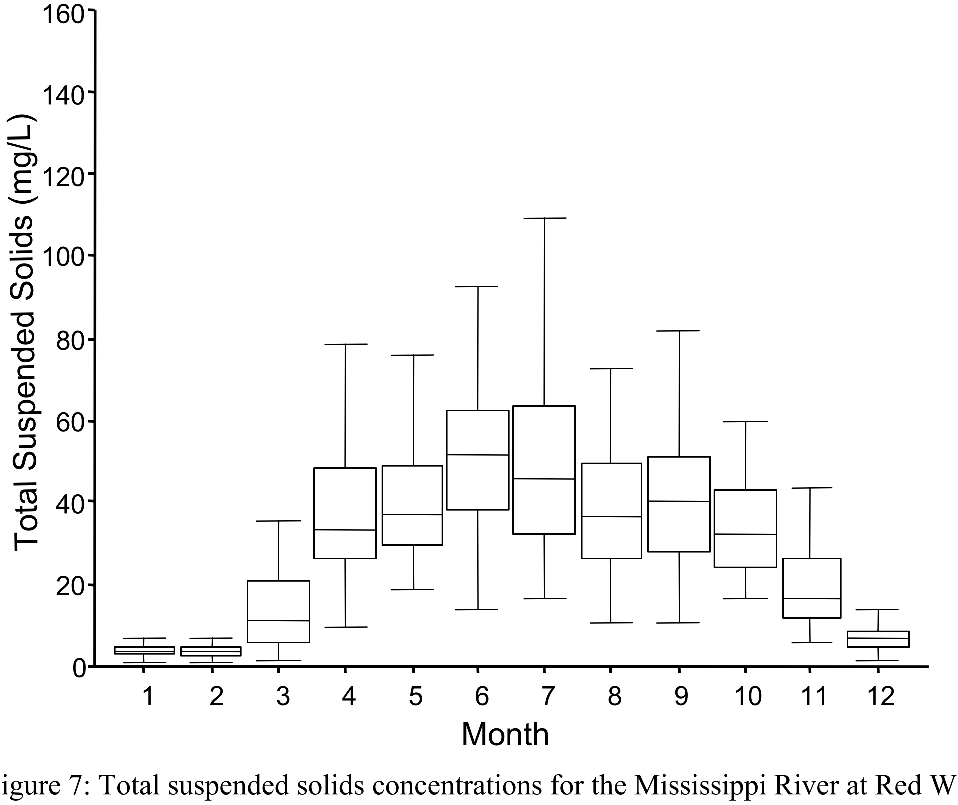

Figure 7: Total suspended solids concentrations for the Mississippi River at Red Wing shows a seasonal pattern with a winter minimum and a late summer maximum.

Trends

Statistically significant trends were found at each of the four study sites for at least a few water quality variables. The results of the trend analyses are discussed here; the trend charts for all water quality variables and all sites are contained in Appendix A.

Minnesota River at Jordan

The Minnesota River at Jordan exhibited significant decreasing trends in concentration for fecal coliform bacteria, NO_x, BOD5, TKN, and NH_4 (Table 3). No change was indicated for chl-a or DO at this site. The Kendall Tau test also indicated decreasing trends for TP, TSS, and turbidity, but a graphical examination of these data indicated that these trends are not monotonic and therefore may not be best described by this test. The LOWESS trend lines show decreasing flow-adjusted values for each of these parameters from the late 1970s up to about 1993 or 1994 (Figure 8 and 9). Afterwards, the trend lines indicate an increase in concentration. A separate Kendall Tau test was performed on TP, TSS and turbidity for the period from April 1993 through 2002. Total phosphorus was found to have a significant upward trend at a 95% confidence level (a one-tailed test for an upward trend) and TSS was found to have a significant upward trend at a 90% confidence level (also a one-tailed test for an upward trend). Turbidity did not have a significant trend for this period, probably as a result of it relatively high variability compared to the slope of the potential trend.

For the five water quality variables that did have significant monotonic trends, the magnitude of the trend was determined using a LOWESS fit of the flow-adjusted data to time. The largest trends were for fecal coliform bacteria and NH_4 with decreases of 71% and 72% for the period of record (Table 3). Total 5-day biochemical oxygen demand declined nearly 40% for the period, while NO_x and TKN showed a decrease of about 20% each.

Mississippi River at Anoka

The Mississippi River at Anoka had decreasing trends for BOD5, NH_4, TP, TSS, and turbidity and an increasing trend for NO_x. A decreasing trend was also indicated for TKN, but as with TP, TSS, and turbidity at the Jordan site, this trend appears to be non-monotonic. No change was indicated for chl-a, DO, or fecal coliform bacteria at this site. The largest trend was for NH_4, with a decline of 78%, followed by BOD5, with a decline of 52%. The trends for TP, TSS, and turbidity were roughly similar to each other, with declines of 37%, 45% and 30% respectively. The only water quality variable at this site to show a significant upward trend was NO_x, with an increase of 31%.

Table 3
Trend Magnitude for the Minnesota, Mississippi and St. Croix Rivers, 1976 - 2002

Variable	Minnesota River at Jordan	Mississippi River at Anoka	St. Croix River at Stillwater	Mississippi River at Red Wing
Ammonium*	-72%	-78%	-81%	-91%
BOD, 5-Day	-38%	-52%	-58%	-59%
Chlorophyll-a	---	---	---	8%
Dissolved Oxygen	---	---	4%	---
Fecal Coliform*	-71%	---	-64%	-71%
Nitrate plus Nitrite	-20%	31%	17%	12%
Total Kjeldahl Nitrogen	-19%	NM	-33%	-34%
Total Phosphorus	NM	-37%	---	-20%
Total Suspended Solids	NM	-45%	-43%	---
Turbidity	NM	-30%	-37%	---

* - The data for these variables were log transformed prior to analysis.
--- - No significant trend was found for these variables at $p \leq 0.05$.
NM - The trend was non-monotonic and is not described well by the statistical test used here.

St. Croix River at Stillwater

The St. Croix River at Stillwater showed decreasing trends for fecal coliform bacteria, BOD5, TKN, NH_4, TSS, and turbidity and increasing trends for DO and NO_x. There was no change indicated for chl-a or TP. The largest trend was for NH_4 with a decrease of 81% followed by decreases of 64% and 58% for fecal coliform bacteria and BOD5. Trends for TSS and turbidity were comparable, with declines of 43% and 37% respectively. Similar to the Mississippi River at Anoka, NO_x at Stillwater exhibited an upward trend, with an increase of 17%. The Stillwater site was the only site to show any change in DO, although the change was minor with an increase of only 4% over the period of record.

Mississippi River at Red Wing

The Mississippi River at Red Wing showed decreasing trends for fecal coliform bacteria, BOD5, TKN, NH_4, and TP and increasing trends for chl-a and NO_x. No change was indicated for DO, TSS, or turbidity. The largest trend was for NH_4, with a decrease of 91% followed by decreases of 71% and 59% for fecal coliform and BOD5. More modest trends were found for TKN and TP, with decreases of 34% and 20%. NO_x showed an increase of 12%, while chl-a showed a slight increase of 8% over the period of record.

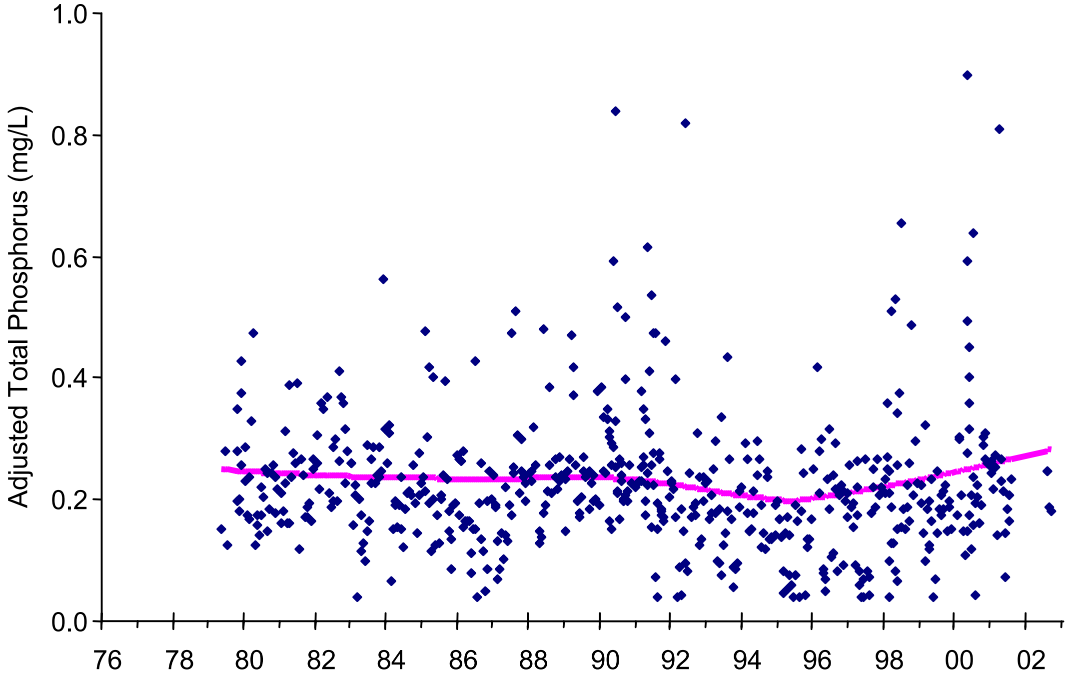

Figure 8: The total phosphorus trend for the Minnesota River at Jordan shows an increase from 1993 to 2002.

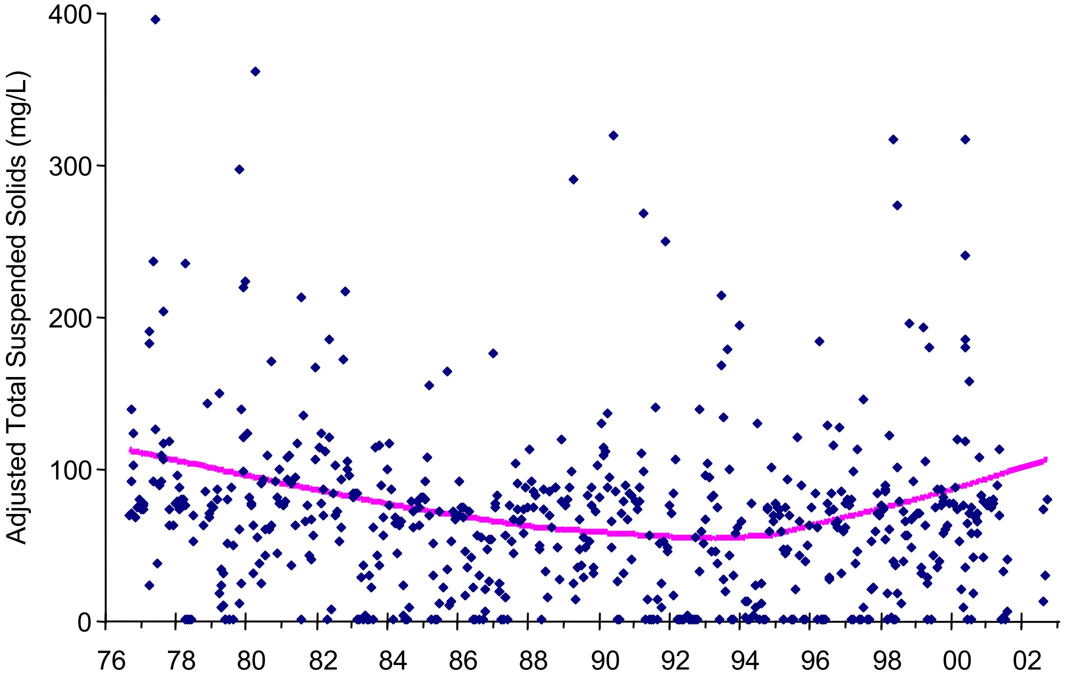

Figure 9: The total suspended solids trend for the Minnesota River at Jordan shows a decrease from 1980 to 1993 and an increase from 1993 to 2002.

Loads

The results of the pollutant load analysis for NO_x, TKN, TP, and TSS are described here, with additional details and statistics provided in Appendix B.

Flow

Pollutant mass loads entering and leaving the TCMA are strongly dependent upon flow volume and, in turn, flow volume depends upon numerous climatic variables, particularly precipitation amount. The combined annual flow volume entering the TCMA from the three main rivers is nearly equal to the annual volume leaving the TCMA (Figure 10). The volume of water gained or lost in the river system as it passes through the TCMA is practically negligible for this analysis. The mean relative contributions of the three major rivers to the total incoming water volume are reasonably comparable, with 25 – 30% of the flow coming from each of the Minnesota River and the St. Croix River and a slightly larger volume 40 – 45% coming from the Mississippi River. The minimum annual flow volume occurred in 1988, which was an extreme drought year. Significant flow peaks occurred in 1986, 1993, and 2001, which were all flood years. This significance of the cycle of drought and flood can be easily seen in the pattern of pollutant loads for NO_x, TKN, TP, and TSS (Figures 11, 12, 13, and 14).

Nitrate plus Nitrite

Although the volume contributions of water coming from the three main rivers are somewhat comparable, the mass load of NO_x is largely dominated by the contribution of the Minnesota River, which contributes, on average, about 75% of the overall incoming load. The Mississippi River at Anoka contributes about 20% of the total incoming load, while the St. Croix River only contributes about 5% of the load. The difference in these relative contributions can be explained by the much higher NO_x concentrations that occur in the Minnesota River. The median flow-weighted mean concentrations from 1992-2001 was 5.96 mg/L. This is about 6.5 times greater than the typical flow-weighted mean concentration in the Mississippi River at Anoka and almost 17 times higher than the typical flow-weighted mean concentration in the St. Croix River at Stillwater. The total incoming mass load of NO_x is very close to the outgoing mass load of NO_x at Red Wing, except for the drought years of 1987-1989 when the outgoing mass load is higher than the incoming load.

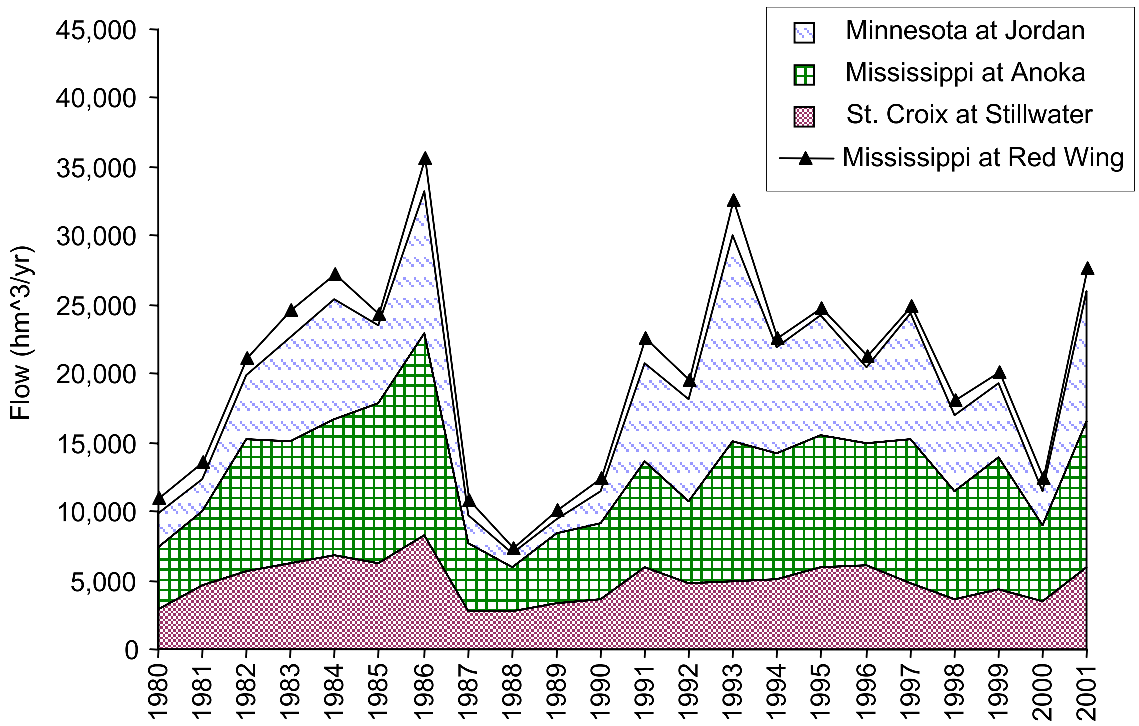

Figure 10: Comparison of the incoming flow volume from the three major rivers to the outgoing flow volume for the Mississippi River at Red Wing. The amount of water leaving the TCMA is nearly equal to the total amount of water that enters.

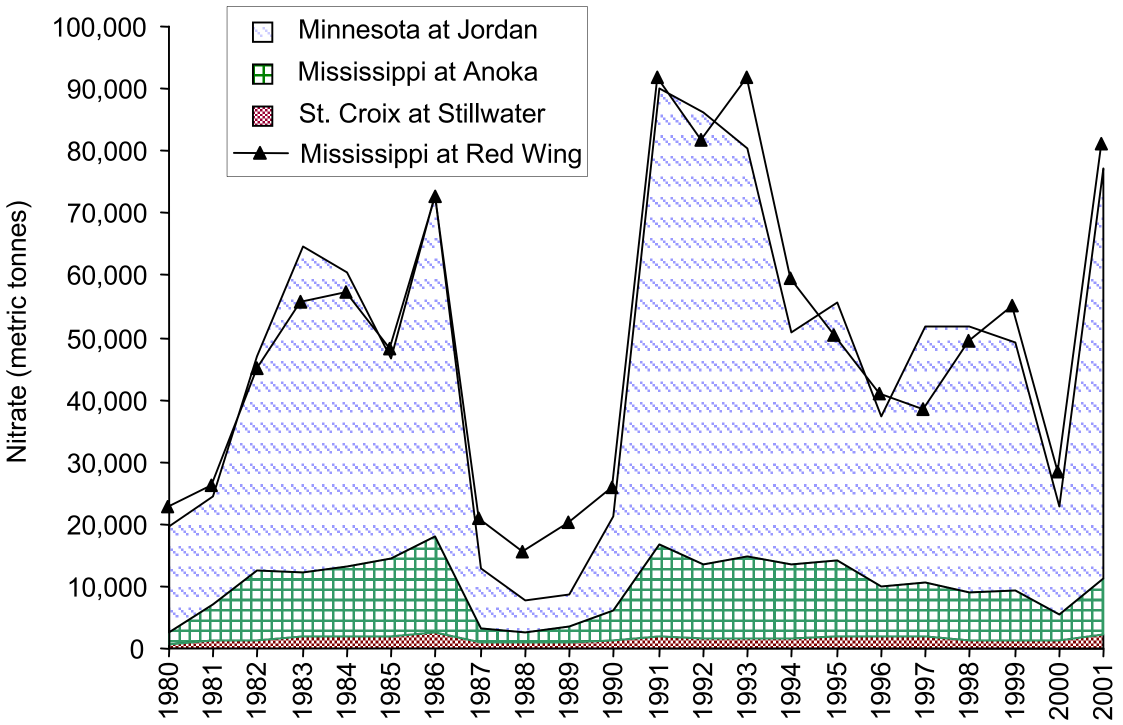

Figure 11: Comparison of the incoming nitrate plus nitrite mass from the three major rivers to the outgoing pollutant mass for the Mississippi River at Red Wing.

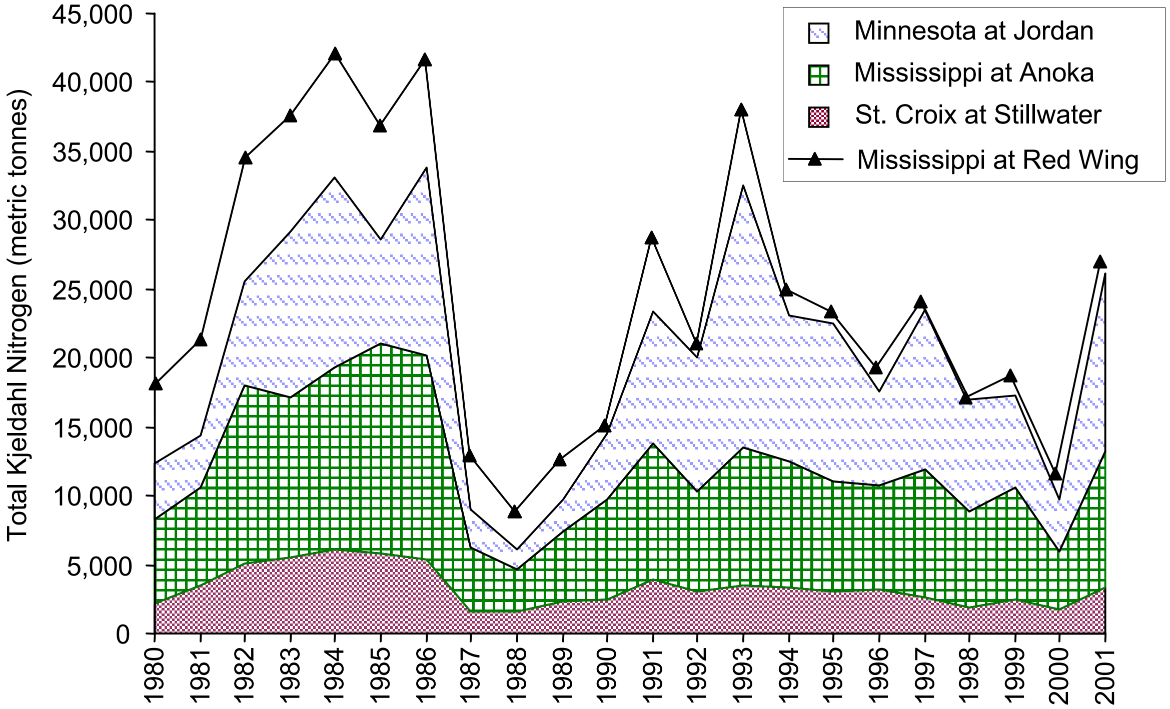

Figure12: Comparison of the incoming total Kjeldahl nitrogen mass from the three major rivers to the outgoing pollutant mass for the Mississippi River at Red Wing.

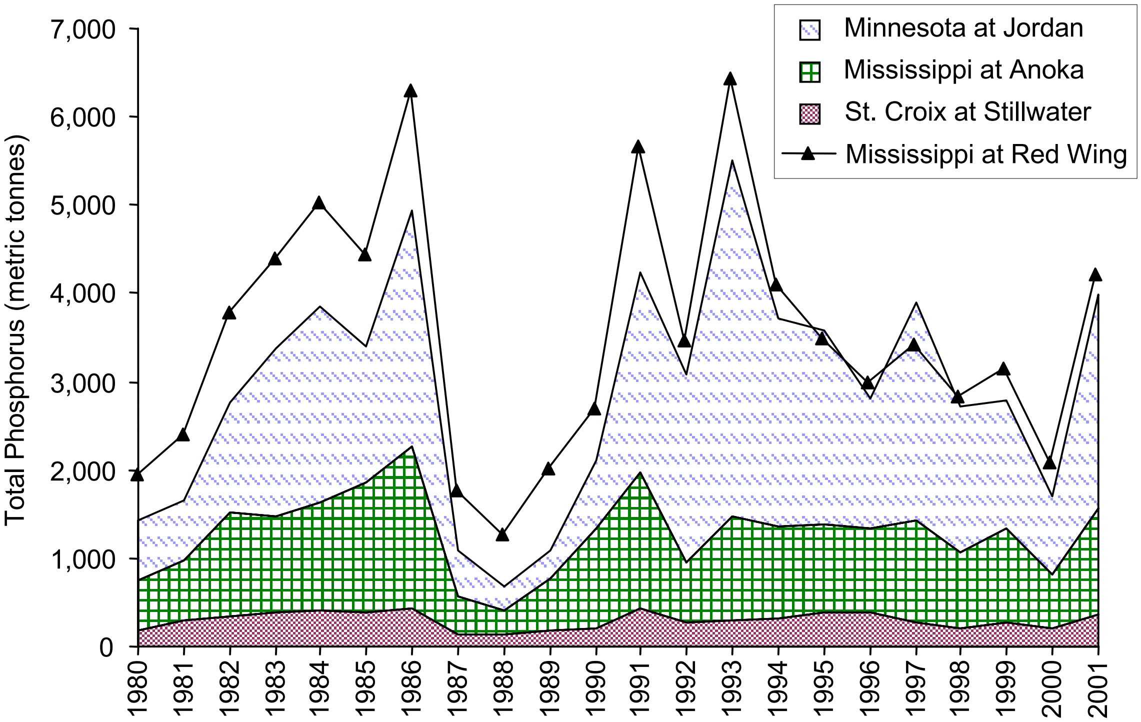

Figure 13: Comparison of the incoming total phosphorus mass from the three major rivers to the outgoing pollutant mass for the Mississippi River at Red Wing.

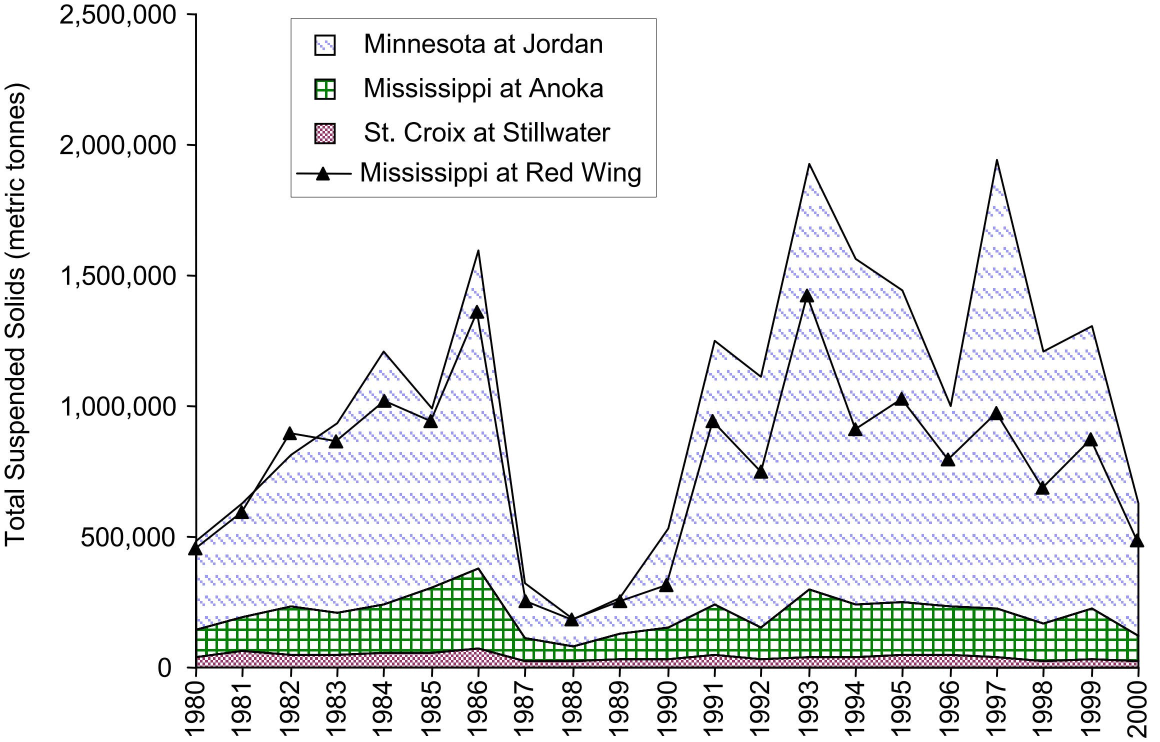

Figure 14: Comparison of the incoming total suspended solids mass from the three major rivers to the outgoing pollutant mass for the Mississippi River at Red Wing. The amount of suspended solids leaving the TCMA is less than the total amount coming into the area.

Given the contribution of both point and nonpoint sources within the TCMA, the comparability of incoming and outgoing loads suggest that there is a significant loss of NO_x occurring somewhere in the TCMA, possibly as a result of denitrification in the river system. The drought-flood cycle has a major effect on NO_x loading, especially for the Minnesota River. The total incoming NO_x load increased from less than 10,000 metric tonnes per year in 1988 and 1989 to about 90,000 metric tonnes in 1991, a flood-year following the drought.

Total Kjeldahl Nitrogen

The mean relative contribution of TKN from the Mississippi River at Anoka is 44%, which is similar to its water volume contribution. At 39%, the TKN contribution from the Minnesota River is somewhat higher than its water contribution. The TKN contribution from the St. Croix River to incoming TKN load is 17%, which is slightly lower than its water contribution. The outgoing mass load of TKN at Red Wing has been higher than the total incoming load for every year from 1980-2001 with the difference commonly being 20 – 25%. The additional load may be attributed to wastewater discharge in the TCMA as well as stormwater runoff. However, since 1993, the difference between the combined incoming load and the outgoing load appears to have decreased, possibly as a result of the reduction in ammonium discharged from WWTPs.

Total Phosphorus

The incoming mass load of TP is dominated by the Minnesota River at Jordan, contributing 53% of the total load on average. The Mississippi River at Anoka contributes 36% and the St. Croix River at Stillwater contributes 11%. The difference between the outgoing TP load and the combined incoming TP load has apparently decreased since 1994 (Figure 15). On average, the outgoing load of TP was 750 metric tonnes (±180 tonnes) higher than the combined incoming load from 1980 through 1993. From 1994 through 2001, the outgoing load of TP exceeded the incoming load by only 140 metric tonnes (±250 tonnes). The relative size of the increase was largest during the drought period from 1987-89, but this appears to be mostly due to drastically smaller incoming TP load. Given the contribution of phosphorus from both point and nonpoint sources within the TCMA, the overall comparability of incoming and outgoing TP load suggests that there is a significant loss of TP occurring in the TCMA. This may be explained by the settling of TP associated with aquatic particles in the relatively quiescent pools in the river system.

Total Suspended Solids

The Minnesota River at Jordan, the Mississippi River at Anoka, and the St. Croix River at Stillwater contributed about 75%, 20%, and 5% of the TSS load, respectively. The relative TSS contributions from the three incoming rivers are nearly identical to the contributions for NO_x; however, the fate of these two pollutants are quite different because TSS is particulate and thus subject to settling. The outgoing load of TSS was lower than the total incoming load of TSS for nearly every year from 1980 – 2001, indicating that the TCMA is a net sink for TSS. The results indicate that in a typical year, about 425,000 tonnes of TSS are deposited somewhere in the river system or floodplain within the TCMA.

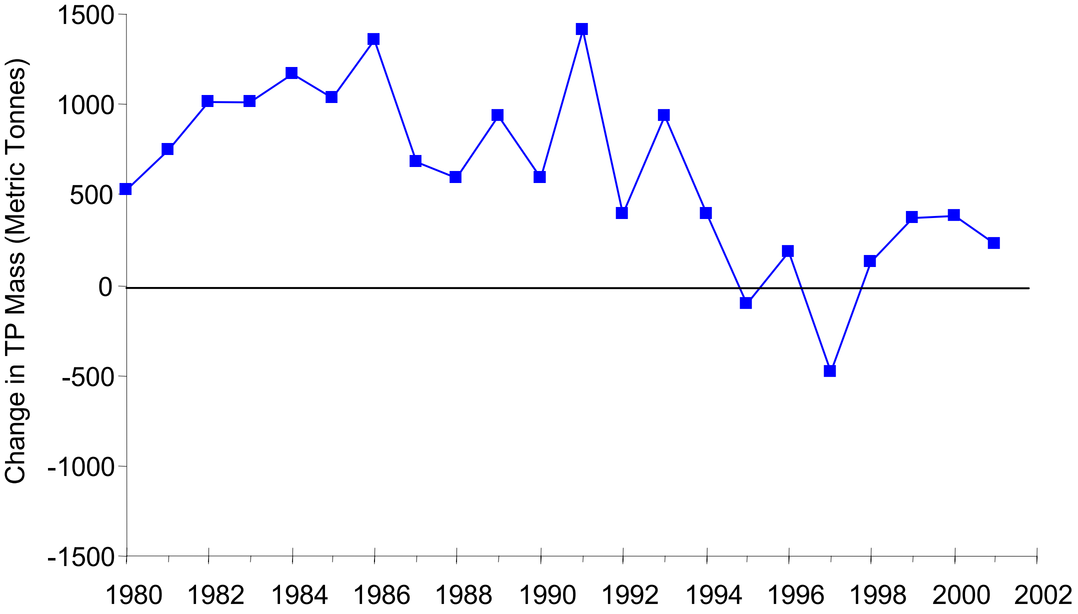

Figure 15: Trend line depicting annual difference between outgoing and combined incoming load of total phosphorus for the TCMA. Positive values indicate that the TCMA is net source of phosphorus; negative values indicate that the TCMA is a net sink of phosphorus.

DISCUSSION

Trends

In comparing the results from this trend analysis to that of other studies, some similarities emerge as well as some apparent discrepancies. A major study of the Upper Mississippi River Basin by the USGS analyzed phosphorus and nitrogen trends from 1971 to 1994 (Kroening and Andrews 1997). Both the USGS study and this analysis found large decreases in NH_4 concentrations at each of the four sites included in this report (Table 4). The USGS study found an increase in NO_x at the Red Wing site; however, their analysis indicated no trend in NO_x for the other three sites. The trend results for TP reported by the USGS were also partially similar to the results in this report. The USGS study did not find any trends in TP for the four sites in this report, while this study found no trend in TP for two sites and only a relatively small decreasing trend for TP at Anoka and Red Wing. The USGS study did find a significant decrease in TP for the Mississippi River at Monticello, Minnesota, which is located about 25 miles upstream of Anoka.

The Minnesota Pollution Control Agency (MPCA) published results of a water quality trend analysis for the Minnesota River Basin that included an analysis of trends from 1977 through 2001 for BOD5, TSS, TP, NH_4, and NO_x at Jordan (MPCA 2002). The trend analysis results from the MPCA study compares favorably in significance and direction with the results contained in this report (Table 4). In addition, the estimated magnitude of the trends for BOD5 and NH_4 are comparable for these two studies. The MPCA study found that BOD5 decreased by 34% over the period as compared to a BOD5 decrease of 38% reported here. The MPCA study also reported that NH_4 decreased by 84%, which is similar to the decrease of 72% reported here. Both the MPCA study and this study found no statistically significant change in TP over the analysis period; however, this report suggests a non-monotonic change in TP. The TP trend for the Minnesota River at Jordan appears to be flat or slightly decreasing up to 1993 and then increasing after that. A Kendall Tau test showed an upward trend in TP from 1993 through 2002. The MPCA report and this report both indicate a statistically significant downward trend in TSS at Jordan overall, but again, the trend is composed from two distinctly different trends: a decreasing trend from 1976 to 1993 followed by an increasing trend from 1993 to 2002. In addition, the trend analysis results between the two studies also differed for NO_x. The MPCA study indicated no trend for NO_x, while this report indicates a decrease of 20%.

Table 4
Comparison of Trend Significance and Direction for the Minnesota, Mississippi, and St. Croix Rivers

Site	NH_4	BOD5	NO_x	TP	TSS
Minnesota River at Jordan					
Met Council 2004	↓	↓	↓	↔*	↓*
Kroening and Andrews 1997	↓		↔	↔	
MPCA 2002	↓	↓	↔	↔	↓
Mississippi River at Anoka					
Met Council 2004	↓		↑	↓	
Kroening and Andrews 1997	↓		↔	↔	
St. Croix River at Stillwater					
Met Council 2004	↓		↑	↔	
Kroening and Andrews 1997	↓		↔	↔	
Mississippi River at Red Wing					
Met Council 2004	↓		↑	↓	
Kroening and Andrews 1997	↓		↑	↔	

* - These trends were non-monotonic and may not be described well by the statistical test used.

The potential reasons for the differences in trend analysis results can be broadly classified as either resulting from differences in method of analysis or differences in the data sets. The trend analysis methods used for these three studies were similar: the data were flow-adjusted using LOWESS and then the trend analysis was performed using the seasonal Kendall Tau test. There were some slight differences in the flow-adjustment method and the number of seasons specified for the Kendall Tau test also differed. In addition, the method of estimating the magnitude of the trend differed. Instead of assuming a linear or exponential trend, the analysis for this report used a LOWESS procedure to fit a trend line to the flow-adjusted residuals. These differences in method, although slight, may account for some of the discrepancy in the results. Another difference is in the data used. All three studies used data from collected by the Metropolitan Council. However, the USGS study only covered the period up to 1994. The analysis period for the MPCA study and this report are most similar, and therefore the results of these two efforts more closely agree.

The analysis conducted for this report found that the largest trends have occurred for NH_4, BOD5, and fecal coliform bacteria (Table 3). The NH_4 concentrations for all four sites decreased more than 70%. Assuming an exponential decrease, this translates into a decrease of more than 4.5% per year. Fecal coliform bacteria trends were significant at three of the four sites, with decreases between 64% and 71%. BOD5 decreased more than 50% at three of four sites; a reduction of more than 2.6% per year assuming an exponential decrease. While there were significant trends for other water quality variables, the magnitude of the trends were relatively small. For example, NOx trends at three of the four sites showed changes of 20% or less over the study period. This translates into a change of less than 1% per year.

The decreasing trends for NH_4 and BOD5 are probably due, in large part, to improvements in point source controls that occurred over the period from 1976 to 2002. The rationale for this hypothesis has three parts. First, point sources have been a leading source of pollutants to rivers and streams (EPA 2002), and NH_4 and BOD5 are among the significant pollutants of concern discharged by point sources. Second, reductions of NH_4 and BOD5 loads from Minnesota's largest point source, the Metropolitan Wastewater Treatment Plant (Metro Plant), have been well documented (EPA 2000). Following the 1972 Clean Water Act, the Metropolitan Council's Environmental Services Division (formerly the Metropolitan Waste Control Commission) spent more than $350 million to upgrade and expand the Metro Plant. Loading for 5-day biochemical oxygen demand decreased from 77,000 lbs/day in 1973 to 17,000 lbs/day in 1998. After upgrading the plant to include nitrification, NH_4 loading from the plant dropped from 25,500 lbs/day in 1982 to 2,600 lbs/day in 1998. While the discharge from the Metro Plant only affects the water quality at one of the four sites in this study (the Mississippi River at Red Wing), the Clean Water Act and state water quality regulations required similar improvements at other major wastewater treatment facilities in Minnesota, including those upstream of the other three sites in this study. Third, the fact that similar decreasing trends are observed for NH_4 and BOD5 in each of the three major watersheds (the Mississippi, the Minnesota, and the St. Croix), despite the fact that these watersheds have vastly different land uses, geology, and soils, suggests that changes in nonpoint source loads are not a major contributor to the observed trends.

Trends for TKN, fecal coliform, and NO_x are also likely influenced by changes in point source controls although probably to a lesser degree than NH_4 and BOD5. Because TKN is comprised of organic nitrogen and NH_4, it is to be expected that large decreases in NH_4 would result in a decrease in TKN. With regard to fecal coliform bacteria, there have been historical improvements made to the disinfection processes at wastewater treatment facilities, but most of these were probably in-place prior to 1976; the beginning of the study period for this report. In the 1960s, the total coliform densities below the Metro Plant were more than an order of magnitude greater than those upstream (EPA 2000). More recently, the fecal coliform concentrations below the Metro Plant have decreased to the point where it is nearly equal to the upstream concentration. The decreases in fecal coliform bacteria found over the period from 1976 to 2002 may be due to the separation of combined sanitary and storm sewers during the 1980s and 1990s. The Council and the cities of Minneapolis and St. Paul were required to eliminate combined sewer overflows, which were a potentially significant source of fecal coliform bacteria. Increases in NO_x are also probably a result of changes in point source pollution control. The nitrification process, which has been added to many wastewater treatment facilities, decreases NH_4 concentrations by converting NH_4 to NO_x. One apparent exception to this expected response for NO_x is the Minnesota River at Jordan, where a small decrease in NO_x occurred. NO_x concentrations in the Minnesota River are heavily influenced by agricultural nonpoint source pollution. Therefore, the expected increase due to the addition of nitrification at wastewater treatment facilities may be overwhelmed by changes in nonpoint source loading of NO_x in the Minnesota River.

In contrast, the trends in TSS and turbidity are most likely due to changes in nonpoint source loading because loading of TSS and turbidity is clearly dominated by nonpoint sources. Using point source flow information recently compiled for the Minnesota Pollution Control Agency (MPCA 2004), and using relatively high estimates of wastewater TSS concentrations, the total TSS load from point sources above the three incoming major river sites was less than 1% of the load estimated from the monitoring data. Turbidity trends closely follow trends in TSS as expected. The largest sources of TSS and turbidity are undoubtedly overland erosion, especially of cropland, and stream bank erosion, but facing a paucity of comprehensive information on the load contribution from these sources over time, we can only speculate on a more detailed explanation of these trends.

A mixed picture emerges from the analysis of TP trends. In the Minnesota River, the TP trend appears to partially mirror the TSS and turbidity trends, with a period of slight decline (or at least no change) from 1976 to 1993, followed by an increase from 1993 to 2002. However, the regulatory trend has been to lower point source permit limits for phosphorus, especially in the past decade (MPCA 2002). In addition, a statewide ban on the use of phosphorus in laundry detergent was implemented in 1977 (MPCA 2002), which could also be expected to help bring down phosphorus loading to the rivers from point sources. This suggests that nonpoint sources may be particularly important contributors to TP in the Minnesota River Basin. There has been a moderate decrease in TP for the Mississippi River at Anoka and a slight decrease in TP at Red Wing, possibly reflecting lower point source loading of phosphorus. There has been no change in TP for the St. Croix River. A comparison of the combined incoming mass of TP to outgoing mass of TP shows a recent decline in the net export of TP from the Twin Cities region (Figure 15). This corresponds to a period when effluent concentrations of TP were declining for three Twin Cities wastewater treatment facilities: Seneca, Blue Lake, and Metro WWTPs.

Loads

Uncertainty in pollutant mass loads is inevitable; therefore, quantifying this uncertainty is vital to the interpretation of the results. Uncertainty is significantly affected by the design of the monitoring program, the calculation method used, and the uncertainty in the measurement of flow and concentration (Richards 1999). The uncertainty estimates provided by the FLUX program can be helpful when selecting the calculation method and stratifying the data. This estimate of uncertainty is based on a Jacknife test that describes the effect of successive omission of each measurement. However, this method probably understates the uncertainty somewhat because it doesn't consider all possible sources of error. The FLUX estimate of relative error for NO_x loads ranges from ±12% to ±22%, which is fairly close to the relative error estimated for TSS loads (±10% to ±22%). The relative errors for TKN and TP loads are slightly smaller, ranging from ±8% to ±14% for TKN and ±8% to ±12% for TP.

Direct comparison of annual loads from this study to other published studies is not possible, but Kroening and Andrews (1997) did report median NO_x, TKN, and TP loads for the period of 1984-93. For comparison, the median for the same 10-year period was calculated from the results of this study. When compared to the 10-year median loads calculated for this study, the 10-year median NO_x loads reported in Kroening and Andrews (1997) were 47% higher at Jordan, 17% lower at Anoka, 14% lower at Stillwater, and 9% higher at Red Wing. In a site-to-site comparison, the 10-year medians between these two studies were all within ±14% for TKN and within ±23% for TP. These differences would likely be larger if the comparisons were between annual loads rather than the 10-year median loads. A report by Meyer and Schellhaass (2002) included an analysis of annual pollutant loads for the same three TCMA rivers. Additional unpublished data provided by the authors of this report allow a direct comparison of annual loads. When annual loads are compared between the present study and Meyer and Schellhaas (2002), the annual pollutant loading estimates were found to vary by as much as 40% for TP, 50% for TSS, and 80% for NO_x.

Comparisons of loading estimates from this study to estimates from other studies suggest that the uncertainty surrounding pollutant loads may be larger than the FLUX estimate of uncertainty. The differences between these three sets of pollutant loading estimates are largely due to differences in calculation method, because each of these studies relied on much of the same data. All three studies used water quality data from the Council's routine river monitoring program. This study also used data from the nonpoint source monitoring program for the Minnesota River at Jordan, which includes numerous storm event composite samples for the years 1989-2001. Kroening and Andrews (1997) used the

ESTIMATOR program to calculate loads. This program uses a multiple-regression model to estimate pollutant loads, which is a substantially different technique than the methods available through FLUX. Both this study and the Meyer and Schellhaass (2002) study used FLUX to estimate loads, but there are several different calculation methods available within FLUX. In addition, data stratification within FLUX can have a significant effect on the pollutant load estimate. These two studies used different calculation methods as well as data stratification schemes.

The comparison of loading results from these three studies raises several questions. What is the source of the difference in loading results between these studies? Is bias being introduced by one or more of these calculation methods? Or is the large variability more random in nature? The apparent discrepancies between loading estimates are troubling; however, without detailed documentation and diagnostics for each of these three studies, it is impossible to determine the source of these differences. Based on best professional judgement, some of the bigger differences in loading estimates are likely due to method bias or analyst error. Uncertainty for annual estimates of pollutant loads in this report are probably on the order of 30% - 40%. Uncertainty decreases when a longer period is considered. The uncertainty in the 10-year mean or median pollutant load is probably on the order or 10% - 20%. Given these estimates of uncertainty, there is reasonable agreement between the annual TP loads in this report and the results of Meyer and Schellhaas (2002). There is also reasonable agreement between the 10-year median loads between this study and the results of Kroening and Andrews (1997) for all variables except NO_x at Jordan. Further study will be required to develop better estimates of uncertainty. In any case, this comparison points out the need for providing detailed documentation of pollutant loading calculations in order for data users to make informed judgments on the quality of the calculated results.

The Council's benchmark water quality goal states that the water quality leaving the TCMA should be as good or better than when it enters the region. Because water enters the TCMA in three major rivers and leaves through one major river that combines all of the inputs, a fair comparison requires that the incoming water quality must be weighted relative to the flow contribution of the three incoming rivers. This can be accomplished by comparing the combined incoming load to the outgoing load. Furthermore, given the improvement in precision gained by increasing the analysis period from annual pollutant loads to 10-year median loads, it is recommended that evaluation of the Council's benchmark water quality goal for the region should be based on 10-year median loads.

A comparison of 10-year median pollutant loads for incoming and outgoing major rivers shows that the TCMA adds slightly to the overall pollutant mass of NO_x and TKN with increases of 2% and 5%

respectively (Table 5). However, these differences fall within the margin of error for the load estimates. The region passes on slightly less TP on to downstream communities than what it receives, with a decrease of 1%, which is also within the margin of error. However, the TCMA retains a significant amount of TSS, presumably through sedimentation in the quiescent pools created by the lock and dam system and also Lake St. Croix. The TSS load leaving the TCMA is 31% lower than the combined incoming load of TSS, well beyond the margin of error. The estimated mass of suspended sediment that is retained in the TCMA river system is about 400,000 metric tonnes per year (880 million pounds per year).

Table 5
10-Year (1992-2001) Median Pollutant Mass Budget (tonnes/year)

Site	NO_x	TKN	TP	TSS
Inputs				
Minnesota River at Jordan	41,307	10,203	2,171	1,062,942
St. Croix River at Stillwater	1,739	3,044	278	38,824
Mississippi River at Anoka	8,965	8,034	1,018	188,889
Outputs				
Mississippi River at Red Wing	52,833	22,353	3,441	890,897
Net Change	821	1,073	-26	-399,757
Percent Change	2%	5%	-1%	-31%

Based upon a comparison of incoming and outgoing 10-year median loads of NO_x, TKN, TP, and TSS, the Council's benchmark water quality goal for the TCMA is being met. However, this goal is likely being met in large part due to sedimentation of solids and particulate associated nitrogen and phosphorus. Additional analysis is planned to further quantify the importance of sedimentation as well as other sources and sinks of pollutants within the TCMA. With this additional information, it may be possible to consider the adverse impact of excessive sedimentation on the health of the TCMA river system in future water quality goals for the region.

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APPENDIX A – RIVER WATER QUALITY TRENDS CHARTS

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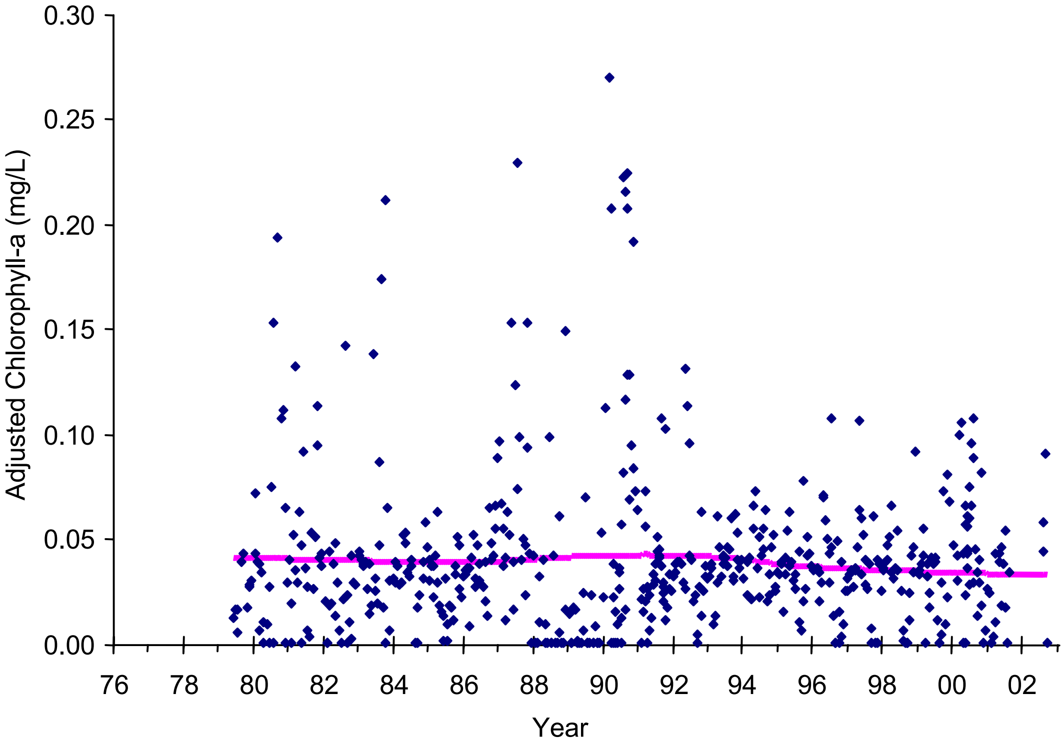
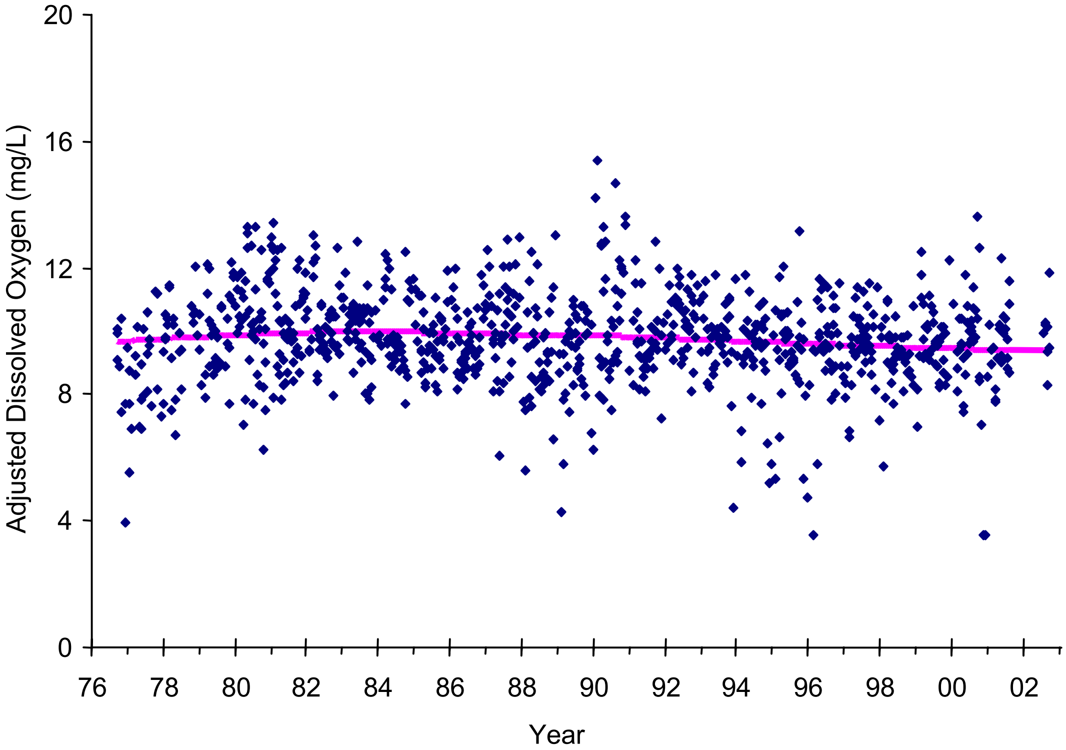
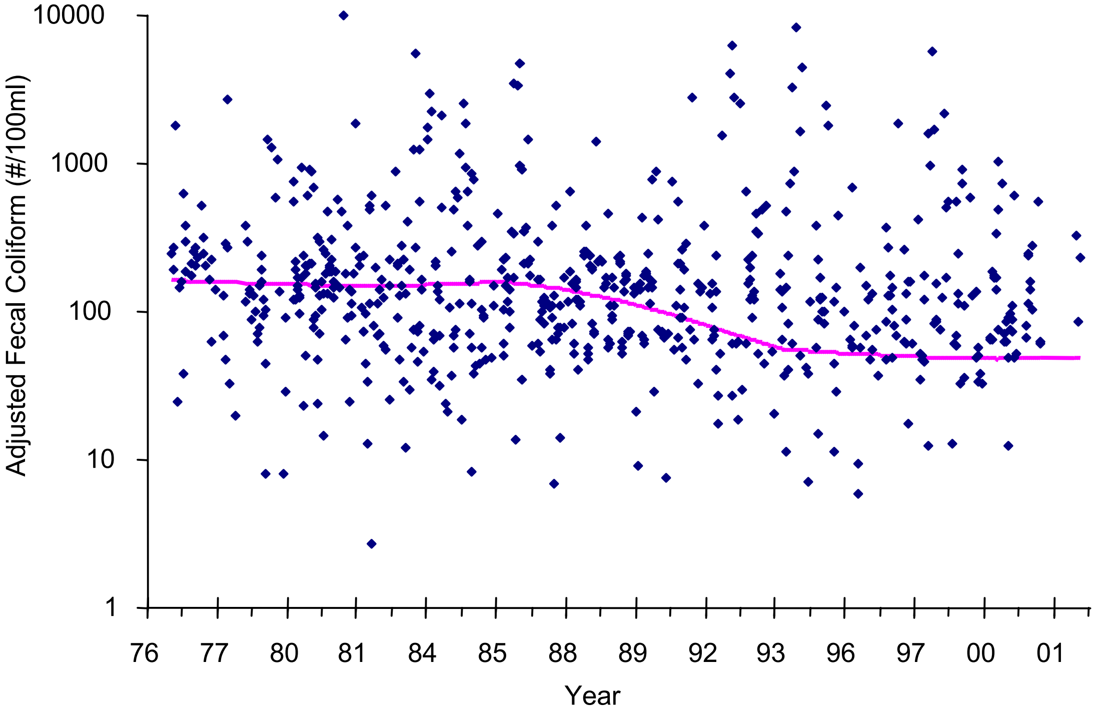


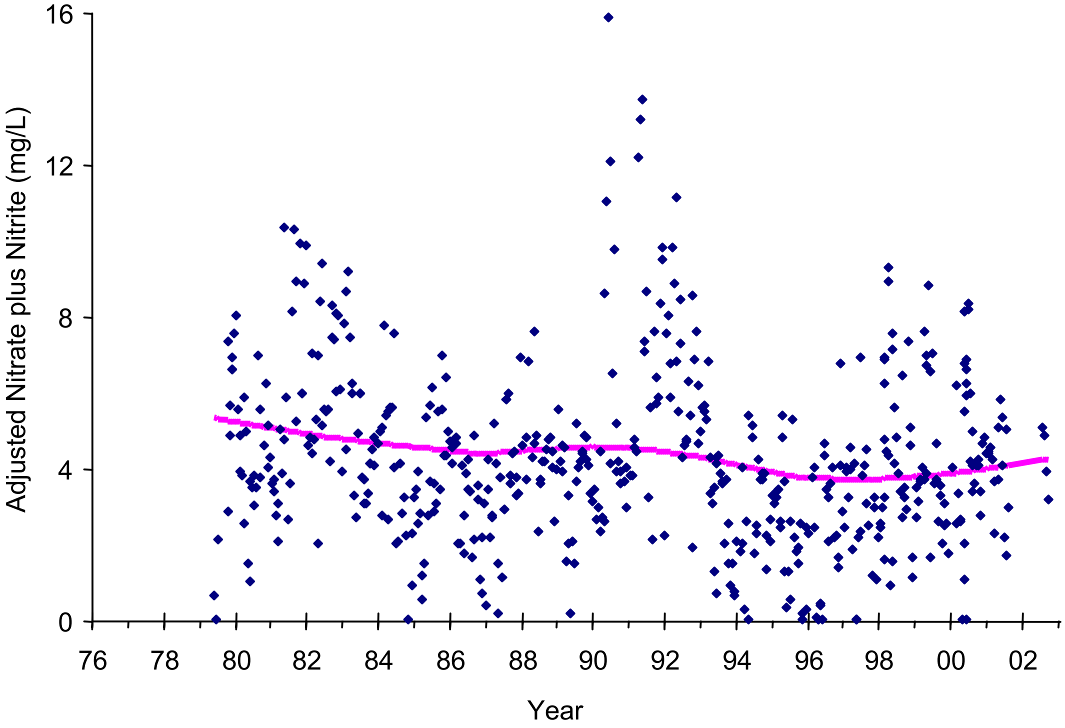
Flow-adjusted chlorophyll-a concentrations plotted against time for the Minnesota River at Jordan.



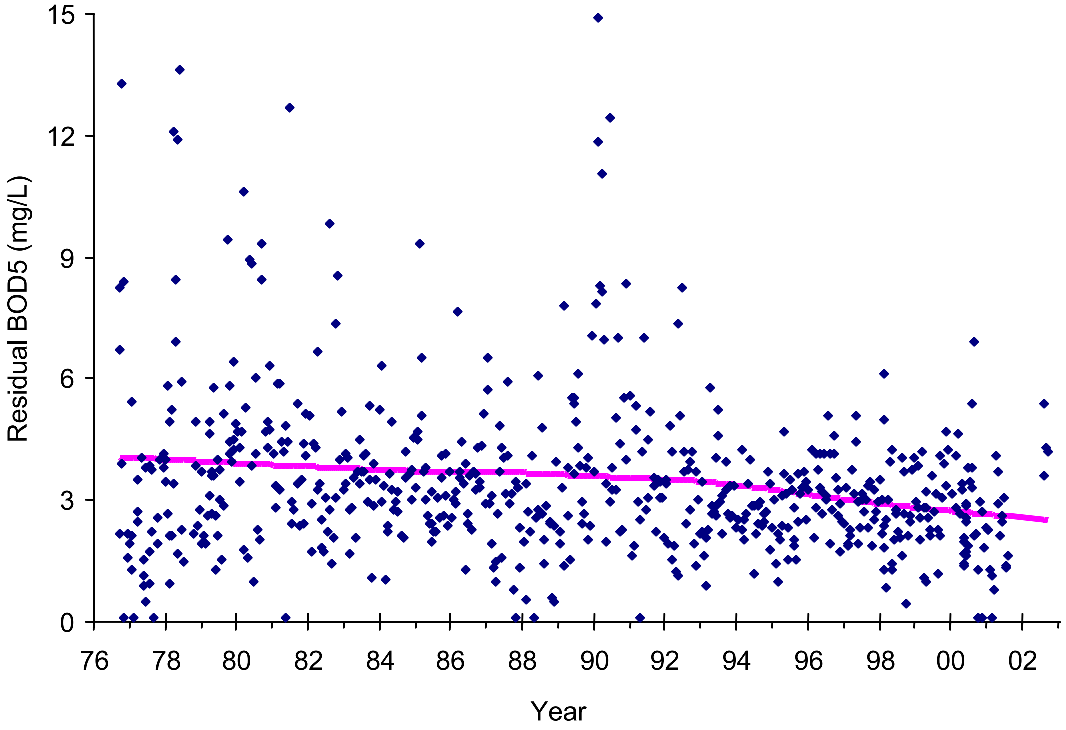
Flow-adjusted dissolved oxygen concentrations plotted against time for the Minnesota River at Jordan.



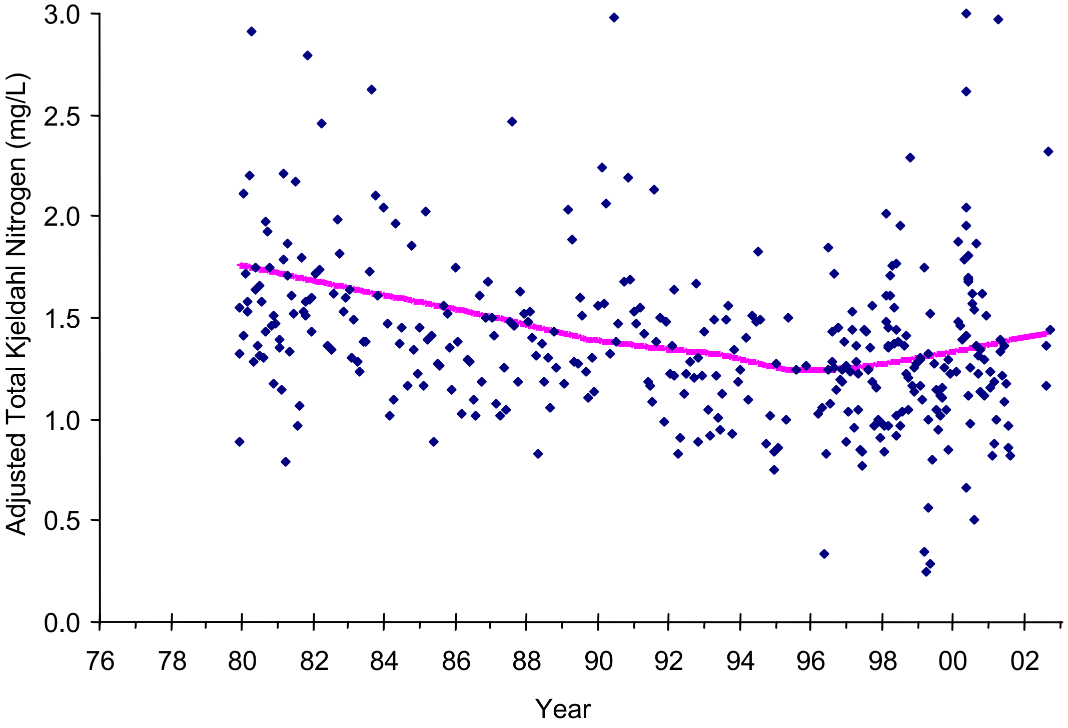
Flow-adjusted fecal coliform bacteria concentrations plotted against time for the Minnesota River at Jordan.



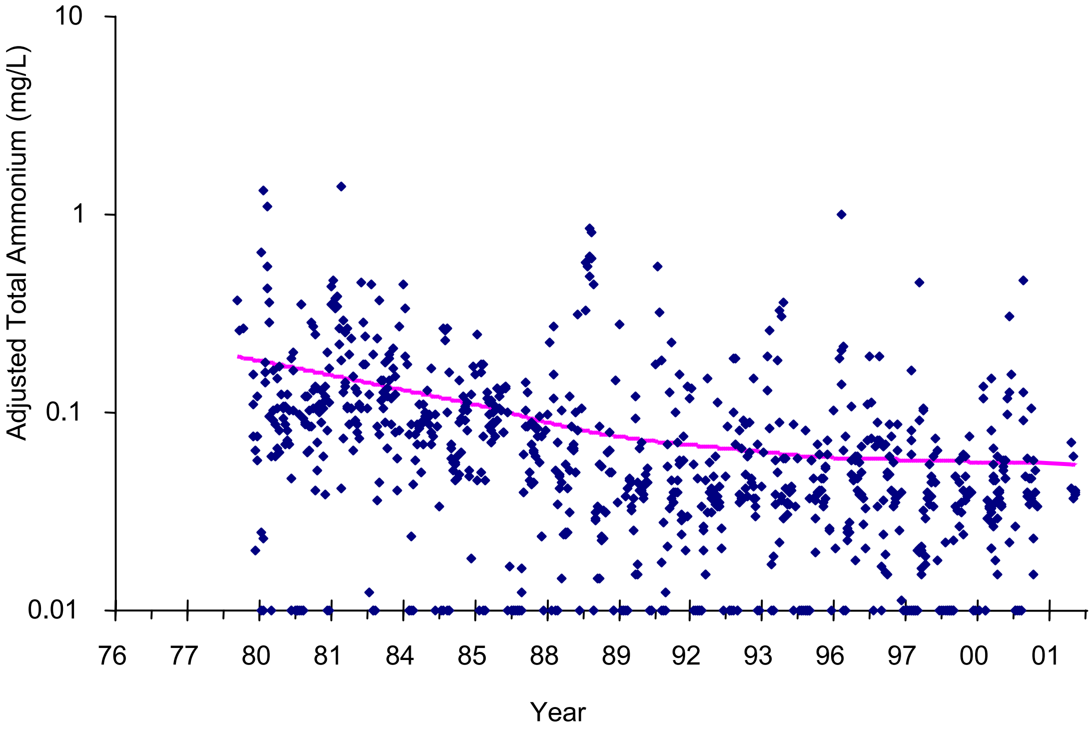
Flow-adjusted nitrate plus nitrite concentrations plotted against time for the Minnesota River at Jordan.



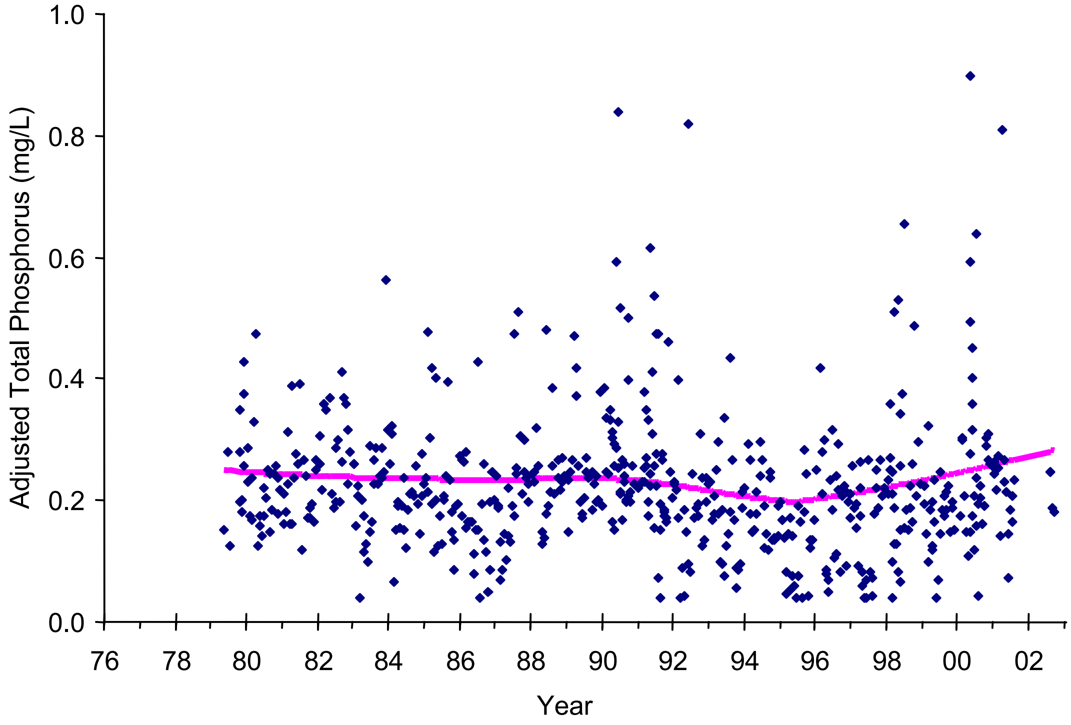
Flow-adjusted 5-day, biochemical oxygen demand concentrations plotted against time for the Minnesota River at Jordan.



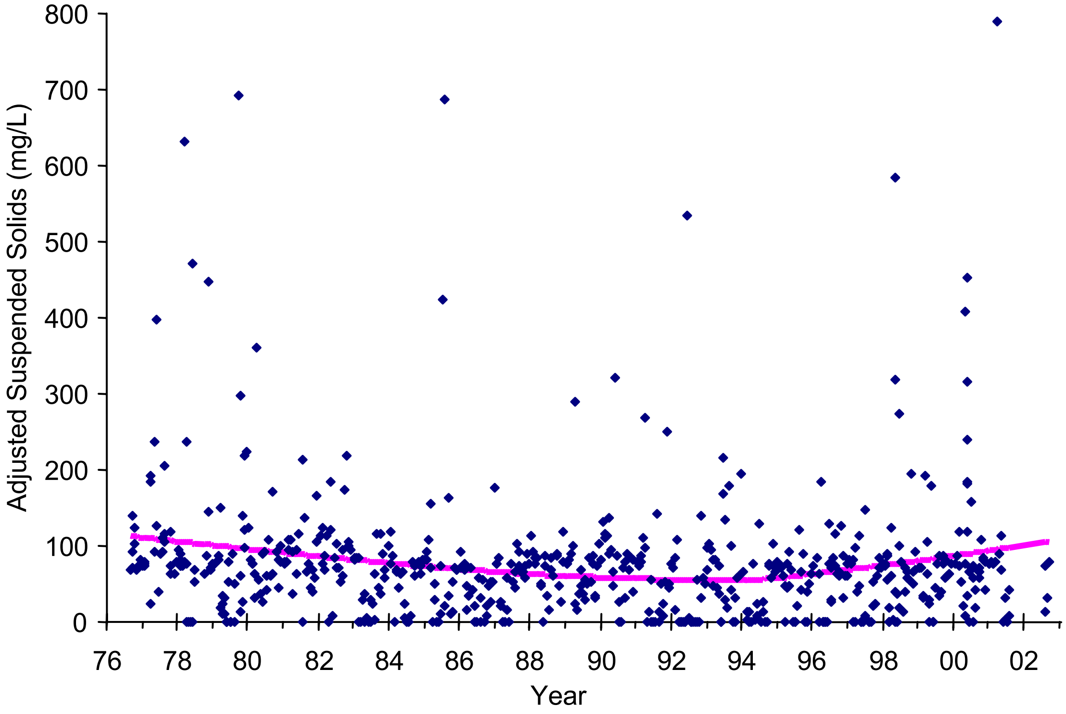
Flow-adjusted total Kjeldahl nitrogen concentrations plotted against time for the Minnesota River at Jordan.



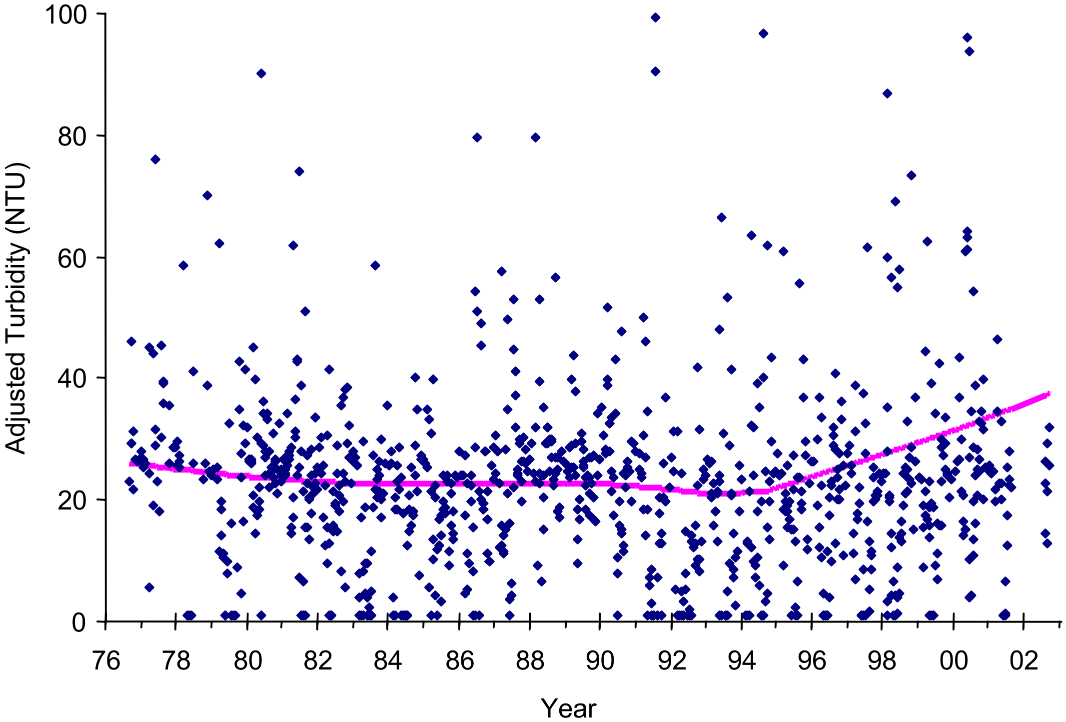
Flow-adjusted ammonia concentrations plotted against time for the Minnesota River at Jordan.



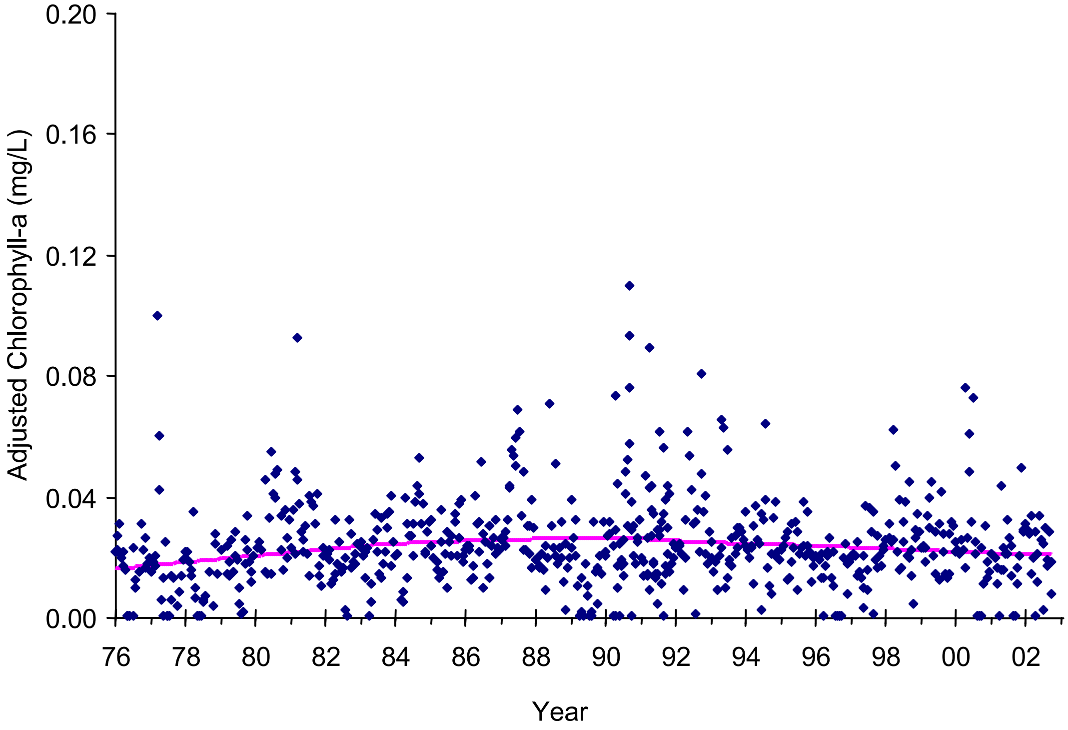
Flow-adjusted total phosphorus concentrations plotted against time for the Minnesota River at Jordan.



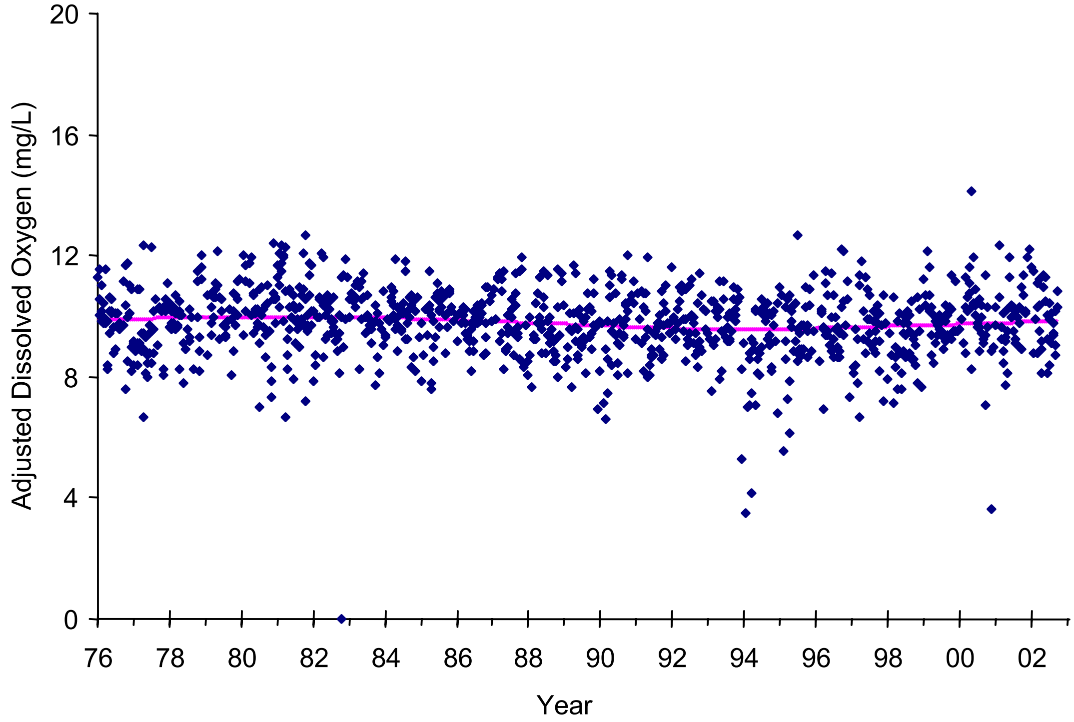
Flow-adjusted total suspended solids concentrations plotted against time for the Minnesota River at Jordan.



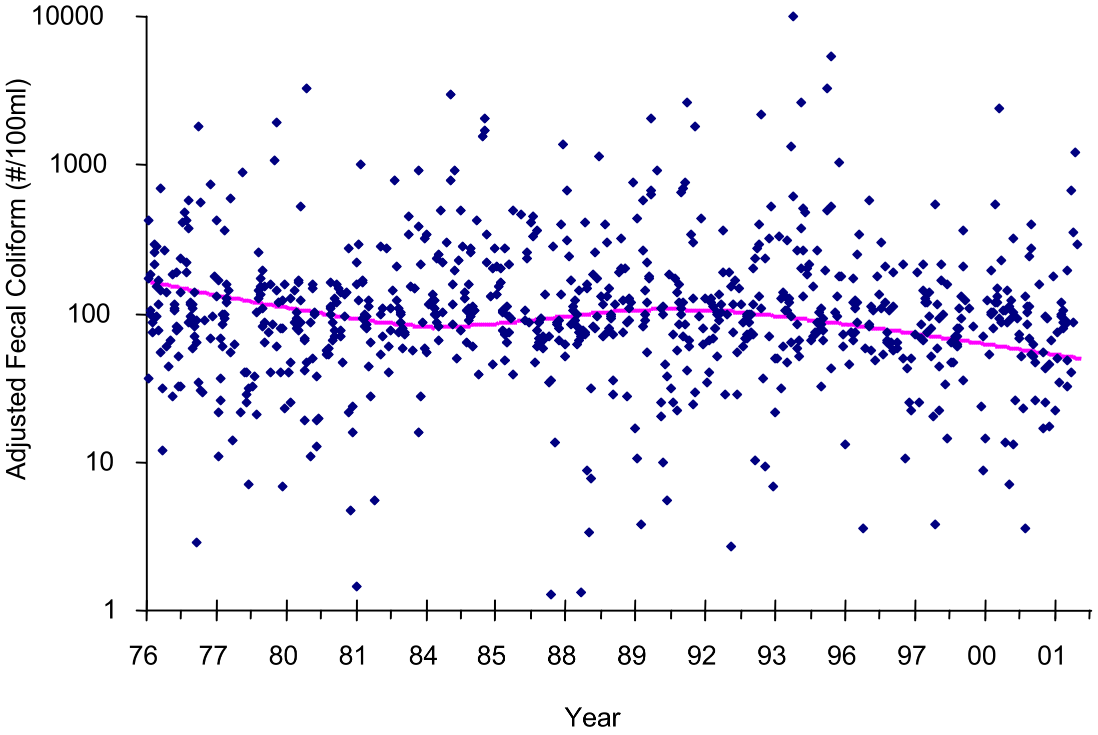
Flow-adjusted turbidity plotted against time for the Minnesota River at Jordan.



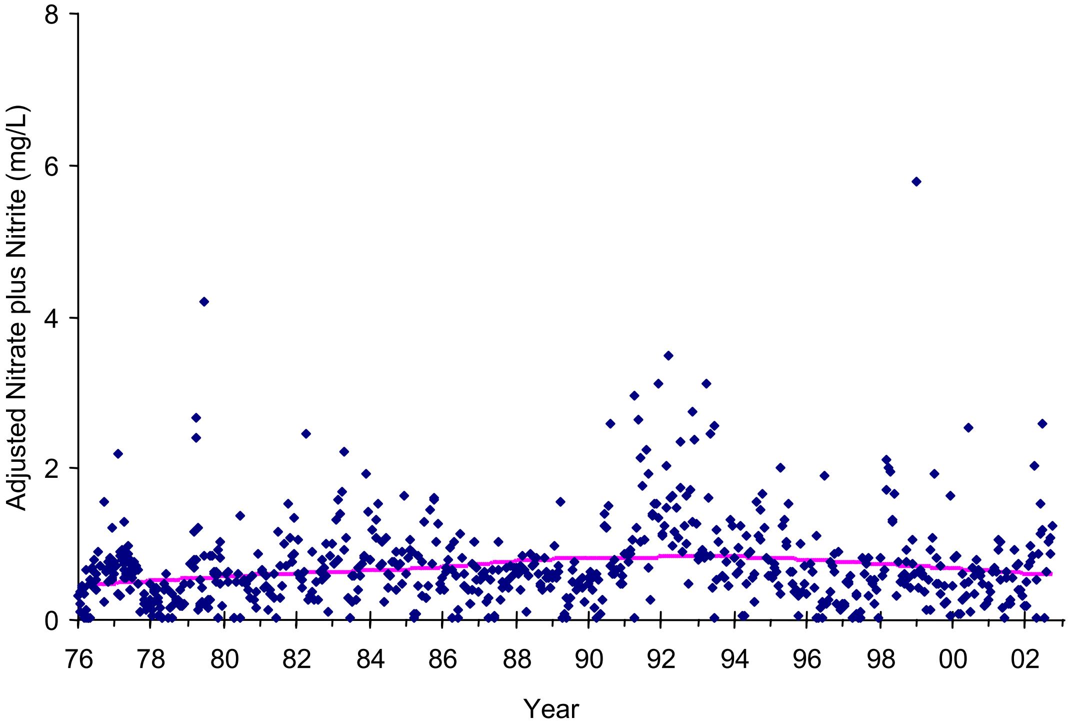
Flow-adjusted chlorophyll-a concentrations plotted against time for the Mississippi River at Anoka.



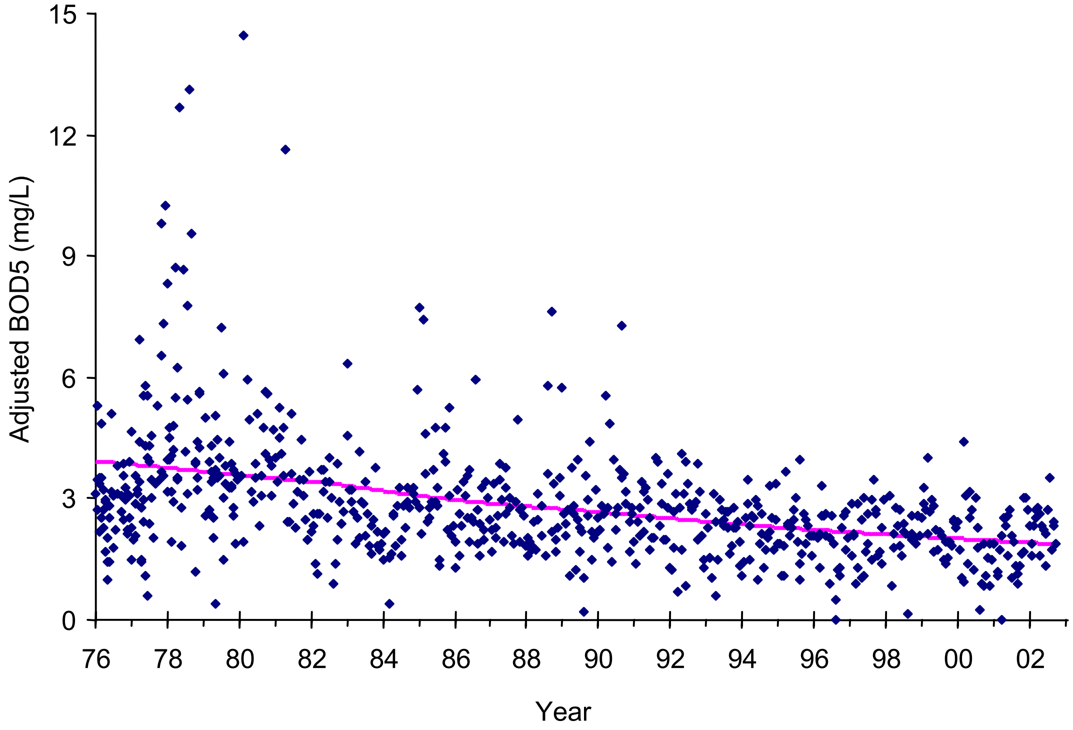
Flow-adjusted dissolved oxygen concentrations plotted against time for the Mississippi River at Anoka.



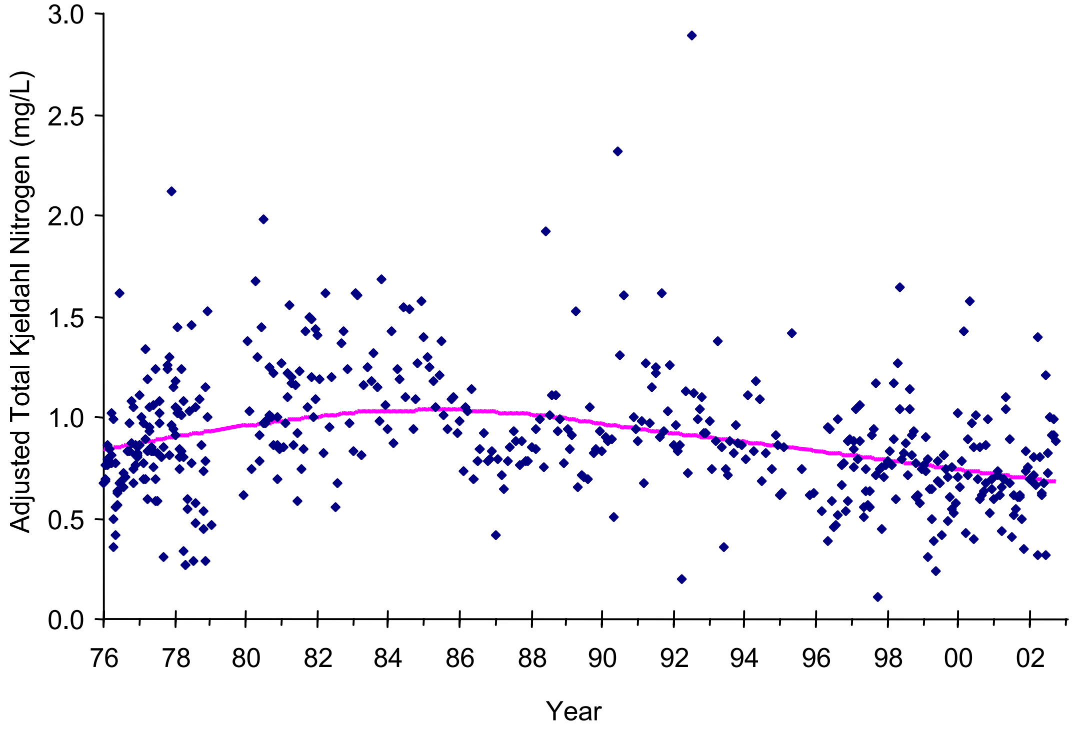
Flow-adjusted fecal coliform bacteria concentrations plotted against time for the Mississippi River at Anoka.



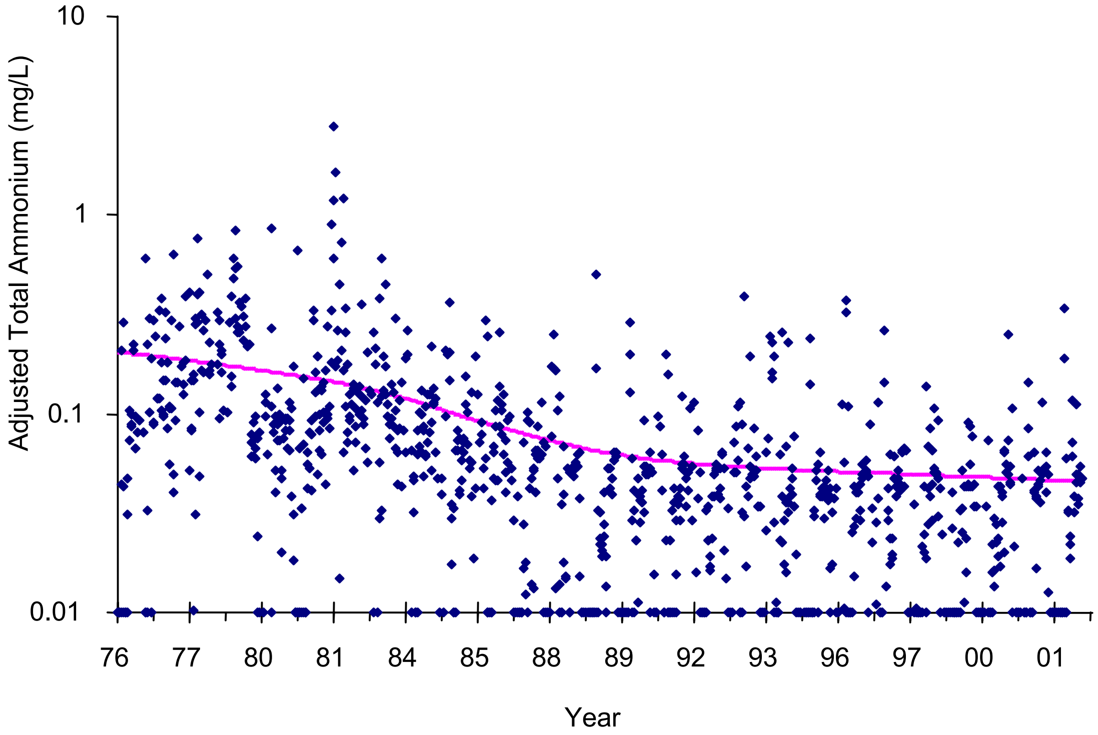
Flow-adjusted nitrate plus nitrite concentrations plotted against time for the Mississippi River at Anoka.



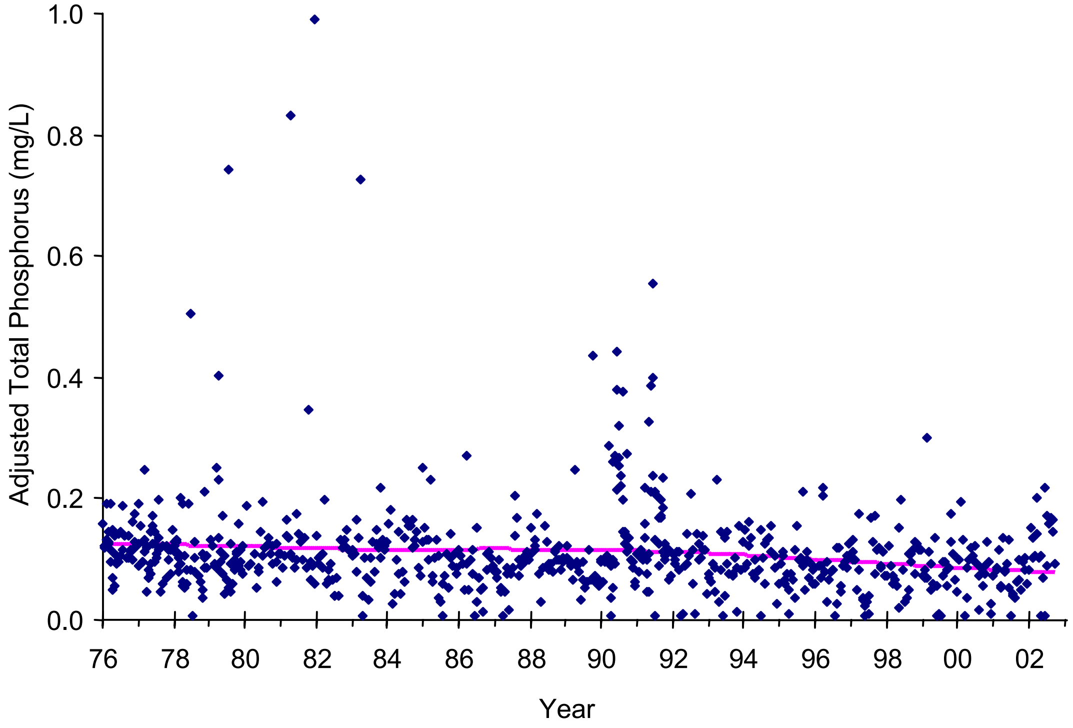
Flow-adjusted 5-day, biochemical oxygen demand concentrations plotted against time for the Mississippi River at Anoka.



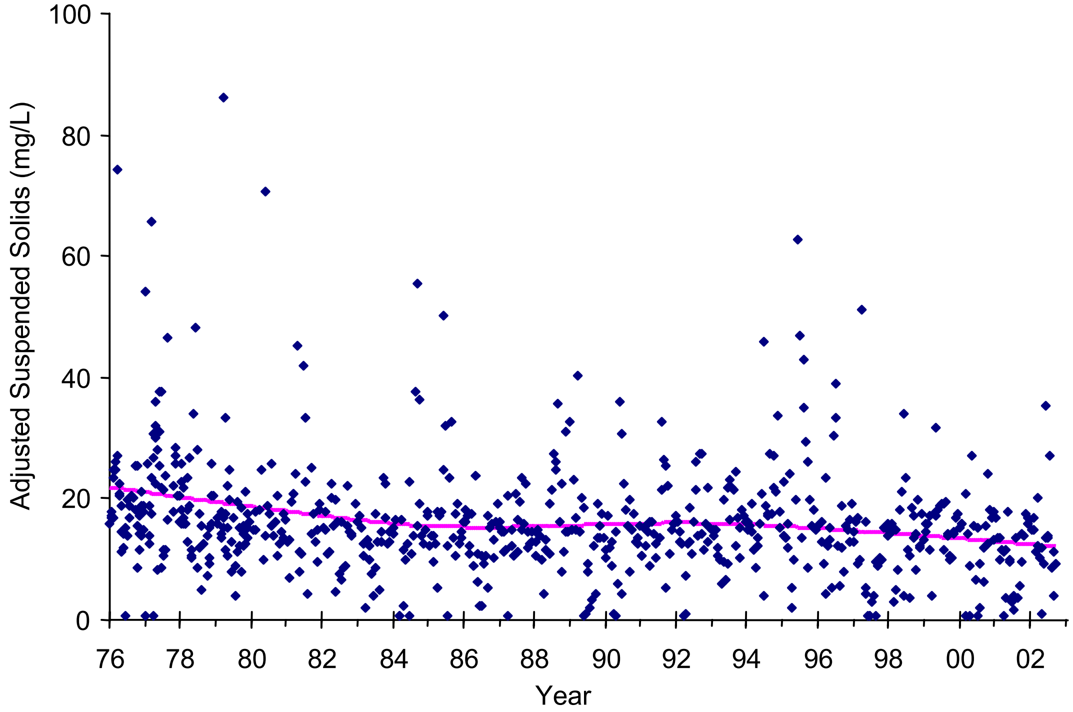
Flow-adjusted total Kjeldahl nitrogen concentrations plotted against time for the Mississippi River at Anoka.



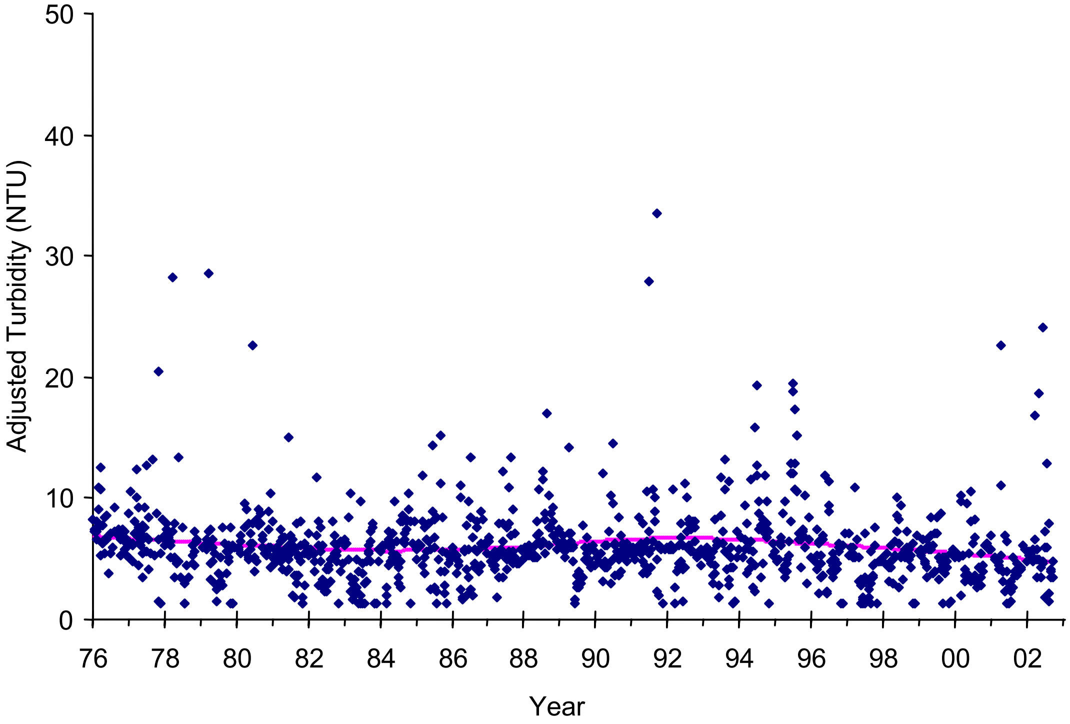
Flow-adjusted ammonia concentrations plotted against time for the Mississippi River at Anoka.



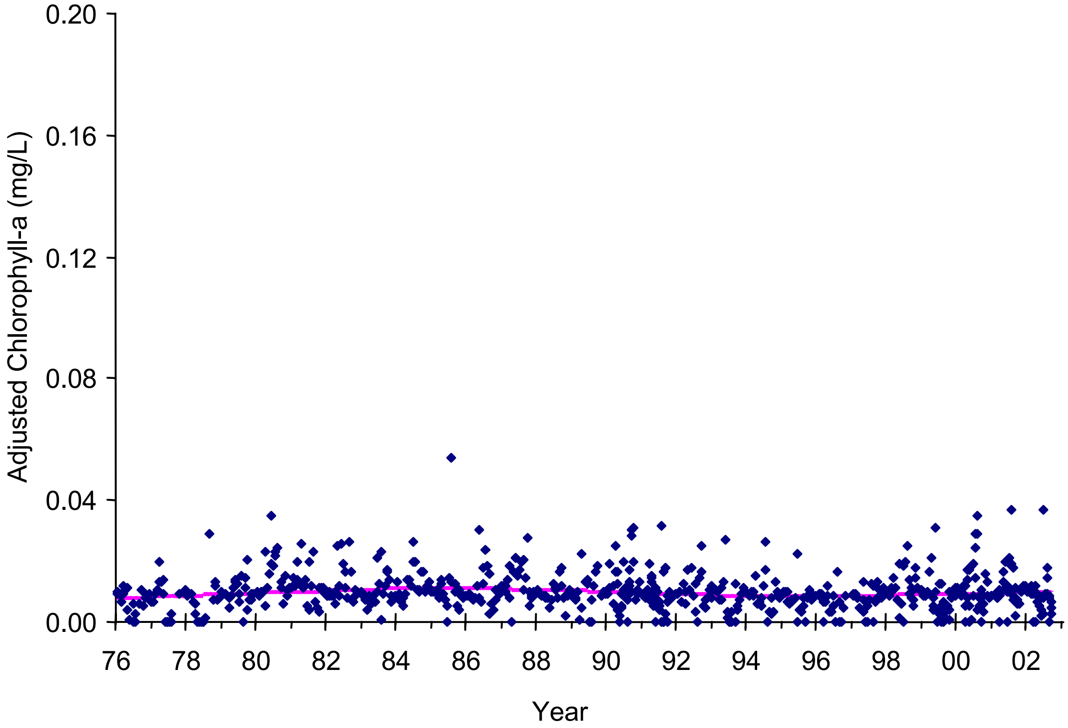
Flow-adjusted total phosphorus concentrations plotted against time for the Mississippi River at Anoka.



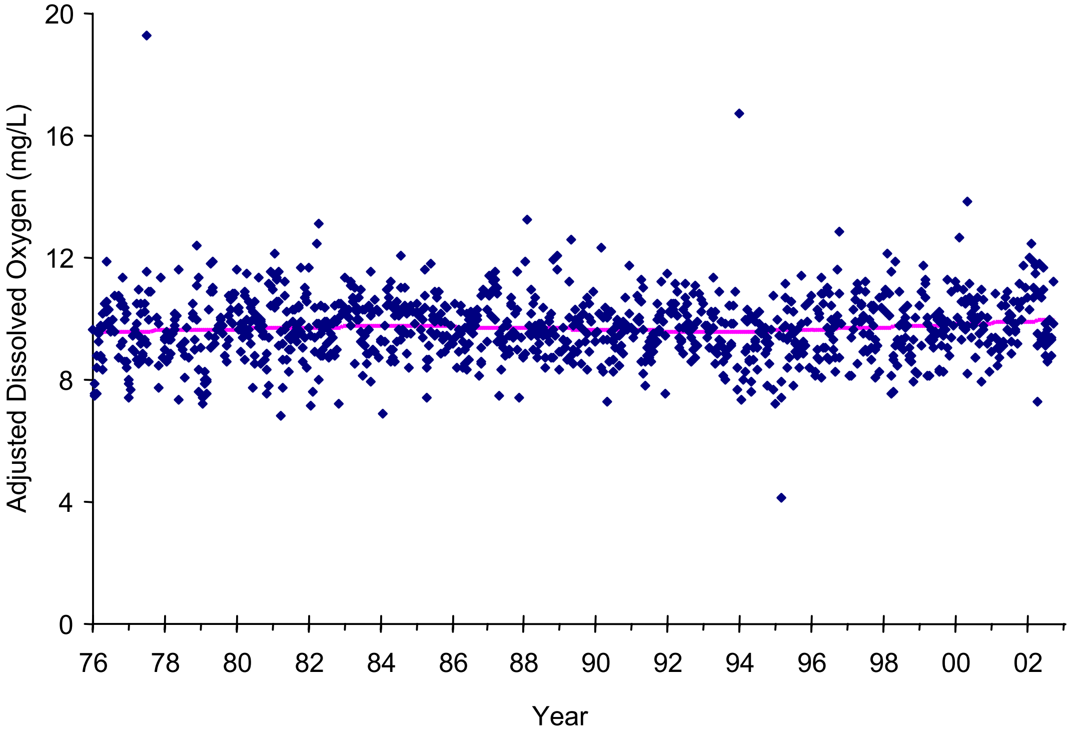
Flow-adjusted total suspended solids concentrations plotted against time for the Mississippi River at Anoka.



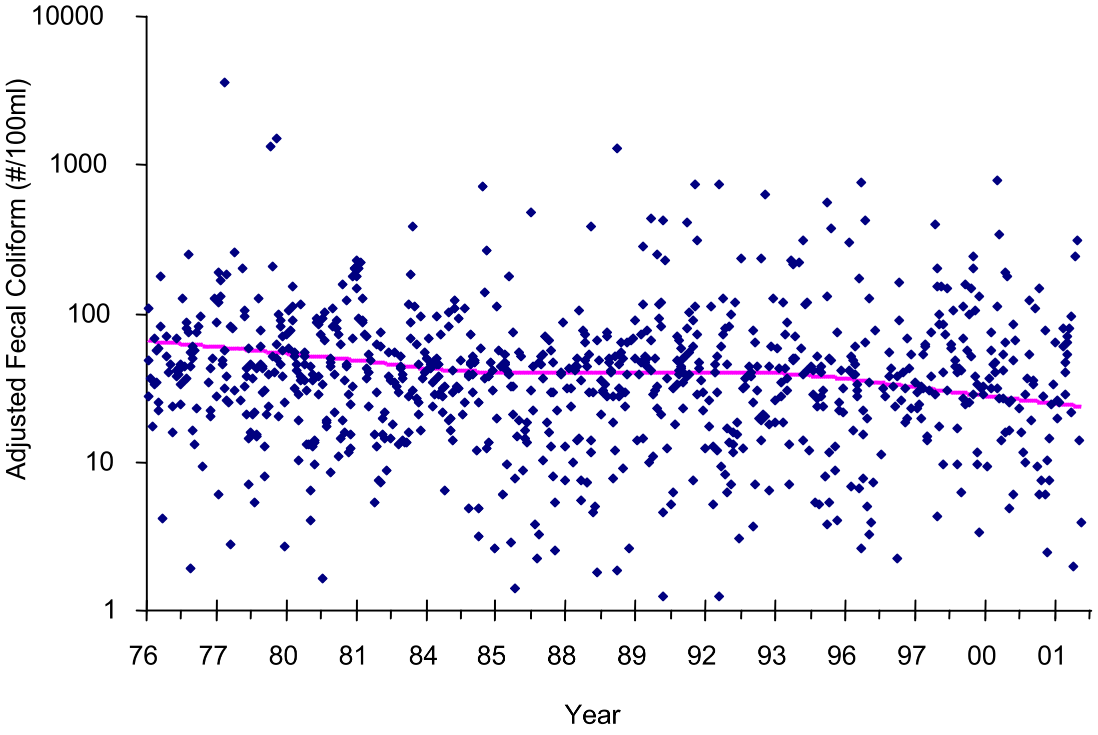
Flow-adjusted turbidity plotted against time for the Mississippi River at Anoka.



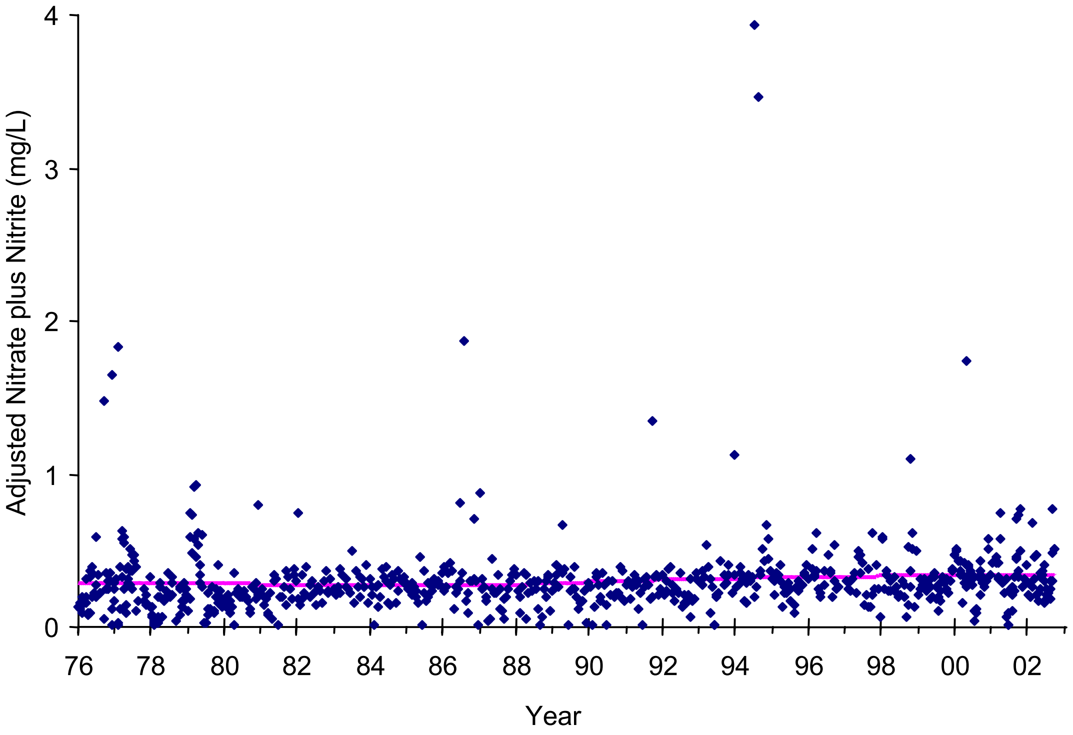
Flow-adjusted chlorophyll-a concentrations plotted against time for the St. Croix River at Stillwater.



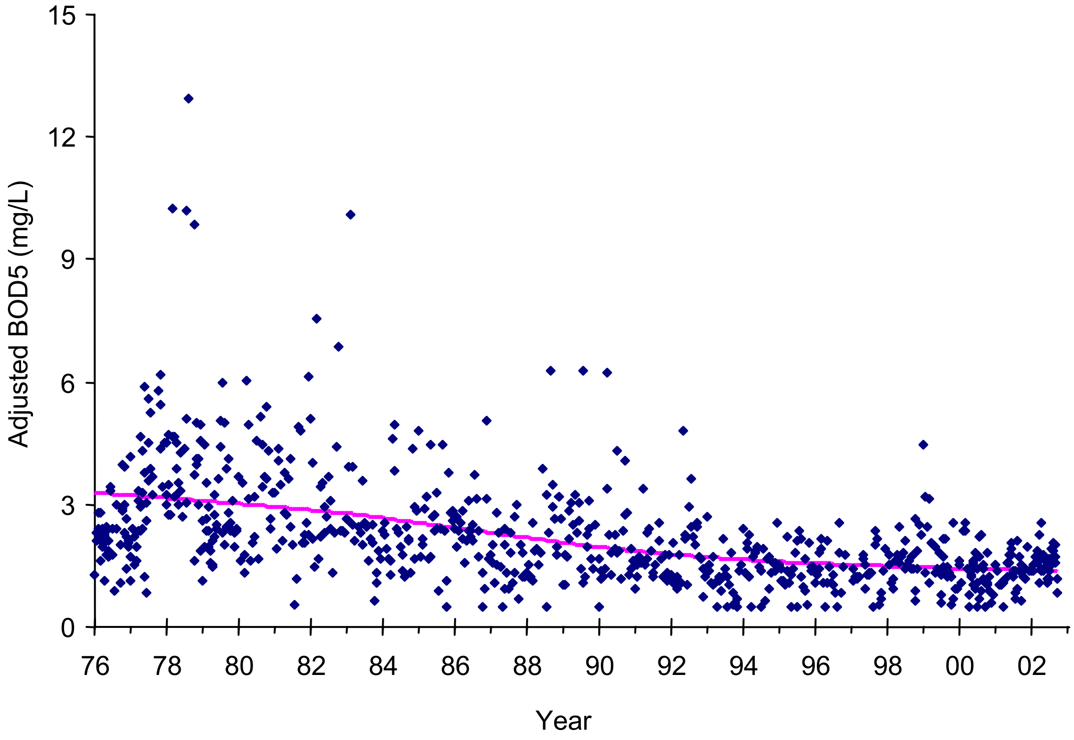
Flow-adjusted dissolved oxygen concentrations plotted against time for the St. Croix River at Stillwater.



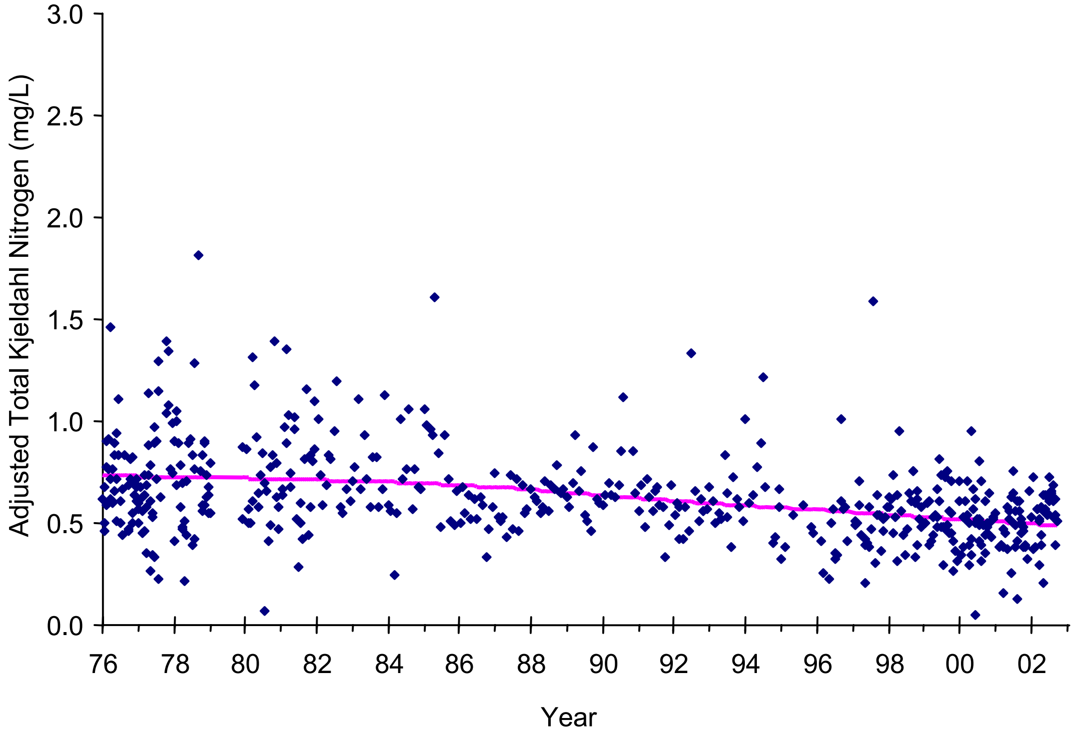
Flow-adjusted fecal coliform bacteria concentrations plotted against time for the St. Croix River at Stillwater.



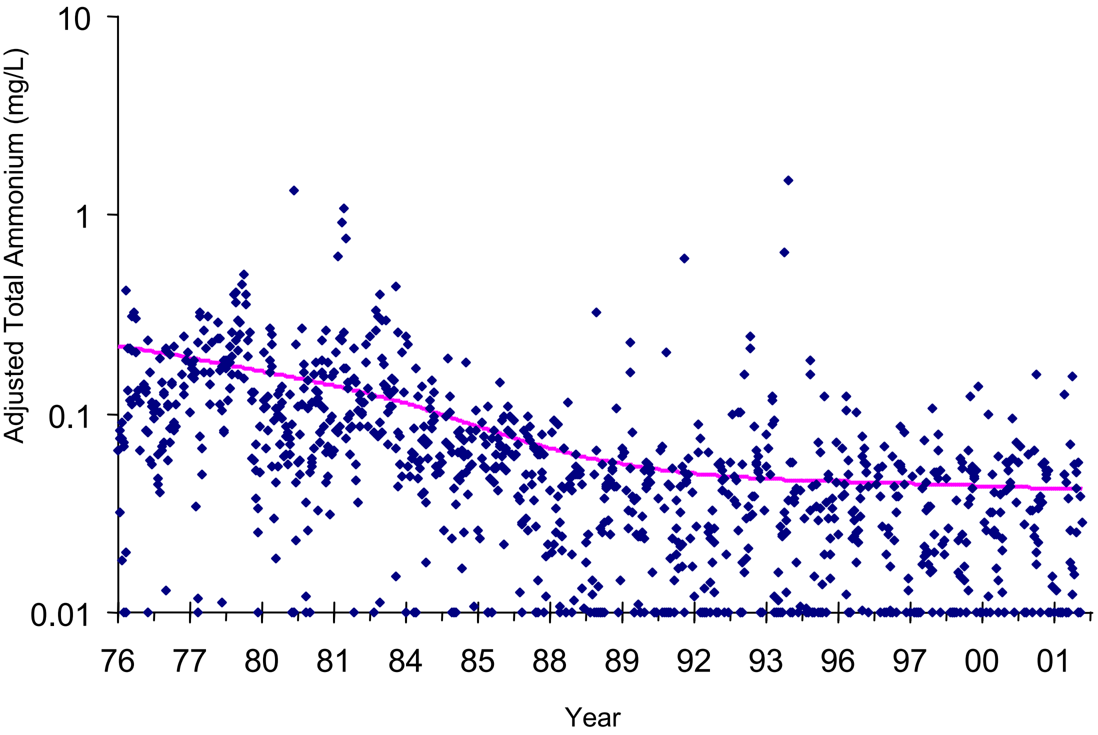
Flow-adjusted nitrate plus nitrite concentrations plotted against time for the St. Croix River at Stillwater.



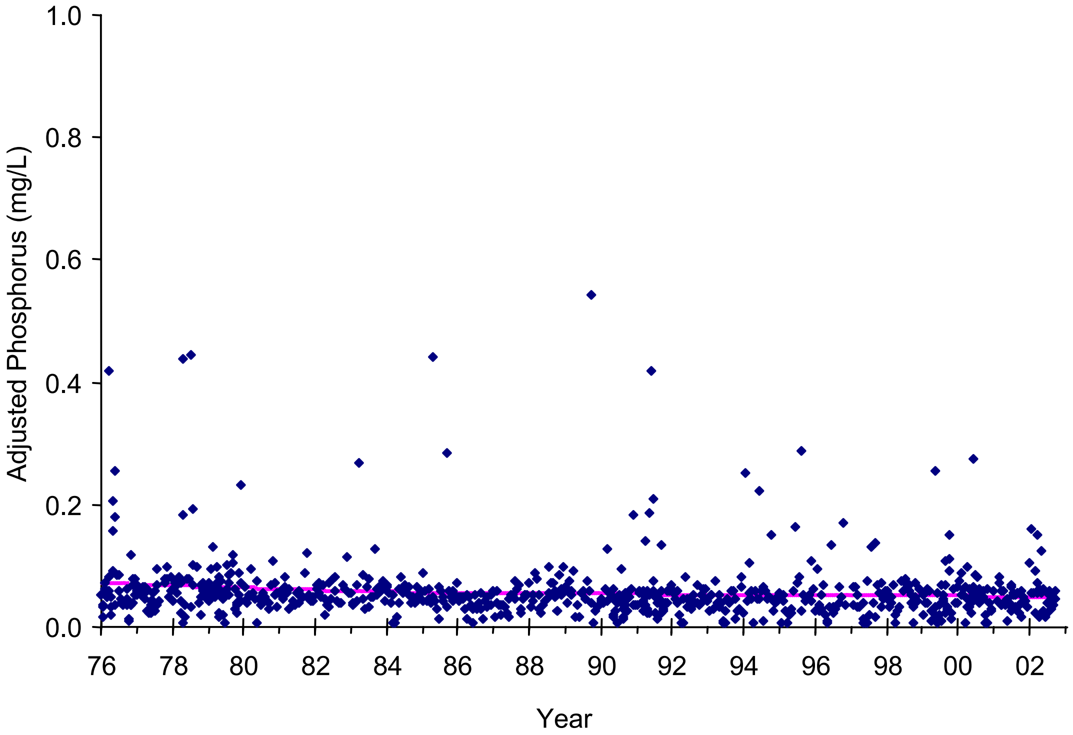
Flow-adjusted 5-day, biochemical oxygen demand concentrations plotted against time for the St. Croix River at Stillwater.



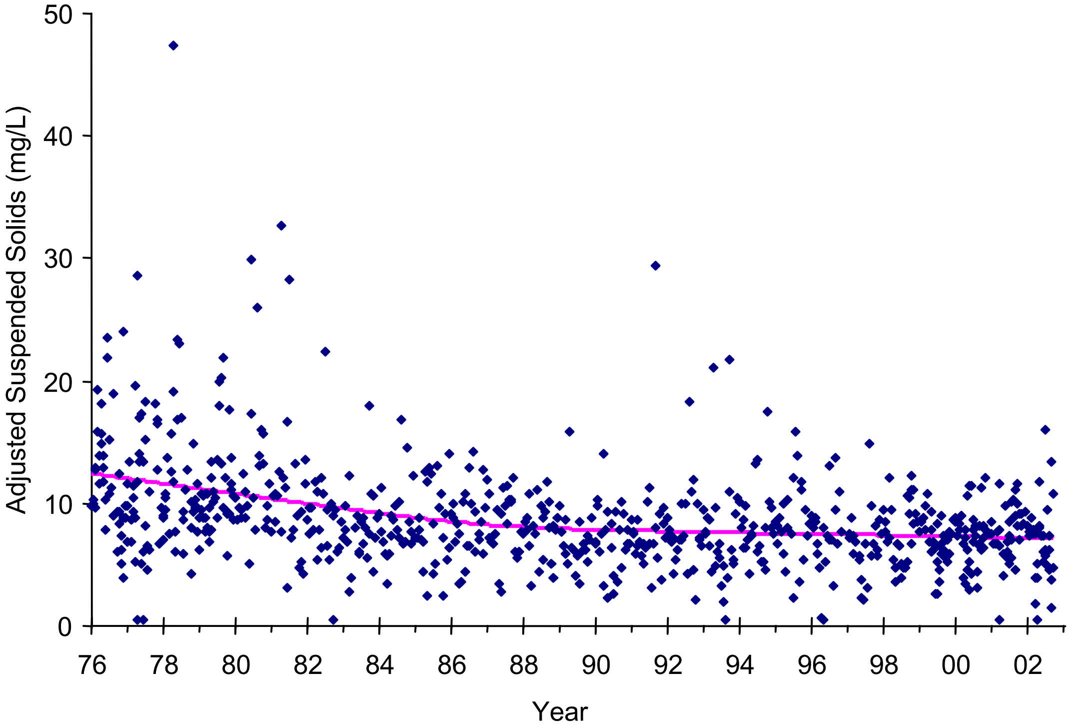
Flow-adjusted total Kjeldahl nitrogen concentrations plotted against time for the St. Croix River at Stillwater.



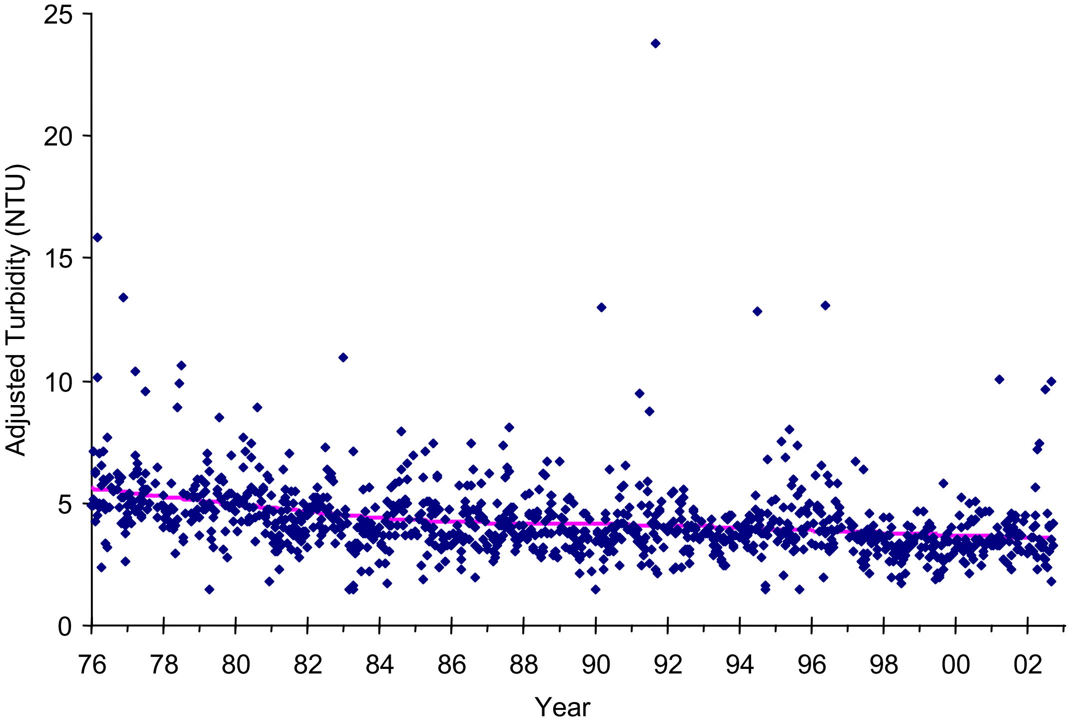
Flow-adjusted ammonia concentrations plotted against time for the St. Croix River at Stillwater.



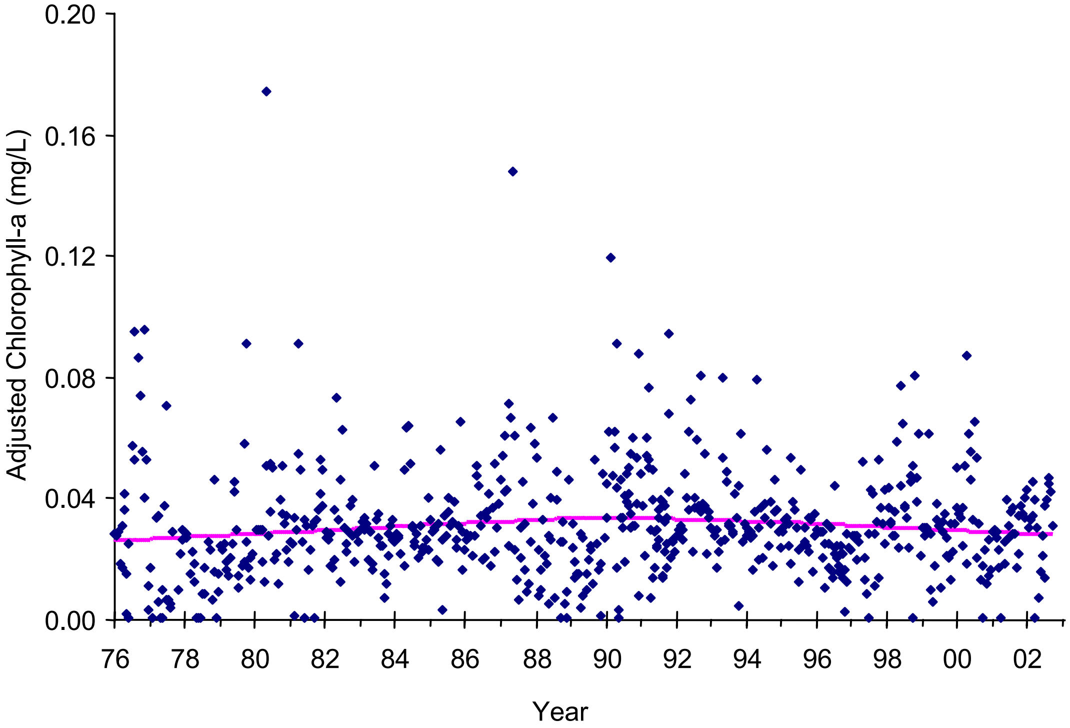
Flow-adjusted total phosphorus concentrations plotted against time for the St. Croix River at Stillwater.



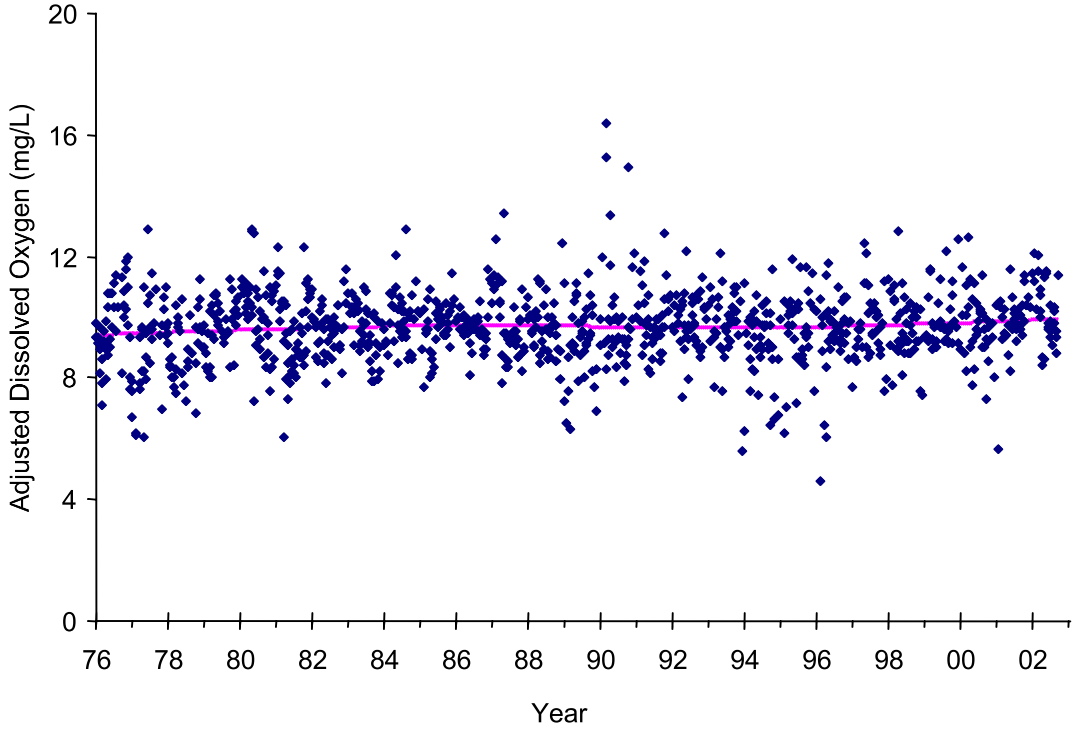
Flow-adjusted total suspended solids concentrations plotted against time for the St. Croix River at Stillwater.



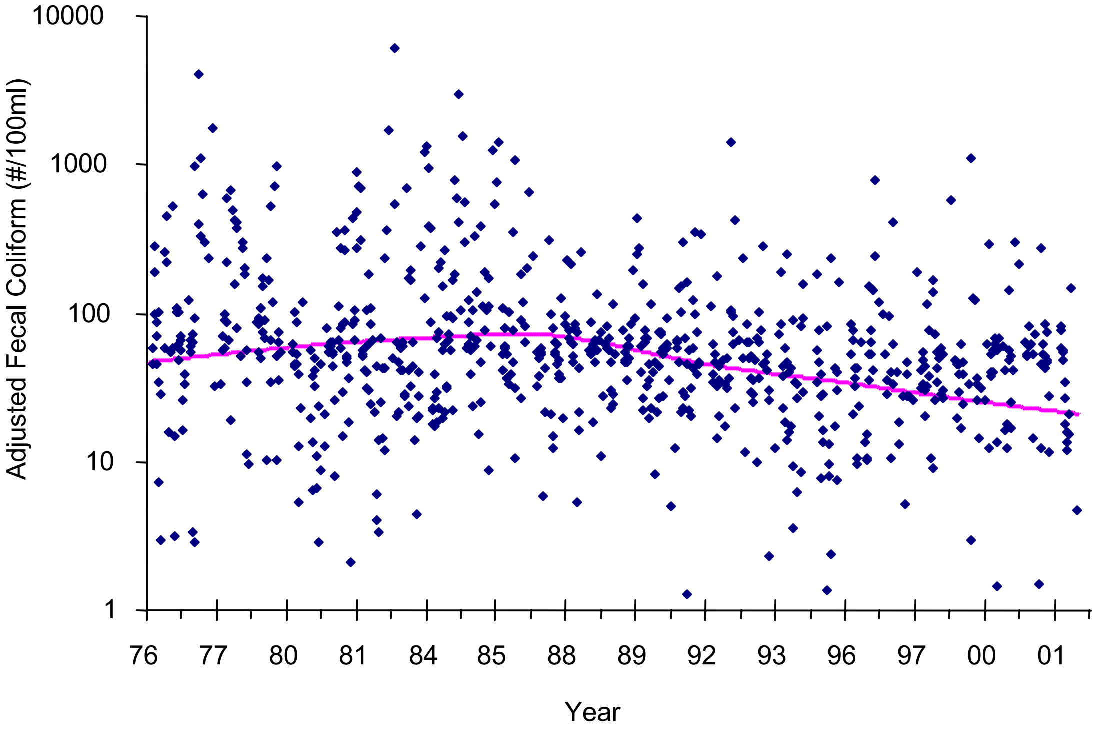
Flow-adjusted turbidity plotted against time for the St. Croix River at Stillwater.



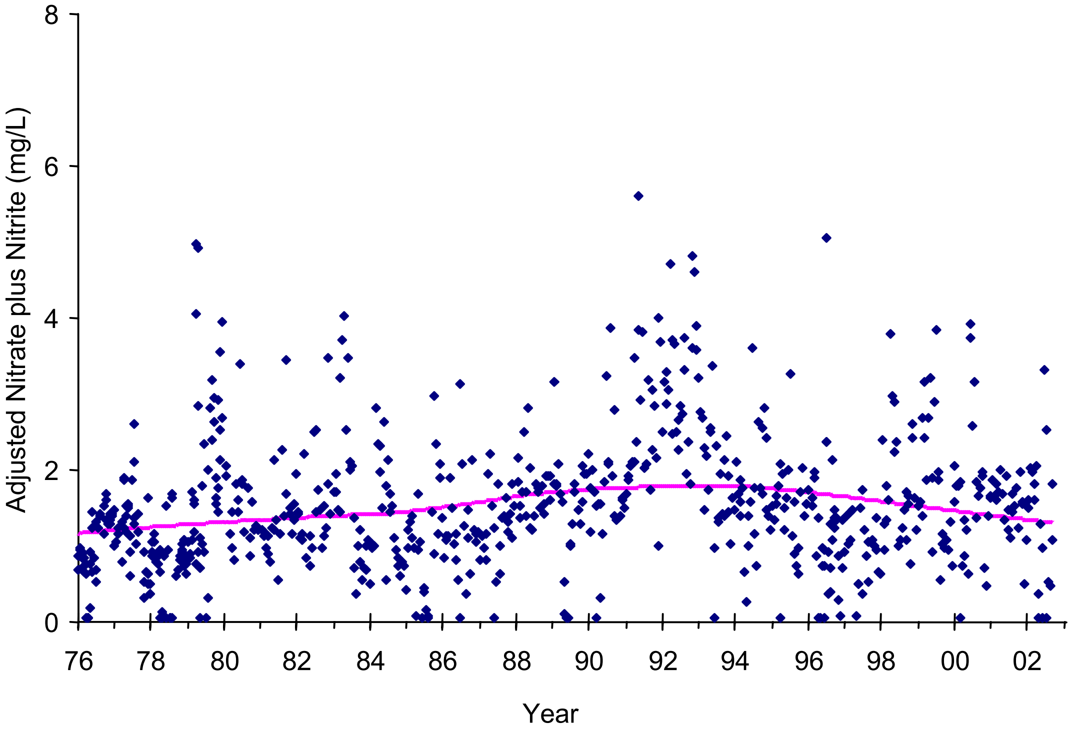
Flow-adjusted chlorophyll-a concentrations plotted against time for the Mississippi River at Red Wing.



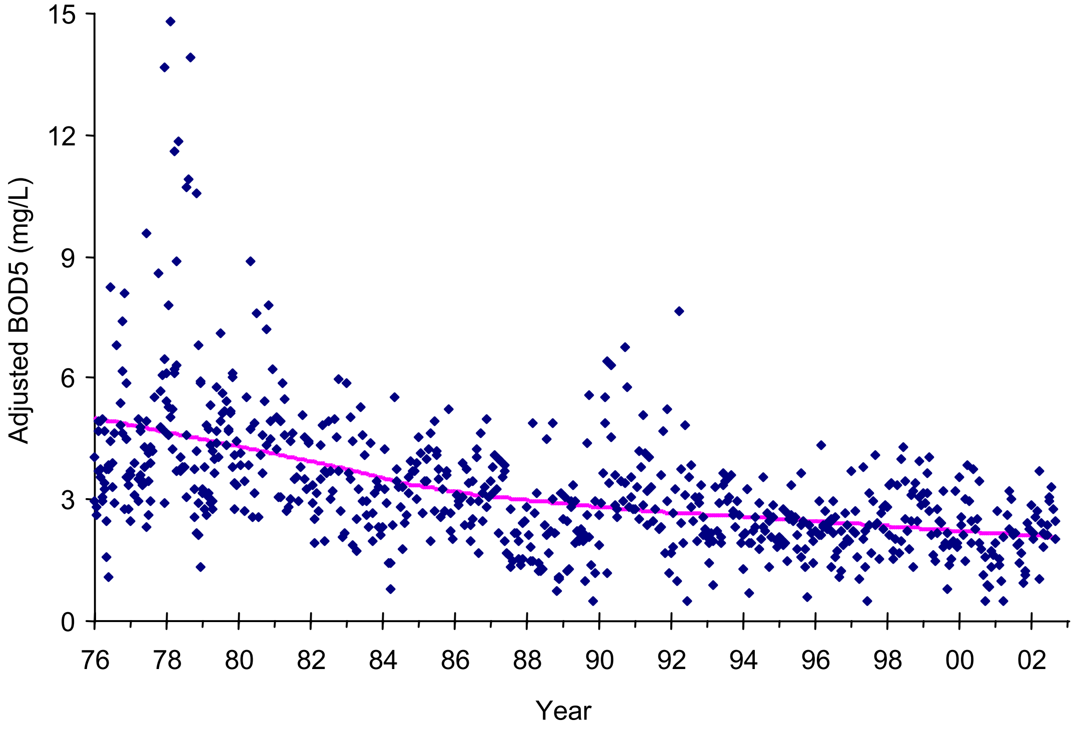
Flow-adjusted dissolved oxygen concentrations plotted against time for the Mississippi River at Red Wing.



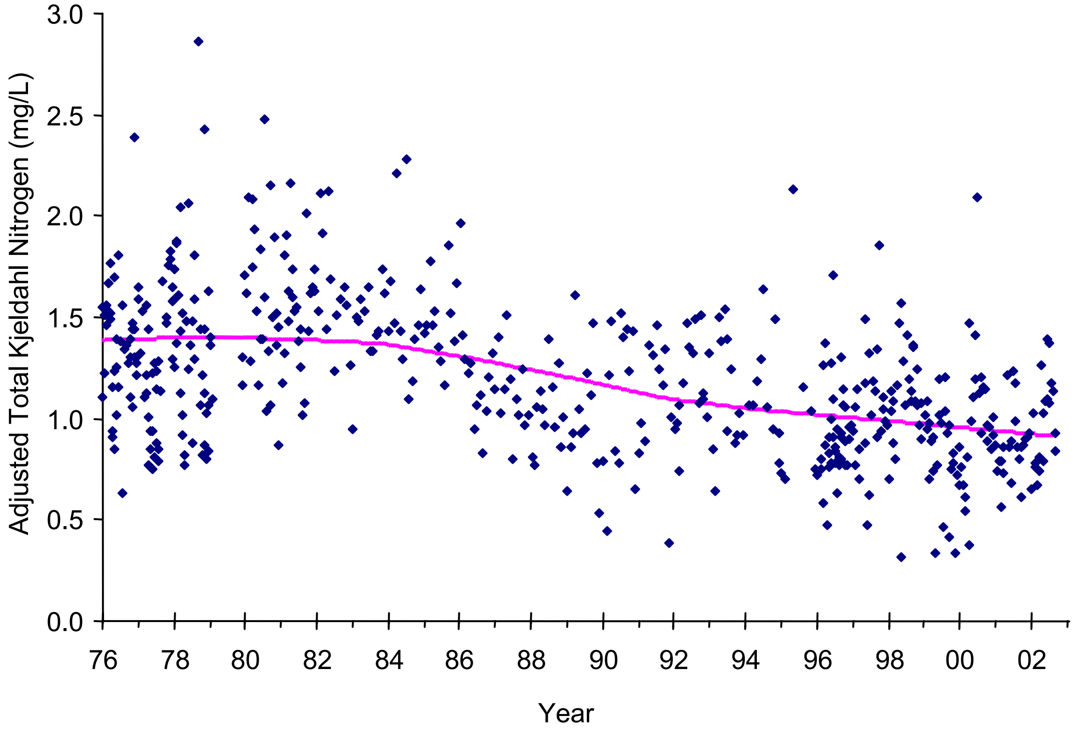
Flow-adjusted fecal coliform bacteria concentrations plotted against time for the Mississippi River at Red Wing.



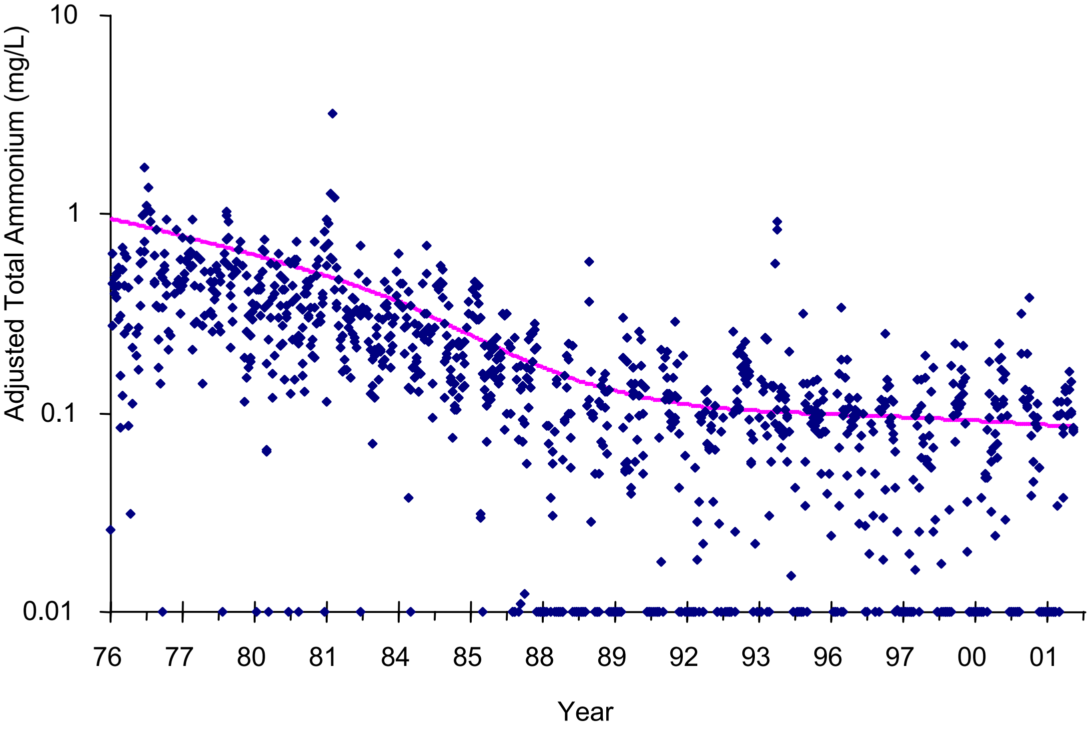
Flow-adjusted nitrate plus nitrite concentrations plotted against time for the Mississippi River at Red Wing.



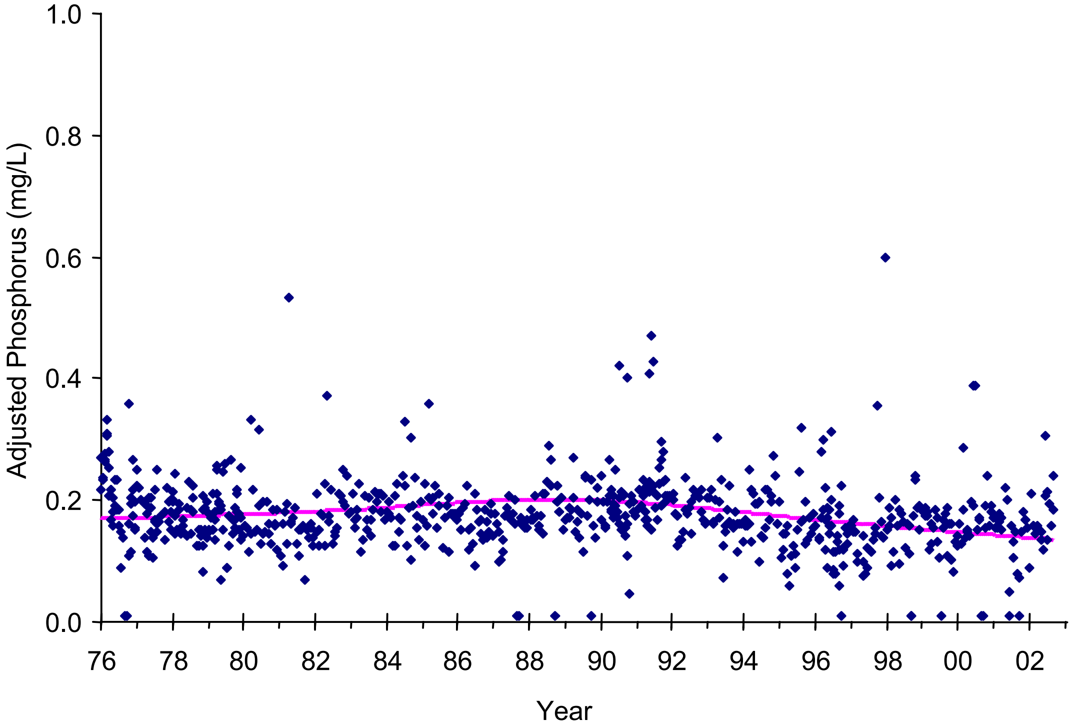
Flow-adjusted 5-day, biochemical oxygen demand concentrations plotted against time for the Mississippi River at Red Wing.



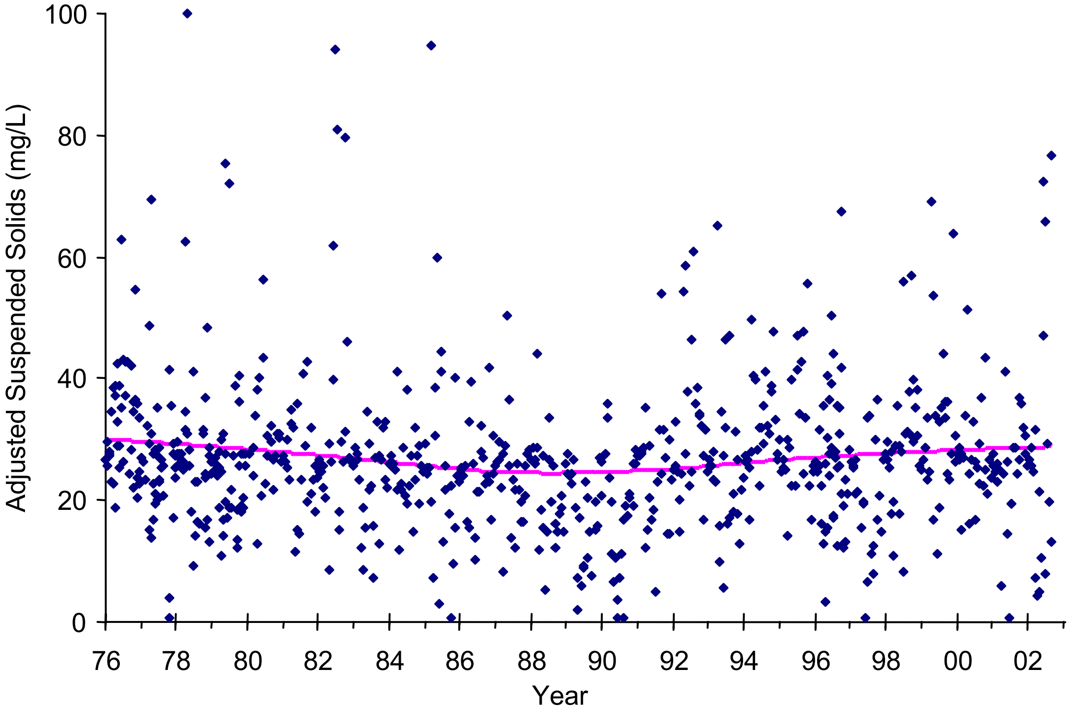
Flow-adjusted total Kjeldahl nitrogen concentrations plotted against time for the Mississippi River at Red Wing.



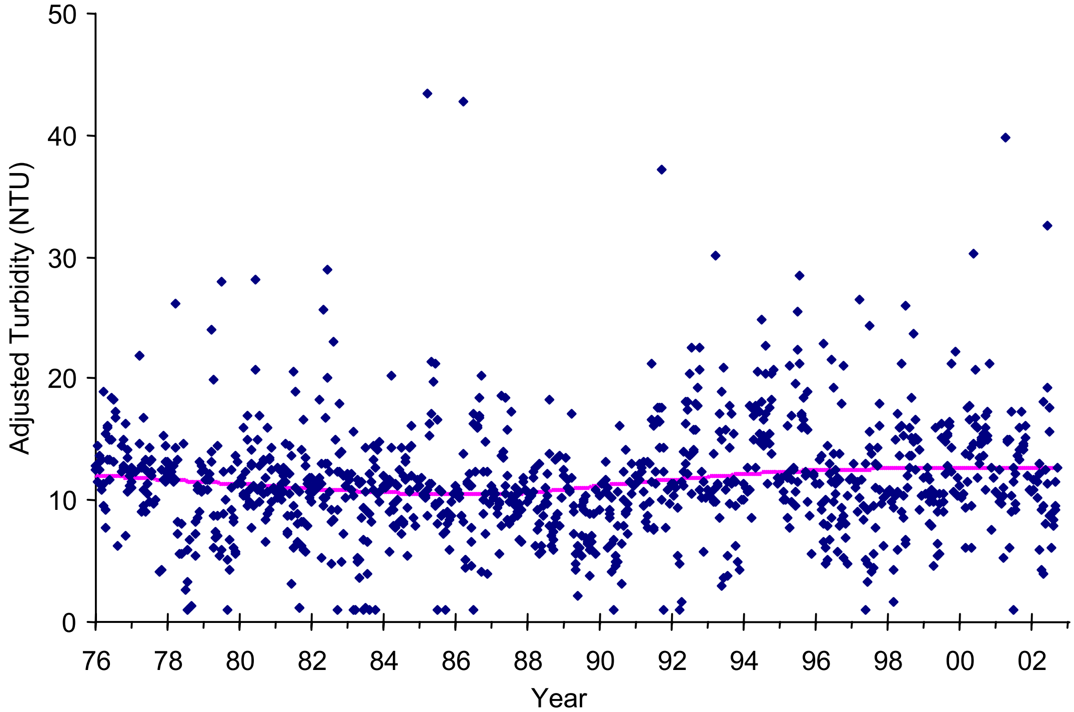
Flow-adjusted ammonia concentrations plotted against time for the Mississippi River at Red Wing.



Flow-adjusted total phosphorus concentrations plotted against time for the Mississippi River at Red Wing.



Flow-adjusted total suspended solids concentrations plotted against time for the Mississippi River at Red Wing.



Flow-adjusted turbidity plotted against time for the Mississippi River at Red Wing.

APPENDIX B – POLLUTANT LOADING METADATA

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Site	Parameter	Analysis Period	Year	Stratification Scheme	Calculation Method	Confidence Rating	Samples Used	Flow (hm3)	Model-Conc (mg/L)	Model-Mass (tonnes)	CV	Interp-Conc (mg/L)	Interp-Mass (tonnes)
MI0394	NOx	1980-83	1980	Seasonal	4 REG-1	Good	23	2,495	7.344	18,323	0.075	6.855	17,102
MI0394	NOx	1980-83	1981	Seasonal	4 REG-1	Good	23	2,375	7.144	16,968	0.075	7.308	17,355
MI0394	NOx	1980-83	1982	Seasonal	4 REG-1	Good	22	4,640	7.552	35,042	0.075	7.408	34,374
MI0394	NOx	1980-83	1983	Seasonal	4 REG-1	Good	23	7,545	7.581	57,193	0.075	6.970	52,585
MI0394	NOx	1984-86	1984	Seasonal	4 REG-1	Excellent	20	8,639	5.537	47,829	0.079	5.477	47,315
MI0394	NOx	1984-86	1985	Seasonal	4 REG-1	Excellent	24	5,674	5.584	31,685	0.079	5.640	32,002
MI0394	NOx	1984-86	1986	Seasonal	4 REG-1	Excellent	24	10,202	5.578	56,901	0.079	5.378	54,860
MI0394	NOx	1987-90	1987	Seasonal	4 REG-1	Good	23	2,082	4.940	10,282	0.169	4.591	9,555
MI0394	NOx	1987-90	1988	Seasonal	4 REG-1	Good	20	1,089	4.643	5,056	0.169	4.760	5,184
MI0394	NOx	1987-90	1989	Seasonal	4 REG-1	Good	22	1,127	4.984	5,617	0.169	4.663	5,255
MI0394	NOx	1987-90	1990	Seasonal	4 REG-1	Good	23	2,314	6.794	15,724	0.169	6.560	15,183
MI0394	NOx	1991 – 01	1991	Seasonal	4 REG-1	Excellent	22	7,157	10.110	72,357	0.090	10.25	73,345
MI0394	NOx	1991 – 01	1992	Seasonal	4 REG-1	Excellent	24	7,342	10.209	74,954	0.090	9.88	72,502
MI0394	NOx	1991 – 01	1993	Seasonal	4 REG-1	Excellent	62	14,913	4.913	73,268	0.029	4.39	65,513
MI0394	NOx	1991 – 01	1994	Seasonal	4 REG-1	Excellent	58	7,657	4.725	36,179	0.029	4.86	37,190
MI0394	NOx	1991 – 01	1995	Seasonal	4 REG-1	Excellent	64	8,692	4.812	41,826	0.029	4.76	41,383
MI0394	NOx	1991 – 01	1996	Seasonal	4 REG-1	Excellent	50	5,558	4.947	27,495	0.029	4.96	27,540
MI0394	NOx	1991 – 01	1997	Seasonal	4 REG-1	Excellent	47	9,060	4.879	44,204	0.029	4.55	41,232
MI0394	NOx	1991 – 01	1998	Seasonal	4 REG-1	Good	38	5,561	7.792	43,331	0.069	7.71	42,886
MI0394	NOx	1991 – 01	1999	Seasonal	4 REG-1	Good	44	5,438	7.393	40,203	0.038	7.34	39,904
MI0394	NOx	1991 – 01	2000	Seasonal	4 REG-1	Good	33	2,455	6.740	16,547	0.032	7.12	17,470
MI0394	NOx	1991 – 01	2001	Seasonal	4 REG-1	Good	17	9,430	7.425	70,018	0.032	6.971	65,737
MI0394	TKN	1980-84	1980	Seasonal	4 REG-1	Excellent	23	2,495	1.611	4,020	0.087	1.651	4,119
MI0394	TKN	1980-84	1981	Seasonal	4 REG-1	Excellent	22	2,375	1.608	3,819	0.087	1.600	3,800
MI0394	TKN	1980-84	1982	Seasonal	4 REG-1	Excellent	11	4,640	1.625	7,540	0.087	1.636	7,591
MI0394	TKN	1980-84	1983	Seasonal	4 REG-1	Excellent	12	7,545	1.608	12,132	0.087	1.589	11,991
MI0394	TKN	1980-84	1984	Seasonal	4 REG-1	Excellent	11	8,639	1.618	13,976	0.087	1.594	13,769
MI0394	TKN	1985-88	1985	Seasonal	4 REG-1	Excellent	12	5,674	1.327	7,528	0.035	1.334	7,570
MI0394	TKN	1985-88	1986	Seasonal	4 REG-1	Excellent	11	10,202	1.341	13,685	0.035	1.333	13,600
MI0394	TKN	1985-88	1987	Seasonal	4 REG-1	Excellent	12	2,082	1.319	2,745	0.035	1.316	2,740
MI0394	TKN	1985-88	1988	Seasonal	4 REG-1	Excellent	11	1,089	1.296	1,412	0.035	1.294	1,409
MI0394	TKN	1989-90	1989	Seasonal	4 REG-1	Excellent	11	1,127	2.017	2,273	0.183	2.015	2,271
MI0394	TKN	1989-90	1990	Seasonal	4 REG-1	Excellent	11	2,314	2.117	4,899	0.183	2.121	4,908
MI0394	TKN	1991 – 01	1991	Seasonal	4 REG-1	Good	12	7,157	1.340	9,590	0.022	1.337	9,567
MI0394	TKN	1991 – 01	1992	Seasonal	4 REG-1	Good	14	7,342	1.330	9,765	0.022	1.323	9,714
MI0394	TKN	1991 – 01	1993	Seasonal	4 REG-1	Good	51	14,913	1.350	20,133	0.022	1.279	19,073
MI0394	TKN	1991 – 01	1994	Seasonal	4 REG-1	Good	47	7,657	1.340	10,260	0.022	1.396	10,692
MI0394	TKN	1991 – 01	1995	Seasonal	4 REG-1	Good	53	8,692	1.340	11,647	0.022	1.330	11,560
MI0394	TKN	1991 – 01	1996	Seasonal	4 REG-1	Good	52	5,558	1.340	7,448	0.022	1.228	6,824
MI0394	TKN	1991 – 01	1997	Seasonal	4 REG-1	Good	63	9,060	1.370	12,412	0.022	1.283	11,624

Site	Parameter	Analysis Period	Year	Stratification Scheme	Calculation Method	Confidence Rating	Samples Used	Flow (hm3)	Model-Conc (mg/L)	Model-Mass (tonnes)	CV	Interp-Conc (mg/L)	Interp-Mass (tonnes)
MI0394	TKN	1991 – 01	1998	Seasonal	4 REG-1	Good	49	5,561	1.340	7,452	0.022	1.478	8,218
MI0394	TKN	1991 – 01	1999	Seasonal	4 REG-1	Good	52	5,438	1.350	7,341	0.022	1.234	6,709
MI0394	TKN	1991 – 01	2000	Seasonal	4 REG-1	Good	34	2,455	1.340	3,290	0.022	1.507	3,701
MI0394	TKN	1991 – 01	2001	Seasonal	4 REG-1	Good	17	9,430	1.370	12,919	0.022	1.360	12,825
MI0394	TP	1980-90	1980	Seasonal	4 REG-1	Excellent	23	2,495	0.272	679	0.052	0.277	691
MI0394	TP	1980-90	1981	Seasonal	4 REG-1	Excellent	22	2,375	0.287	681	0.052	0.287	682
MI0394	TP	1980-90	1982	Seasonal	4 REG-1	Excellent	20	4,640	0.252	1,169	0.052	0.268	1,245
MI0394	TP	1980-90	1983	Seasonal	4 REG-1	Excellent	23	7,545	0.258	1,949	0.052	0.252	1,904
MI0394	TP	1980-90	1984	Seasonal	4 REG-1	Excellent	22	8,639	0.268	2,311	0.052	0.257	2,224
MI0394	TP	1980-90	1985	Seasonal	4 REG-1	Excellent	24	5,674	0.263	1,491	0.052	0.271	1,540
MI0394	TP	1980-90	1986	Seasonal	4 REG-1	Excellent	24	10,202	0.270	2,750	0.052	0.261	2,661
MI0394	TP	1980-90	1987	Seasonal	4 REG-1	Excellent	24	2,082	0.261	543	0.052	0.249	518
MI0394	TP	1980-90	1988	Seasonal	4 REG-1	Excellent	21	1,089	0.251	273	0.052	0.249	271
MI0394	TP	1980-90	1989	Seasonal	4 REG-1	Excellent	23	1,127	0.255	287	0.052	0.267	301
MI0394	TP	1980-90	1990	Seasonal	4 REG-1	Excellent	37	2,314	0.301	696	0.052	0.332	769
MI0394	TP	1991 – 01	1991	Seasonal	4 REG-1	Good	38	7,157	0.294	2,104	0.029	0.318	2,274
MI0394	TP	1991 – 01	1992	Seasonal	4 REG-1	Good	24	7,342	0.297	2,181	0.029	0.290	2,130
MI0394	TP	1991 – 01	1993	Seasonal	4 REG-1	Good	63	14,913	0.305	4,548	0.029	0.270	4,024
MI0394	TP	1991 – 01	1994	Seasonal	4 REG-1	Good	58	7,657	0.291	2,228	0.029	0.307	2,354
MI0394	TP	1991 – 01	1995	Seasonal	4 REG-1	Good	72	8,692	0.280	2,434	0.029	0.255	2,213
MI0394	TP	1991 – 01	1996	Seasonal	4 REG-1	Good	58	5,558	0.285	1,584	0.029	0.266	1,476
MI0394	TP	1991 – 01	1997	Seasonal	4 REG-1	Good	63	9,060	0.283	2,564	0.029	0.273	2,474
MI0394	TP	1991 – 01	1998	Seasonal	4 REG-1	Good	49	5,561	0.282	1,568	0.029	0.297	1,652
MI0394	TP	1991 – 01	1999	Seasonal	4 REG-1	Good	52	5,438	0.284	1,544	0.029	0.266	1,446
MI0394	TP	1991 – 01	2000	Seasonal	4 REG-1	Good	35	2,455	0.305	749	0.029	0.360	884
MI0394	TP	1991 – 01	2001	Seasonal	4 REG-1	Good	17	9,430	0.258	2,433	0.029	0.258	2,433
MI0394	TSS	1980-90	1980	Seasonal	4 REG-1	Excellent	23	2,495	124.6	310,850	0.12	135.8	338,738
MI0394	TSS	1980-90	1981	Seasonal	4 REG-1	Excellent	23	2,375	145.1	344,646	0.12	182.4	433,141
MI0394	TSS	1980-90	1982	Seasonal	4 REG-1	Excellent	22	4,640	112.0	519,821	0.12	124.9	579,497
MI0394	TSS	1980-90	1983	Seasonal	4 REG-1	Excellent	23	7,545	107.0	807,421	0.12	95.2	718,290
MI0394	TSS	1980-90	1984	Seasonal	4 REG-1	Excellent	22	8,639	123.3	1,065,222	0.12	112.6	972,623
MI0394	TSS	1980-90	1985	Seasonal	4 REG-1	Excellent	24	5,674	119.3	676,932	0.12	121.5	689,148
MI0394	TSS	1980-90	1986	Seasonal	4 REG-1	Excellent	24	10,202	127.6	1,301,611	0.12	119.4	1,217,846
MI0394	TSS	1980-90	1987	Seasonal	4 REG-1	Excellent	24	2,082	108.3	225,411	0.12	103.4	215,266
MI0394	TSS	1980-90	1988	Seasonal	4 REG-1	Excellent	21	1,089	101.2	110,219	0.12	100.0	108,931
MI0394	TSS	1980-90	1989	Seasonal	4 REG-1	Excellent	23	1,127	111.3	125,430	0.12	119.9	135,103
MI0394	TSS	1980-90	1990	Seasonal	4 REG-1	Excellent	23	2,314	158.7	367,279	0.12	163.5	378,322
MI0394	TSS	1991 – 93	1991	Seasonal	4 REG-1	Excellent	23	7,157	142.1	1,017,017	0.192	141.1	1,009,688
MI0394	TSS	1991 – 93	1992	Seasonal	4 REG-1	Excellent	24	7,342	131.5	965,238	0.192	130.1	954,959
MI0394	TSS	1991 – 93	1993	Seasonal	4 REG-1	Excellent	64	14,913	115.5	1,722,705	0.088	109.4	1,631,575

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MI0394	TSS	1994 – 96	1994	Seasonal	4 REG-1	Excellent	57	7,657	176.5	1,351,759	0.073	173.4	1,327,594
MI0394	TSS	1994 – 96	1995	Seasonal	4 REG-1	Good	72	8,692	151.4	1,316,143	0.065	137.1	1,191,447
MI0394	TSS	1994 – 96	1996	Seasonal	4 REG-1	Good	59	5,558	138.1	767,421	0.065	138.2	767,949
MI0394	TSS	1997 – 99	1997	Seasonal	4 REG-1	Good	62	9,060	208.9	1,892,761	0.060	189.8	1,719,271
MI0394	TSS	1997 – 99	1998	Seasonal	4 REG-1	Good	52	5,561	188.8	1,049,822	0.060	186.9	1,039,273
MI0394	TSS	1997 – 99	1999	Seasonal	4 REG-1	Good	53	5,438	209.1	1,136,966	0.060	199.8	1,086,610
MI0394	TSS	2000	2000	Seasonal	5 REG-2	Good	34	2,455	208.0	510,615	0.140	205.8	505,234
SC0233	NOx	1980-84	1980	Seasonal	4 REG-1	Excellent	23	2,892	0.268	775	0.065	0.262	757
SC0233	NOx	1980-84	1981	Seasonal	4 REG-1	Excellent	23	4,575	0.248	1,136	0.065	0.250	1,144
SC0233	NOx	1980-84	1982	Seasonal	4 REG-1	Excellent	21	5,674	0.254	1,444	0.065	0.253	1,435
SC0233	NOx	1980-84	1983	Seasonal	4 REG-1	Excellent	22	6,297	0.282	1,776	0.065	0.285	1,794
SC0233	NOx	1980-84	1984	Seasonal	4 REG-1	Excellent	24	6,877	0.265	1,820	0.065	0.259	1,779
SC0233	NOx	1985-90	1985	Seasonal	4 REG-1	Excellent	24	6,264	0.310	1,943	0.073	0.300	1,877
SC0233	NOx	1985-90	1986	Seasonal	4 REG-1	Excellent	21	8,245	0.292	2,411	0.073	0.293	2,418
SC0233	NOx	1985-90	1987	Seasonal	4 REG-1	Excellent	24	2,746	0.358	983	0.073	0.352	967
SC0233	NOx	1985-90	1988	Seasonal	4 REG-1	Excellent	23	2,725	0.345	939	0.073	0.340	926
SC0233	NOx	1985-90	1989	Seasonal	4 REG-1	Excellent	22	3,347	0.319	1,069	0.073	0.327	1,094
SC0233	NOx	1985-90	1990	Seasonal	4 REG-1	Excellent	24	3,684	0.322	1,186	0.073	0.327	1,204
SC0233	NOx	1991 – 01	1991	Seasonal	3 IJC	Excellent	24	5,995	0.312	1,870	0.05	0.313	1,875
SC0233	NOx	1991 – 01	1992	Seasonal	3 IJC	Excellent	24	4,774	0.384	1,833	0.05	0.370	1,766
SC0233	NOx	1991 – 01	1993	Seasonal	3 IJC	Excellent	23	4,910	0.310	1,522	0.05	0.312	1,533
SC0233	NOx	1991 – 01	1994	Seasonal	3 IJC	Excellent	22	5,013	0.345	1,729	0.05	0.342	1,712
SC0233	NOx	1991 – 01	1995	Seasonal	3 IJC	Excellent	24	5,993	0.337	2,020	0.05	0.323	1,934
SC0233	NOx	1991 – 01	1996	Seasonal	3 IJC	Excellent	20	6,090	0.348	2,119	0.05	0.340	2,072
SC0233	NOx	1991 – 01	1997	Seasonal	3 IJC	Excellent	23	4,842	0.379	1,835	0.05	0.376	1,822
SC0233	NOx	1991 – 01	1998	Seasonal	3 IJC	Excellent	26	3,681	0.386	1,421	0.05	0.383	1,410
SC0233	NOx	1991 – 01	1999	Seasonal	3 IJC	Excellent	35	4,376	0.320	1,400	0.05	0.321	1,405
SC0233	NOx	1991 – 01	2000	Seasonal	3 IJC	Excellent	38	3,439	0.359	1,235	0.05	0.378	1,300
SC0233	NOx	1991 – 01	2001	Seasonal	3 IJC	Excellent	36	5,994	0.349	2,092	0.05	0.371	2,225
SC0233	TKN	1980-81	1980	Seasonal	4 REG-1	Excellent	23	2,892	0.753	2,178	0.085	0.758	2,191
SC0233	TKN	1980-81	1981	Seasonal	4 REG-1	Excellent	23	4,575	0.783	3,581	0.085	0.777	3,553
SC0233	TKN	1982-85	1982	Seasonal	4 REG-1	Excellent	12	5,674	0.905	5,136	0.075	0.896	5,082
SC0233	TKN	1982-85	1983	Seasonal	4 REG-1	Excellent	12	6,297	0.873	5,498	0.075	0.873	5,498
SC0233	TKN	1982-85	1984	Seasonal	4 REG-1	Excellent	12	6,877	0.894	6,146	0.075	0.886	6,092
SC0233	TKN	1982-85	1985	Seasonal	4 REG-1	Excellent	12	6,264	0.912	5,715	0.075	0.930	5,823
SC0233	TKN	1986-88	1986	Seasonal	4 REG-1	Excellent	12	8,245	0.653	5,385	0.088	0.654	5,393
SC0233	TKN	1986-88	1987	Seasonal	4 REG-1	Excellent	12	2,746	0.584	1,603	0.088	0.579	1,589
SC0233	TKN	1986-88	1988	Seasonal	4 REG-1	Excellent	12	2,725	0.607	1,654	0.088	0.611	1,665
SC0233	TKN	1989-90	1989	Seasonal	4 REG-1	Excellent	12	3,347	0.710	2,375	0.041	0.711	2,380
SC0233	TKN	1989-90	1990	Seasonal	4 REG-1	Excellent	10	3,684	0.687	2,530	0.041	0.688	2,533

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SC0233	TKN	1991 – 94	1991	Seasonal	4 REG-1	Good	13	5,995	0.666	3,993	0.038	0.663	3,974
SC0233	TKN	1991 – 94	1992	Seasonal	4 REG-1	Good	14	4,774	0.626	2,989	0.038	0.629	3,003
SC0233	TKN	1991 – 94	1993	Seasonal	4 REG-1	Good	13	4,910	0.711	3,491	0.038	0.701	3,444
SC0233	TKN	1991 – 94	1994	Seasonal	4 REG-1	Good	11	5,013	0.647	3,243	0.038	0.655	3,284
SC0233	TKN	1995 – 01	1995	Seasonal	4 REG-1	Good	6	5,993	0.516	3,092	0.039	0.515	3,084
SC0233	TKN	1995 – 01	1996	Seasonal	4 REG-1	Good	13	6,090	0.535	3,258	0.039	0.526	3,201
SC0233	TKN	1995 – 01	1997	Seasonal	4 REG-1	Good	23	4,842	0.536	2,595	0.039	0.537	2,599
SC0233	TKN	1995 – 01	1998	Seasonal	4 REG-1	Good	26	3,681	0.504	1,855	0.039	0.509	1,873
SC0233	TKN	1995 – 01	1999	Seasonal	4 REG-1	Good	35	4,376	0.552	2,416	0.039	0.555	2,428
SC0233	TKN	1995 – 01	2000	Seasonal	4 REG-1	Good	40	3,439	0.500	1,720	0.039	0.503	1,729
SC0233	TKN	1995 – 01	2001	Seasonal	4 REG-1	Good	35	5,994	0.571	3,423	0.039	0.561	3,360
SC0233	TP	1980-85	1980	Seasonal	4 REG-1	Excellent	24	2,892	0.059	172	0.073	0.059	171
SC0233	TP	1980-85	1981	Seasonal	4 REG-1	Excellent	23	4,575	0.062	285	0.073	0.062	283
SC0233	TP	1980-85	1982	Seasonal	4 REG-1	Excellent	22	5,674	0.060	341	0.073	0.060	341
SC0233	TP	1980-85	1983	Seasonal	4 REG-1	Excellent	23	6,297	0.058	367	0.073	0.062	390
SC0233	TP	1980-85	1984	Seasonal	4 REG-1	Excellent	24	6,877	0.060	415	0.073	0.058	400
SC0233	TP	1980-85	1985	Seasonal	4 REG-1	Excellent	22	6,264	0.061	384	0.073	0.061	379
SC0233	TP	1986-90	1986	Seasonal	4 REG-1	Excellent	23	8,245	0.053	433	0.074	0.051	421
SC0233	TP	1986-90	1987	Seasonal	4 REG-1	Excellent	24	2,746	0.048	131	0.074	0.046	127
SC0233	TP	1986-90	1988	Seasonal	4 REG-1	Excellent	23	2,725	0.050	135	0.074	0.051	139
SC0233	TP	1986-90	1989	Seasonal	4 REG-1	Excellent	21	3,347	0.053	178	0.074	0.054	180
SC0233	TP	1986-90	1990	Seasonal	4 REG-1	Excellent	37	3,684	0.052	190	0.074	0.053	196
SC0233	TP	1991 – 01	1991	Flow	2 QwtdC	Excellent	40	5,995	0.066	393	0.059	0.073	437
SC0233	TP	1991 – 01	1992	Flow	2 QwtdC	Excellent	24	4,774	0.059	283	0.059	0.057	271
SC0233	TP	1991 – 01	1993	Flow	2 QwtdC	Excellent	24	4,910	0.062	304	0.059	0.058	285
SC0233	TP	1991 – 01	1994	Flow	2 QwtdC	Excellent	24	5,013	0.061	308	0.059	0.064	320
SC0233	TP	1991 – 01	1995	Flow	2 QwtdC	Excellent	24	5,993	0.064	386	0.059	0.063	375
SC0233	TP	1991 – 01	1996	Flow	2 QwtdC	Excellent	20	6,090	0.064	387	0.059	0.062	379
SC0233	TP	1991 – 01	1997	Flow	2 QwtdC	Excellent	23	4,842	0.057	276	0.059	0.056	270
SC0233	TP	1991 – 01	1998	Flow	2 QwtdC	Excellent	26	3,681	0.055	204	0.059	0.054	199
SC0233	TP	1991 – 01	1999	Flow	2 QwtdC	Excellent	35	4,376	0.061	268	0.059	0.060	262
SC0233	TP	1991 – 01	2000	Flow	2 QwtdC	Excellent	40	3,439	0.057	196	0.059	0.059	201
SC0233	TP	1991 – 01	2001	Flow	2 QwtdC	Excellent	35	5,994	0.061	363	0.059	0.060	360
SC0233	TSS	1980-81	1980	Seasonal	2 QwtdC	Excellent	24	2,892	12.6	36,332	0.099	12.6	36,331
SC0233	TSS	1980-81	1981	Seasonal	2 QwtdC	Excellent	23	4,575	13.5	61,893	0.099	13.5	61,733
SC0233	TSS	1982-90	1982	Seasonal	4 REG-1	Excellent	22	5,674	8.6	48,582	0.039	8.9	50,726
SC0233	TSS	1982-90	1983	Seasonal	4 REG-1	Excellent	23	6,297	8.2	51,702	0.039	8.1	50,991
SC0233	TSS	1982-90	1984	Seasonal	4 REG-1	Excellent	23	6,877	8.4	57,813	0.039	8.3	57,357
SC0233	TSS	1982-90	1985	Seasonal	4 REG-1	Excellent	24	6,264	8.9	56,006	0.039	8.9	55,876
SC0233	TSS	1982-90	1986	Seasonal	4 REG-1	Excellent	24	8,245	9.3	76,481	0.039	9.3	76,363

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SC0233	TSS	1982-90	1987	Seasonal	4 REG-1	Excellent	24	2,746	7.7	21,243	0.039	7.7	21,151
SC0233	TSS	1982-90	1988	Seasonal	4 REG-1	Excellent	23	2,725	8.1	22,209	0.039	8.1	22,039
SC0233	TSS	1982-90	1989	Seasonal	4 REG-1	Excellent	22	3,347	8.9	29,833	0.039	8.8	29,483
SC0233	TSS	1982-90	1990	Seasonal	4 REG-1	Excellent	24	3,684	8.9	32,939	0.039	8.8	32,489
SC0233	TSS	1991 – 01	1991	Seasonal	4 REG-1	Good	24	5,995	8.0	48,140	0.048	8.1	48,564
SC0233	TSS	1991 – 01	1992	Seasonal	4 REG-1	Good	24	4,774	7.3	34,850	0.048	7.2	34,456
SC0233	TSS	1991 – 01	1993	Seasonal	4 REG-1	Good	25	4,910	8.4	41,048	0.048	8.2	40,268
SC0233	TSS	1991 – 01	1994	Seasonal	4 REG-1	Good	24	5,013	7.9	39,402	0.048	8.3	41,475
SC0233	TSS	1991 – 01	1995	Seasonal	4 REG-1	Good	22	5,993	7.7	45,906	0.048	7.7	46,259
SC0233	TSS	1991 – 01	1996	Seasonal	4 REG-1	Good	21	6,090	7.9	47,807	0.048	7.8	47,776
SC0233	TSS	1991 – 01	1997	Seasonal	4 REG-1	Good	23	4,842	7.8	37,864	0.048	7.7	37,380
SC0233	TSS	1991 – 01	1998	Seasonal	4 REG-1	Good	27	3,681	7.2	26,650	0.048	7.2	26,437
SC0233	TSS	1991 – 01	1999	Seasonal	4 REG-1	Good	35	4,376	8.4	36,627	0.048	8.0	34,876
SC0233	TSS	1991 – 01	2000	Seasonal	4 REG-1	Good	40	3,439	7.4	25,517	0.048	7.5	25,779
SC0233	TSS	1991 – 01	2001	Seasonal	4 REG-1	Good	37	5,994	8.2	49,211	0.048	8.5	50,738
UM7969	NOx	1980-90	1980	Seasonal	4 REG-1	Excellent	22	11,176	2.116	23,651	0.045	2.107	23,549
UM7969	NOx	1980-90	1981	Seasonal	4 REG-1	Excellent	23	13,683	1.996	27,304	0.045	1.979	27,084
UM7969	NOx	1980-90	1982	Seasonal	4 REG-1	Excellent	22	21,225	2.136	45,347	0.045	2.140	45,424
UM7969	NOx	1980-90	1983	Seasonal	4 REG-1	Excellent	24	24,678	2.153	53,124	0.045	2.257	55,697
UM7969	NOx	1980-90	1984	Seasonal	4 REG-1	Excellent	24	27,293	2.094	57,164	0.045	2.097	57,224
UM7969	NOx	1980-90	1985	Seasonal	4 REG-1	Excellent	24	24,513	2.085	51,103	0.045	1.982	48,574
UM7969	NOx	1980-90	1986	Seasonal	4 REG-1	Excellent	23	35,804	2.101	75,226	0.045	2.018	72,244
UM7969	NOx	1980-90	1987	Seasonal	4 REG-1	Excellent	23	10,990	2.068	22,728	0.045	1.980	21,756
UM7969	NOx	1980-90	1988	Seasonal	4 REG-1	Excellent	24	7,591	2.144	16,279	0.045	2.174	16,501
UM7969	NOx	1980-90	1989	Seasonal	4 REG-1	Excellent	24	10,221	2.184	22,321	0.045	2.060	21,058
UM7969	NOx	1980-90	1990	Seasonal	4 REG-1	Excellent	24	12,607	2.051	25,860	0.045	2.124	26,775
UM7969	NOx	1991 – 92	1991	Seasonal	4 REG-1	Excellent	23	22,738	4.030	91,634	0.051	4.004	91,051
UM7969	NOx	1991 – 92	1992	Seasonal	4 REG-1	Excellent	24	19,728	4.110	81,082	0.051	4.118	81,242
UM7969	NOx	1993 – 94	1993	Seasonal	4 REG-1	Excellent	25	32,685	2.770	90,537	0.054	2.786	91,046
UM7969	NOx	1993 – 94	1994	Seasonal	4 REG-1	Excellent	24	22,659	2.680	60,726	0.054	2.629	59,565
UM7969	NOx	1995 – 96	1995	Seasonal	4 REG-1	Excellent	24	24,921	1.980	49,344	0.099	2.031	50,603
UM7969	NOx	1995 – 96	1996	Seasonal	4 REG-1	Excellent	34	21,378	2.030	43,397	0.099	1.935	41,359
UM7969	NOx	1997	1997	Seasonal	5 REG-2	Fair	22	24,989	1.560	38,983	0.147	1.561	39,013
UM7969	NOx	1998 – 99	1998	Seasonal	4 REG-1	Excellent	24	18,205	2.740	49,882	0.079	2.733	49,757
UM7969	NOx	1998 – 99	1999	Seasonal	4 REG-1	Excellent	25	20,217	2.730	55,192	0.079	2.724	55,062
UM7969	NOx	2000 – 01	2000	Seasonal	4 REG-1	Good	24	12,569	2.280	28,657	0.076	2.311	29,043
UM7969	NOx	2000 – 01	2001	Seasonal	4 REG-1	Good	23	27,809	2.960	82,315	0.076	2.906	80,824
UM7969	TKN	1980-82	1980	Seasonal	2 QwtdC	Excellent	23	11,176	1.626	18,177	0.03	1.632	18,240
UM7969	TKN	1980-82	1981	Seasonal	2 QwtdC	Excellent	23	13,683	1.577	21,574	0.03	1.572	21,516
UM7969	TKN	1980-82	1982	Seasonal	2 QwtdC	Excellent	12	21,225	1.632	34,631	0.03	1.632	34,637

Site	Parameter	Analysis Period	Year	Stratification Scheme	Calculation Method	Confidence Rating	Samples Used	Flow (hm3)	Model-Conc (mg/L)	Model-Mass (tonnes)	CV	Interp-Conc (mg/L)	Interp-Mass (tonnes)
UM7969	TKN	1983-85	1983	Seasonal	2 QwtdC	Excellent	12	24,678	1.538	37,945	0.046	1.530	37,764
UM7969	TKN	1983-85	1984	Seasonal	2 QwtdC	Excellent	12	27,293	1.532	41,819	0.046	1.546	42,189
UM7969	TKN	1983-85	1985	Seasonal	2 QwtdC	Excellent	12	24,513	1.520	37,253	0.046	1.511	37,051
UM7969	TKN	1986-88	1986	Seasonal	2 QwtdC	Excellent	12	35,804	1.163	41,648	0.04	1.166	41,751
UM7969	TKN	1986-88	1987	Seasonal	2 QwtdC	Excellent	12	10,990	1.187	13,043	0.04	1.182	12,994
UM7969	TKN	1986-88	1988	Seasonal	2 QwtdC	Excellent	12	7,591	1.191	9,043	0.04	1.184	8,991
UM7969	TKN	1989-90	1989	Seasonal	2 QwtdC	Excellent	12	10,221	1.252	12,795	0.023	1.250	12,775
UM7969	TKN	1989-90	1990	Seasonal	2 QwtdC	Excellent	12	12,607	1.208	15,229	0.023	1.210	15,249
UM7969	TKN	1991	1991	None	2 QwtdC	Excellent	10	22,738	1.270	28,877	0.045	1.269	28,864
UM7969	TKN	1992 – 94	1992	Seasonal	2 QwtdC	Excellent	14	19,728	1.070	21,109	0.034	1.075	21,215
UM7969	TKN	1992 – 94	1993	Seasonal	2 QwtdC	Excellent	13	32,685	1.170	38,241	0.034	1.168	38,191
UM7969	TKN	1992 – 94	1994	Seasonal	2 QwtdC	Excellent	10	22,659	1.100	24,925	0.034	1.109	25,123
UM7969	TKN	1995 – 01	1995	Seasonal	2 QwtdC	Excellent	6	24,921	0.927	23,102	0.036	0.943	23,491
UM7969	TKN	1995 – 01	1996	Seasonal	2 QwtdC	Excellent	38	21,378	0.937	20,031	0.036	0.911	19,471
UM7969	TKN	1995 – 01	1997	Seasonal	2 QwtdC	Excellent	23	24,989	0.958	23,939	0.036	0.968	24,200
UM7969	TKN	1995 – 01	1998	Seasonal	2 QwtdC	Excellent	24	18,205	0.923	16,803	0.036	0.952	17,326
UM7969	TKN	1995 – 01	1999	Seasonal	2 QwtdC	Excellent	24	20,217	0.954	19,287	0.036	0.930	18,804
UM7969	TKN	1995 – 01	2000	Seasonal	2 QwtdC	Excellent	24	12,569	0.914	11,488	0.036	0.938	11,784
UM7969	TKN	1995 – 01	2001	Seasonal	2 QwtdC	Excellent	23	27,809	0.990	27,531	0.036	0.974	27,084
UM7969	TP	1980-86	1980	Seasonal	4 REG-1	Excellent	23	11,176	0.176	1,967	0.045	0.175	1,958
UM7969	TP	1980-86	1981	Seasonal	4 REG-1	Excellent	23	13,683	0.177	2,418	0.045	0.175	2,392
UM7969	TP	1980-86	1982	Seasonal	4 REG-1	Excellent	23	21,225	0.176	3,738	0.045	0.178	3,774
UM7969	TP	1980-86	1983	Seasonal	4 REG-1	Excellent	24	24,678	0.181	4,474	0.045	0.178	4,395
UM7969	TP	1980-86	1984	Seasonal	4 REG-1	Excellent	24	27,293	0.179	4,880	0.045	0.184	5,028
UM7969	TP	1980-86	1985	Seasonal	4 REG-1	Excellent	23	24,513	0.178	4,375	0.045	0.181	4,432
UM7969	TP	1980-86	1986	Seasonal	4 REG-1	Excellent	23	35,804	0.179	6,407	0.045	0.176	6,287
UM7969	TP	1987-88	1987	Seasonal	4 REG-1	Excellent	24	10,990	0.163	1,787	0.037	0.161	1,775
UM7969	TP	1987-88	1988	Seasonal	4 REG-1	Excellent	23	7,591	0.166	1,257	0.037	0.167	1,269
UM7969	TP	1989-90	1989	Seasonal	4 REG-1	Excellent	24	10,221	0.201	2,053	0.063	0.197	2,014
UM7969	TP	1989-90	1990	Seasonal	4 REG-1	Excellent	37	12,607	0.212	2,667	0.063	0.215	2,706
UM7969	TP	1991	1991	Seasonal	2 QwtdC	Excellent	38	22,738	0.249	5,662	0.087	0.249	5,653
UM7969	TP	1992 – 94	1992	Seasonal	2 QwtdC	Excellent	24	19,728	0.178	3,512	0.035	0.176	3,470
UM7969	TP	1992 – 94	1993	Seasonal	2 QwtdC	Excellent	25	32,685	0.196	6,406	0.035	0.197	6,439
UM7969	TP	1992 – 94	1994	Seasonal	2 QwtdC	Excellent	24	22,659	0.181	4,101	0.035	0.181	4,102
UM7969	TP	1995 – 97	1995	Seasonal	2 QwtdC	Excellent	24	24,921	0.141	3,514	0.047	0.140	3,487
UM7969	TP	1995 – 97	1996	Seasonal	2 QwtdC	Excellent	40	21,378	0.135	2,886	0.047	0.140	2,998
UM7969	TP	1995 – 97	1997	Seasonal	2 QwtdC	Excellent	23	24,989	0.139	3,473	0.047	0.137	3,412
UM7969	TP	1998 – 01	1998	Seasonal	2 QwtdC	Excellent	24	18,205	0.155	2,822	0.043	0.156	2,841
UM7969	TP	1998 – 01	1999	Seasonal	2 QwtdC	Excellent	25	20,217	0.159	3,215	0.043	0.156	3,149
UM7969	TP	1998 – 01	2000	Seasonal	2 QwtdC	Excellent	24	12,569	0.157	1,973	0.043	0.166	2,081

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UM7969	TP	1998 – 01	2001	Seasonal	2 QwtdC	Excellent	23	27,809	0.154	4,283	0.043	0.152	4,222
UM7969	TSS	1980-82	1980	Seasonal	4 REG-1	Excellent	23	11,176	39.3	438,741	0.148	38.8	433,390
UM7969	TSS	1980-82	1981	Seasonal	4 REG-1	Excellent	23	13,683	43.2	590,913	0.148	42.3	578,336
UM7969	TSS	1980-82	1982	Seasonal	4 REG-1	Excellent	23	21,225	41.9	888,698	0.148	42.3	897,476
UM7969	TSS	1983-86	1983	Seasonal	4 REG-1	Excellent	24	24,678	36.3	896,769	0.110	35.1	865,757
UM7969	TSS	1983-86	1984	Seasonal	4 REG-1	Excellent	24	27,293	37.5	1,024,380	0.110	37.4	1,020,845
UM7969	TSS	1983-86	1985	Seasonal	4 REG-1	Excellent	24	24,513	37.5	919,019	0.110	38.5	942,940
UM7969	TSS	1983-86	1986	Seasonal	4 REG-1	Excellent	23	35,804	39.0	1,397,987	0.110	38.5	1,378,703
UM7969	TSS	1987-88	1987	Seasonal	4 REG-1	Excellent	24	10,990	20.3	223,216	0.124	20.6	226,705
UM7969	TSS	1987-88	1988	Seasonal	4 REG-1	Excellent	24	7,591	21.0	159,349	0.124	20.6	156,180
UM7969	TSS	1989-90	1989	Seasonal	4 REG-1	Good	22	10,221	22.2	227,271	0.071	21.8	222,836
UM7969	TSS	1989-90	1990	Seasonal	4 REG-1	Good	24	12,607	22.6	284,491	0.071	22.7	286,568
UM7969	TSS	1991 – 01	1991	Seasonal	4 REG-1	Excellent	23	22,738	42.100	957,270	0.043	41.5	943,998
UM7969	TSS	1991 – 01	1992	Seasonal	4 REG-1	Excellent	24	19,728	36.300	716,126	0.043	37.4	738,152
UM7969	TSS	1991 – 01	1993	Seasonal	4 REG-1	Excellent	25	32,685	44.800	1,464,288	0.043	44.1	1,440,486
UM7969	TSS	1991 – 01	1994	Seasonal	4 REG-1	Excellent	24	22,659	39.400	892,765	0.043	40.1	909,444
UM7969	TSS	1991 – 01	1995	Seasonal	4 REG-1	Excellent	23	24,921	41.100	1,024,253	0.043	41.3	1,029,639
UM7969	TSS	1991 – 01	1996	Seasonal	4 REG-1	Excellent	41	21,378	38.600	825,191	0.043	36.8	787,056
UM7969	TSS	1991 – 01	1997	Seasonal	4 REG-1	Excellent	23	24,989	40.300	1,007,057	0.043	39.1	977,048
UM7969	TSS	1991 – 01	1998	Seasonal	4 REG-1	Excellent	25	18,205	36.500	664,483	0.043	37.2	677,593
UM7969	TSS	1991 – 01	1999	Seasonal	4 REG-1	Excellent	25	20,217	41.800	845,071	0.043	43.1	872,350
UM7969	TSS	1991 – 01	2000	Seasonal	4 REG-1	Excellent	24	12,569	36.800	462,539	0.043	37.3	468,248
UM7969	TSS	1991 – 01	2001	Seasonal	4 REG-1	Excellent	23	27,809	42.400	1,179,102	0.043	40.9	1,137,654
UM8716	NOx	1980	1980	Seasonal	4 REG-1	Excellent	21	4,553	0.405	1,842	0.304	0.405	1,843
UM8716	NOx	1981-86	1981	Seasonal	4 REG-1	Excellent	23	5,443	1.074	5,846	0.08	1.066	5,800
UM8716	NOx	1981-86	1982	Seasonal	4 REG-1	Excellent	22	9,588	1.209	11,594	0.08	1.171	11,231
UM8716	NOx	1981-86	1983	Seasonal	4 REG-1	Excellent	24	8,769	1.141	10,001	0.08	1.183	10,373
UM8716	NOx	1981-86	1984	Seasonal	4 REG-1	Excellent	23	9,872	1.136	11,213	0.08	1.154	11,393
UM8716	NOx	1981-86	1985	Seasonal	4 REG-1	Excellent	24	11,553	1.122	12,965	0.08	1.094	12,644
UM8716	NOx	1981-86	1986	Seasonal	4 REG-1	Excellent	24	14,740	1.167	17,202	0.08	1.067	15,731
UM8716	NOx	1987-89	1987	Seasonal	4 REG-1	Excellent	24	4,926	0.455	2,241	0.155	0.456	2,249
UM8716	NOx	1987-89	1988	Seasonal	4 REG-1	Excellent	23	3,171	0.479	1,520	0.155	0.471	1,493
UM8716	NOx	1987-89	1989	Seasonal	4 REG-1	Excellent	24	5,023	0.468	2,352	0.155	0.458	2,300
UM8716	NOx	1990	1990	Seasonal	4 REG-1	Excellent	24	5,446	0.919	5,007	0.099	0.910	4,958
UM8716	NOx	1991 – 92	1991	Seasonal	5 REG-2	Excellent	22	7,676	1.930	14,815	0.09	1.92	14,732
UM8716	NOx	1991 – 92	1992	Seasonal	5 REG-2	Excellent	23	5,991	1.960	11,742	0.09	1.97	11,794
UM8716	NOx	1993 – 95	1993	Seasonal	5 REG-2	Excellent	23	10,237	1.280	13,103	0.087	1.30	13,276
UM8716	NOx	1993 – 95	1994	Seasonal	5 REG-2	Excellent	24	9,285	1.340	12,442	0.087	1.29	11,941
UM8716	NOx	1993 – 95	1995	Seasonal	5 REG-2	Excellent	24	9,598	1.290	12,381	0.087	1.28	12,254
UM8716	NOx	1996 – 99	1996	Seasonal	5 REG-2	Excellent	23	8,871	0.914	8,108	0.113	0.88	7,843

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UM8716	NOx	1996 – 99	1997	Seasonal	5 REG-2	Excellent	23	10,417	0.889	9,261	0.113	0.84	8,760
UM8716	NOx	1996 – 99	1998	Seasonal	5 REG-2	Excellent	23	7,756	0.883	6,849	0.113	0.96	7,449
UM8716	NOx	1996 – 99	1999	Seasonal	5 REG-2	Excellent	22	9,510	0.846	8,045	0.113	0.84	8,009
UM8716	NOx	2000 – 01	2000	Seasonal	5 REG-2	Good	23	5,588	0.760	4,247	0.109	0.75	4,210
UM8716	NOx	2000 – 01	2001	Seasonal	5 REG-2	Good	25	10,561	0.897	9,473	0.109	0.87	9,170
UM8716	TKN	1980-85	1980	Seasonal	4 REG-1	Excellent	21	4,553	1.317	5,995	0.028	1.330	6,056
UM8716	TKN	1980-85	1981	Seasonal	4 REG-1	Excellent	23	5,443	1.308	7,121	0.028	1.302	7,083
UM8716	TKN	1980-85	1982	Seasonal	4 REG-1	Excellent	12	9,588	1.350	12,943	0.028	1.344	12,883
UM8716	TKN	1980-85	1983	Seasonal	4 REG-1	Excellent	12	8,769	1.320	11,572	0.028	1.327	11,638
UM8716	TKN	1980-85	1984	Seasonal	4 REG-1	Excellent	12	9,872	1.336	13,186	0.028	1.336	13,186
UM8716	TKN	1980-85	1985	Seasonal	4 REG-1	Excellent	12	11,553	1.326	15,317	0.028	1.320	15,250
UM8716	TKN	1986-89	1986	Seasonal	4 REG-1	Excellent	12	14,740	1.000	14,747	0.053	1.004	14,798
UM8716	TKN	1986-89	1987	Seasonal	4 REG-1	Excellent	12	4,926	0.948	4,672	0.053	0.936	4,612
UM8716	TKN	1986-89	1988	Seasonal	4 REG-1	Excellent	12	3,171	0.951	3,014	0.053	0.956	3,030
UM8716	TKN	1986-89	1989	Seasonal	4 REG-1	Excellent	12	5,023	1.010	5,075	0.053	1.011	5,080
UM8716	TKN	1990	1990	Seasonal	4 REG-1	Good	10	5,446	1.313	7,151	0.278	1.308	7,125
UM8716	TKN	1991 – 92	1991	Seasonal	3 IJC	Good	13	7,676	1.290	9,902	0.065	1.286	9,873
UM8716	TKN	1991 – 92	1992	Seasonal	3 IJC	Good	13	5,991	1.220	7,309	0.065	1.230	7,370
UM8716	TKN	1993 – 94	1993	Seasonal	3 IJC	Excellent	13	10,237	0.976	9,991	0.048	0.979	10,018
UM8716	TKN	1993 – 94	1994	Seasonal	3 IJC	Excellent	11	9,285	0.987	9,164	0.048	0.984	9,141
UM8716	TKN	1995 – 96	1995	Seasonal	3 IJC	Excellent	6	9,598	0.817	7,842	0.103	0.824	7,910
UM8716	TKN	1995 – 96	1996	Seasonal	3 IJC	Excellent	16	8,871	0.850	7,540	0.103	0.842	7,473
UM8716	TKN	1997 – 99	1997	Seasonal	3 IJC	Good	23	10,417	0.893	9,302	0.048	0.888	9,255
UM8716	TKN	1997 – 99	1998	Seasonal	3 IJC	Good	23	7,756	0.862	6,686	0.048	0.894	6,930
UM8716	TKN	1997 – 99	1999	Seasonal	3 IJC	Good	23	9,510	0.880	8,369	0.048	0.858	8,157
UM8716	TKN	2000 – 01	2000	Seasonal	3 IJC	Excellent	22	5,588	0.746	4,169	0.059	0.758	4,238
UM8716	TKN	2000 – 01	2001	Seasonal	3 IJC	Excellent	22	10,561	0.943	9,959	0.059	0.935	9,878
UM8716	TP	1980-86	1980	Seasonal	4 REG-1	Excellent	21	4,553	0.123	560	0.055	0.125	568
UM8716	TP	1980-86	1981	Seasonal	4 REG-1	Excellent	21	5,443	0.122	665	0.055	0.125	681
UM8716	TP	1980-86	1982	Seasonal	4 REG-1	Excellent	23	9,588	0.125	1,198	0.055	0.123	1,175
UM8716	TP	1980-86	1983	Seasonal	4 REG-1	Excellent	23	8,769	0.124	1,085	0.055	0.124	1,085
UM8716	TP	1980-86	1984	Seasonal	4 REG-1	Excellent	23	9,872	0.124	1,224	0.055	0.125	1,237
UM8716	TP	1980-86	1985	Seasonal	4 REG-1	Excellent	24	11,553	0.127	1,468	0.055	0.128	1,480
UM8716	TP	1980-86	1986	Seasonal	4 REG-1	Excellent	23	14,740	0.128	1,883	0.055	0.125	1,848
UM8716	TP	1987-88	1987	Seasonal	4 REG-1	Excellent	24	4,926	0.092	451	0.083	0.091	446
UM8716	TP	1987-88	1988	Seasonal	4 REG-1	Excellent	23	3,171	0.084	267	0.083	0.085	269
UM8716	TP	1989	1989	Seasonal	3 IJC	Excellent	24	5,023	0.119	597	0.186	0.119	596
UM8716	TP	1990	1990	Seasonal	4 REG-1	Excellent	38	5,446	0.215	1,171	0.091	0.211	1,147
UM8716	TP	1991	1991	Seasonal	5 REG-2	Excellent	40	7,676	0.200	1,535	0.099	0.199	1,529
UM8716	TP	1992 – 01	1992	Seasonal	5 REG-2	Excellent	24	5,991	0.113	677	0.053	0.114	681

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UM8716	TP	1992 – 01	1993	Seasonal	5 REG-2	Excellent	24	10,237	0.120	1,228	0.053	0.117	1,198
UM8716	TP	1992 – 01	1994	Seasonal	5 REG-2	Excellent	24	9,285	0.111	1,031	0.053	0.112	1,036
UM8716	TP	1992 – 01	1995	Seasonal	5 REG-2	Excellent	24	9,598	0.110	1,056	0.053	0.104	1,000
UM8716	TP	1992 – 01	1996	Seasonal	5 REG-2	Excellent	24	8,871	0.109	967	0.053	0.109	964
UM8716	TP	1992 – 01	1997	Seasonal	5 REG-2	Excellent	24	10,417	0.114	1,188	0.053	0.110	1,147
UM8716	TP	1992 – 01	1998	Seasonal	5 REG-2	Excellent	23	7,756	0.111	861	0.053	0.111	860
UM8716	TP	1992 – 01	1999	Seasonal	5 REG-2	Excellent	25	9,510	0.114	1,084	0.053	0.112	1,069
UM8716	TP	1992 – 01	2000	Seasonal	5 REG-2	Excellent	23	5,588	0.109	609	0.053	0.109	609
UM8716	TP	1992 – 01	2001	Seasonal	5 REG-2	Excellent	24	10,561	0.114	1,204	0.053	0.114	1,204
UM8716	TSS	1980-81	1980	Seasonal	4 REG-1	Excellent	21	4,553	23.1	105,001	0.089	23.1	105,047
UM8716	TSS	1980-81	1981	Seasonal	4 REG-1	Excellent	23	5,443	24.4	132,958	0.089	24.3	132,029
UM8716	TSS	1982-90	1982	Seasonal	4 REG-1	Excellent	22	9,588	19.6	188,008	0.039	19.4	186,052
UM8716	TSS	1982-90	1983	Seasonal	4 REG-1	Excellent	24	8,769	18.7	164,278	0.039	18.5	162,525
UM8716	TSS	1982-90	1984	Seasonal	4 REG-1	Excellent	23	9,872	19.0	187,324	0.039	18.5	182,280
UM8716	TSS	1982-90	1985	Seasonal	4 REG-1	Excellent	24	11,553	20.8	240,022	0.039	21.4	247,770
UM8716	TSS	1982-90	1986	Seasonal	4 REG-1	Excellent	24	14,740	20.8	306,985	0.039	20.3	299,025
UM8716	TSS	1982-90	1987	Seasonal	4 REG-1	Excellent	24	4,926	17.9	88,249	0.039	17.9	87,986
UM8716	TSS	1982-90	1988	Seasonal	4 REG-1	Excellent	23	3,171	17.2	54,669	0.039	17.5	55,492
UM8716	TSS	1982-90	1989	Seasonal	4 REG-1	Excellent	24	5,023	20.2	101,354	0.039	20.5	102,943
UM8716	TSS	1982-90	1990	Seasonal	4 REG-1	Excellent	24	5,446	21.7	117,998	0.039	22.2	121,096
UM8716	TSS	1991 – 96	1991	Seasonal	4 REG-1	Excellent	24	7,676	24.0	184,224	0.057	25.0	192,004
UM8716	TSS	1991 – 96	1992	Seasonal	4 REG-1	Excellent	24	5,991	20.6	123,415	0.057	20.3	121,679
UM8716	TSS	1991 – 96	1993	Seasonal	4 REG-1	Excellent	25	10,237	26.3	269,233	0.057	25.1	256,772
UM8716	TSS	1991 – 96	1994	Seasonal	4 REG-1	Excellent	24	9,285	21.3	197,771	0.057	21.4	199,000
UM8716	TSS	1991 – 96	1995	Seasonal	4 REG-1	Excellent	23	9,598	21.3	204,437	0.057	21.3	204,703
UM8716	TSS	1991 – 96	1996	Seasonal	4 REG-1	Excellent	23	8,871	21.4	189,839	0.057	21.2	187,762
UM8716	TSS	1997 – 01	1997	Seasonal	4 REG-1	Excellent	24	10,417	18.7	194,798	0.073	18.2	189,506
UM8716	TSS	1997 – 01	1998	Seasonal	4 REG-1	Excellent	24	7,756	17.4	134,954	0.073	18.2	140,864
UM8716	TSS	1997 – 01	1999	Seasonal	4 REG-1	Excellent	25	9,510	19.1	181,641	0.073	19.8	188,272
UM8716	TSS	1997 – 01	2000	Seasonal	4 REG-1	Excellent	23	5,588	16.6	92,761	0.073	17.1	95,801
UM8716	TSS	1997 – 01	2001	Seasonal	4 REG-1	Excellent	25	10,561	20.0	211,220	0.073	18.4	194,322