MINNESOTA RIVER BASIN STATISTICAL TREND ANALYSIS

Photo: Metropolitan Council Environmental Services

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EXECUTIVE SUMMARY

This study summarizes statistical trend modeling results for water quality monitoring sites across the Minnesota River Basin (Basin). Water quality data from 21 stream and river monitoring stations in the Basin were analyzed for trends using two different statistical tests—QWTREND and Seasonal Kendall. The stations are distributed throughout the Basin and vary in scale from the Minnesota River itself to smaller streams such as Chetomba Creek and the Little Cobb River. Four water quality indicators were analyzed—total suspended solids, total phosphorus, orthophosphorus, and nitrate-nitrogen. Most of the data was collected over the past 10 years; although the Minnesota River stations at Mankato and St. Peter have records that go back about 40 years. Trend analyses were performed on three mainstem, eight major tributary, and nine minor tributary monitoring sites. Results are presented in tables (Appendix B & C) and maps (Appendix D-G).

Results for most stations exhibited either improving water quality or no change over the past 10 years. Total suspended solids (TSS), total phosphorus (TP), and orthophoshorus (OP) results generally show improving water quality (decreasing water quality pollutant trends) or no trends. The exception was nitrate-nitrogen, where stations in the western portion of the Minnesota River Basin showed declining water quality, while stations in the eastern portion of the basin showed improving water quality.

For the Minnesota River at Mankato, suspended sediment concentrations have decreased an estimated 20 percent since 1967. For the Minnesota River at St. Peter, total suspended solids concentrations decreased an estimated 30 percent since 1971, while concentrations of total phosphorus decreased 47 percent. These findings are consistent with previous long-term trend analyses performed on mainstem sites by University of Minnesota (Johnson, 2006) and MPCA (Christopherson, 2002). The trends work in this study did not include an analysis of the many factors that may explain the observed trends.

INTRODUCTION

The Minnesota River

The Minnesota River flows more than 335 miles from its source near the Minnesota-South Dakota boarder to its confluence with the Mississippi River at Minneapolis/St. Paul. The Minnesota River is the state's largest tributary to the Mississippi River. The land that drains into the Minnesota River, the Minnesota River Basin, encompasses roughly 15,000 square miles and contains all or parts of 37 Minnesota counties. The river drains nearly 20 percent of Minnesota and winds through a predominantly agricultural landscape.

History of Water Quality Monitoring

State and federal agencies have collected water quality data at various times in various locations throughout the Minnesota River Basin during the past thirty years. The most comprehensive study of water quality Minnesota River Basin, the Minnesota River Assessment Project, was conducted 1989-1994. The study concluded that the Minnesota River was impaired by excessive nutrient and sediment concentrations. Subsequent to those findings, considerable attention and support have been given to clean up efforts. Today, large portions of the Basin do not meet state water quality standards for bacteria, turbidity, dissolved oxygen, ammonia, and biota and are listed on Impaired Waters List (303(d) List). (MPCA Impaired Waters: http://www.pca.state.mn.us/water/tmdl/index.html).

Since 2000, a multi-agency team has developed surface water quality summary reports that consolidate data collected by multiple agencies and organizations across the Basin. The State of the Minnesota River reports (produced every two years) can be found on the Minnesota River Basin Data Center website: http://mrbdc.mnsu.edu/mnbasin/state/index.html

Statistical Trend Analysis

As the length of water quality records grew to a decade or more in many locations, there was sufficient data to use trend modeling programs to determine water quality trends in the Minnesota River mainstem, major tributary, and minor tributaries. Data sets from each monitoring site were analyzed for water quality trends in total suspended solids, total phosphorus, nitrate + nitrite-nitrogen and orthophosphorus. Two separate trend models were used in the analysis: QWTrend and Seasonal Kendall. Trend analyses were performed on three mainstem, eight major tributary, and nine minor tributary monitoring sites.

Water quality data for QWTREND and Seasonal Kendall analysis were derived from the MPCA Environmental Data Access (EDA) and Metropolitan Council Environmental Information Management System (EIMS) databases. Discharge data were obtained primarily from the United States Geological Survey (USGS), as well as the Minnesota Department of Natural Resources (MDNR), and the Minnesota Pollution Control Agency (MPCA). Sites were assessed to determine those meeting model requirements. A final list of sites used in the trend analysis is supplied in Appendix A. Statistical trend results are presented in table format in Appendices B and C and map format in Appendices D through F. A comparison of other trend studies is provided in Appendix G.

DESCRIPTIONS OF STATISTICAL TESTS USED

In this study, two methods were used to examine water quality trends in the Minnesota River Basin: the non-parametric Seasonal Kendall (SK) trend model; and the parametric technique Quality of Water trend analysis program (QWTREND) developed by USGS. QWTREND uses a parametric time series model that accounts for seasonality and streamflow-related anomalies to detect non monotonic trends. In contrast to the SK analysis, QWTREND can detect complex non-monotonic trends in concentration in the presence of interannual and seasonal variability in daily discharge (Vecchia 2006). Nonparametric-Statistics are generally the safer statistics to use because they are not as dependent on assumptions about data distribution. Both models were used in this analysis.

SEASONAL KENDALL - NON-PARAMETRIC TREND ANALYSIS

Overview

The Seasonal Kendall test was developed by Maurice Kendall in 1938. It compares the relationship between points at separate time periods or seasons and determines if there is a trend. It is considered a highly robust, non-parametric test and relatively powerful; a recommended method for most water quality trend monitoring (Aroner, 2001, DEQ 2009). The following summary of advantages and drawbacks of Seasonal Kendall were drawn from Vecchia (2003) and Johnson (2006).

Advantages of Seasonal Kendall

"The nonparametric Seasonal Kendall trend analysis and associated slope estimator works well with data that is not normally distributed, have values less than the detection limits, have seasonal cycles, is serially correlated, and trends are monotonic" (Johnson, 2006).

- Easy to compute
- Requires fewer assumptions than QWTREND analysis
- Robust to outliers
- Handles censoring (single threshold, no flow-adjustment)
- Good for handling lots of data from lots of stations

Drawbacks of Seasonal Kendall

- Assumes monotonic trend - The model can only test for one trend (monotonic)
- Must define seasons, perhaps combine or throw out data
- Limited to monthly or longer time step
- Flow-adjustment must be done separately
- Difficult to interpret trends in "ranks"
- Trends from the SK analysis are very sensitive to differences in data transformations such as averaging (Johnson, 2009)

Methods for Calculating

The methods used for calculating the Seasonal Kendall trend test statistic and the slope estimator are derived from the discussion of these methods in McBride (2000), Johnson (2006), and USGS (2009).

Broadly speaking, the Kendall trend test is calculated by comparing every potential pair of data values. "If the later value in the pair (in time) is higher than the first, a plus sign is scored. If the later value in the pair is lower than the first, a minus sign is scored. If the results find an equal number of pluses and minuses, then there is no discernible trend. This is done for all of the data pairs. "This analysis is considered to be robust because it ignores the degree of the change, and takes into account only the yearly positive or negative change" (Helsel and Hirsch, 1991).

To eliminate the effect of seasonality in the trend analysis, January values are compared with other January values, February values with February and so on (Hirsch et al., 1982). With this modification the Kendall test then becomes the Seasonal Kendall test.

Preparing Input Data Files

Water quality data for QWTREND and Seasonal Kendall analysis were derived from the MPCA Environmental Data Access (EDA) and Metropolitan Council Environmental Information Management System (EIMS) databases. Flow data were primarily obtained from the USGS. The constituents run through both models were total suspended solids, nitrate-N, total phosphorus and orthophosphorus.

For each site, the water quality data by date was copied into a MS Excel spreadsheet. The columns included site, date, daily flow, TSS, TP, OP and NO2+NO3-N. The flow column was filled in with the daily average flow for the sample date. Each date was entered into another column as month and year. A pivot table was then made with the mean for each parameter and flow by month and year.

The following details the steps for the Seasonal Kendall Trend Analysis. (Steps excerpted from USGS, 2005).

1. Classify a time-series data set by month of the year.

2. For each month *i*:

    a) Compute the sign of all possible value differences within the set of values for that month, sign(value_m - value_n) where value *m* is from a year that is later than value *n*. For example, all October values are compared to each other, but not to any November or September values. For 5 years of data, there would be 10 pairs, for 6 years of data 12 pairs, and so forth.
    b) Convert the positive signs to +1, negative signs to -1, and 0 results to 0. Then add the results and call that S_i.
    c) Compute the variance of S_i, Var(S_i), from $[n(n-1)(2n+5)-\text{Summation}(t_{ip}(t_{ip}-1)(2t_{ip}+5))]/18$ where *n* is the number of (monthly) values in the set, t_{ip} is the number of tied data in p^{th} tied group for the i^{th}, and the summation is over the number of tied groups for that month.

    For computational purposes, group size is considered to be 2 (number of terms in the initial difference comparison). This results in a higher variance in cases where there are multiple tied values of the same value - for example, treating three equivalent values as 2 ties of two members instead of 1 tie of three values. The higher variance, in turn, results in a lower test statistic, and consequently an overall stricter test for overturning the null hypothesis (The null hypothesis is that there is NO monotonic trend in the data.) The resulting variance computation is the simpler $[n(n-1)(2n+5)-18*t_{ip}]/18$

3. Compute S as the sum of the S_i series over all months.

4. Compute the variance of S, by summing the variance Var(S_i) over all months.

5. Compute the test statistic (Z_{sK}) from the large sample normal approximation, with a continuity correction of one unit, where:

$$Z_{sK} = (S-1)/(\text{Var}(S)^{0.5} \text{ if } S > 0$$

$Z_{sK} = 0$ if $S = 0$

$Z_{sK} = (S+1)/(\mathrm{Var}(S))^{0.5}$ if $S < 0$

6. Consider the null hypothesis to be invalid if $|Z_{sK}| > Z_{\alpha/2}$, where α is the chosen significance level and $Z_{\alpha/2}$ is the value of the abscissa that cuts off an area = $\alpha/2$ in the right tail of the unit normal distribution.

Seasonal Kendall formula requires $n>10$ where n is the number of years. (Helsel and Hirsch, 1992).

Adjustment for Flow:
Concentrations are widely affected by flow. To account for this, there needs to be flow adjustment prior to running the Seasonal Kendall analysis. This was done by the smoothing technique LOWESS (Locally Weighted Scatter plot Smooth) which describes the relationship between *Y* (concentration) and *X* (flow).

Given the LOWESS fitted values $\hat{Y}$ the residuals R are computed as:

$R = Y - \hat{Y}$

Then the Kendall S statistic is computed from the R,T data pairs, and tested to see if it is significantly different from zero. The test for S is the test for trend which is adjusted for the flow.

QWTREND – PARAMETRIC TREND ANALYSIS

Overview
The QWTREND program was developed by Skip Vecchia at the US Geological Survey. QWTREND is short for "quality of water trend analysis program". This computer program analyzes trends in water quality concentration. It is based on a parametric time series model for streamflow, described below. Software packages (both stand-alone and S-Plus version) are available (Vecchia, 2004). The advantages and disadvantages are drawn from Vecchia (2003 and 2004) and Johnson (2006).

Advantages and Drawbacks of the Model

Advantages of QWTREND Analysis
Vecchia explained that the compound flow adjustment model was better in accounting for flow variability in water quality data than the simple regression model of natural log of concentration versus natural log of flow like in the Seasonal Kendall test.

> "Concentrations of water quality constituents commonly are related to stream flow. Variations in streamflow may exist on many different time scales, such as daily, seasonally, and annually which can affect concentrations in complex and diverse ways. The QWTREND model filters out as much natural streamflow-related variability in concentration as possible before analyzing for concentration trends. The model also filters out serial persistence, or autocorrelation, between constituent concentrations that are adjacent in time; autocorrelation can bias estimated trends and their significance levels. The model separates streamflow data into components of annual variability, seasonal variability, and high-frequency deviations from the basic conditions or "noise" (USGS, 2006).

Advantages of QWTREND analysis (continued)

- Has the ability to pick up multiple trends over a given period (Johnson)
- Can be used to model complex (non-monotonic) trends
- The parametric model appears to be an improvement over the SK model for complex trends (Johnson)
- Good for explanatory, not just exploratory, analysis
- Uses full power and flexibility of maximum likelihood theory
- Flow and concentration modeled jointly
- The program uses relatively complex statistical methods to identify trends in concentration data after accounting for variation due to flow (or discharge).
- Compound flow adjustment models that account for multiple time scales anomalies are better in deciphering the true trends in water quality (Vecchia/Johnson).
- Ancillary data (fertilizer use, turbidity, etc.) can be included
- The QWTREND model is more stable to the effects of extreme precipitation records (Johnson)
- "Model can detect complex non-monotonic trends in concentration in the presence of interannual and seasonal variability in daily discharge" (Vecchia, 2003).

Drawbacks of QWTREND analysis

- Requires specification of a parametric model
- Computationally intensive (requires nonlinear optimization)
- Requires care fitting the model and verifying assumptions
- May require more data than non-parametric methods
- Requires more flow data to run the analysis (5 years before the first water quality sample through the end of the record (Vecchia, 2004)
- Requires small percentage (< 10 percent) censored data

Methods for Calculating trend by using QWTREND program

1. QWTREND was run on splus statistical software which uses the Periodic Autoregressive Moving average (PARMA) time series model.

   $\text{Log}(Q) = M_Q + ANN_Q + SEAS_Q + HFV_Q$
   where Log denotes the base-10 logarithm
   Q is daily streamflow, in cubic feet per second
   M_Q is the logarithmic mean for streamflow
   ANN_Q is the annual anomaly for streamflow
   $SEAS_Q$ is the seasonal anomaly for streamflow.
   HFV_Q is the high-frequency variability for streamflow.

2. The concentration data in the QWTREND analysis is partitioned the same way as the streamflow data but various concentrations anomalies are estimated from flow anomalies.

   $\text{Log}(C) = M_C + ANN_C + SEAS_C + TND_C + HFV_C$
   where Log denotes the base-10 logarithm
   C is concentration, in milligrams or micrograms per liter
   M_C is the logarithmic mean for concentration
   ANN_C is the annual anomaly for concentration
   $SEAS_C$ is the seasonal anomaly for concentration
   TND_C is the concentration trend
   HFV_C is the high-frequency variability for concentration

3. The QWTREND output given below shows the analysis of total phosphorus in Redwood River near Redwood Falls, MN for 1990 to 2008 data. USGS site number 05316500.

   The mean daily stream flow for the day was paired with the corresponding concentration by running the :

   ```
   >makeqwiv2('E:\\qwtrendv2\\Redwood2\\Redwood2',c(1,2,3,4),1990,2008,3)
   ```

   ```
   '#    USGS 05316500 REDWOOD RIVER NEAR REDWOOD FALLS, MN'
   'E:\WaterQuality\qwtrendv2\Redwood\Redwood2.fl'
   19 3 5 0
   'DAILY DISCHARGE, IN CUBIC FEET PER SECOND'
   'TSS Conc'
   'NO3 Conc'
   'TP Conc'
   'PO4 Conc'
   1990   1   5      4.1   -999   -999.00  -999.00  -999.000
   1990   1  15      4.1   -999   -999.00  -999.00  -999.000
   1990   1  25      4.1   -999   -999.00  -999.00  -999.000
      (bunch of lines left out here)

   2008  10  31     48.0     48     25.00     2.67     0.748
   2008  11   5     40.0   -999   -999.00  -999.00  -999.000
   2008  11  15     71.0   -999   -999.00  -999.00  -999.000
   2008  11  25     55.0     55      7.00     5.89     1.880
   2008  12   5   -999.0   -999   -999.00  -999.00  -999.000
   2008  12  15   -999.0   -999   -999.00  -999.00  -999.000
   2008  12  25   -999.0   -999   -999.00  -999.00  -999.000
   ```

In any given month, the time is split up into three approximately 10-day intervals; the 1st day-10th day, the 11th day to 20th day and the 21st day to 30th or 31st day. The QWI file has the three values per month for the 5th, 15th and 25th of the month. As shown in the table above.

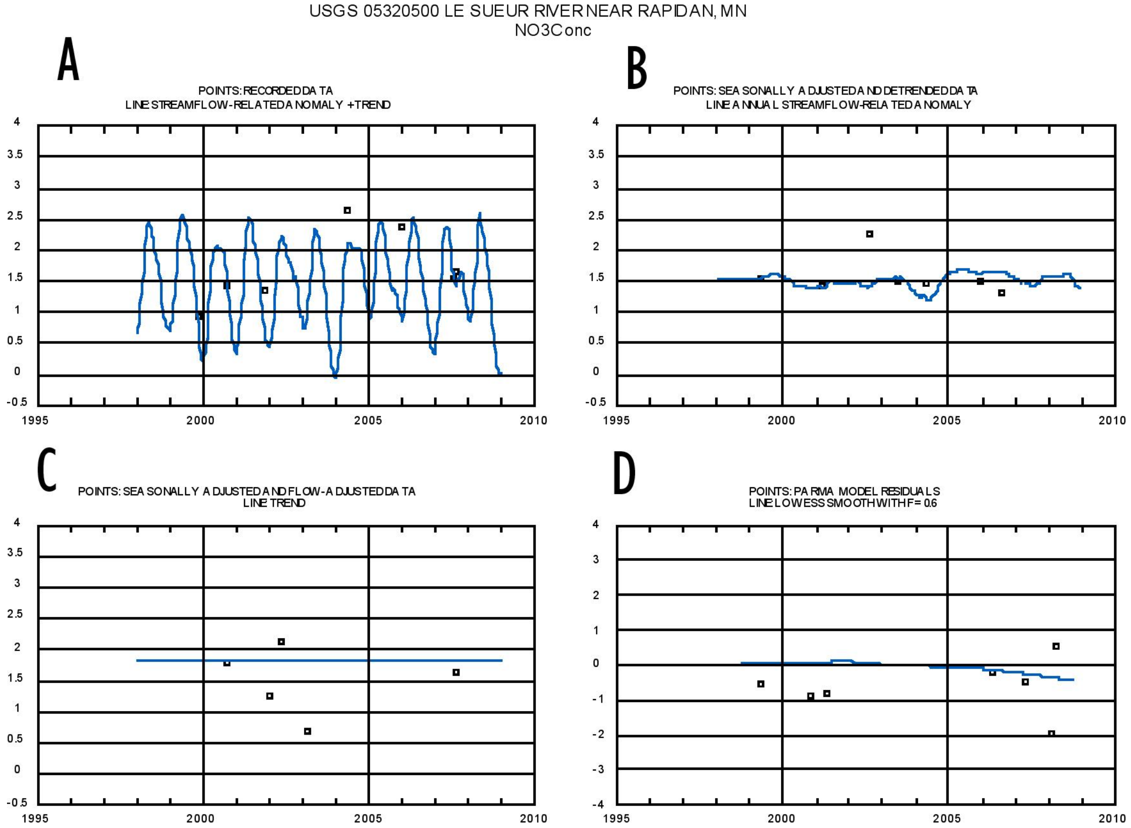
4. Running the QWTREND program will generate the mle output file and the graphs. As shown in the table below:

   ```
   '#    USGS 05316500 REDWOOD RIVER NEAR REDWOOD FALLS, MN'
               3           4           3           3

    ***************
   variable  1  DAILY DISCHARGE, IN CUBIC FEET PER SECOND
   variable  2  TPConc
    -2 ln L      8476.88     AIC      8550.88     error code  1
     Coefficient  i  j  lag   Fourier parameters
    AR        2  1  0          0.244    -0.090    -0.241    -0.109     0.200
    AR        2  2  1          0.366    -0.038    -0.033    -0.213    -0.161
    Res SD    2  2  0          0.683    -0.227    -0.123    -0.179     0.221
      MA      2  1  0          0.135    -0.068     0.038    -0.182    -0.315
      MA      2  2  1          0.365    -0.145     0.064    -0.176    -0.289
      sfanom:  qanoms qanoms2  qanom5  qanom1 qanom12
     est coef   0.446   0.005  -0.196   0.512  -0.215
     est/serr  10.632   0.140  -0.633   6.671  -1.492
        step:
     est coef
     est/serr
     monotnd:  m****, 5.0
     est coef      -0.072
     est/serr      -0.563
       ancil:
   ```

```
est coef
est/serr
```

5. From this output the rate of increase or decrease can be calculated by:
   Rate= 100(10^est. coeff.-1)
   In the above data Rate= 100(10^(-0.072)-1)= -15.27726
   This means the 15.28% decrease in total phosphorus from 1990 to 2008.
   The p-value is calculated using chi-square table as **0.5734349.**



Examples of the QWTREND output graphs are provided above. The plots above were produced by pltqwtndv2. The plots show the following information:

A: Recorded data, Y(t), and the line showing MC + ANNC + SEASC +TNDC

B: Seasonally adjusted and detrended data, Y(t) – SEASC – TNDC, and the line showing MC + ANNC

C: Seasonally adjusted and flow-adjusted data, Y(t) – SEASC – ANNC, and the line showing MC + TNDC. Note that "flow-adjusted data" here refers to a different flow-adjustment process than simply regressing concentration on streamflow

D: PARMA model residuals and a line showing the lowess smooth.

Model Data Requirements

Generally, how much data are "enough" to run the model depends on individual stations or constituents but Vecchia provided some general guidelines:

- Record length of at least 15 years (although not necessarily consecutive)
- Average of at least 4 samples per year (sampling frequency many vary from year to year)
- At least 10 samples during each 3-month season (Jan-Mar, Feb-Apr, Mar-May, …, Dec-Feb) At least 1 sample is each of 10 separate years,
- No more than 10 percent of values below detection limit (may be more, but extra care required to interpret results)
- Full record of daily streamflow from 5 years before the first water quality sample through the end of the record (Vecchia, 2004)

Preparing Input Files

The model required a water chemistry and daily mean flow input file. As a first step for preparing the water chemistry file, all field duplicate samples were deleted so that no date had more than one sample result. Several of the monitoring sites had both grab and composite samples. For these sites, the data was run through the model twice, with composites included and without. For the dataset with composite samples, the daily mean flow over the period the sample was collected was used.

The next step was to verify that the dataset was adequate for running the model. At minimum there needs to be sixty water samples over a period of at least fifteen years. Sampling frequency need not be consistent and samples need not be present every year. The model then uses up to three samples per month, for a total of thirty-six samples per year. The model automatically selects the three samples per month, picking samples at a 10-day interval. The intervals for any given month are the 1st day through the 10th day, the 11th day through 20th day, and the 21st day through the end of the month. If there is more than one sample collected during any of these 10 day periods, the sample closest to the 5th, 15th and 25th are selected. Along with water chemistry data, the water chemistry input file contains the daily mean flow for each sample date.
A second file is used by the model that contains all available daily mean flow values. The flow values should precede the water chemistry data by at least five years.

RESULTS

Trend analyses were conducted on datasets from 21 water quality monitoring stations across the Minnesota River Basin: three mainstem, eight major tributary, and nine minor tributary monitoring sites. Data represents 18 different waterways in the Minnesota River Basin. Stations were selected on the basis of sample size, period of reporting, and availability of flow data. Stations are maintained by United States Geological Survey, Minnesota State University, Mankato Water Resources Center, and watershed projects. Trend analyses were performed using the two statistical methods discussed. In some cases, due to data gaps or limitations, it was not possible to run both tests. Results discussed in this section are for trends that were found to be statistically significant (at a 95% confidence level). More detail about results can be found in "Appendix B: Table of Results by Site" and "Appendix C: Table of Results by Parameter" and maps in Appendix D-G.

Overall Results

Results for most stations exhibited either improving water quality or no change over the past 10 years. Total suspended solids (TSS), total phosphorus (TP), and orthophoshorus (OP) results generally show improving water quality (decreasing water quality pollutant trends) or no trends. The exception was nitrate-nitrogen, where stations in the western portion of the Minnesota River Basin showed declining water quality, while stations in the eastern portion of the basin showed improving water quality.

For the Minnesota River at Mankato, suspended sediment concentrations have decreased an estimated 20 percent since 1967. For the Minnesota River at St. Peter, total suspended solids concentrations decreased an estimated 30 percent since 1971, while concentrations of total phosphorus decreased 47 percent. The trends work did not include an analysis of the many factors that may explain the observed trends.

Total Suspended Solids (TSS)

- For TSS, most results show decreasing trends (improving water quality) or no trends across the basin with the Seasonal Kendall test. The QWTREND analysis shows increasing (declining water quality) trends at three sites: St. Peter, Chippewa, and Le Sueur.
- The longer-term USGS record at Mankato shows a decreasing trend in Total Suspended Sediment Concentrations (similar to TSS) from 1967 to 2007.
- Results for SK test show all (10 out of 10) sites indicate decreasing TSS levels (1998-2008). Two mainstem, 4 major and 4 minor tributaries show reduction in TSS trends.
- QWTREND mainstem results are mixed with Mankato Total Suspended Sediment concentrations (SSC) indicating a decreasing trend while St. Peter shows an increasing trend. (Note: Total Suspended Sediment and Total Suspended Solids are related but different parameters.)
- QWTREND major watershed sites also show mixed trends with two indicating increasing trends, and one indicating decreasing trends.
- Two sites show conflicting (opposite) test results between models. For Chippewa and St. Peter, SK results indicate improving water quality trends, while QWTREND results show declining water quality trends.
- Six SK tests and four QWTREND tests at 9 different sites show no significant trend.
- Overall results (i.e. decreasing trend at most sites) seem to align with previous trend analyses performed by University of Minnesota (Johnson, 2006) and MPCA (Christopherson, 2002). From 1976-2001, these studies found declining trends in TSS levels at Fort Snelling, Jordan, and Blue Earth monitoring sites (see Appendix H).

Nitrate + Nitrite-Nitrogen (Nitrate-N)

- For Nitrate-N, stations in the western portion of the basin show mostly no trends with three increasing trend (decreasing water quality) and one mixed (Redwood River). The Greater Blue Earth River Basin (Watonwan, Blue Earth, and Le Sueur) in the eastern portion stations shows decreasing trends (improving water quality) while the Minnesota River mainstem site at Judson shows mixed trends.
- The two tests generally had differing results for Nitrate-N. For mainstem and major watershed SK results indicate increasing trends (declining water quality) (except Little Cobb) while QWTREND results indicate decreasing trends (improving water quality). The mainstem site at Judson and the Redwood River are examples of this contradiction.

- On the other hand, you can see consistent results within the QWTREND tests for 1998-2008. All QWTREND (5 of 5) results show decreasing Nitrate-N trends: one mainstem (Judson) and four major tributary sites.
- SK results show increasing trends at 1 mainstem (Judson), two major watershed, and two minor watershed sites and decreasing trends at one minor (Little Cobb).
- Thirteen SK tests and three QWTREND tests at 14 different sites show no significant trend.
- Other SK trend studies (see Appendix H) showed decreasing Nitrate-N trends at Jordan (1976-2001). This study found mixed results with decreasing trends at St. Peter and increasing trends at Judson.

Total Phosphorus

- For total phosphorus, "no trend" results predominate in the western portion of the basin while the eastern portion shows decreasing trends in the Greater Blue Earth River Basin (Watonwan, Blue Earth, and Le Sueur River watersheds). Only the Minnesota River at St. Peter and Chetomba Creek (a tributary to Hawk Creek) indicate increasing trends.
- All SK results indicate decreasing trends (improving water quality) for total phosphorus (TP) during the 1998-2008 time period except for one minor watershed with increasing results (Dry Weather). The longer-term St. Peter site from 1971-2006 also indicates a decreasing trend.
- QW Trend results are mixed. Results from two sites show decreasing trends for TP, while one shows an increasing trend.
- There are conflicting results for the Minnesota River mainstem. The site at St. Peter shows increasing trends while the site at Judson indicates a decreasing trend St. Peter (1998-2008).
- Overall, the results illustrate six sites with decreasing trends and two sites with increasing trends for one or both tests. Watonwan had decreasing trend results for both tests.
- Thirteen SK tests and five QWTREND tests at 16 different sites showed no significant trend.
- Other long-term SK trend studies (see Appendix H) showed decreasing TP trends for mainstem sites. Overall, this study further supports those findings.

Orthophosphorus

- Overall, eight out of nine monitoring sites with statistically significant results indicate decreasing trends (improving water quality) or no trends with the exception being Dry Weather (a tributary to the Chippewa River) which shows an increasing trend.
- All SK results (with the exception of Dry Weather) show decreasing OP trends.
- All QWTREND results also indicate decreasing trends. These include two mainstem and four major tributary sites.
- Fifteen SK tests and one QWTREND test at 15 different sites showed no significant trend.

CHALLENGES & CONCERNS

Differences Between the Models

The two methods generally showed similar trends but in some cases contradicted each other. Johnson (2009) laid out rationale for the differences in model results: “These differences appear to be associated with the conceptual difference in the way flow-related variability is removed from the concentration data.” She noted that the SK model seems more influenced by extreme changes in precipitation than the QWTREND model. Another possible reason for the difference between the models is the use of monthly mean concentrations in SK analysis versus up to three individual concentrations per month in QWTREND analysis. “The QWTREND analysis also has a distinct advantage in that it uses a more rigorous method for flow adjustment and the trends for different time intervals are fitted simultaneously rather than individually” (Johnson, 2009).

Trend modeling is a statistical exercise and these two models handle data differently. Part of this study was to further investigate which modeling techniques to employ in future trend analyses. We are still assessing which techniques are preferable to use and will continue researching which model is a more appropriate technique for particular data sets and parameters. The broad long-term goal is to move towards a consistent methodology to analyze the effects of climate, changes in land use practices, and contributions of various pollutant sources at different watershed scales.

Precipitation and Flow

Flow data were run through the Seasonal Kendall test for four sites, but none of the sites had statistically significant trends. For the longer trend period (since the 1970s), Minnesota’s precipitation increased during the 1990s compared to the long-term average. Higher precipitation has resulted in higher runoff, increased river flows, and increased pollutant loading (MPCA, 2002).

Length of Data Sets

“A universal problem with trend analysis lies with the question of how long a data set should be to accurately assess if there is a trend” (Johnson, 2006). Vecchia stated that the ability to detect trends depends on the complexity and duration of it, the amount and number of water quality samples, the overall quality of the water quality data, quality of streamflow data and finally, the statistical methodology used to identify the trend (Vecchia, 2004). In most cases, the water quality monitoring data sets utilized in this study meet the minimum data requirements for the trend models. Data sets in this study range from 8 to 40 years with most around 10 years (see Appendix A). Because this study utilizes relatively short-term data sets and conditions in the Minnesota River basin are highly variable from year to year, the team approached the conclusions with caution. Continuing the data collection and increasing the periods of record for these data sets will provide important information and raise confidence in model results over time. Considering this study in the context of other trend studies with longer periods of record did improve the confidence of the team in some cases (see trend comparison in Appendix H).

Challenges Working with Data

Trend monitoring assumes that the same or equivalent methods and protocols are used for all the monitoring. This was not always the case. Challenges of working with data include 1) data collected from stations that were started, stopped, and then restarted years later, 2) shifts in sampling regimes and techniques 3) data sets may include results from different water quality testing laboratories, and 4) water quality concentrations are skewed high or low and tied to streamflow, which has seasonal tendencies (Johnson, 2006).

Grab and Composite Samples

Five of the sites, the Blue Earth River, Le Sueur River, Little Cobb River, Minnesota River at Judson and Minnesota River at St. Peter, had samples that were collected by both grab and composite sampling methods. These sites were instrumented with automated samplers that collected samples during snowmelt and storm runoff periods. The automated samplers were programmed to activate during the initial rise in stream level and then collect a flow-based composite sample over time. These composited samples represented the flow weighted mean concentration from the river during the sampling period. Typically these composite samples were collected over a period of one to four days during high flow and storm runoff periods. During moderate and low flow periods, grab samples were collected.

For the trend analysis study the composite samples proved to be problematic. As described previously, both QWTREND and Seasonal Kendall programs require a daily mean value along with discrete water chemistry data for the input file. It was felt that inclusion of the composite samples was important as they represented much of the higher flow periods. In order to include these samples a daily mean flow was derived by averaging the daily mean flows from the time period the composite sample represented. This average flow was entered into the input files for the trend programs. However, it was also noted that these programs were not designed for running composite samples and perhaps it would be better to exclude the samples. In the end it was decided to run these five sites through the models both with composites included and removed (see “with composite” and “without composite” notes on result tables). Results indicated that when composites are taken out, results changed but the overall trend remained the same.

Drawing Conclusions: Impacts of Conservation Measures on Trends

Trend modeling is a relatively new technique and most of the datasets employed in this study just meet the minimum model requirements. Our confidence in the trend modeling results will increase as the period of record increases. The project team preferred to think of these results as qualitative tendencies (e.g. concentrations appear to be decreasing) rather than quantitative certainty. Other trend researchers caution that: “It is imperative to remember that detection of trends with the Seasonal Kendall trend analysis does not necessarily mean that the changes in water quality concentrations are due to changes in practices on the landscape (Smith, 1982). These changes can also occur because of changes in flow volume over time” (Johnson 2009).

On the other hand, there are cases where increasing or decreasing trends in pollutants documented in this study are further supported by other, longer-term trend analyses. In these cases especially, potential causal linkages between water quality improvement or deterioration and changes in the land use practices and policies should be explored. These results suggest the possibility that reduction in pollutants could be a result of best management practices and other focused efforts to improve water quality in the basin. Other factors limit our ability to make causal links with certainty, but some significant efforts have been underway over the past two decades.

From 1998-2002, the Conservation Reserve Enhancement Program (CREP) was completed securing 100,000 acres of critically sensitive cropland. Farmland was converted into permanent easements of native grasses, wetland restoration, and buffer strips. According to the Board of Water and Soil Resources (2008), the area under active contracts for all conservation programs from 1987 to 2001 was about 14.8% of the cropland area in the 37 counties of the MRB (Johnson et al, 2009). Conservation tillage has been increasing across the basin. According to data compiled from tillage transect surveys, conservation tillage shifted from 20.2 percent of soybean acres in 1989 to 56.6 percent in 2007. Residue on corn fields, however, peaked at 27.2 percent in 1993. Decreasing trends in TSS, TP, and OP concentrations shown in the results of this report may be due to these conservation measures in the basin. Researchers from longer-term trend studies have concluded that "it appears that some of the decrease in TSS, TP, and OP concentrations may be due to adoption of conservation measures in the basin, especially in the lower Minnesota River between Mankato and Fort Snelling" (Johnson et al, 2009).

The decreasing trend in phosphorus and orthophosphorus detected in this study may be linked to the significant investment and effort to upgrade wastewater treatment facilities across the basin. Minnesota developed the Phosphorus General Permit in 2005 to reduce phosphorus discharged by point sources into the Minnesota River Basin. Reduction in the amount of phosphorus being discharged into the Minnesota River due to wastewater plant upgrades is significant (90,000 kgs in 2005 to 55,000 kgs in 2008). Additionally, there has been progress addressing undersewered communities and failing septic systems during the past decade.

Commercial nitrogen fertilizer sales have steadily increased in Minnesota over the past decade and more acres of corn in the basin were harvested from 2002-2007 so it is likely that more nitrogen has been applied to more corn acres. Additionally, some land has been taken out of conservation programs such as Conservation Reserve Program. Considering these types of changes, some would consider the finding of "no statistically significant trend," which occurred commonly in this study, to be encouraging. Studies are currently underway to better understand the changes in drainage and runoff over the past decade. These studies will provide additional insight into how changes in flow regimes affect pollutant concentration trends.

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