STREAM POLLUTANT TREND UPDATE METHODOLOGY

Background

The Twin Cities metropolitan area of Minnesota has a wealth of streams that traverse its landscape and ultimately flow into one of three major rivers – the Mississippi, the Minnesota, and the St. Croix. These streams provide rich habitat for aquatic life and wildlife and enhance the recreational and aesthetic value of the metro area.

The Metropolitan Council is committed to the conscientious stewardship of the region's streams and tributary rivers and works with its partners to maintain and improve their health and function. The foundation for these efforts is the collection and interpretation of high-quality, long-term data to produce insightful, actionable information.

Pollutant trends are a valuable tool to understand how a stream's water quality is changing over time. The Met Council first calculated statistical trends on Twin Cities streams and tributary rivers that are part of its monitoring programs in the 2014 *Comprehensive Water Quality Assessment of Select Metropolitan Area Streams*[1] (subsequently referred to as the 2014 Stream Report). This report is available online at https://metrocouncil.org/Wastewater-Water/Services/Water-Quality-Management/Stream-Monitoring-Assessment.aspx. At that time, water quality trends were calculated for total suspended solids (TSS), total phosphorus (TP), and nitrate through the year 2012[2]. In addition, in 2021 the Met Council calculated chloride trends for their monitored streams. The chloride trend results are reported in a series of memos which are available on the Met Council's Environmental Information Management System (EIMS) website: https://eims.metc.state.mn.us/Documents.

The purpose of this new effort is to update the trends originally published in the 2014 Stream Report data using data through the end of 2021 and an updated version of the flow-adjusted trend calculation software, R-QWTREND. This document is a record of the methodology used to calculate the updated trends.

Recommended Citation

Please use the following to cite this methodology document or the series of memos reporting the trend results:

Metropolitan Council. 2023. In *Stream Pollutant Trend Update*. Saint Paul: Metropolitan Council.

[1] Metropolitan Council. 2014. Comprehensive water quality assessment of select metropolitan area streams. Saint Paul: Metropolitan Council.

[2] Metropolitan Council. 2022. Regional assessment of chloride in select Twin Cities metro streams (1999-2019). Saint Paul: Metropolitan Council.

Trend Software

Trend analysis was performed using the software package R-QWTREND Version 1.2 (March 2023), developed by the US Geological Survey (USGS). The R-QWTREND package is a collection of functions written in R, an open-source language and a general environment for statistical computing and graphics. It uses a parametric time-series model to express logarithmically transformed concentration in terms of flow-related variability, trend, and serially correlated model errors. R-QWTREND uses daily average flow and water quality concentration datasets to perform the trend assessment.

Data

Water Quality

Parameters

Trends were analyzed for total suspended solids (TSS), total phosphorus (TP), and total nitrate+nitrite (NO3+NO2). Using NO3+NO2 was a change from the 2014 Stream Report, which calculated trends on just nitrate. This change was made to be consistent with state partners who do their assessments on NO3+NO2, such as the Minnesota Pollution Control Agency's load and trend calculations. Since nitrite in flowing waters usually makes up a small percentage of NO3+NO2, it was assumed that differences between a nitrate trend and a NO3+NO2 trend would be small.

The water quality data for each stream were collected, reviewed, and approved by Metropolitan Council or their partners in the Watershed Outlier Monitoring Program. The data are publicly available and can be downloaded from the Environmental Information Management Systems data portal at https://eims.metc.state.mn.us/.

Processing the NO3+NO2 dataset

The NO3+NO2 data required additional processing before use with R-QWTREND. The Metropolitan Council recorded nitrate and nitrite results separately until the middle of 2018. After that, NO3+NO2 was also recorded. The datasets were merged to create one consistent timeseries of NO3+NO2 for each site, using the following guidelines:

- Used the NO3+NO2 result, if available (after mid-2018)
- If there was a nitrate and nitrite result, but no NO3+NO2 result (before mid-2018), add together the nitrate and nitrite results, unless either has a < sign:
    - If both nitrate and nitrite have a < sign, use the nitrate result with a < sign (i.e. treat the < nitrite result as 0)
    - If only the nitrite result has a < sign, use the nitrate result (i.e. treat the < nitrite result as 0)
    - If only the nitrate result has a < sign, drop the < sign from the NO_3 result and add together the nitrate and nitrite results
    - If either the nitrate or nitrite result was missing, then report no result

Censored Values

The water quality data contained both left censored (<) and right censored (>) results. The R-QWTREND software includes techniques to include the left censored values in the analysis, so they were kept in the datasets. Right censored results (very rare) were removed from the datasets.

In the NO3+NO2 dataset, there was a noticeable shift in the lower limit of the left censored values in 2019. Due to changes in the laboratory where the water samples were analyzed, most left censored NO3+NO2 results changed from < 0.05 mg/L to < 0.20 mg/L. There was concern that the change in the lower limit might cause a false upward trend in the analysis after 2019, especially at sites where there were many results reported at the lower limit. To avoid this, all NO3+NO2 datasets were re-censored to use a lower limit of < 0.20 mg/L - any result lower than 0.20 mg/L before 2019 was replaced with < 0.20 mg/L.

Flow

At most streams, flow data were collected, reviewed, and approved by Metropolitan Council or their partners in the Watershed Outlier Monitoring Program. A timeseries of daily average flows were calculated using reviewed 15-minute flow data. Any gaps in the record of flow data were filled using estimated values based on rating curves or other methods of estimation. Use the contact information listed at the end of this document if you would like to request a copy of the Council's 15-minute flow data.

Metropolitan Council does not measure flow on the Cannon River, Crow River, or Rum River. Instead, flow records for these sites were downloaded from nearby United States Geological Survey (USGS) monitoring stations.

Trend Assessment Approach

The trend analysis using R-QWTREND was performed using a combination of recommendations from the R-QWTREND manual[3] and decisions made by Metropolitan Council staff for the purposes of this specific study.

Fitting Potential Trend Models

R-QWTREND has four different types of trend terms that can be used to fit a model: piecewise monotonic trends, time interval-based step trends, attribute-based step trends, and user specified variable trends. Piecewise monotonic trend terms are used to model gradual, multiyear changes in the flow-adjusted concentrations. Since the goal of this study was to identify long term trend shapes, only monotonic trend terms spanning five years or longer were used to fit models, except when there was known information about activity in the stream or watershed to justify using a shorter period.

For each stream location and parameter, several potential trend models were fit to the data. First, a model with no trend terms was calculated as the baseline, null model. Then, more complex models were tested by adding additional monotonic trend terms and setting different years for the start and end of each term. The start and end years were generally determined by reviewing the shape of the quadratic splines (a piecewise polynomial function calculated by R-QWTREND) of the attempted models. This process is described in more detail in the R-QWTREND manual.

The -2lnLik value (negative two times the natural logarithm of the maximized likelihood function) of each attempted model was used to calculate an overall p-value of the model using a generalized likelihood ratio (GLR) test against the null model. Models with an overall p-value at or above a significance level of 0.1 were considered non-significant and discarded. Models with an overall p-value below 0.1 were considered significant and a viable model for selection.

Selecting a Model

Significant trend models were then compared using their -2lnLik value to help identify one "best-fit" model. Models with a different number of monotonic trend terms were compared using a GLR test statistic calculated from the -2lnLik values of the models. When the GLR test statistic between two models was at or above a significance level of 0.01, the model with less trend terms was preferred. When the GLR test statistic was below the significance level, the model with more trend terms was preferred. A lower significance level of 0.01 was used for this comparison to avoid selecting overly complicated models, following the recommendation of the R-QWTREND manual.

Due to how the GLR test statistic is calculated, it could not be used to compare models with the same number of monotonic trend terms (for example, models that each had three monotonic trend terms, but the terms started and ended with different years). To compare two models with the same number of trend terms, the model with

[3] Vecchia, A.V., and Nustad, R.A., 2020, Time-series model, statistical methods, and software documentation for R–QWTREND—An R package for analyzing trends in stream-water quality (ver. 1.2, March 2023): U.S. Geological Survey Open-File Report 2020–1014, 51 p., https://doi.org/10.3133/ofr20201014.

the lower -2lnLik value was preferred, unless the -2lnLik values were within a value of one from each other, and then the models were considered to fit the data equally well.

In some situations, one final “best fit” model could not be identified using the -2lnLik values, either due to inconclusive results from the pairwise GLR tests or because several attempted models were considered to fit the data equally well. In these cases, additional information was considered on a case-by-case basis to select a final model, such as the shape of the model residuals, the shape of the models’ quadratic splines, known information about the site or parameter, or other factors.

The R-QWTREND model also calculates a p-value for each individual trend term in a model. In this study, a significance level of 0.1 was applied to determine the significance of a trend term. A trend term with a p-value at or above 0.1 was considered non-significant, meaning that an upward or downward trend direction could not be detected among the natural variability of the dataset. A trend term with a p-value below 0.1 was considered significant, meaning the model was able to detect an upward or downward trend in the data that is likely to be a true pattern and not due to random variability in the data.

For quality assurance, the results of each trend analysis were reviewed, discussed, and approved by an internal verification team.

Outliers

The R-QWTREND software flags potential outliers in the water quality datasets. Including outliers in the trend calculation increases the chances of producing a trend line that does not accurately represent the long-term changes in the dataset. This is counter-intuitive to the goals of this assessment– one or two datapoints out of hundreds of samples should not be strongly influencing the shape of long-term trends.

To determine if the outliers were strongly affecting the results of the trend analysis, the final selected “best fit” trend model was run with and without any flagged outliers. If the statistics of these two models were similar, then the outliers were left in the dataset. However, if removing the outliers caused the direction or significance of a monotonic trend term to change or caused the estimated percent coefficient value of a trend term to change by a value of more than 10, then the assessment was re-run with the outliers removed from the start. If the same model was still selected after the re-run, and the trend terms had the same direction and significance, then the outliers were kept in the model. Otherwise, the result from the re-run without the outliers was selected as the final model.

For Additional Information

Met Council staff are available for additional discussions about this trend analysis. Please contact Dan Henely, Assistant Manager, Water Resources, daniel.henely@metc.state.mn.us, with any questions.

The raw data used to calculate trends is available on the Met Council’s EIMS website: https://eims.metc.state.mn.us/.

Previous technical analysis, including the 2014 Stream Report and 2021 chloride fact sheets can be found on the EIMS document repository: https://eims.metc.state.mn.us/Documents