Appendix 4. Methods—Trend Analysis Using Coupled Statistical Model of Streamflow and Water Quality

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This appendix describes the use of coupled statistical models of streamflow and water quality to determine “flow-adjusted concentration trends,” “modeled instream concentration trends,” and “trends in load” in support of the analysis of nutrient concentrations, trends, and loads in the northeastern United States. The modeled instream concentration trend, or non-flow-adjusted trend in concentration, is referred to as “total trend in concentration” in this appendix. Many other alternative descriptive titles are used for trend results of this nature, including: non-flow-adjusted trend, unadjusted trend, full trend, total parametric trend, and modeled instream concentration trend. The phrase “modeled instream concentration trend” has been used in this report to refer to the non-flow-adjusted trend in concentration. The non-flow-adjusted trend in load is referred to as simply “trend in load” in this appendix and in this report.

Definition of Non-Flow-Adjusted Trend

Trend in load and total trend in concentration are defined as the percent changes in model-estimated, smoothed trend in load and concentration over the period of the water-quality record, divided by the length of the record. The model-estimated trend in load and concentration is determined by fitting separate trend models for streamflow and water-quality concentration. The streamflow model, estimated from all daily streamflow measurements available over the analysis period (water years 1993–2003, 1982–2003, 1979–2003, or 1975–2003 in this report), relates the logarithm of daily streamflow to an intercept, a linear trend term (measured by time expressed as a decimal), and sine and cosine seasonal factors (also functions of decimal time). The water-quality model, estimated from all water-quality measurements collected during the analysis period, relates the logarithm of constituent concentration to an intercept, possibly nonlinear functions of the logarithm of streamflow and decimal time, and to seasonal factors consisting of sine and cosine functions of decimal time. The smoothed trend in the logarithm of water-quality concentration is determined by the streamflow and time trend components of the water-quality model, where the smoothed trend in the logarithm of streamflow is substituted for the actual logarithm of streamflow in the streamflow component. Smoothed trend in the logarithm of streamflow is a simple linear function of decimal time, computed over the water-quality period of record, the function value being given by the average logarithm of streamflow over the water-quality period of record plus the product of the streamflow model trend coefficient and the deviation of decimal time from the mid-point of decimal time for the water-quality period of record. Total trend in concentration is obtained by transforming the model-estimated, smoothed water-quality trend from logarithm space to real space, computing the percent change corresponding to the first and last dates of the water-quality record period, and normalizing by the decimal time length of this period. Trend in load is computed similarly, except the smoothed trend in the logarithm of streamflow is added to the smoothed trend in the logarithm of water-quality prior to retransformation to real space. A formal mathematical description of this method is presented in Sprague and others (2007, p. 10–12), with additional discussion of the estimation of the streamflow and water-quality models, and an explanation of the associated statistical tests for trend.

Flow-Adjusted Trend in Concentration

The estimation of flow-adjusted trend in concentration is similar to total trend, the only difference being that the streamflow component of the water-quality model is not included in the determination of the smoothed water-quality trend; otherwise, the estimation methods are the same. The estimation of the trend in streamflow is based on the smoothed streamflow trend corresponding to the simple linear function of decimal time described in the previous section. The conversion of this smoothed trend to a trend estimate follows the same procedure described for total parametric trend, the only difference being that the period of the trend is defined by the beginning and ending dates for the flow record in the analysis period, rather than the beginning and ending dates of the water-quality record.

Unit Trends and Reference Values

The results also report estimates of unit trends—trends expressed in the units of load or concentration (for example, kilograms per year per year or milligrams per liter per year). The unit trends in load and concentrations are determined by multiplying the load and concentration trend estimates (either flow adjusted or total—depending on the trend concept being described, expressed as rates rather than in percentage) by appropriate reference values of load and concentration. The reference value for the logarithm of concentration is obtained by evaluating the water-quality model at reference conditions consistent with the trend in water quality at the beginning of the water-quality period of record. These conditions include setting the logarithm of streamflow to its smoothed trend value corresponding to the first day of the water-quality period, setting the trend term to the decimal equivalent of the first day of the water-quality period, and setting the sine and cosine seasonal factors to their average values over the full water-quality period. The logarithm value of the reference concentration is transformed to real space and a multiplicative retransformation factor is applied to correct for statistical bias arising from sample error in the water-quality model coefficients (Sprague and others, 2007). The reference load is computed similarly, except the logarithm of streamflow trend, as determined by the linear streamflow equation evaluated at the starting date of the water-quality period, is added to the logarithm value of the reference concentration prior to transformation to real space; also, a multiplicative constant is applied to convert the result to appropriate load units. The same reference concentration is used to derive total unit trend and flow-adjusted unit trend in concentration; the same reference load is used in the evaluation of unit trend in load and flow-adjusted unit trend in load.

Additional Interpretive Notes

Flow-adjusted trend, being independent of streamflow conditions, is best used to evaluate changes in water quality arising from changes in contamination sources or management activities in a watershed; conversely, total trend is indicative of the water-quality changes that riverine habitats have actually experienced. If no trend in streamflow is observed over time, the two estimates of trend will be equivalent. Because the water-quality model used to derive these trends includes streamflow as a predictor, the estimates of trend are immune to bias arising from preferential water-quality sampling during high-streamflow events. Care should be taken, however, in interpolating or extrapolating these trend estimates within or beyond the period of record for a site, or in making comparisons of trend across sites that have different periods of record. Because of the possible nonlinearity of trend, as arising from nonlinear specifications of the water-quality model streamflow or trend components, trends within the water-quality period, or trends experienced outside this period could be quite different from the trends reported here. The methodology used to evaluate trend is insensitive to changes in the variability of streamflow or to changes in the unexplained variability of water-quality, both changes potentially resulting in trends in water-quality arising from nonlinearity in the specification of the water-quality model. Accommodation of these uncertainty effects awaits future research.

Reference

Sprague, L.A., Clark, M.L., Rus, D.L., Zelt, R.B., Flynn, J.L., and Davis, J.V., 2007, Nutrient and suspended-sediment trends in the Missouri River Basin, 1993–2003: U.S. Geological Survey Scientific Investigations Report 2006–5231, 80 p.