Appendix 8.

Comparison of Trends Determined Using the Seasonal Kendall Test and the Weighted Regressions on Time, Discharge, and Season (WRTDS) Model

Introduction

Water-quality time series data were analyzed by using the Seasonal Kendall test to provide additional information about trends at the study locations. The Seasonal Kendall test is a robust nonparametric trend test that has been used widely in trend analysis of water-quality data. Seasonality is incorporated into the analysis by computing trend statistics separately for defined seasons and then combining the results to compute an overall trend statistic (Hirsch and Slack, 1984). Because the Seasonal Kendall test is a nonparametric trend test, it tends to be less powerful in detecting trends than a parametric trend test like Weighted Regressions on Time, Discharge, and Season (WRTDS), when all of the assumptions of the parametric test are met. However, the Seasonal Kendall test is less computationally intensive and requires fewer assumptions about data quality or model form. Results from the Seasonal Kendall test were compared to those from the WRTDS model to provide a better understanding of how the choice of trend method can affect the trend estimate.

Methods

Data Preparation

The same data initially were input into the Seasonal Kendall test that were input into the WRTDS analysis. The one exception was that all available data from inside and outside the target trend periods were used to calibrate the WRTDS models; only data from inside the target trend period were used in the Seasonal Kendall test. Target parameters included alkalinity, ammonia, calcium, chloride, dissolved organic carbon, magnesium, nitrate, orthophosphate, potassium, sodium, specific conductance, sulfate, suspended sediment concentration, total dissolved solids, total nitrogen, total organic carbon, total phosphorus, and total suspended solids (see “Water-Quality Data Preparation” section of the main report). Only trends in concentration were obtained with the Seasonal Kendall test; there is no applicable process to obtain trends in load with the test. Steps in the data preparation included (1) harmonizing parameter names; (2) harmonizing remark codes; (3) excluding composite samples; (4) excluding field analyzed samples (with the exception of alkalinity); (5) excluding duplicate samples; (6) making adjustments on the basis of historical memoranda; and (7) recensoring data to the long-term method detection level between 1998 and 2010. These procedures are described in the “Water-Quality Data Preparation” section of the main report. Steps for gage matching and site compositing are described in the “Streamgage Matching” and “Final Screening for Data Coverage” sections of the main report.

Seasonal Kendall Trend Test

For the purposes of this analysis, each year was assumed to consist of four “seasons,” defined as January–March, April–June, July–September, and October–December. To be included in the analysis, a site was required to have data in 80 percent of the seasons for the first and last 2 years of the trend period, as well as in 60 percent of the seasons in all other years. A single value in each season of each year then was identified. In cases where a single sample was reported in the original data set for a season, that value was used in the analysis. When a season contained multiple samples, the median of all values during the season was used in the analysis. In cases where censored values were present, the median of multiple samples in a season was calculated by using the flipped Kaplan-Meier method (Helsel, 2012).

The trend periods of interest were 1972–2012, 1982–2012, 1992–2012, and 2002–12. Sites were included if they had sufficient data for analysis during any of the time periods; some sites had results for multiple trend periods.

Flow Adjustment

Two types of trends were determined using the Seasonal Kendall test—an estimated non-flow-adjusted trend and a flow-adjusted trend. The non-flow-adjusted trend was determined using the seasonal data with no further adjustments. The flow-adjusted trend was calculated by removing the streamflow variability from the seasonal data prior to running the trend test, resulting in a trend that was conceptually similar to the flow-normalized trends from WRTDS.

Availability of streamflow data to use for obtaining a flow-adjusted trend in concentration was a requirement for sites to be included in the Seasonal Kendall test. The streamflow screens used for the Seasonal Kendall test were the same as those used for WRTDS, as described in the section “Streamgage Selection.” Flow adjustment was performed by fitting a locally-weighted regression (Loess) (Cleveland and others, 1988) to the log(concentration)-log(streamflow) relation for each station-time period-constituent combination. The log flow-adjusted concentrations (LC_{FA}) were the log of the residuals of the regression, defined as

$$LC_{FA} = LC_{OBS} - LC_{PRED} \quad (1)$$

where

LC_{OBS} is the log of the reported concentration, and

LC_{PRED} is the predicted log concentration from the log(concentration)-log(streamflow) Loess model.

LC_{FA} was transformed to linear scale by back transforming to real space and using a transformation bias correction (Koch and Smillie, 1986). The Seasonal Kendall test was then performed on the residual (C_{FA}) values to test for temporal trends. No flow adjustment was performed in cases where a station concentration time series contained greater than 5 percent censored values.

Censored Data

The Seasonal Kendall test can be run on time series with left-censored values, but uncertainty associated with the censored values precludes the use of flow adjustment (Schertz and others, 1991); therefore, time series with greater than 5 percent censored data only were analyzed by using a non-flow-adjusted Seasonal Kendall test. Datasets with zero to 5 percent censored data were analyzed by using both a non-flow-adjusted and a flow-adjusted Seasonal Kendall test.

Constituents calculated as a sum of several parameters (for example, total nitrogen = unfiltered Kjeldahl nitrogen + inorganic nitrogen) can be interval censored if one or more of the summands is censored. When interval-censored values were present, the result value was set to the median of the censoring interval and treated as uncensored data.

Time series with greater than 80 percent censored data were excluded from both the non-flow-adjusted and the flow-adjusted Seasonal Kendall tests.

Computation and Statistics

Seasonal Kendall trends were computed by using the U.S. Geological Survey EStimate TREND (ESTREND) method (Schertz and others, 1991), implemented in the R package R-ESTREND (available online at https://github.com/USGS-R/restrend/). Trend-analysis results were categorized on the basis of significance, with *p*-values less than 0.1 considered highly significant, *p*-values between 0.2 and 0.1 considered marginally significant, and *p*-values greater than 0.2 considered not significant. Sen slopes (Sen, 1968; Schertz and others, 1991) were used to express the annualized rate of change in concentration. Change rate was also expressed as percent per year by dividing the Sen slope by the median concentration in the first year of the trend period, dividing by the number of years in the analysis, and multiplying by 100. This calculation was done for both flow-adjusted and non-flow-adjusted analyses. Complete results of the Seasonal Kendall test are available in the Mills and others (2017) data release.

Results

A comparison of the results from the Seasonal Kendall test with those from the WRTDS models was conducted to assess the comparability of the methods. Because the WRTDS model and Seasonal Kendall test were based on the same input data, the models should yield similar results when the assumptions of the WRTDS model are met.

The results presented are an aggregate of all individual trend results for all time periods of interest, including all parameters. Of the 10,662 individual trend results determined using both WRTDS and the Seasonal Kendall test, more than 7,500, or 71 percent, had the same result for trend direction and significance—that is, both models were not significant, or both models were significantly decreasing, or both models were significantly increasing (table 8–1). In about 18 percent of cases, a significantly decreasing or increasing trend was detected by using WRTDS, but the corresponding trend was found to be not significant by using the Seasonal Kendall test (table 8–1). In 11 percent of cases, a significantly decreasing or increasing trend was detected by using the Seasonal Kendall test, but the corresponding trend was found to be not significant by using WRTDS (table 8–1). In 31 cases, or 0.3 percent, the Seasonal Kendall test and WRTDS found significant trends but in opposite directions (table 8–1).

Among trend constituents, the percentage of trend results showing agreement between WRTDS and Seasonal Kendall test ranged from 64 to 83 percent, with suspended sediment concentration having the lowest percentage agreement and unfiltered orthophosphate having the highest percentage agreement (table 8–2). In the vast majority of cases, disagreement between the methods resulted from only one method having significant trends (table 8–2). Of the 31 instances in which WRTDS and the Seasonal Kendall test returned significant results with differing directions, 10 instances occurred with ammonia as the modeled constituent, and 4 instances occurred with both total suspended solids and specific conductance as the modeled constituent. Visual inspection indicated that disagreements between the methods occurred primarily when the water-quality record contained a large number of censored values, especially at the end of the trend period. This outcome could be attributed to the different ways that censored values are handled between the two methods.

Overall, the results were largely consistent between the modeling approaches, with a slightly greater tendency for WRTDS than the Seasonal Kendall test to detect significant trends; this is consistent with the greater power of parametric trend tests in general. However, the overall consistency of results suggests that broad interpretations should be comparable.

Table 8–1. Comparison of trend results between Weighted Regressions on Time, Discharge, and Season (WRTDS) and the Seasonal Kendall test (SKT). For this analysis, a trend result was considered significant if the p-value was less than 0.1. Percentage of total trends analyzed (n = 10,662) are displayed in each cell.

SKT result	WRTDS result		
	Not significant (percent)	Significantly decreasing (percent)	Significantly increasing (percent)
Not significant	42	10	8
Significantly decreasing	5	16	0.1
Significantly increasing	6	0.2	13

Table 8–2. Comparison of trend results between Weighted Regressions on Time, Discharge, and Season (WRTDS) and the Seasonal Kendall test. For this analysis, a trend result was considered significant if the p-value was less than 0.1. Percentage of total trends analyzed (n = 10,662) are displayed in each cell.

Parameter	Models agree (percent)	One model found significant trends and the other did not (percent)	Models found significant trends in opposite directions (percent)
Alkalinity	71	29	0.0
Ammonia	69	29	1.5
Calcium	74	26	0.0
Chloride	71	29	0.2
Dissolved organic carbon	78	22	0.0
Magnesium	69	30	0.3
Nitrate	70	30	0.2
Orthophosphate, filtered	73	27	0.0
Orthophosphate, unfiltered	83	17	0.0
Potassium	73	27	0.0
Sodium	72	28	0.0
Specific conductance	72	28	0.2
Sulfate	73	27	0.2
Suspended sediment concentration	64	35	1.0
Total dissolved solids	69	31	0.6
Total nitrogen	71	29	0.3
Total organic carbon	71	29	0.0
Total phosphorus	72	28	0.1
Total suspended solids	70	30	0.0

References

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