# Appendix 6.

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# Analysis of Trends in Annual Streamflow

# Introduction

Trends in water quality and pesticide concentrations and loads and trends in ecological endpoints are extremely sensitive to trends in underlying streamflow distributions. This fact is especially true for applications of Weighted Regressions on Time, Discharge, and Season (WRTDS) for water-quality constituents (Hirsch and others, 2010) and SEAWAVE-Q for pesticides (Vecchia and others, 2008; Ryberg and Vecchia, 2013). Trends in concentrations and fluxes can be the result of changing loads, driven by natural or human-related trends in streamflow, or some combination of both. For this reason, it is important to consider trends in the underlying streamflow distributions as an indication of how such trends may affect the results in the body of this report and in the associated data releases. This appendix begins to address the concerns arising from underlying streamflow trends; however, it is not precisely or quantifiably known how trends in underlying streamflow distributions affect trends in water-quality constituents or flow-normalized results from WRTDS analyses. For this reason, only a cursory assessment of streamflow trends can be conducted and evaluated in this appendix. Better methods are needed to determine the quantifiable link between streamflow and water-quality trends and how to adjust water-quality trends for streamflow trends.

Daily streamflow data were used to derive concentrations and fluxes of water-quality parameters, pesticide concentrations, and ecological endpoints. Because of the high degree of complexity involved in identifying trends in daily streamflow, these statistics were aggregated to 7-day minimum, mean daily, and 1-day maximum streamflows, which are referred to as annual minimum 7-day mean, annual mean, and annual maximum streamflows in this appendix. Evaluation of these annual metrics provides some indication of trends in the underlying streamflow distribution. Although it is possible to consider additional metrics of higher complexity, it may not be worthwhile because the link between streamflow trends and water-quality trends identified by WRTDS has not been quantified.

The first type of nonstationarity considered in each metric was the presence of at least one step trend or change point. A change point is a time at which previous streamflows represent a different distribution than later streamflows. Such change points are distinct from gradual trends and are not easily addressed when using tools like flow normalization in WRTDS (Hirsch and others, 2010). Change points were computed by using the Pettitt test, a nonparametric test quantifying the frequency with which the medians of two periods differ (Pettitt, 1979), as implemented in the trend package (Pohlert, 2016) of the R programing environment (R Core Team, 2014). The null hypothesis assumed there are no change points in the time series, whereas the alternative hypothesis was that there is at least one change point in a time series. The probability of the null hypothesis given the data, commonly known as the p-value, gives no indication of multiple change points. Once the presence of at least one change point is established, the data series can be further examined to determine if multiple change points are present; however, this additional step was not completed in this analysis.

The second type of nonstationarity considered in each metric was the presence of a monotonic trend in annual values, which was assessed using the Mann-Kendall trend test, a nonparametric test measuring the probability of median slopes in a dataset (Mann, 1945). The Mann-Kendall trend test does not assume the trend is a specific shape (e.g. linear or quadratic) but instead tests if values increase or decrease overall. This null hypothesis statistical test was conducted by using the rkt package (Marchetto, 2015) of the R programming environment (R Core Team, 2014). The alternative hypothesis was the presence of a nonzero monotonic trend in annual streamflow statistics. Tests were executed using water year as the explanatory variable and the annual streamflow metrics, unadjusted and as a common logarithm, as the response variables. The use of logarithmic transformations detected no monotonic trends that were dissimilar to the direct annual streamflow metric; for ease of intersite comparison, the results from the logarithmic transformation of the response, which allows for a percentage interpretation, are reported here.

Although this approach provides a first-order understanding of two basic types of streamflow trends (change-points and monotonic trends), there are some distinct limitations. The same daily streamflow records used as input for WRTDS, SEAWAVE-Q, and ecology trend modeling were used for this analysis of annual streamflow trends, but some of these records, as described in the body of this report, contain estimated values for unobserved daily measurements. The results of this analysis also do not control for regional dependence of the streamflow trends at individual sites. Finally, the direct link between streamflow trends and water-quality trends has yet to be established, and we are unsure of the magnitude or type of change in streamflow that results in a change in water quality. For these reasons, the results provided herein are a general overview of streamflow trends at sites across our study area and could serve as basis for future exploration into this topic.

Pursuant to U.S. Geological Survey data and model archive policies, the input data, output data, and scripts that execute all tests and produce all figures herein can be found in Farmer and others (2017).

## Water-Quality Sites

Trends in annual streamflows at or associated with water-quality sites were analyzed across four time periods, all ending with water year 2012. The periods started with water years 1972, 1982, 1992, and 2002. Although there were 2,100 sites in total, not all sites were active for every complete time period. Only sites with complete records were considered for each time period. In addition to considering these four fixed trend periods, trend analyses were also conducted for

streamflows across complete calibration periods corresponding to actual water-quality sampling.

For the period beginning with water year 1972, 1,299 sites were considered. Of these sites, 164 sites (12.63 percent) showed at least one significant change point (alpha = 0.05, the same significance level is used throughout this appendix) in the annual mean streamflow. Of the remaining 1,135 sites without a change point in annual mean streamflow, 106 sites showed significant monotonic trends in annual mean streamflows (log-transformed). Of these sites, 11 sites showed positive monotonic trends, with a median (50th percentile) of 0.56 percent per year, while 95 sites showed negative monotonic trends, with a median of -0.55 percent per year. For 1,029 sites (79.21 percent of all sites), test results showed no significant trends (no change point nor monotonic trend) in annual mean streamflows. In terms of the annual maximum streamflows, 93 sites (7.16 percent of the total sites for this period) showed at least one change point. Of the remaining 1,206 sites, 76 showed significant monotonic trends. With a median of 0.6 percent per year, 17 sites showed positive monotonic trends; 59 sites showed negative monotonic trends, with a median of -0.79 percent per year. For 1,130 sites (86.99 percent of all sites), test results showed neither a significant change point nor a significant monotonic trend in annual maximum streamflows. The annual minimum 7-day mean streamflow showed a significant change point at 466 sites (35.87 percent). Of sites without change points, monotonic trends in the annual minimum 7-day mean streamflow were significant at 103 sites. Nine sites had positive monotonic trends, with a median of 0.52 percent per year, while 94 sites had negative monotonic trends, with a median of -0.64 percent per year. Of all the sites considered, 730 sites (56.2 percent) showed neither a significant change point nor a significant monotonic trend in annual minimum 7-day mean streamflows. The distributions of the slope for both positive and negative significant monotonic trends for each annual streamflow metric for this time period are displayed in figure 6–1. Summarizing across all three statistics, 772 sites (59.43 percent) had no significant change points in any of the three statistics. Of these sites, 633 sites also had no monotonic trends in any statistics, meaning that 48.73 percent of all sites had no trend (neither a significant change point nor a significant monotonic trend) in any of the three statistics across the period beginning with water year 1972 through water year 2012.

For the period beginning with water year 1982, 1,466 sites were considered. Of these sites, 153 sites (10.44 percent) showed significant change points (alpha = 0.05, throughout) in the annual mean streamflow at some point in the record. Of the remaining 1,313 sites without a change point in annual mean streamflow, 73 sites showed significant monotonic trends in annual mean streamflows (log transformed). Of these 73 sites, 13 sites showed positive monotonic trends, with a median of 0.48 percent per year, while 60 sites showed negative monotonic trends, with a median of -1.03 percent per year. For 1,240 sites (84.58 percent of all sites), test results showed neither a significant change point nor a significant monotonic trend in annual mean streamflows. In terms of the annual maximum streamflows, 63 sites (4.3 percent of the total sites for this period) showed change points. Of the remaining 1,403 sites, 57 sites showed significant monotonic trends. With a median of 1.01 percent per year, 14 sites showed positive monotonic trends; 43 sites showed negative monotonic trends, with a median of -1.31 percent per year. For 1,346 sites (91.81 percent of all sites), test results showed no trend (neither a significant change point nor a significant monotonic trend) in annual maximum streamflows. The annual minimum 7-day mean streamflow showed a significant change point at 328 sites (22.37 percent). Of sites without change points, monotonic trends in the annual minimum 7-day mean streamflow were significant at 66 sites. Eighteen sites had positive monotonic trends, with a median of 0.64 percent per year, while 48 sites had negative monotonic trends, with a median of -0.84 percent per year. Of all the sites considered, 1,072 sites (73.12 percent) showed neither a significant change point nor a significant monotonic trend in annual minimum 7-day mean streamflows. The slope of monotonic trends for each annual streamflow metric for this time period are displayed in figure 6–2. Summarizing across all three statistics, 1,048 sites (71.49 percent) had no significant change points in any of the three statistics. Of these sites, 949 sites had no monotonic trends in any statistics, meaning that 64.73 percent of all sites had no trend (neither a significant change point nor a significant monotonic trend) in any of the three statistics across the period beginning with water year 1982 through water year 2012.

For the period beginning with water year 1992, 1,720 sites were considered. Of these sites, 90 sites (5.23 percent) showed significant change points (alpha = 0.05, throughout) in the annual mean streamflow at some point in the record. Of the remaining 1,630 sites without a change point in annual mean streamflow, 123 sites showed significant monotonic trends in annual mean streamflows (log-transformed). Of these 123 sites, 12 sites showed positive monotonic trends, with a median of 0.97 percent per year, while 111 sites showed negative monotonic trends, with a median of -2.09 percent per year. For 1,507 sites (87.62 percent of all sites), test results showed neither a significant change point nor a significant monotonic trend in annual mean streamflows. In terms of the annual maximum streamflows, 53 sites (3.08 percent of the total sites for this period) showed at least 1 change point. Of the remaining 1,667 sites, 67 sites showed significant monotonic trends. With a median of 1.72 percent per year, 14 sites showed positive monotonic trends; 53 sites showed negative monotonic trends, with a median of -2.24 percent per year. For 1,600 sites (93.02 percent of all sites), test results showed neither a significant change point nor a significant monotonic trend in annual maximum streamflows. The annual minimum 7-day mean streamflow showed a significant change point at 262 sites (15.23 percent). Of sites without change points, monotonic trends in the annual minimum 7-day mean streamflow were significant at 155 sites. Forty-three sites had positive monotonic trends, with a median of 0.9 percent per year, while 112 sites had negative monotonic trends,

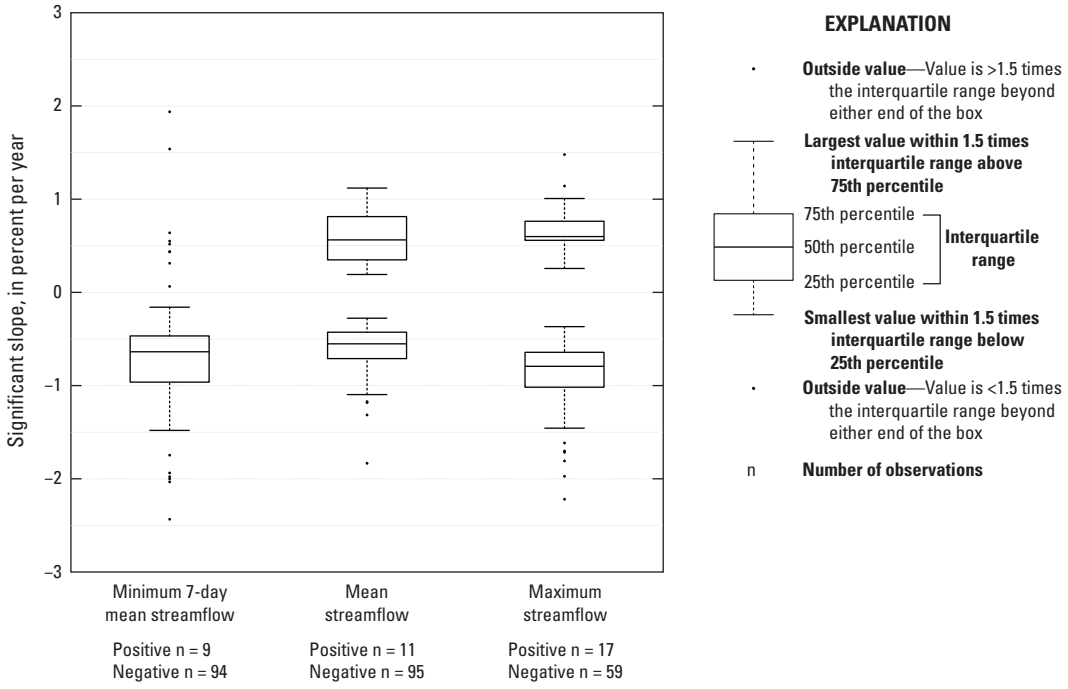


**Figure 6–1.** Boxplots showing slopes of significant monotonic trends in three annual streamflow metrics at water-quality sites without significant change points (alpha = 0.05) for the trend period 1972–2012. For each metric, positive slopes are summarized in the upper boxplot, and negative slopes are in the lower boxplot.

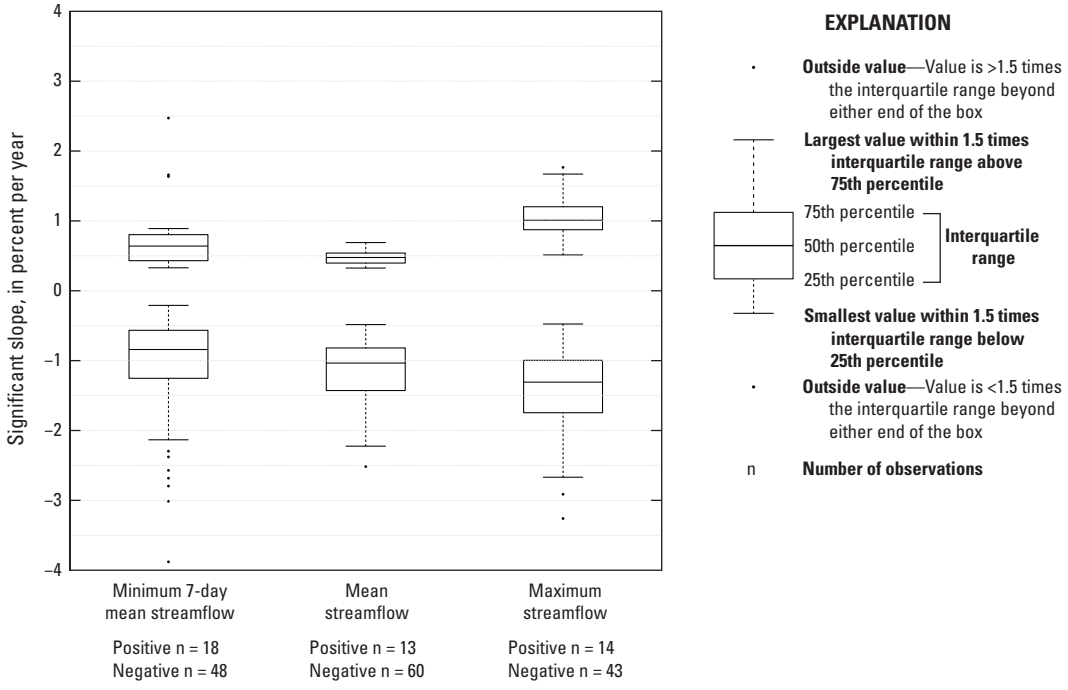


**Figure 6–2.** Boxplots showing slopes of significant monotonic trends in three annual streamflow metrics at water-quality sites without significant change points (alpha = 0.05) for the trend period 1982–2012. For each metric, positive slopes are summarized in the upper boxplot, and negative slopes are in the lower boxplot.

with a median of -1.61 percent per year. Of all the sites considered, 1,303 sites (75.76 percent) showed neither a significant change point nor a significant monotonic trend in annual minimum 7-day mean streamflows. The slope of significant monotonic trends for each annual streamflow metric for this time period are displayed in figure 6–3. Summarizing across all three statistics, 1,378 sites (80.12 percent) had no significant change points in any of the three statistics. Of these sites, 1,173 sites had no monotonic trends in any statistics, meaning that 68.2 percent of all sites had no trend (neither a significant change point nor a significant monotonic trend) in any of the three statistics across the period beginning with water year 1992 through water year 2012.

For the period beginning with water year 2002, 2,100 sites were considered. Of these sites, 70 sites (3.33 percent) showed significant change points (alpha = 0.05, throughout) in the annual mean streamflow at some point in the record. Of the remaining 2,030 sites without a change point in annual mean streamflow, 141 sites showed significant monotonic trends in annual mean streamflows (log-transformed). Of these 141 sites, 96 sites showed positive monotonic trends, with a median of 4.1 percent per year, while 45 sites showed negative monotonic trends, with a median of -4.5 percent per year. For 1,889 sites (89.95 percent of all sites), test results showed neither a significant change point nor a significant monotonic trend in annual mean streamflows. In terms of the annual maximum streamflows, 17 sites (0.81 percent of the total sites for this period) showed change points. Of the remaining 2,083 sites, 82 sites showed significant monotonic trends. With a median of 5.96 percent per year, 59 sites showed positive monotonic trends; 23 sites showed negative monotonic trends, with a median of -6.54 percent per year. For 2,001 sites (95.29 percent of all sites), test results showed neither a significant change point nor a significant monotonic trend in annual maximum streamflows. The annual minimum 7-day mean streamflow showed a significant change point at 111 sites (5.29 percent). Of sites without change points, monotonic trends in the annual minimum 7-day mean streamflow were significant at 237 sites. With a median of 2.8 percent per year, 155 sites had positive monotonic trends, while 82 sites had negative monotonic trends, with a median of -5.22 percent per year. Of all the sites considered, 1,752 sites (83.43 percent) showed no trend (neither a significant change point nor a significant monotonic trend) in annual minimum 7-day mean streamflows. The slopes of significant monotonic trends for each annual streamflow metric for this time period are displayed in figure 6–4. Summarizing across all three statistics, 1,934 sites (92.1 percent) had no significant change points in any of the three statistics. Of these sites, 1,608 sites had no monotonic trends in any statistics, meaning that 76.57 percent of all sites had no trend (neither a significant change point nor a significant monotonic trend) in any of the three statistics across the period beginning with water year 2002 through water year 2012.

Of the 7,084 sites with full calibration periods, 7,017 sites match complete daily streamflow records. Summarizing across annual mean streamflows, annual maximum streamflows, and annual minimum 7-day mean streamflows, 5,390 sites (76.81 percent) had no significant change points in any of the three statistics. Of these sites, 4,783 sites also had no monotonic trends in any statistics, meaning that 68.16 percent of all sites had neither a significant change point nor a significant monotonic trend in any of the three statistics.

## Pesticide Sites

Trends in pesticides were considered at 76 sites. Annual streamflows at these sites were analyzed to detect trends across two time periods, beginning in water years 1992 and 2002 and ending with water year 2012. Not all sites were active for every complete time period. Only sites with complete records were considered for each time period.

For the period beginning with water year 1992, six sites were considered. None of these six sites showed significant change points (alpha = 0.05, throughout) or monotonic trends in either the annual mean streamflow or the annual maximum streamflow. Although no significant change points were identified in the annual minimum 7-day mean streamflows, one site showed a negative monotonic trend in the annual minimum 7-day mean streamflow, with a rate of -3.55 percent per year. Summarizing across all three statistics, six sites (100 percent) had no significant change points in any of the three statistics. Of these sites, five sites had no monotonic trends in any statistics, meaning that 83.33 percent of all sites had no trend (neither a significant change point nor a significant monotonic trend) in any of the three statistics across the period beginning with water year 1992 through water year 2012.

For the period beginning with water year 2002, 73 sites were considered. Of these sites, three sites (4.11 percent) showed significant change points (alpha = 0.05, throughout) in the annual mean streamflow at some point in the record. Of the remaining 70 sites without a change point in annual mean streamflow, three sites showed significant monotonic trends in annual mean streamflows (log-transformed). All three sites showed positive monotonic trends, with a median of 2.18 percent per year. For 67 sites (91.78 percent of all sites), test results showed neither a significant change point nor a significant monotonic trend in annual mean streamflows. In terms of the annual maximum streamflows, none showed change points; however, three sites showed significant monotonic trends. With a median of 2.19 percent per year, two sites showed positive monotonic trends; one site showed a negative monotonic trend, with a rate of -2.6 percent per year. For 70 sites (95.89 percent of all sites), test results showed no trend (neither a significant change point nor a significant monotonic trend) in annual maximum streamflows. The annual minimum 7-day mean streamflow showed a significant change point at five sites (6.85 percent). Of sites without change points, monotonic trends in the annual minimum 7-day

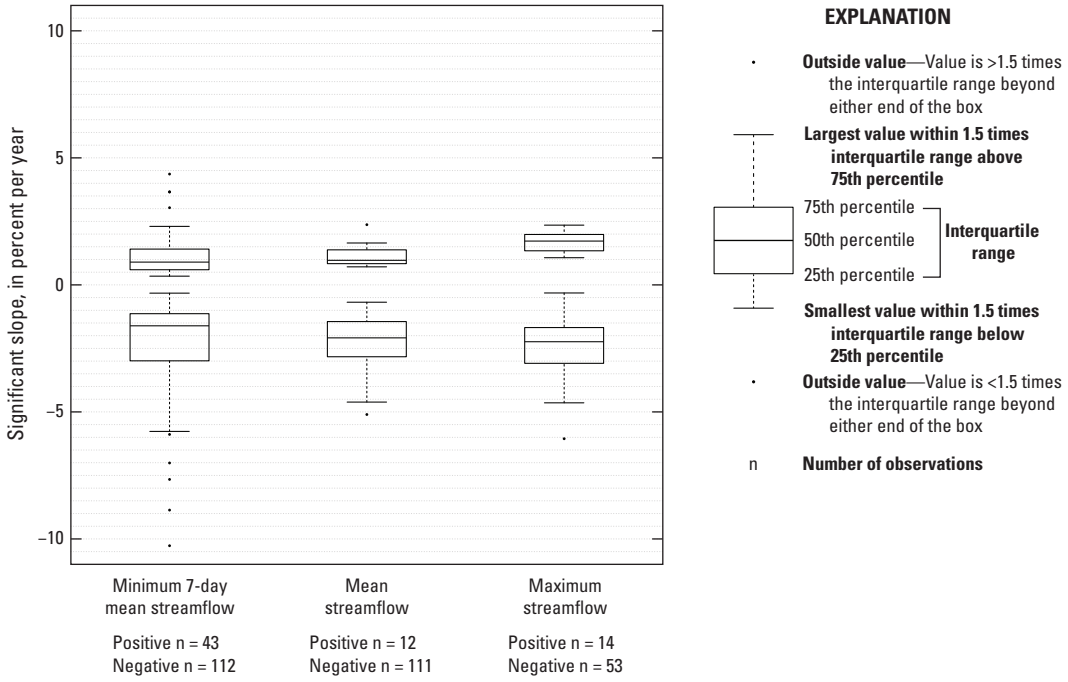


**Figure 6–3.** Boxplots showing slopes of significant monotonic trends in three annual streamflow metrics at water-quality sites without significant change points (alpha = 0.05) for the trend period 1992–2012. For each metric, positive slopes are summarized in the upper boxplot, and negative slopes are in the lower boxplot.

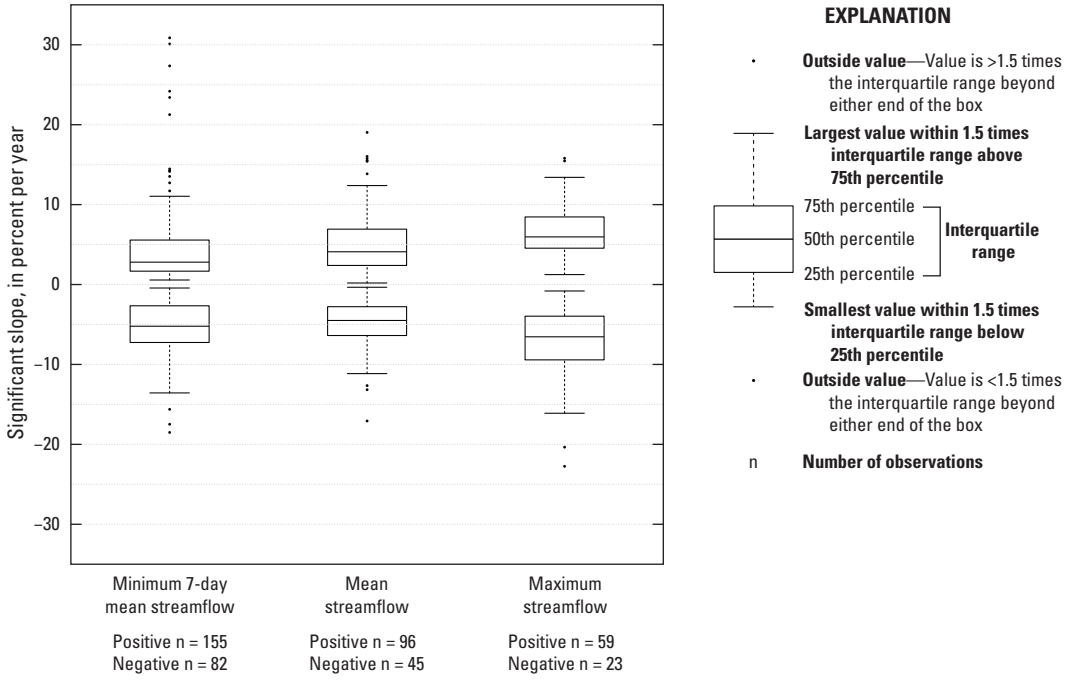


**Figure 6–4.** Boxplots showing slopes of significant monotonic trends in three annual streamflow metrics at water-quality sites without significant change points (alpha = 0.05) for the trend period 2002–12. For each metric, positive slopes are summarized in the upper boxplot, and negative slopes are in the lower boxplot.

mean streamflow were significant at six sites. Two sites had positive monotonic trends, with a median of 1.05 percent per year, while four sites had negative monotonic trends, with a median of -2.48 percent per year. Of all the sites considered, 62 sites (84.93 percent) showed neither a significant change point nor a significant monotonic trend in annual minimum 7-day mean streamflows. The slopes of significant monotonic trends for each annual streamflow metric for this time period are displayed in figure 6–5. Summarizing across all three statistics, 65 sites (89.04 percent) had no significant change points in any of the three statistics. Of these sites, 58 sites had no monotonic trends in any statistics, meaning that 79.45 percent of all sites had no trends (neither a significant change point nor a significant monotonic trend) in any of the three statistics across the period beginning with water year 2002 through water year 2012.

## Ecology Streamflow Sites

Trends in annual streamflows at sites used for hydrologic ecology trends were analyzed across two time periods, beginning in water years 1992 and 2002 and ending with water year 2012. Although there were 51 sites in total, not all sites were active for every complete time period. Only sites with complete records were considered for each time period.

For the period beginning with water year 1992, 38 sites were considered. Of these sites, four sites (10.53 percent) showed significant change points (alpha = 0.05, throughout) in the annual mean streamflow at some point in the record. Of the remaining 34 sites without a change point in annual mean streamflow, two sites showed significant monotonic trends in annual mean streamflows (log-transformed). Of these two sites, both showed negative monotonic trends, with a median of -1.46 percent per year. For 32 sites (84.21 percent of all sites), test results showed neither a significant change point nor a significant monotonic trend in annual mean streamflows. In terms of the annual maximum streamflows, three sites (7.89 percent of the total sites for this period) showed change points. Of the remaining 35 sites, one site showed a significant monotonic trend, with a value of 1.65 percent per year. For 34 sites (89.47 percent of all sites), test results showed neither a significant change point nor a significant monotonic trend in annual maximum streamflows. The annual minimum 7-day mean streamflow showed a significant change point at 10 sites (26.32 percent). Of sites without change points, monotonic trends in the annual minimum 7-day mean streamflow were significant at five sites. All five sites had negative monotonic trends, with a median of -2.68 percent per year. Of all the sites considered, 23 sites (60.53 percent) showed neither a significant change point nor a significant monotonic trend in annual minimum 7-day mean streamflows. The slopes of significant monotonic trends for each annual streamflow metric for this time period are displayed in figure 6–6. Summarizing across all three statistics, 26 sites (68.42 percent) had no significant change points in any of the three statistics. Of these sites, 20 sites had no monotonic trends in any statistics, meaning that 52.63 percent of all sites had no trends (neither a significant change point nor a significant monotonic trend) in any of the three statistics across the period beginning with water year 1992 through water year 2012.

For the period beginning with water year 2002, 50 sites were considered. Of these sites, two sites (4 percent) showed significant change points (alpha = 0.05, throughout) in the annual mean streamflow at some point in the record. Of the remaining 48 sites without a change point in annual mean streamflow, five sites showed significant monotonic trends in annual mean streamflows (log-transformed). Of these sites, two sites showed positive monotonic trends, with a median of 1.19 percent per year, while three sites showed negative monotonic trends, with a median of -4.5 percent per year. For 43 sites (86 percent of all sites), test results showed neither a significant change point nor a significant monotonic trend in annual mean streamflows. In terms of the annual maximum streamflows, one site (2 percent of the total sites for this period) showed a change point. Of the remaining 49 sites, none showed significant monotonic trends; therefore, 49 sites (98 percent of all sites) showed neither a significant change point nor a significant monotonic trend in annual maximum streamflows. The annual minimum 7-day mean streamflow showed a significant change point at two sites (4 percent). Of sites without change points, monotonic trends in the annual minimum 7-day mean streamflow were significant at six sites. Three sites had positive monotonic trends, with a median of 6.02 percent per year, while three sites had negative monotonic trends, with a median of -3.53 percent per year. Of all the sites considered, 42 sites (84 percent) showed neither a significant change point nor a significant monotonic trend in annual minimum 7-day mean streamflows. The slopes of significant monotonic trends for each annual streamflow metric for this time period are displayed in figure 6–7. Summarizing across all three statistics, 46 sites (92 percent) had no significant change points in any of the three statistics. Of these sites, 37 sites had no monotonic trends in any statistics, meaning that 74 percent of all sites had no trend (neither a significant change point nor a significant monotonic trend) in any of the three statistics across the period beginning with water year 2002 through water year 2012.

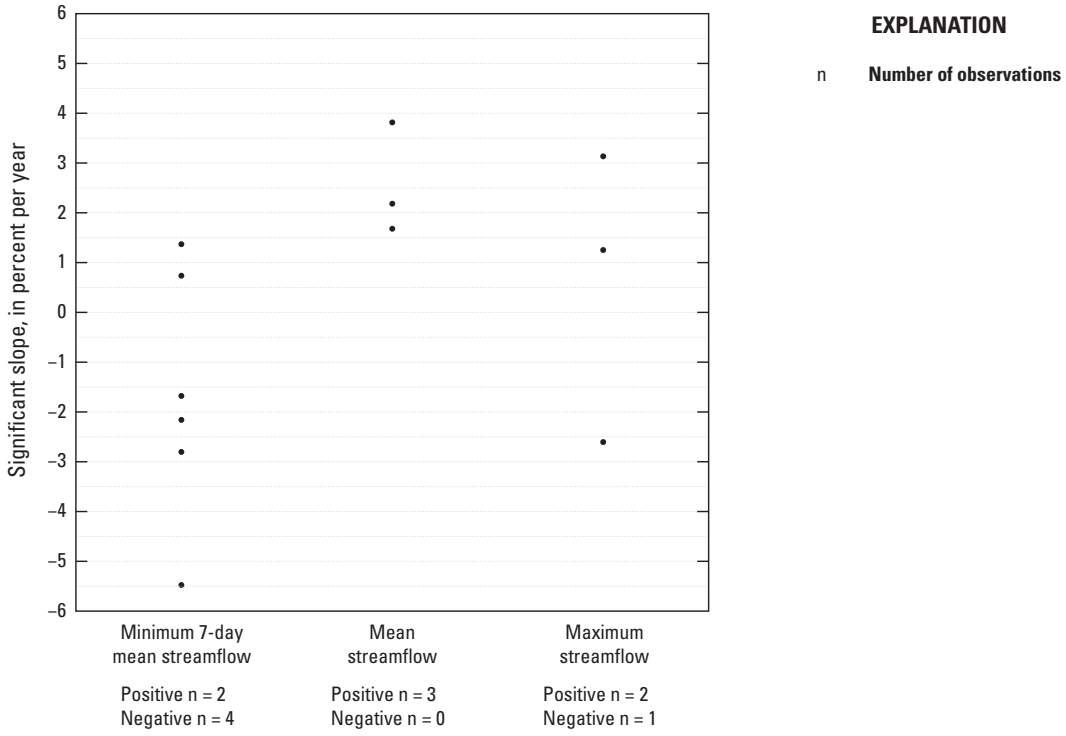


**Figure 6–5.** Graphs showing slopes of significant monotonic trends in three annual streamflow metrics at pesticide sites without significant change points (alpha = 0.05) for the trend period 2002–12.

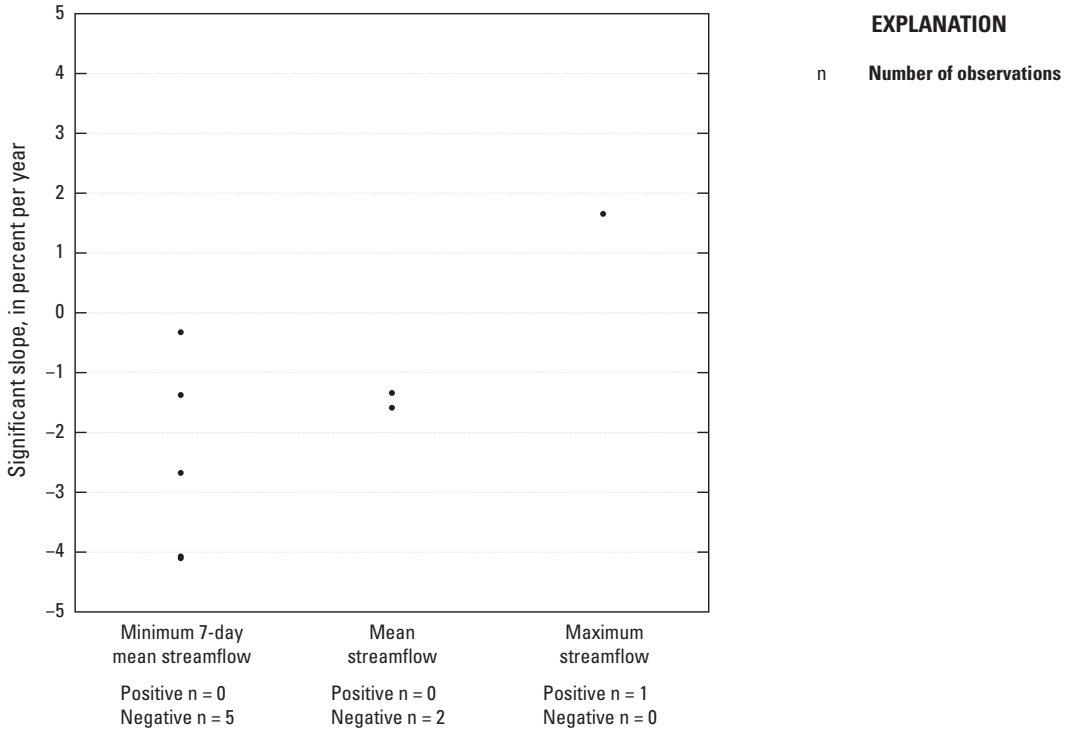


**Figure 6–6.** Graphs showing slopes of significant monotonic trends in three annual streamflow metrics at ecology sites without significant change points (alpha = 0.05) for the trend period 1992–2012.

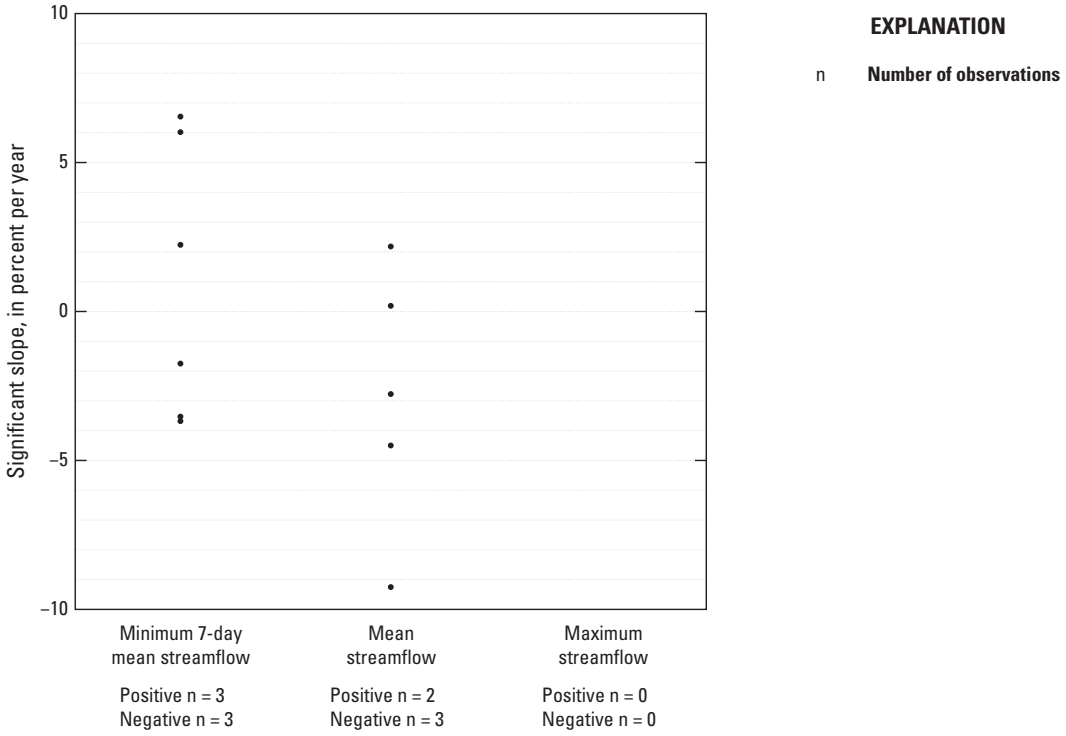


**Figure 6–7.** Graphs showing slopes of significant monotonic trends in three annual streamflow metrics at ecology sites without significant change points (alpha = 0.05) for the trend period 2002–12.

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