Flow-Adjusted Trends

Flow-Adjusted Concentration (FAC) trend analyses of water quality and flow data collected at Danville, Lewisburg, Newport, and Conestoga were completed for the period January 1984 through December 2011. Both Marietta and Towanda began later and their respective trend periods are 1986-2011 and 1988-2011. Trends were estimated based on the USGS water year, October 1 to September 30, using the USGS 7-parameter, log-linear regression model (ESTIMATOR) developed by Cohn and others (1989) and described in Langland and others (1999). ESTIMATOR relates the constituent concentration to water discharge, seasonal effects, and long-term trends, and computes the best-fit regression equation. These tests were used to estimate the direction and magnitude of trends for discharge, SS, TOC, and several forms of nitrogen and phosphorus. Slope, p-value, and sigma (error) values are taken directly from ESTIMATOR output. These values are then used to calculate flow-adjusted trends using the following equations:

Trend =
100*(exp(Slope *(end yr – begin yr)) – 1)

Trend minimum =
100*(exp((Slope – (1.96*sigma)) *(end yr – begin yr)) – 1)

Trend maximum =
100*(exp((Slope + (1.96*sigma)) *(end yr – begin yr)) – 1)

The computer program S-Plus with the USGS ESTREND library addition was used to conduct Seasonal Kendall trend analysis on flows (Schertz and others, 1991). Trend results were reported for monthly mean discharge (FLOW) and individual parameter FACs. Trends in FLOW indicate any natural changes in hydrology. Changes in flow and the cumulative sources of flow (base flow and overland runoff) affect the observed concentrations and the estimated loads of nutrients and SS. The FAC is the concentration after the effects of flow are removed from the concentration time series. Trends in FAC indicate that changes have occurred in the processes that deliver constituents to the stream system. After the effects of flow are removed, this is the concentration that relates to the effects of nutrient-reduction activities and other actions taking place in the watershed. A description of the methodology is included in Langland and others (1999).

INDIVIDUAL SITES

Towanda

2011 precipitation and discharge values at Towanda are listed in Table A1. 2011 had above average flows during all months except for January, February, and July. Although two of three winter months were below their respective LTMs, the total flow for the season was 126 percent of LTM due to an early wet spring. Highest seasonal flow during 2011 occurred during summer, which is normally the lowest flow time period. This was due to the two historical storm events that occurred during August and September resulting in summer flows that were 301 percent of the LTM. Annual flows at Towanda were 166 percent of the LTM. Highest flows occurred during March, April, and September.

2011 loads for TP, SS, TON, and TOC were above the flow LTM of 166 percent at Towanda including 412 percent of LTM for SS. TNO_{23}, DNO_{23}, and DP were lower than the flow LTM with DP at 100 percent of LTM. Tables A3 and A4 look at closer time periods showing that the majority of the SS load was moved during September. As a percentage of annual load, September accounted for 14 percent of the TN load, 40 percent of the TP load, and 73 percent of the SS load. The three highest flow months, including March, April, and September, amounted for 54 percent of the annual flow, 57 percent of TN, 77 percent of TP, and 94 percent of the SS load.

2011 TN yields at Towanda were below the predictions of all four baseline comparisons while both TP and SS yields were above all baseline predictions. The 2011 seasonal yields were lower than the initial five-year baseline predictions for winter, spring, and fall except for SS during winter. Table A6 shows that the R^2

value for the SS baseline was 0.02 and thus unreliable at predicting the 2011 value. Closer inspection of the baseline data for this period shows that there was one outlier that led to the low R^2 value. The spring of 1993 contained a very large snow melt that resulted in high SS levels. This snow melt had a large effect on March SS concentrations but a small effect on the average flow for the time period, thus creating the outlier. 2011 yield for summer, which contained both Hurricane Irene and Tropical Storm Lee, were dramatically higher than the predicted values for TP and SS. Summer discharge was 478 percent of the LTM resulting in 2011 SS yields of 2,027 pounds/acre (lbs/ac) while the baseline prediction was 73 lbs/ac.

Trend directions remained unchanged from 2010 except for DP, which changed from no trend to an improving trend. Trend magnitudes in other parameters fluctuated while not altering the actual trend direction. Notable magnitude changes included TOC and DOP with the magnitude of the TOC improving trend increasing and the magnitude of the DOP degrading trend decreasing.

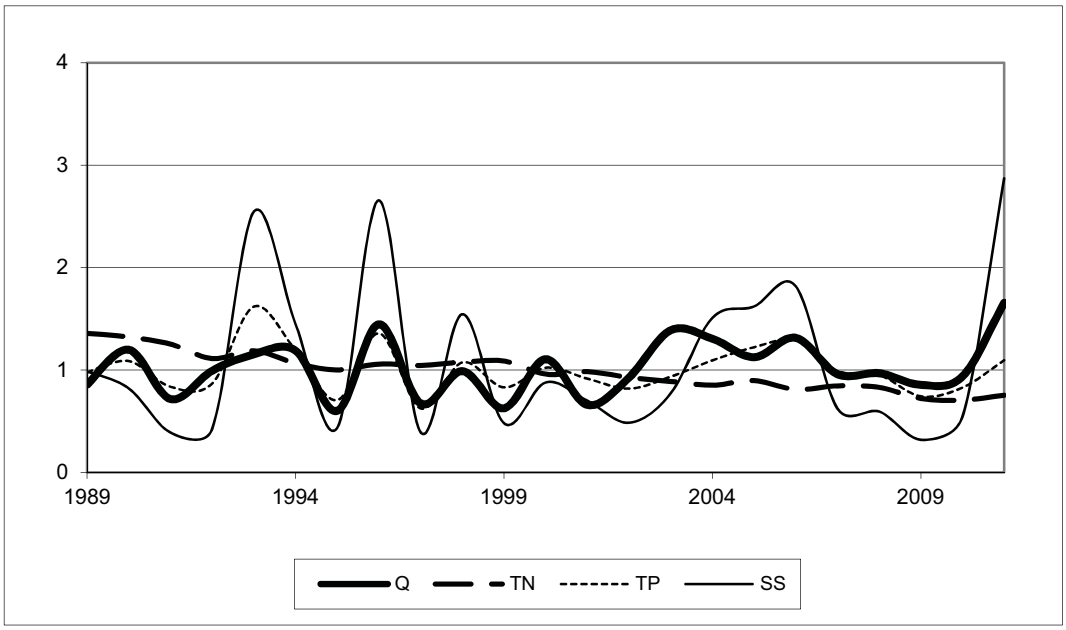

Figure 4. Annual Discharge and Calculated Annual TN, TP, and SS Concentrations Expressed as LTM Ratio

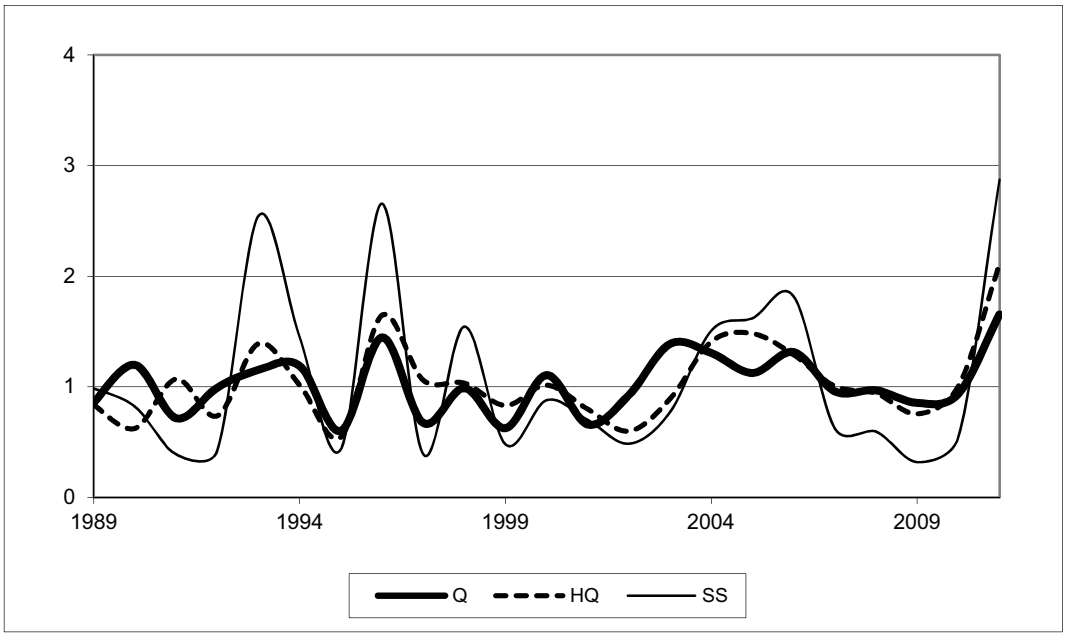

Figure 5. Annual Discharge and Annual Daily Mean High Discharge and Calculated Annual SS Concentration Expressed as LTM Ratio

Danville

2011 annual rainfall above Danville was 11.68 inches above the LTM resulting in flows that were 186 percent of the LTM. Largest departures for precipitation occurred during the spring and summer seasons. Flow values exceeded LTM during all seasons with 133 percent during winter and 363 percent during the summer. Although highest flows and subsequent highest loads of all constituents occurred during T.S. Lee in September, nine months recorded flow above the LTM with highest departures during September, October, and May, respectively.

2011 seasonal loads for TN, TNOx, and TNH_3 were higher during winter and spring than summer. The high flow months within these seasons were similar with 69,235, 64,007, and 64,923 cfs occurring for March, April, and September, respectively. Although these flows were similar, TN was highest during March and April and lowest during September, while TP and SS were the opposite. The difference within the months was high sustained flows with a lower peak during March and April and a very high peak event during September, which accounted for 13 percent, 39 percent, and 72 percent of the annual load of TN, TP, and SS, respectively.

Baseline comparisons for TN and TP show that 2011 yields were below all predictions except for the baseline using the second half of the dataset for TN. 2011 SS yields were substantially above all baseline predictions. The 2011 SS yield was 170 percent of the baseline prediction using the five-year baseline and 243 percent of the baseline when using the second half dataset baseline.

The seasonal baseline comparisons show that much of the annual baseline deviation from predictions was due to the summer, specifically T.S. Lee. Seasonal comparison to baselines showed 2011 TN yields below predictions for all seasons, while both TP and SS yields were above including the 2011 SS yield being 2,121 percent higher than the baseline prediction. Consideration of the value should include that of T.S. Lee's anomalous effects. The baseline created for the summer at Danville included years with discharge ratios ranging from 0.66 to 1.39, whereas the discharge ratio for 2011 was 4.94. Considering that SS loads may not increase linearly with increased flow, using a

linear regression line likely makes the prediction and actual value seem further apart.

There were no changes in trend directions from 2010 to 2011 although there were a few notable magnitude changes. The larger changes in magnitude included a decrease for TNH_3 and an increase for TP and TOC. There were no trends for flow.

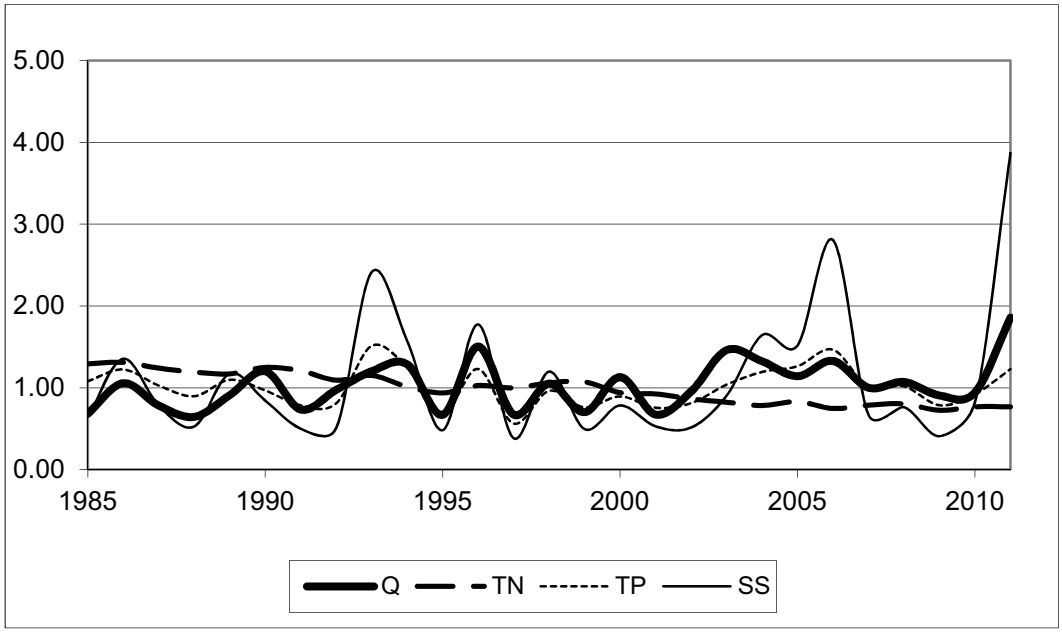

Figure 6. Annual Discharge and Calculated Annual TN, TP, and SS Concentrations Expressed as LTM Ratio

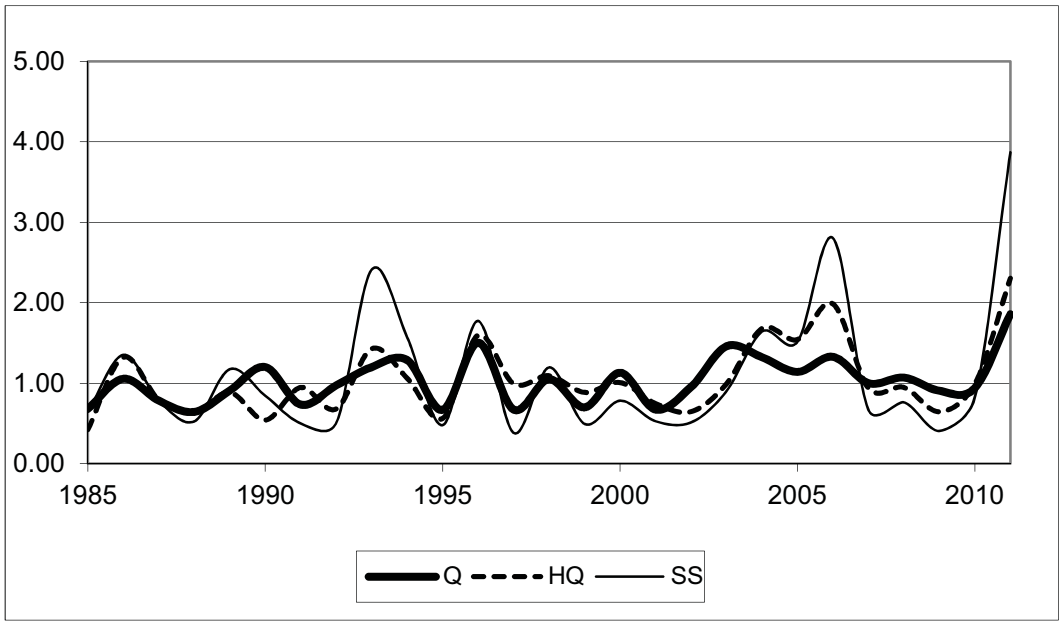

Figure 7. Annual Discharge and Annual Daily Mean High Discharge and Calculated Annual SS Concentration Expressed as LTM Ratio

Marietta

2011 annual rainfall in the basin above Marietta was 18.87 inches above the LTM with the majority of the departure during spring and summer. Annual discharge was 183 percent of the LTM ranging from 130 percent during winter to 294 percent during summer.

2011 annual loads expressed as a percentage of LTMs were below the 183 percent discharge value for all parameters except TP, SS, TON, and TOC. Calculated average annual concentration values for these parameters were 113 percent of the LTM for TOC and TON and 145 percent and 269 percent of LTM for TP and SS, respectively. All other parameters had annual concentration values below the LTM by at least 15 percentage points.

2011 monthly flow was highest for March, April, and September, respectively, with September being the lowest average but highest departure from the LTM. Similar to Danville, nine of 12 months were above LTM flow values. While April and September flows were comparable with 148,010 and 137,867 cfs, respectively, TN load for September was 100 percent of April's load. TP and SS loads were 303 percent and 508 percent, respectively, for the same monthly comparison.

2011 annual and seasonal yields were below all baseline predictions for TN while annual yields for TP and SS were above all baseline predictions. Seasonal yields for both parameters were above baseline predictions for winter and summer.

2011 trend directions remained unchanged from 2010 for all parameters; however, many trend magnitudes increased. Increases in trend magnitude included DON, TNOx, DNOx, TP, DP, TOC, and SS. There were no flow trends.

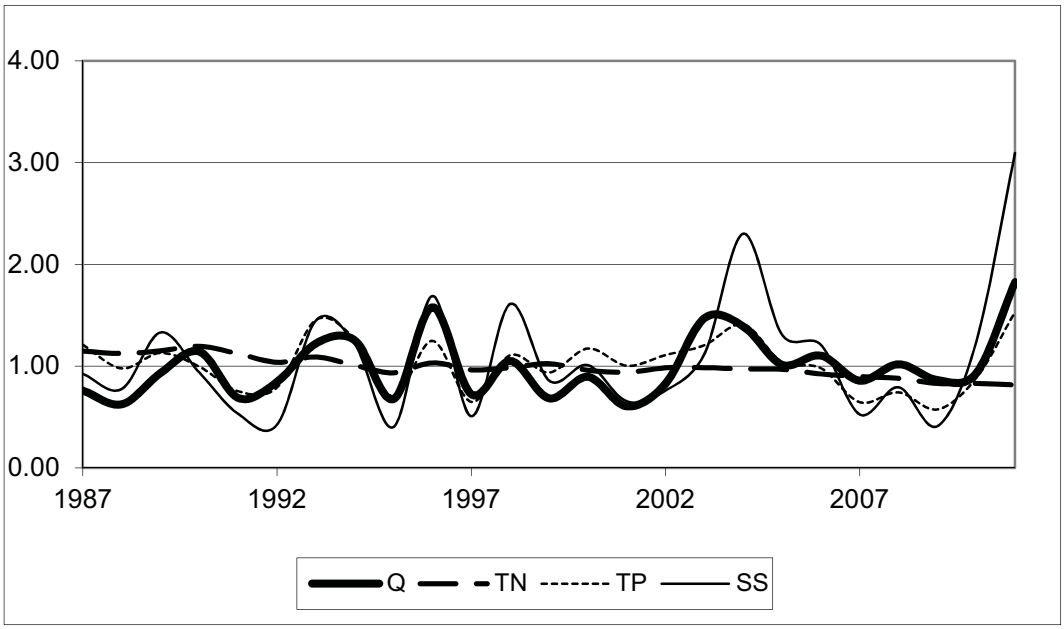

Figure 8. Annual Discharge and Calculated Annual TN, TP, and SS Concentrations Expressed as LTM Ratio

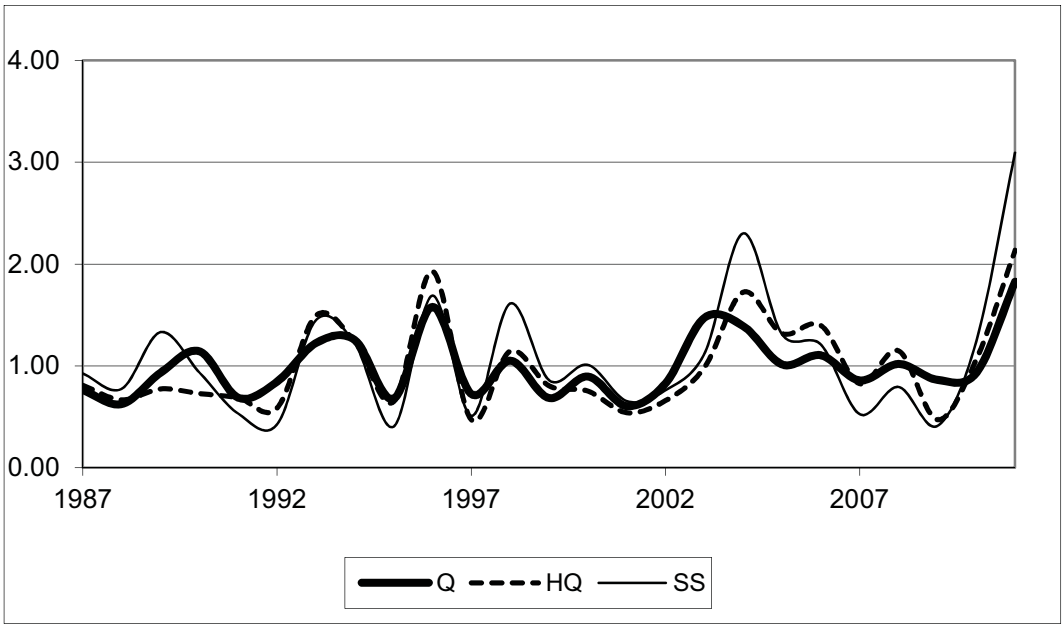

Figure 9. Annual Discharge and Annual Daily Mean High Discharge and Calculated Annual SS Concentration Expressed as LTM Ratio

Lewisburg

2011 seasonal and annual precipitation and discharge were above LTMs at Lewisburg. Precipitation ranged from 3.34 inches above the LTM for winter to 9.67 inches above LTM for summer. Although rainfall and departure from the LTM were larger for summer, the discharge percent of LTM was greatest for spring which had sustained high flow through April and May.

Annual loads were above LTMs for all parameters except DP and DOP, which were 59 and 70 percent of the LTM, respectively. Annual average concentrations were below the LTM for all parameters except TOC. Although the annual peak flow occurred in September, the monthly averages were half the monthly averages of April and May. This resulted in loads for TN and TP for both March and April being higher than September loads. Only September SS load was higher than March and April loads but only by 11 and 2 percent, respectively. September at Lewisburg accounted for 26 percent of the annual sediment load as compared to 72 percent at Danville.

2011 TN, TP, and SS yields were below both annual and seasonal baselines predictions. The exception was SS during summer as compared to the initial five-year baseline. This baseline has a low R^2 value due to a tropical storm that occurred in 1988 which dumped a heavy and isolated amount of rainfall over the West Branch of the Susquehanna. This resulted in a pulse of sediment while not overly influencing the average seasonal flow used to calculate the baseline. With the outlier removed, the prediction changed to 23 lbs/acre which remained substantially lower than the actual 2011 yield. Thus, the low R^2 was not the driving factor in the comparison.

Trends remained relatively unchanged from 2010 with the only exceptions being increased magnitude of the downward trend for TP and SS. There were no flow trends.

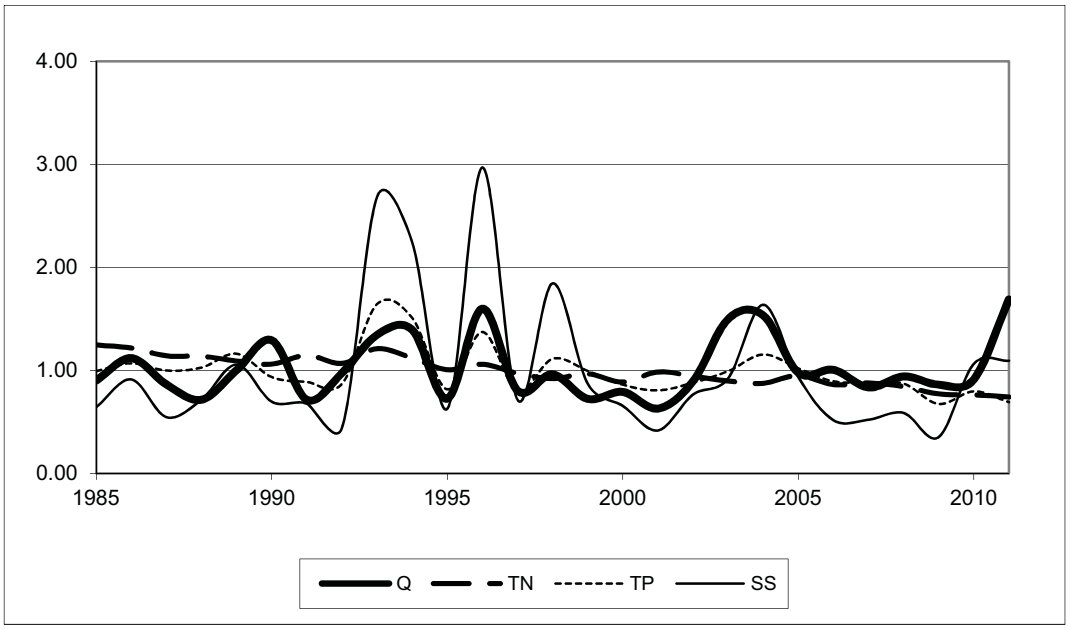

Figure 10. Annual Discharge and Calculated Annual TN, TP, and SS Concentrations Expressed as LTM Ratio

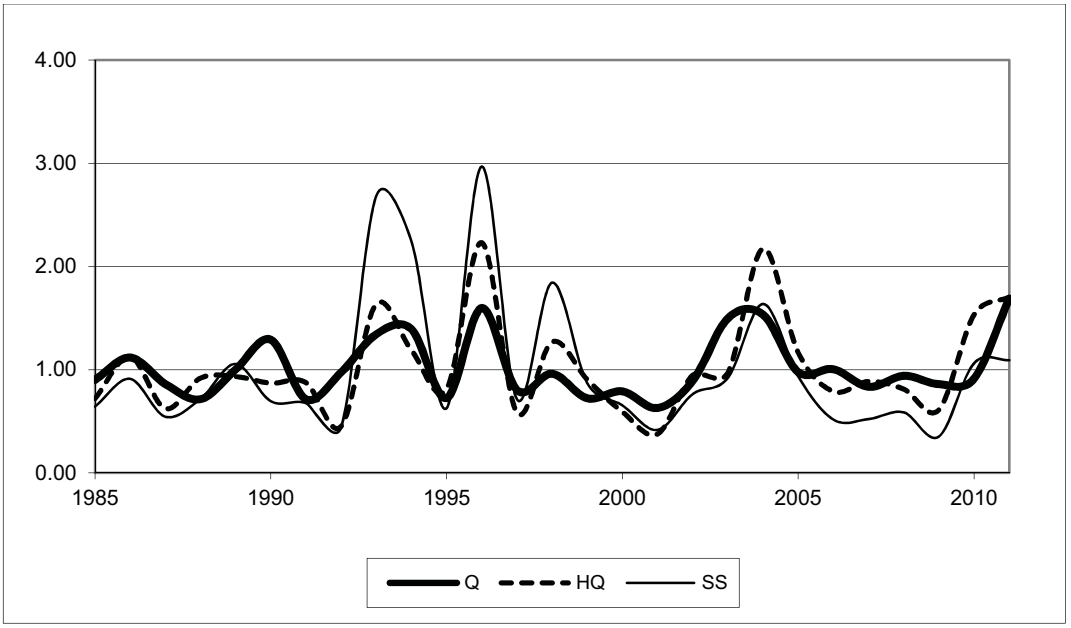

Figure 11. Annual Discharge and Annual Daily Mean High Discharge and Calculated Annual SS Concentration Expressed as LTM Ratio

Newport

2011 precipitation and discharge at Newport were unique as compared to the other five sites. Although the highest amount of rainfall occurred in summer, the highest average flow and highest peak flow occurred during spring. Summer had the second highest peak flow and the lowest average discharge of all four seasons. September had the fourth highest average monthly discharge. Annual discharge at Newport was 175 percent of the LTM.

2011 annual SS load was 200 percent of the LTM while all other parameters were below 175 percent of their respective LTMs. DP loads were the only parameter below the LTM at 91 percent and had an annual average concentration that was 52 percent of the LTM.

Monthly average discharge during March and April was greater than September and resulted in higher TN loads during these months. TP and SS loads were highest during September due to the effects of T.S. Lee even though March contained a higher peak event.

Baseline comparisons show 2011 yields to be lower than all predictions for TN, TP, and SS. All 2011 seasonal yields were below baseline predictions with SS being the only exception during summer. The predicted baseline yield was 151 lbs/ac compared to the actual 2011 yield of 159 lbs/ac.

2011 trends directions remained unchanged from 2010 although all existing trends improved in magnitude. This included a reduction in the upward trend for DOP. All other parameters with downard trends increased in magnitude. TNO_{23} and DNO_{23} continue to show no trends while being the highest contributor to the TN load. Largest reductions for TN and DN occurred for TON and DON. There were no flow trends.

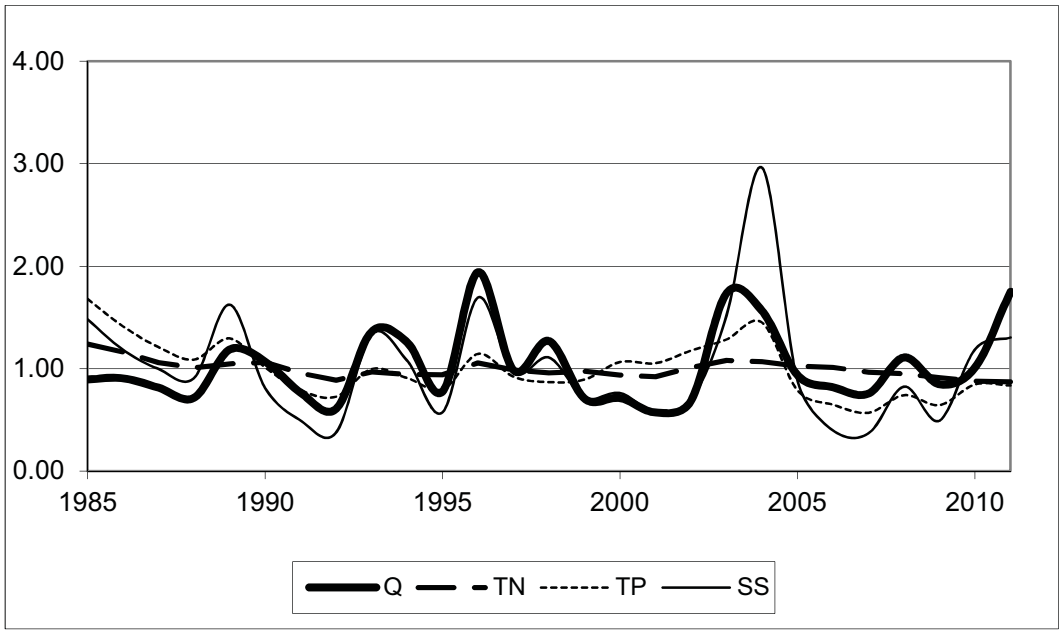

Figure 12. Annual Discharge and Calculated Annual TN, TP, and SS Concentrations Expressed as LTM Ratio

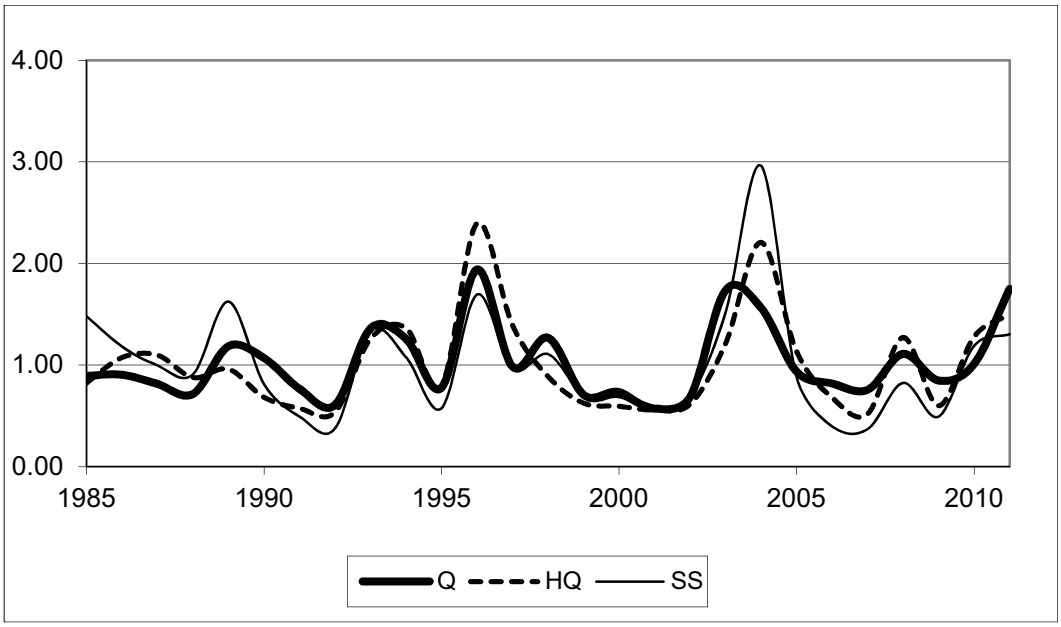

Figure 13. Annual Discharge and Annual Daily Mean High Discharge and Calculated Annual SS Concentration Expressed as LTM Ratio

Conestoga

T.S. Lee had a dramatic effect on Conestoga during 2011. Annual precipitation was 16.28 inches above the LTM with 10.08 inches falling during the summer months that contained T.S. Lee. Annual discharge was 165 percent of the LTM with summer having the highest deviation from the LTM at 275 percent. Peak flow for T.S. Lee surpassed 25,000 cubic feet per second (cfs) while the second highest peak flow for 2011 was near 7,500 cfs.

Annual loads were all above the respective LTMs except for DON. Greatest departure from LTMs occurred for TP and SS with 274 percent and 425 percent, respectively. While TN loads were evenly distributed throughout the four seasons, TP and SS were greatest during summer. Although TN was evenly distributed among seasons, the summer load was concentrated in September as were TP and SS with 75 percent of the annual TP load and 89 percent of the annual SS load being delivered during the month.

2011 annual and seasonal TN yields were below all baseline predictions. Both TP and SS annual yields were above all annual predictions, which were dominated by the summer event. Only summer had yield values above the seasonal baseline predictions with 2011 TP at 392 percent of the prediction and SS at 355 percent of the prediction.

2011 trends for all parameters remained unchanged from 2010. Increases in the magnitude of the trends did increase for TON, DON, TP, DOP, TOC, and SS. TNO_{23} and DNO_{23}, the largest load contributors to TN and DN, continue to have no significant trends. TNH_3 and DNH_3 had the highest magnitude trends but the lowest overall effect as they were the smallest portion of the TN and DN load.