Nutrient Load Estimation and Analysis of Water Quality Monitoring Data from the South Washington Watershed District, 2000-2014

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Introduction

This report contains the results of an analysis of water quality monitoring data collected by the Washington Conservation District (WCD) at the primary monitoring and regional assessment sites in the South Washington Watershed District (SWWD) during 2000 – 2014. The MS-1, MS-2, Central Ravine, Newport, St. Paul Park, Trout Brook, and Wilmes Lake Outlet sites were included in the analysis. Water quality parameters analyzed in this study included water volume and major nutrients, including total phosphorus (TP), total suspended solids (TSS), and chloride (Cl). The primary purpose of the analysis was to provide annual (monitoring season) estimates of water and nutrient loading at these monitoring sites over the entirety of their monitoring records. Additional outcomes included an investigation of the effects of seasonality and precipitation on nutrient loads and concentrations, and an initial assessment of the effectiveness of the monitoring program for determining nutrient loading.

The first section of the report describes the methods used to calculate nutrient loads, estimate baseflow and identify discrete runoff events, and includes a description of the parameters used in the regression analysis. The second section describes broader patterns of seasonality and precipitation effects on nutrient loads and concentrations across the five storm drain sites (MS-1, MS-2, Central Ravine, Newport, and St. Paul Park). The third section of the report includes a simple assessment of the monitoring program, with recommendations for future efforts. Loading and analysis summaries for all sites are included in the Appendix.

Acknowledgements

The author is grateful for the assistance of Erik Anderson of the Washington Conservation District, who provided supplemental data as well as information about monitoring data and protocols, data cleaning methods, and details of monitoring sites and equipment installations. Feedback on early versions of the work and watershed information were provided by John Loomis of the South Washington Watershed District.

1. Methods

1.1. Baseflow Separation

Several methods were investigated for baseflow identification, including sliding interval (Sloto and Crouse, 1996), constant slope, and recursive filtering (Eckhardt 2005; WMO 2008). The constant slope method requires identification of an inflection point on the receding limb of the hydrograph and is therefore somewhat subjective and manually intensive, and was not used. The recursive filter method also requires identification of several parameters and makes event identification more difficult, and was also rejected for the purposes of load calculations.

The sliding interval method determines baseflow as the "lowest discharge in one half the interval minus 1 day… before and after the day being considered and assigns it to that day" (Sloto and Crouse, 1996). It was chosen due to its ease of implementation and ability to assist in identifying discrete events, though it has been shown to over-estimate baseflow (Gonzales et al. 2009) and is dependent upon selection of the interval of analysis. The analysis interval, $2N^*$, is the interval (in number of time steps) over which the analysis is carried out, based on N, the time in days from peak flow to when direct runoff has ceased for a given event (Gonzales et al. 2009). N is estimated as $N = 0.8*A^{0.2}$, where A is the watershed area in km^2.

The data were analyzed at an hourly time step, so the analysis interval ($2N^*$) was multiplied by 24 so that baseflow could be assigned on an hourly time scale. Baseflow ratio (BR was then defined for flow intervals as the ratio of baseflow volume to combined (baseflow + stormflow) volume.

1.2. Event Identification

An event breakpoint, where one event ended and the next began, was determined in the hydrograph at any place where baseflow (as estimated by the sliding interval method) was equal to total flow, i.e. a local minimum in the hydrograph as identified by the method. The entire hydrograph and breakpoints were inspected manually, primarily to combine multiple low-flow intervals and to check data for gaps and errors.

Flow type (stormflow, baseflow, or snowmelt) was assigned to each sample based on classification in the WCD or SWWD monitoring reports if available, or by use of baseflow ratio and interval precipitation. If the flow regime was not obviously dominated by stormflow or baseflow, it was not classified and was thus not included in flow regime summaries.

1.3. Precipitation

Precipitation data from MS-1, MS-2, Trout Brook, 100th Street, the St. Paul Airport (KSTP), the Minneapolis Airport (KMSP), and Hastings Dam were used. Precipitation was averaged into hourly intervals when available (generally post-2002), and KMSP was only used for determining snowfall.

Precipitation was assigned to flow intervals using a lag that was based on the approximate time of concentration for first flush at the site, as estimated from inspection of the hydrographs and hyetographs. This lag time ranged from 2 hours at St. Paul Park to 4 hours at MS-2 and Trout Brook. Precipitation intensity was determined by dividing the total precipitation depth of the interval by the total time over which non-zero precipitation was measured (rather than dividing by the length of the interval).

1.4. Load Calculations

Characteristic concentrations of TP, TSS, and Cl were assigned to each flow interval. For intervals in which samples had been taken, whether grabs or composites, the observed concentrations were used. If several samples were taken during the interval, the observed concentrations from the samples were averaged together, weighted by the volume represented by each sample in the interval. For un-sampled intervals, a concentration was assigned; this concentration was a monthly median concentration from all of the data in the record at the site (both grabs and composite samples), averaged with all observations within 14 days before and after the interval to allow any observations to influence the assigned concentration. Median concentration was used instead of mean concentration to prevent inflation of load estimates by extreme values, which were especially prevalent in the TSS and Cl data.

It is acknowledged that monthly bins for concentration data are somewhat arbitrary given that year-to-year variation in snow cover and ice out, leaf out, and leaf drop can influence the timing of major seasonal fluxes of water and nutrients. However, concentration was assigned by month rather than by flow rate or volume because a seasonal effect is generally present in the data (see following sections), while concentration vs. flow relationships were very poor for most sites.

Some flow intervals had to be estimated due to spans of bad or missing data. If precipitation during the interval was negligible, intervals were filled in by linear interpolation. Larger or rainier intervals of missing data were left uncorrected. In order to allow year-to-year comparisons of loading at a given site, all seasonal loads were scaled to the period April 1 – October 31. For each year at a given site, uncorrected and/or un-monitored intervals within this seasonal period were aggregated; water volumes and nutrient loads were then scaled in proportion to the amount of rainfall occurring during the aggregated intervals relative to the amount of rainfall during the rest of the monitored period. Seasonal loading tables presented in this report have been scaled in this manner, with the number of missing days listed by year.

Only two sites, MS-1 and MS-2, have consistent data records prior to 2006. Load calculations were completed for these sites from 2001 to present due to issues with consistency and data quality at the sites in 2000.

1.5. Statistical Methods: Effect of Seasonality and Antecedent Precipitation on Nutrient Loading

The effect of seasonality on nutrient loading was illustrated using boxplots of event nutrient loading rates (lb/day) and event nutrient concentrations (mg/L) by month and by season. Boxes represent the interquartile (1^{st} – 3^{rd}) range, whiskers are the range of all data within 1.5*IQR, single dots are outliers (i.e. beyond 1.5*IQR), horizontal bars within the boxes are medians, and diamonds are means. The data in the boxplots are restricted to sampled events only, whether by grab or composite (or both). Events are assigned to a month by the mid-point of the interval, such that an event beginning in one month and finishing in the next is assigned to one or the other rather than being split between them, potentially introducing some error to the results. No effort was made to distinguish between stormflow and baseflow events in order to present more general trends in the loading data, and because of the uncertainty in identifying baseflow intervals at sites with long residence times.

Seasons were assigned by grouping months, with “Spring” consisting of all samples during March – May, “Summer” including June – July, and “Fall” including September – November. It is acknowledged that few samples were collected during the shoulder months (March and November especially) and that seasonal designations are somewhat arbitrary, but the seasonal bins were useful for quantifying seasonality. Differences among seasons were assessed using a Mann-Whitney-Wilcoxon rank sum test (Helsel and Hirsch, 2001), with differences considered significant at $p < 0.05$. This test was also used in the evaluation of the monitoring data to compare grab and composite samples, as well as baseflow and stormflow samples.

Simple linear regression was used to investigate the effect of several precipitation and flow parameters on observed volumes and observed nutrient loads and concentrations, as well as to illustrate any relationships between the parameters themselves. For these analyses, only observations were used (i.e. intervals with assigned concentrations were excluded). Regressions were considered significant at $p < 0.05$, and results are reported in terms of the Pearson correlation coefficient, r.

At the **annual** scale, dependent variables included flow rate (cfs), water yield (ft^3 per in. rainfall) and baseflow ratio, as well as the nutrient load (lb), load rate (lb/day) and yield (lb per in. rainfall) of TP, TSS, and Cl. All quantities were un-scaled for missing intervals. Independent variables included all dependent variables, as well as year, precipitation depth (in.), and antecedent snowfall (inches of snowfall during preceding winter).

At the **event** scale, dependent variables included total, storm and baseflow volumes, flow rate, and load (lb) and concentration (mg/L) of TP, TSS, and Cl. Independent variables included dependent variables in addition to month, antecedent rainfall over the previous 7, 14 and 28 days, and mean stage during the previous 6 hours and during the previous 7 days.

2. Broader Patterns of Seasonality and Precipitation Influence on Nutrient Loading Across Major SWWD Monitoring Sites

Site-to-site variation in water and nutrient loading by year are illustrated in Section 2.2 for all SWWD sites included in the analysis. The broader effects of seasonality and antecedent conditions on water and nutrient export in SWWD were considered by aggregating estimated loads and monitoring data across five of the major storm drain sites: MS-1, MS-2, Central Ravine, Newport, and St. Paul Park. Drainage areas of the included sites spanned several orders of magnitude: 30 ac (St. Paul Park), 300 ac (Newport), 1,482 ac (MS-1), 2,720 ac (Central Ravine), and 10,000 ac (MS-2). Over 643 samples total were collected from 2000 to 2014, with data records for MS-1 and MS-2 beginning in 2000, Newport and St. Paul Park in 2006, and Central Ravine in 2009. Wilmes Lake Outlet (3243 ac) and Trout Brook (4343 ac) were excluded from this analysis because the sites represent more distinct surface water entities (i.e. a lake and a stream, respectively) and therefore potentially respond differently to rainfall and seasonality than the other sites.

Seasonal and antecedent flow and precipitation effects were assessed at the event scale only, with data summarized in a series of boxplots and regression tables in Sections 2.3 – 2.5. Loading tables, summary plots, and regression tables are included separately for all 7 sites in the Appendix.

2.1. Year-to-year Variability in Climate

For reference, seasonal (April – October) rainfall (in.) and antecedent snowfall (in. of snow during the preceding winter) are shown for 2001 – 2014 in Figure 2.1. Rainfall is the inverse-distance weighted average of all gauges based on the centroid of MS-2, with snowfall as measured at the Minneapolis-St. Paul Airport (KMSP). Considerable variability was present in precipitation over the monitoring period, with snowy winters in 2001, 2002, 2004, 2011, 2013, and 2014. High precipitation was observed in 2002, 2005, 2010, and 2014, with drought occurring in 2003 and 2007-2009. Very dry fall periods occurred during 2011, 2012, and 2013.

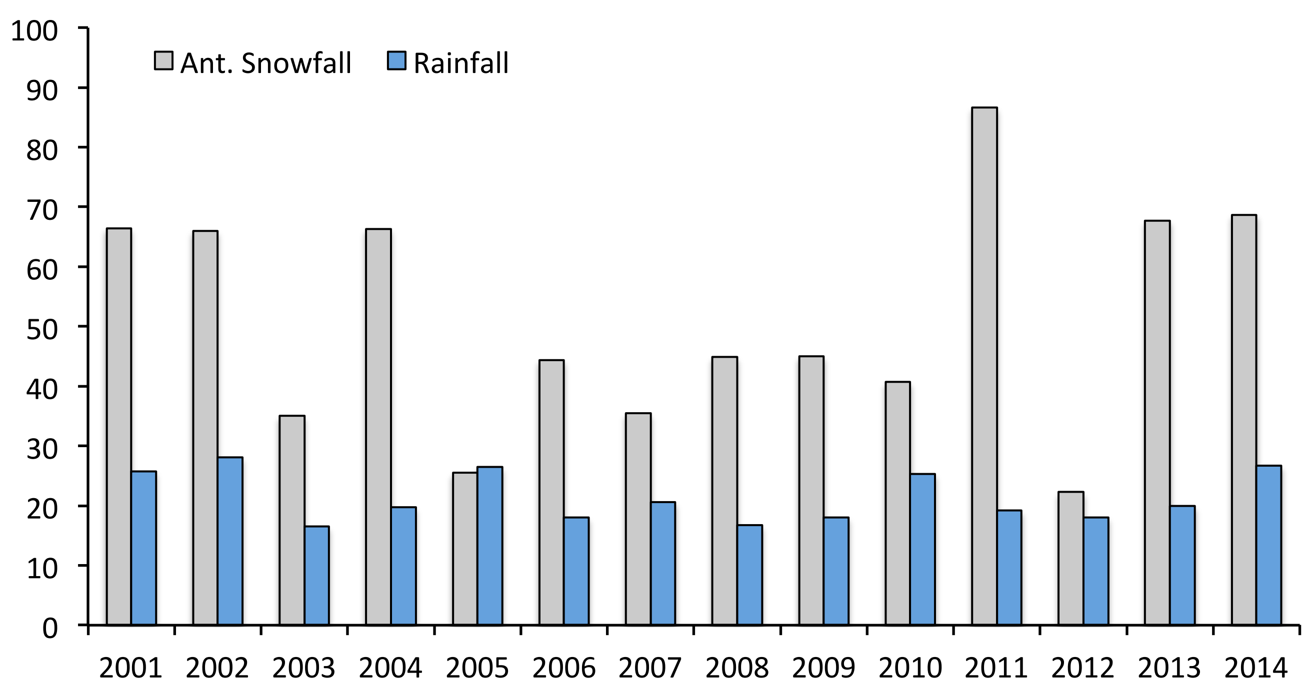


Figure 2.1. April-October total rainfall (in.) and snowfall during the preceding winter (in.) by year at MS-2.

2.2. Summary of Seasonal (April – October) Water Yields and Nutrient Loads Across Sites

Estimated loads of water, TP, TSS, and Cl over the entire monitoring period (2001-2014) are summarized in Figures 2.2 – 2.5 for all sites. Loads are normalized by watershed area to allow for comparison across sites, and have been scaled for data gaps within each year proportional to the precipitation occurring during gaps relative to that occurring during monitored intervals.

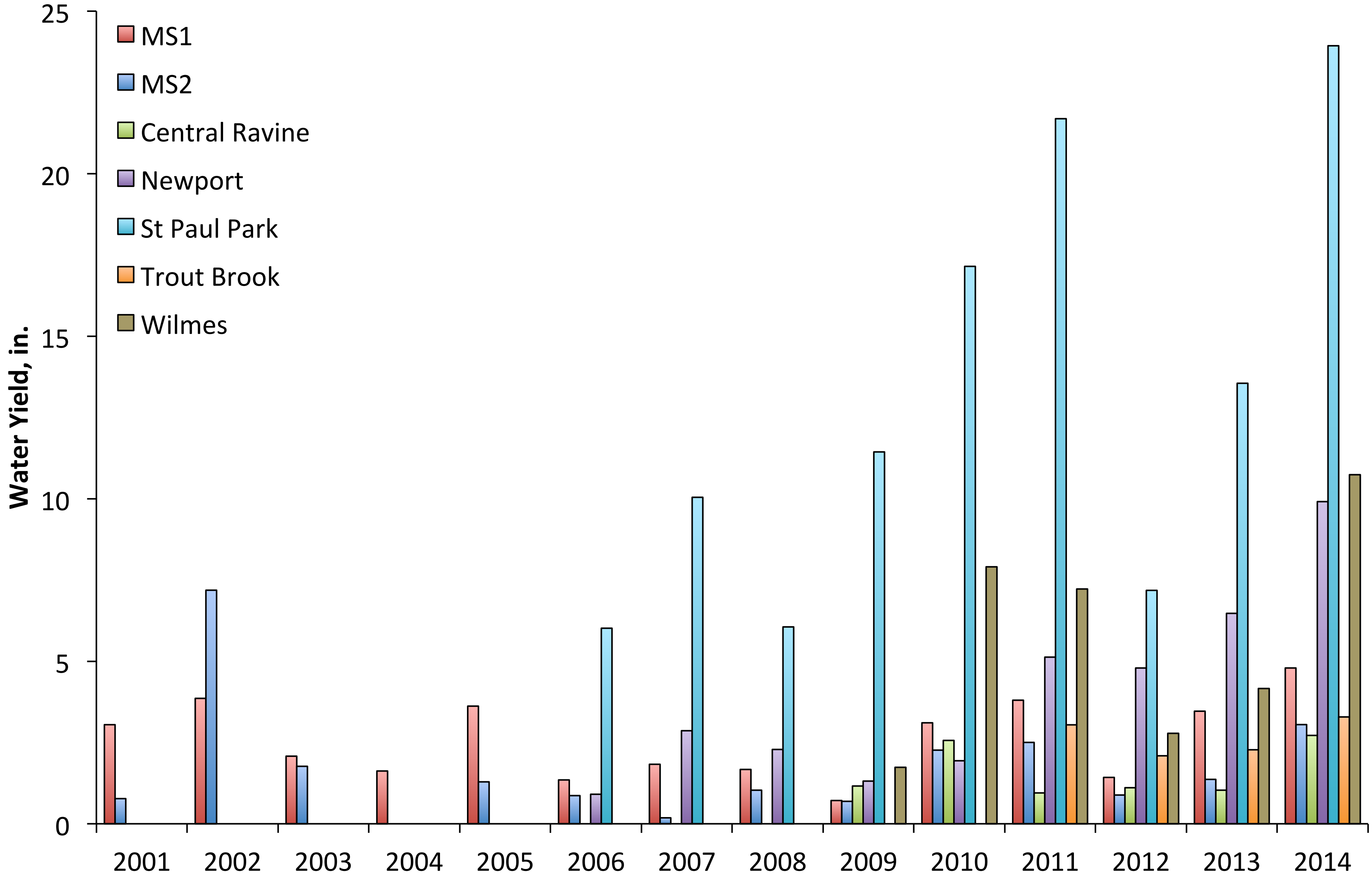


Figure 2.2. Seasonal (April-October) water yields (in.) by site over the 2001-2014 monitoring period.

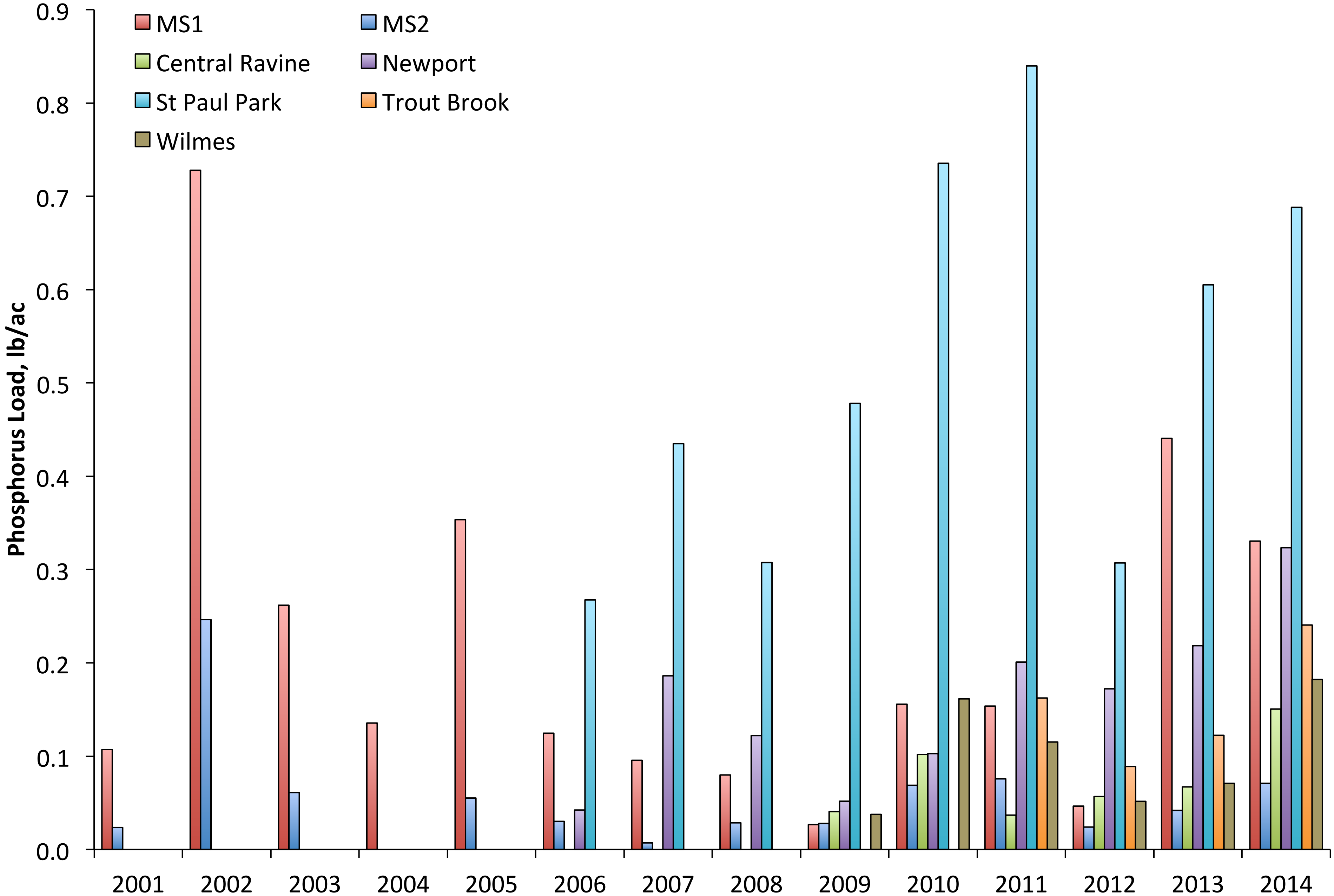


Figure 2.3. Seasonal (April-October) TP loading (lb/ac) by site over the 2001-2014 monitoring period.

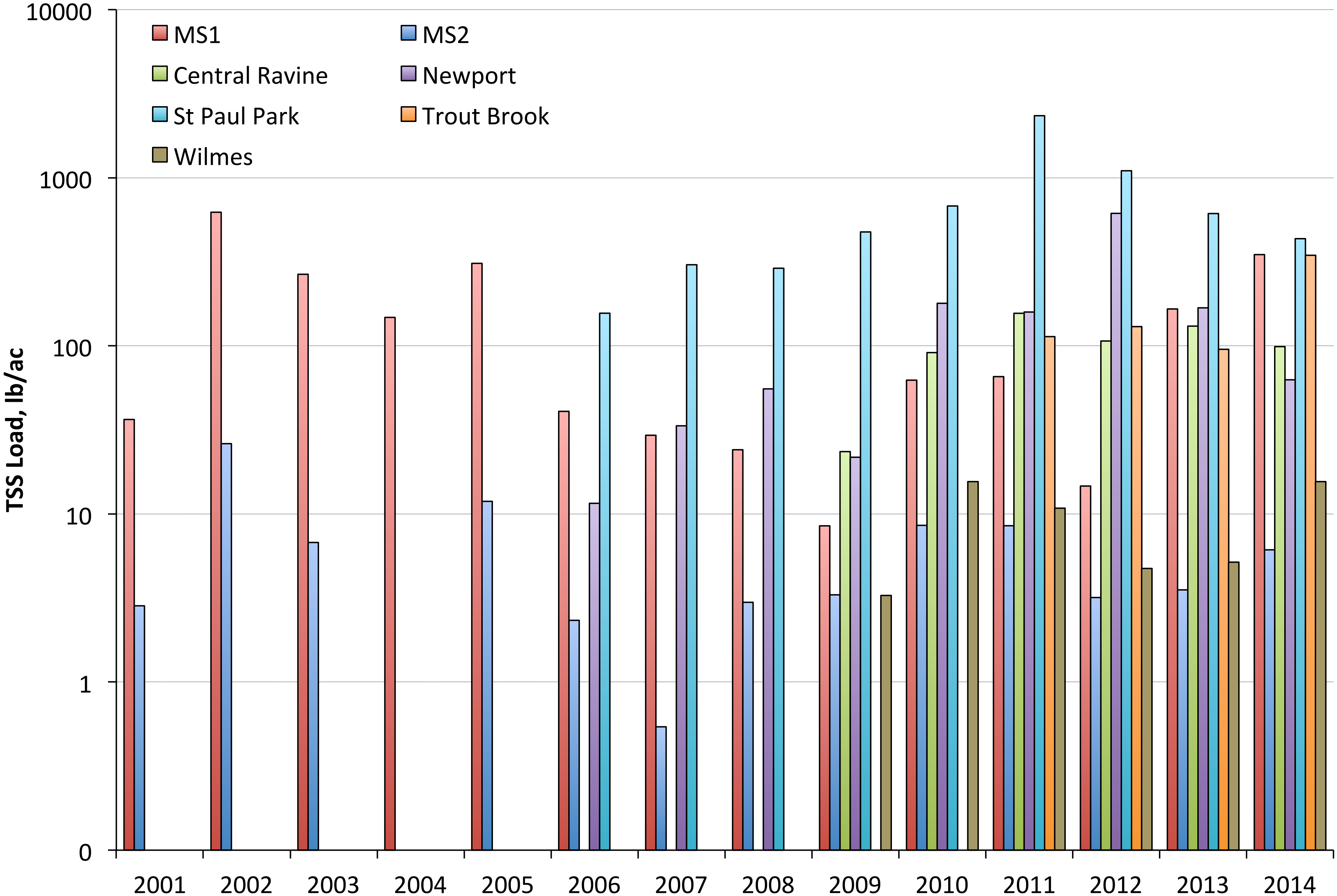


Figure 2.4. Seasonal (April-October) TSS loading (lb/ac) by site over the 2001-2014 monitoring period; note log scale.

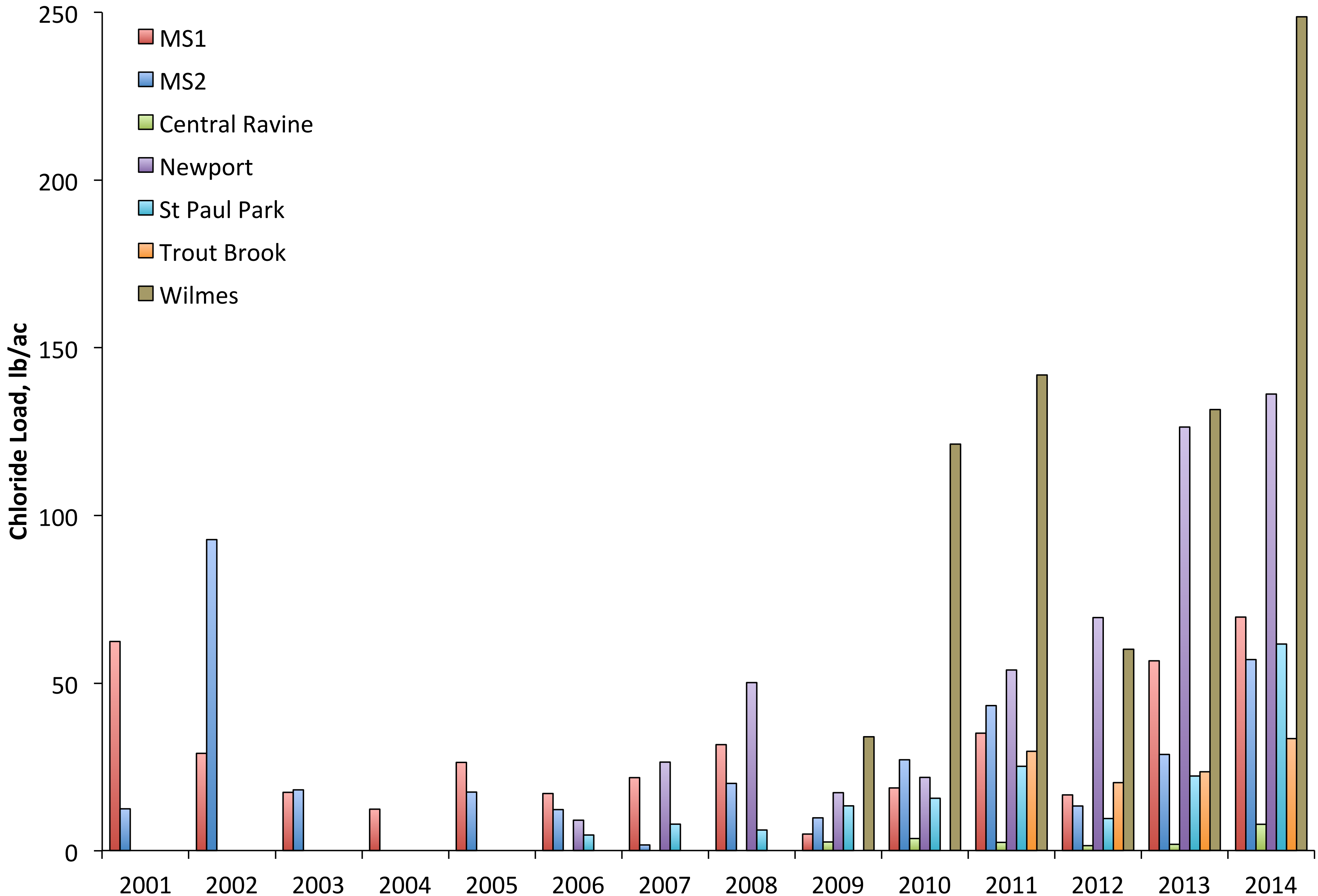


Figure 2.5. Seasonal (April-October) Cl loading (lb/ac) by site over the 2001-2014 monitoring period.

2.3. Year-to-year Variability in Nutrient Concentrations

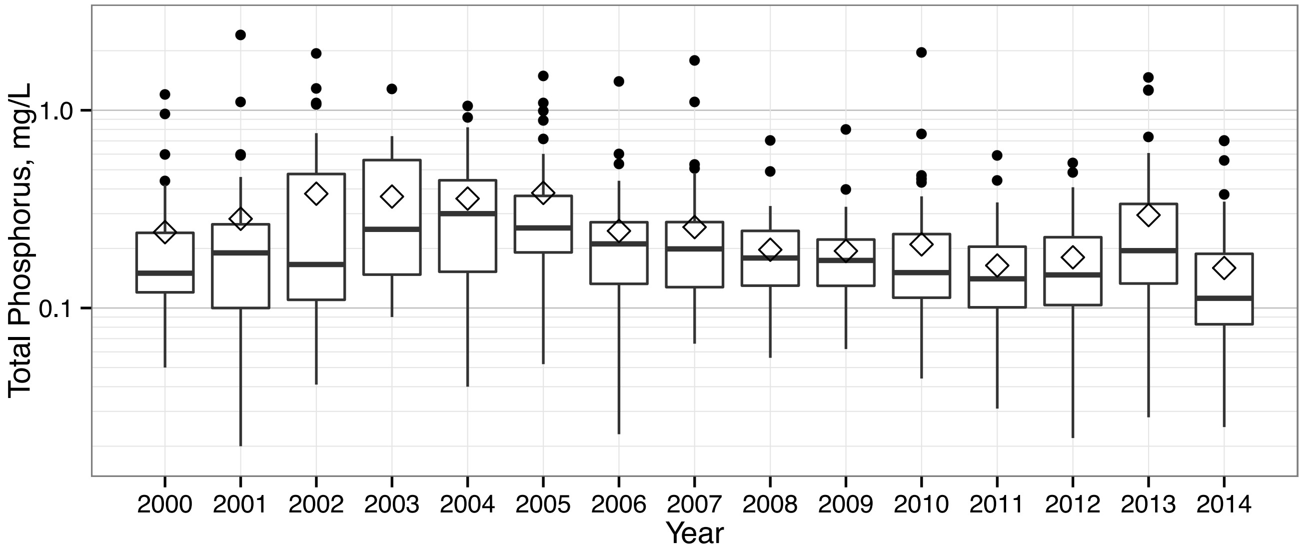
TP, TSS, and Cl concentrations across the five major sub-watersheds (MS-1, MS-2, Central Ravine, Newport, and St. Paul Park) are shown by year in Figure 2.6. Concentrations varied among years, with a general decline in TP from 2002 to 2014 that was weak (r = -0.17) but significant. Given the variability in climate over this period, the trend could indicate some gradual improvement in phosphorus retention or removal in the watersheds, from implementation of best management practices (BMPs), slowed rates of development, and/or improved retention and infiltration capacity. TSS showed peaks around 2003-2004 and 2012, while chloride concentrations were variable, but no significant trends were present for either nutrient.

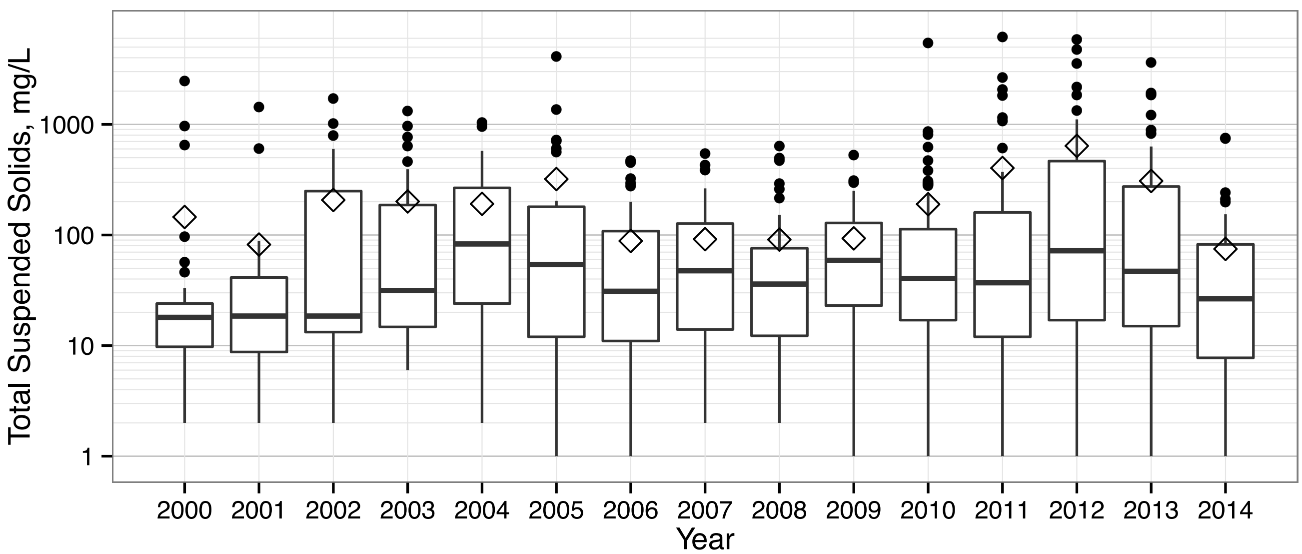
2.4. Seasonal and Monthly Variability in Event Nutrient Loads and Concentrations

Monthly event concentrations of TP, TSS, and Cl across the five major sub-watersheds (MS-1, MS-2, Central Ravine, Newport, and St. Paul Park) are shown in Figure 2.7, with seasonal concentrations shown in Figure 2.4. Concentration of TP and TSS show the same general month-to-month pattern across sites, with the highest concentrations occurring in May, June, and July, perhaps the result of erosion during early summer storms. TP is not significantly different among seasons, though TSS is significantly higher in summer (Fig. 2.8). The decrease in TSS from April to October is significant (r = -0.12; Table 2.1), and the associated decrease in TP may indicate retention in surface water, or be the result of reduced erosion as lawns and vegetation become established in late season. Chloride, which should be present mainly because of road de-icer application during winter months, decreases significantly in concentration from March through September (r = -0.32; Table 2.1) due to flushing or dilution, and is significantly different among all seasons (Fig. 2.8).

Fewer patterns were present in monthly loading of water, TP, TSS, and Cl across the five major sub-watersheds (Fig. 2.9). Flow rates were slightly higher in May, June, and July than during the rest of the season, perhaps due to more frequent or intense summer rainfall events; this period also corresponds to the highest concentrations (Fig. 2.7) and loading rates of TP and TSS. This pattern suggests that primary sources of sediment (and thus of particulate phosphorus) may be soil erosion or entrainment of sediments from shallow lakes or ponds during more intense runoff events. Cl loading rates decreased from April through September, consistent with the trend in monthly Cl concentration. The cause of the slight rebound of Cl concentration and loading rate in October is unclear, but could result from export of Cl from lakes during fall turnover when the potentially more saline hypolimnion is mixed with surface water. Additionally, in sites with groundwater-influenced baseflow, the rise in water tables as evapotranspiration decreases could enhance the connection of Cl-enriched groundwater with the surface drainage network.

Figure 2.6. Boxplots of nutrient concentrations of all sampled **events** across five major SWWD sub-watersheds, by year. Diamonds are mean concentrations and dots are outliers. Note log scale on y-axes.





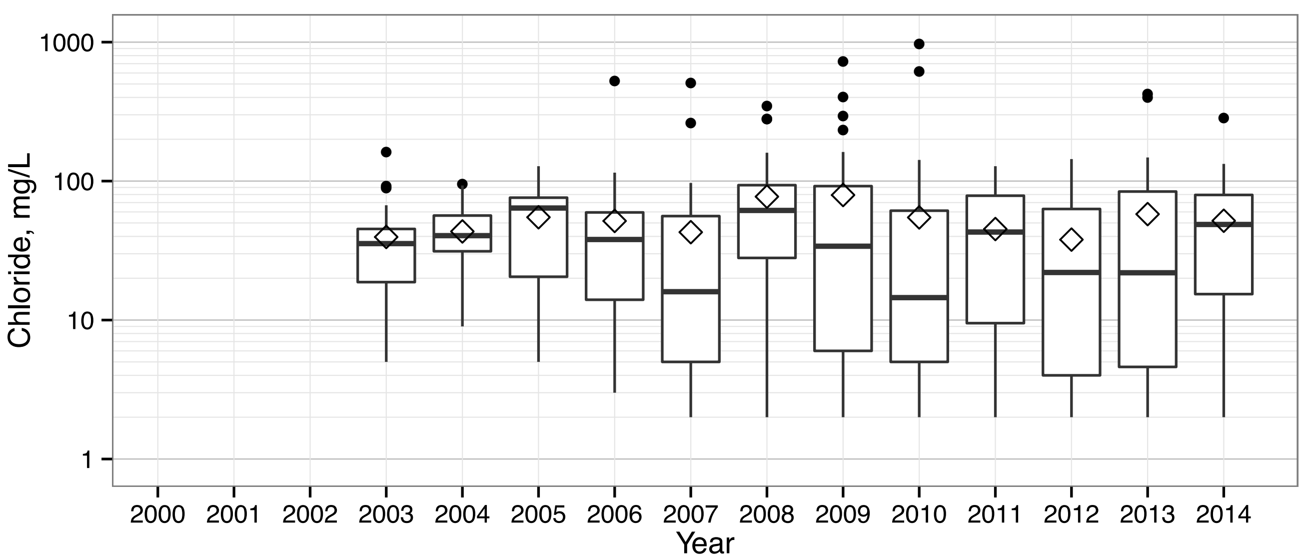
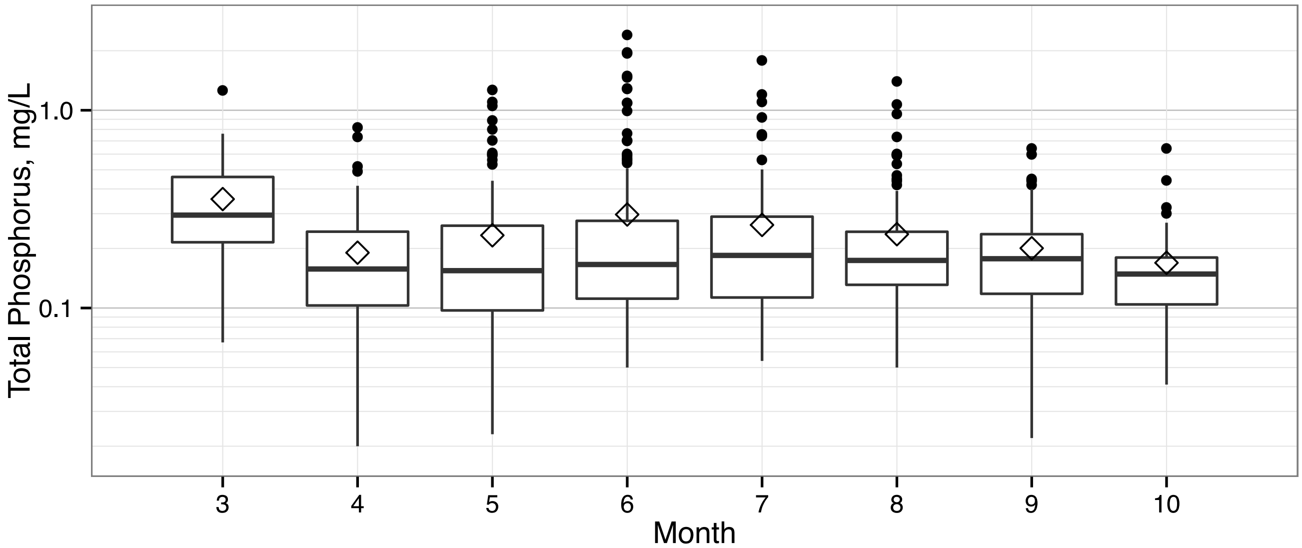
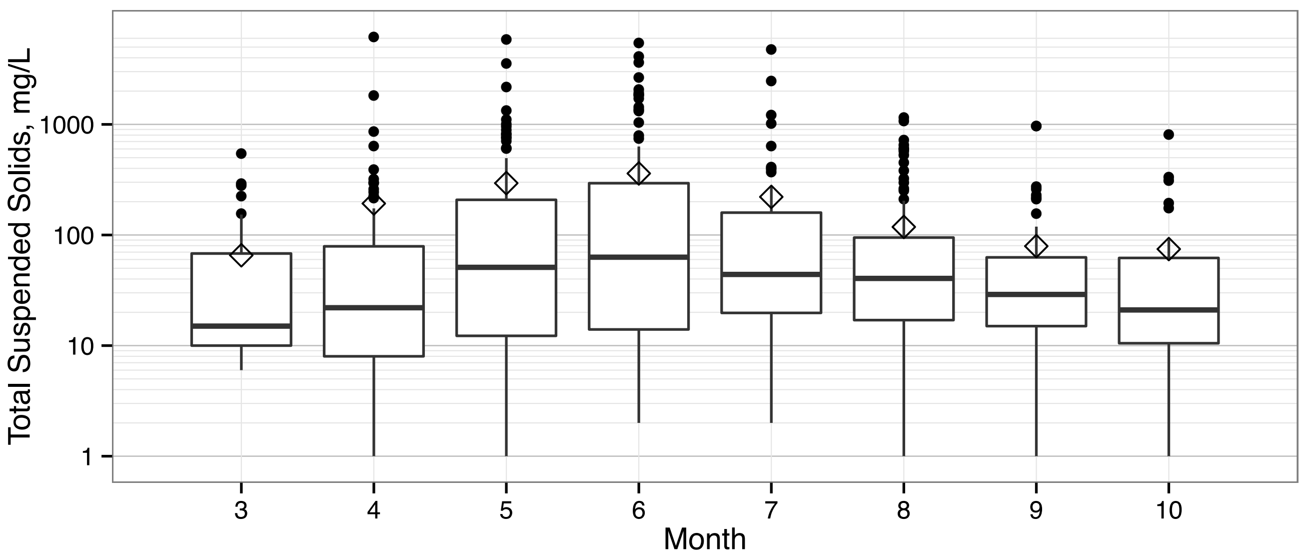


Figure 2.7. Boxplots of monthly nutrient concentrations of all sampled **events** across five major SWWD sub-watersheds. Diamonds are mean concentrations and dots are outliers. Note log scale on y-axes.





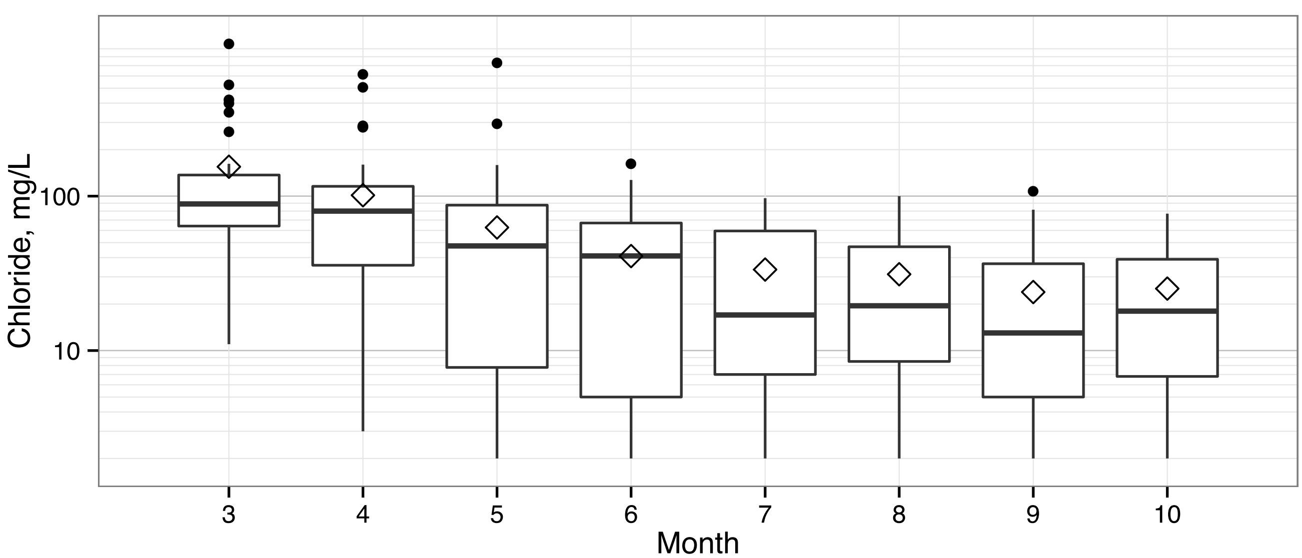


Figure 2.8. Boxplots of seasonal nutrient concentrations of all sampled **events** across five major SWWD sub-watersheds. Diamonds are mean concentrations and dots are outliers; seasons with different letters are significantly different at $p < 0.05$ by Mann-Whitney-Wilcoxon rank sum test. Note log scale on y-axes.

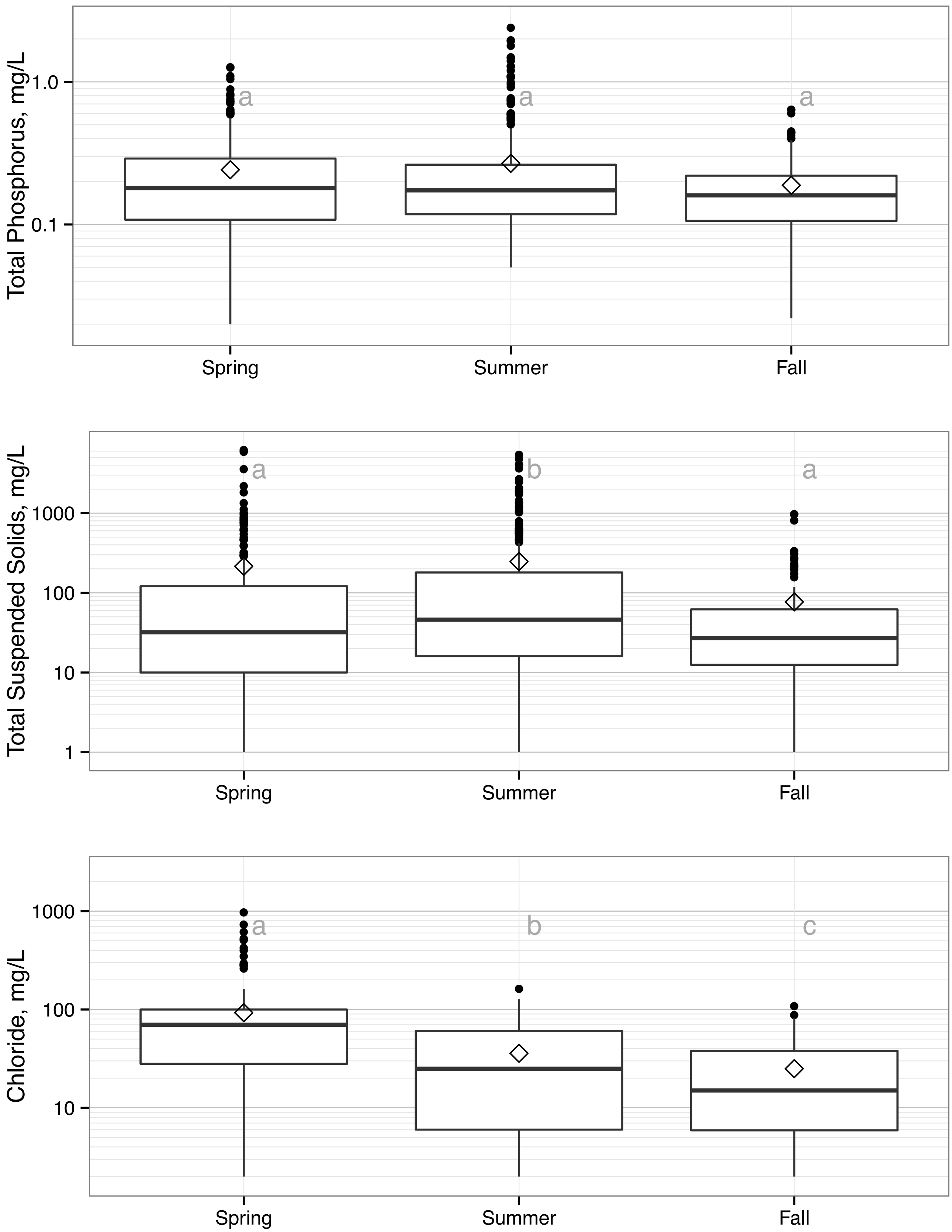
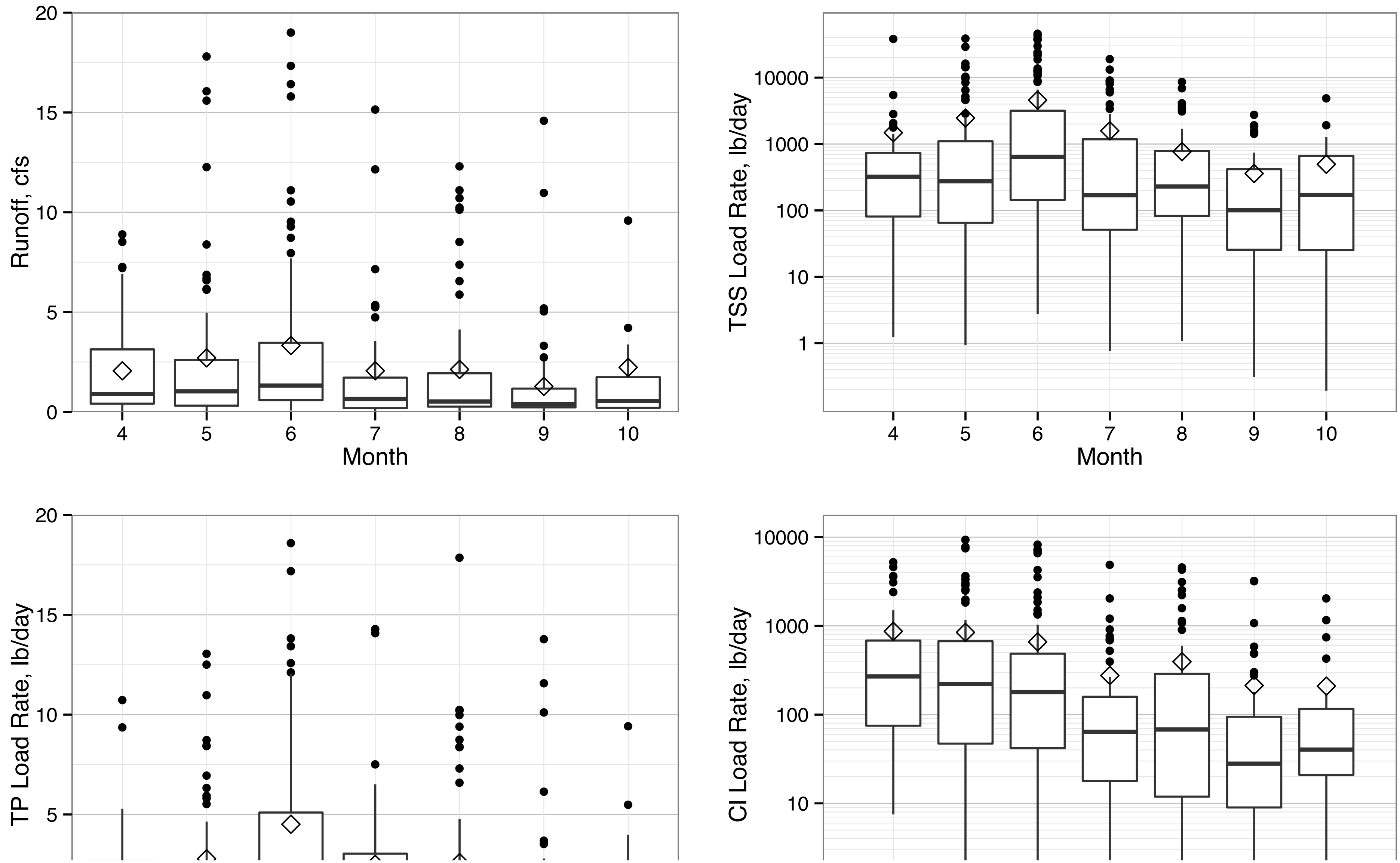


Figure 2.9. Boxplots of flow and nutrient loading rates of all sampled **events** across five major SWWD sub-watersheds, by month. Diamonds are mean concentrations and dots are outliers. Note log scale on y-axes for TSS and Cl.



2.5. Influence of Antecedent Precipitation and Flow Conditions on Event Nutrient Loads and Concentrations

The effect of antecedent flow and precipitation conditions on event nutrient concentrations and loads observed at the five major sub-watersheds was investigated using simple linear regression. Results considering concentration data only are shown in Table 2.1, while results for event loading data are shown in Table 2.2. Note that the concentration data set has more samples than the loading data set because some samples were collected when flow was not monitored, therefore some differences exist in *r* values for similar relationships between the two tables. Pearson *r* are shown in the tables along with significance of the regressions: * indicates significance at $p < 0.05$, ** indicates significance at $p < 0.001$.

Table 2.1. Results of linear regression (Pearson *r*) of event flow and nutrient concentrations vs. several temporal and antecedent precipitation and flow parameters.

Param	Year	Month	Flow	BF	Antecedent Precip			Ant. Stage		TP	TSS	Cl
			Rate	Ratio	*28 Days*	*14 Days*	*7 Days*	*6 Hr*	*7 Days*	Conc	Conc	Conc
Flow Rate	0.12*	0.01		0.02	0.24**	0.21**	0.26**	0.37**	0.29**	0.18**	0.10*	-0.16**
BF Ratio	-0.18**	-0.12*	0.02		0.22**	0.26**	0.22**	0.38**	0.45**	-0.12*	-0.12*	0.27**
TP Conc	-0.17**	-0.03	0.18**	-0.12*	-0.06	-0.07	-0.08	-0.12*	-0.13*		0.38**	-0.08
TSS Conc	0.08	-0.12*	0.10*	-0.12*	0.01	-0.04	-0.01	-0.10*	-0.10*	0.38**		-0.13*
Cl Conc	0.03	-0.32**	-0.16**	0.27**	-0.08	-0.04	-0.01	0.10*	0.15**	-0.08	-0.13*	

Table 2.2. Results of linear regression (Pearson *r*) of event flow and nutrient loading vs. antecedent precipitation and flow parameters.

Param.	Flow	Volume			BF	Precip		Antecedent Precip			Ant. Stage	
	Rate	Total	Baseflow	Storm	Ratio	Depth	Intensity	*28 Days*	*14 Days*	*7 Days*	*6 Hr*	*7 Days*
Flow Rate		0.87**	0.81**	0.91**	0.07	0.51**	0.05	0.30**	0.37**	0.41**	0.78**	0.69**
Vol, Total	0.87**		0.99**	0.96**	0.08	0.49**	-0.02	0.21**	0.28**	0.33**	0.78**	0.71**
Vol, Base	0.81**	0.99**		0.89**	0.10*	0.43**	-0.04	0.19**	0.26**	0.30**	0.78**	0.73**
Vol, Storm	0.91**	0.96**	0.89**		0.05	0.56**	0.00	0.23**	0.31**	0.36**	0.73**	0.62**
BF Ratio	0.07	0.08	0.10*	0.05		-0.04	-0.05	0.06	0.03	0.00	0.11*	0.16**
TP Conc	-0.03	-0.05	-0.07	-0.02	-0.16**	0.14*	0.20**	-0.05	-0.08	-0.09*	-0.13*	-0.15*
TP Load	0.66**	0.75**	0.72**	0.77**	0.03	0.50**	0.01	0.18**	0.20**	0.23**	0.52**	0.47**
TSS Conc	-0.06	-0.07	-0.08	-0.06	-0.04	0.02	0.16**	0.01	-0.06	-0.01	-0.11*	-0.11*
TSS Load	0.17**	0.16**	0.11*	0.22**	-0.06	0.29**	0.05	0.12*	0.08	0.09	0.04	0.05
Cl Conc	0.06	0.08	0.13*	0.08	0.02	-0.09	-0.17**	-0.06	-0.03	-0.01	0.12*	0.16**
Cl Load	0.85**	0.92**	0.93**	0.87**	0.08	0.50**	-0.03	0.22**	0.33**	0.37**	0.75**	0.67**

Though *r* values are generally low, several results of the linear regression are worth noting:

- Event loading is logically controlled by hydrology, with TP, TSS, and Cl loads well-correlated with flow rate and total, storm, and baseflow volumes;
- Precipitation depth has a significant, positive effect on volumes and flow rates, and the relatively strong correlations of precipitation with nutrient loads is likely explained by this strong tie between precipitation and hydrology;
- Event TP concentration (and to a lesser extent TSS concentration) were significantly correlated with increased flow rate and rainfall intensity, and negatively correlated with baseflow ratio and antecedent stage, suggesting that stormflow (low BF Ratio) and associated scour or erosion (high flow rate / rainfall intensity) may be important for TP and TSS;

- TP and TSS concentration were significantly and positively correlated with each other, suggesting that particulate P may be the dominant form of P;
- Baseflow ratio and TP concentration both decreased significantly with year over the study period, while flow rate increased, indicating a reduction in baseflow or increase in stormflow; intense development in some of the watersheds over the study period may have increased impervious areas and thus enhanced flow rates;
- Wetter antecedent conditions (greater antecedent rainfall) and higher antecedent water levels logically led to greater water volumes and nutrient loads, especially for TP and Cl, which move readily in dissolved forms;
- TP and TSS concentrations and baseflow ratio decrease weakly but significantly with month, suggesting a dilution or source reduction effect over the season.

3. Assessment of Monitoring Data and Recommendations for Future Work

This section includes an assessment of the monitoring data for suitability in the calculation of nutrient loads, and recommendations for modifications to monitoring protocols to potentially improve understanding of nutrient sources, and timing and magnitude of nutrient loading.

3.1. Assessment of Monitoring Data

A summary of the quantities of TP samples collected at each of the 7 sites included in the loading analysis is presented in Table 3.1. Sample quantities are grouped by flow regime (snowmelt, stormflow, and baseflow) as well as by sample type (grab or composite). TP was used as the constituent of interest for purposes of illustration only. Sample quantities for TSS should be similar, but may be lower for Cl as it was not analyzed during the first two years at MS-1 and MS-2.

Data from all 7 sites were tested (in aggregate) for significant differences among flow regimes and sample types for the three main constituents, TP, TSS and Cl. A Mann-Whitney-Wilcoxon rank sum test was used for this analysis, and Table 3.2 includes a summary of p-values for all comparisons. Sample sets were considered significantly different for $p < 0.05$; for example, a p-value of 1.52×10^{-18} was calculated for comparison of baseflow and stormflow TP concentrations when considering all sample types (both composites and grabs), which provides very high confidence that baseflow and stormflow TP concentrations were statistically different when considering data from all sites.

Note that this analysis assumes that samples by type and flow regime were evenly distributed across the monitoring periods, which is generally not the case (see Table 3.1). The effect of seasonality in the nutrient concentration data may actually contribute more variability to the data set than sample type or flow regime. Therefore this simplistic approach should be considered a potential starting point for a more in-depth analysis of sample types or timing. It is also reasonable to expect that results would be different if each site was considered separately rather than in aggregate.

A few features of these summaries are worth noting:

- The monitoring data set is biased towards storm composites: Out of 743 samples collected, most (488) were composites, and nearly all of these composite samples were collected during stormflow (457 of 488). This situation is not unusual as it is the nature of stormwater monitoring programs – grab samples are often collected during low flow (baseflow) or off-season periods to supplement the primary monitoring data set (storm composites).
- Accordingly, grab and composite samples were significantly different for TP, TSS, and Cl regardless of flow regime, but especially for stormflow (i.e. much lower p-values; Table 3.2). This is perhaps unsurprising, as nutrient loading during storms can be more dynamic than during baseflow, and therefore storm grabs should not be expected to provide the same characterization of the storm event as a composite.
- When all sample types were considered, baseflow and stormflow samples were significantly different for all constituents; however, when considered also by sample type (composite or grab), p-values increased substantially, and in some cases (Cl) the differences were no longer significant. The implication is that, across sites, the difference among grab and composite samples is greater than the difference between baseflow and stormflow samples.

- Very few snowmelt samples were collected overall (49 of 743, or 7%). At some sites, spring concentrations of TP and TSS were quite high (though variable), indicating that spring snowmelt could be an important time of year for nutrient export.
- Some sites, such as MS-2 and Trout Brook, included more grab samples than composite samples, potentially biasing their data sets relative to the other sites given the differences among grab and composite samples.

Table 3.1. Number of samples collected over the entire monitoring record at each site, separated by flow regime and sample type.

	Snowmelt	Storm	Base	ALL
MS-1				
ALL	24	160	34	234
Grab	24	16	30	81
Composite	0	144	4	153
MS-2				
Total	12	99	37	165
Grab	12	39	23	86
Composite	0	60	14	79
Central Ravine				
Total	2	78	0	80
Grab	2	6	0	8
Composite	0	72	0	72
Newport				
Total	5	62	12	79
Grab	5	4	10	19
Composite	0	58	2	60
St. Paul Park				
Total	6	74	3	83
Grab	6	2	2	10
Composite	0	72	1	73
Trout Brook				
Total	0	34	16	62
Grab	0	6	16	34
Composite	0	28	0	28
Wilmes Lake Outlet				
Total	0	32	8	40
Grab	0	9	8	17
Composite	0	23	0	23
ALL SITES				
Total	49	539	110	743
Grab	49	82	89	255
Composite	0	457	21	488

Table 3.2. Summary of *p*-values for pairwise testing (Mann-Whitney-Wilcoxon rank sum test) of flow regime and sample type for TP, TSS, and Cl concentration of samples collected at all 7 monitoring sites.

comparison	*sample type or regime sub-set*		
Total Phosphorus			
	All	**Composite**	**Grab**
base-storm:	1.52E-18	4.52E-02	2.46E-03
	All	**Composite**	**Grab**
grab-comp:	3.82E-19	1.54E-13	1.98E-03
Total Suspended Solids			
	All	**Composite**	**Grab**
base-storm:	5.78E-31	1.42E-05	8.49E-06
	All	**Composite**	**Grab**
grab-comp:	1.35E-50	1.77E-22	1.67152E-05
Chloride			
	All	**Composite**	**Grab**
base-storm:	8.15E-13	2.97E-03	5.33E-01
	All	**Composite**	**Grab**
grab-comp:	3.10E-30	3.78E-14	1.93E-01

3.2. Grab Samples vs. Composite Samples for Estimation of Nutrient Loads

The substantial difference in nutrient concentrations between grab samples and composite samples implies that some error could be introduced by using grab samples in estimates of nutrient loads. To assess the effect of grab samples on nutrient load estimates, the original loading estimates (which used all sampling data, both grab and composite samples) were compared to loading estimates that utilized only the composite samples; events that were un-sampled or were sampled by grab(s) were assigned a characteristic concentration from a table of monthly median concentrations tabulated from composite samples only. In the original loading estimates, the table of monthly medians used to assign concentrations included data from both grabs and composites.

The comparison of the two estimates of mean annual loading by site and by nutrient is shown in Table 3.3. The percentages shown are the difference in the composite-only loading estimate relative to the original estimate. For all sites, mean annual TP and TSS loads were higher when the composite-only subset was used to estimate loading (except for TP loading at St. Paul Park, for which the composite-only estimate was lower by 1.1%). For most sites, the increases in loading estimates were small, ranging from 1% to 9%. The much higher percentages at Trout Brook are likely due to the substantial presence of baseflow and to the reliance on grab samples for characterizing baseflow chemistry, which is appreciably different than that of stormflow and therefore leads to much different loading estimates when the grab samples are excluded. Cl loading estimates were also affected by exclusion of grab samples, though the effect was not uniform across sites, varying from -9% (MS-1) to 7% (Newport).

These results suggest that the inclusion of grab samples tends to lower estimates of TP and TSS loading when using the load calculation method employed in this study. The differences in loading could be due to sample timing; grab samples are often collected during baseflow or during receding limbs of storm events (i.e. after first flush), when concentrations of TP and TSS may be lower due to lower flow rates, while composite (storm) samples often capture the first flush of storms and therefore higher concentrations would be expected. However, in some cases samplers fill well before the storm events have ceased, potentially resulting in an erroneously high concentration if the composite includes the first flush but not the more dilute tail of the event.

Table 3.3. Comparison of original estimates of mean annual nutrient loads with loading estimates produced using a subset of monitoring data consisting of composite samples only (“Comp-Only”). The percent difference of the composite-only loading estimate relative to the original loading estimate is also shown (“% Diff”).

Site	TP, lb			TSS, lb			Cl, lb		
	Original	Comp-Only	% Diff	Original	Comp-Only	% Diff	Original	Comp-Only	% Diff
MS-1	322	336	4.5%	226,953	238,258	5.0%	44,489	40,679	-8.6%
MS-2	592	628	6.0%	67,494	73,697	9.2%	276,017	280,178	1.5%
Central Ravine	206	207	0.8%	275,489	282,101	2.4%	9,200	9,087	-1.2%
Newport	47	51	7.6%	43,514	44,530	2.3%	17,035	18,235	7.0%
St. Paul Park	16	15	-1.1%	21,301	22,133	3.9%	556	539	-3.1%
Trout Brook	667	1,056	58.4%	743,456	1,666,828	124.2%	116,266	109,726	-5.6%
Wilmes Outlet	335	340	1.5%	29,803	30,599	2.7%	398,611	399,257	0.2%

3.3. Recommendations for Future Monitoring Efforts

Based on the summaries in the two previous sections, as well as on the results of the cross-site analyses in Section 2, a few general recommendations could be made to potentially improve monitoring effectiveness or the ability to accurately estimate future loading:

(1) Given the strong seasonality of nutrient loading and concentrations at most sites, an increase in sampling frequency during the shoulder seasons (early spring, late fall) could provide additional insight into nutrient sources or timing of significant loading. The impact of urban vegetation, such as boulevard trees or lawns, may become especially important with maturation of development in some of the watersheds, and pulses of nutrients tied to tree phenology (i.e. spring leaf out, fall leaf drop) could become more substantial.

(2) More frequent snowmelt sampling might also provide insight into the importance of early season nutrient loading (TP and Cl in particular), especially at the more developed sites. Difficulties in early season sampling are acknowledged, in particular at Wilmes Lake where snowmelt may be finished prior to ice-out. In addition, there might not be large inputs of road de-icer (Cl) in the Trout Brook watershed at present, but knowledge of baseline conditions will be important if the watershed becomes more developed in the future.

(3) Given the substantial differences in nutrient chemistry (Table 3.2) between grab and composite samples, as well as the impact of including grab samples in loading estimates (Table 3.3), the use of grab samples should be considered carefully:

(a) In the case of storm events, composite samples should provide a more accurate characterization of nutrient concentration than grab samples, or at the very least, would provide the most conservative (largest) estimates for most sites and constituents (Table 3.3). It is crucial to capture the first flush of storms, as composite samples are more likely to do. However, it is acknowledged that incompletely sampled events can potentially cause over-estimates of nutrient loads.

(b) The use of grab samples for characterizing storm events should probably be avoided, unless used to supplement composite samples for very large events; this appears especially true for estimates of TP and TSS loading at MS-1, MS-2, and Newport, which had the largest differences in nutrient loads between the loading estimates with and without grabs (Table 3.3). These sites have more baseflow and longer residence times than the other storm drain sites (e.g., days or weeks for large events or rainy periods), and thus may have relied more heavily on grab sampling to completely characterize events.

(c) For baseflow, when nutrient loading is less dynamic, grab samples should be sufficient for load estimates. However, more frequent baseflow composites at sites with significant baseflow (Trout Brook) or long residence times (MS-2) would be useful for understanding baseflow dynamics.

References

Eckhardt K (2005). How to construct recursive digital filters for base flow separation, *Hydrol. Process*., 19: 507–515.

Gonzales AL, Nonner J, Heijkers J, and Uhlenbrook S (2009). Comparison of different base flow separation methods in a lowland catchment. *Hydrol. Earth Syst. Sci. Discuss.,* 6: 3483-3515.

Helsel DR and Hirsch RM (2002). Statistical Methods in Water Resources Techniques of Water Resources Investigations, Book 4, Chapter A3. U.S. Geological Survey. 522 pages.

Houston Engineering Inc (HEI) (2011). South Washington Watershed District Watershed Management Plan, Chapter 4: Review of Relevant Data. Amended May 2011. 25 pp.

Sloto RA and Crouse MY (1996). HYSEP: A Computer Program for Stream Hydrograph Separation and Analysis. Water Resources Investigations Report 96-4040. *U.S. Geological Survey*. 54 pages.

World Meteorological Organization (WMO) (2009). Manual on Low-flow Estimation and Prediction. Operational Hydrology Report No. 50 / WMO-No. 1029. Ed: A Gustard and S Demuth. Koblenz, Germany. 138 pp.

Appendix A. Site Summaries of Nutrient Loading and Monitoring Data Analysis

This section includes summaries by site of annual load calculations and statistical characterization of monitoring data by year, tables of regression results from analysis of seasonal and antecedent precipitation and hydrology, and summary plots of seasonal and monthly nutrient loads and concentrations. Site summaries are included primarily as a reference, and include discussion only of important trends and results.

Contents:

A-1 Analysis Summary: MS-1

A-1.1 Seasonal (April – October) Loading by Year

Estimated loads are shown in Table A-1.1 below for the monitoring period (April – October) of each year. Absolute load (ft^3 or lb), loading rate (ft^3/d or lb/d), and yield (ft^3 or lb per in. of precipitation) are shown by year along with baseflow ratio and runoff coefficient. Precipitation totals are for April 1 – October 31 of each year; volumes and loads have been scaled proportional to the amount of rainfall during data gaps.

Table A-1.1. Seasonal (Apr – Oct) volumes and nutrient loads, precipitation depth, antecedent snowfall, and flow characteristics for all monitored years at the MS-1 site. Loads have been scaled by precipitation depth for gaps in the data record.

	Monitoring	Monitoring	Gaps	Volume			Precip	Ant. Snow	Base	Runoff
Year	Start	End	(d)	Load (ft^3)	Rate (ft^3/d)	Yld (ft^3/in)	in	in	Ratio	Coeff
2001	4/1/01 1:00	10/31/01 23:00	0.0	16,400,909	76655	639,474	25.6	66.4	0.29	0.12
2002	4/12/02 12:00	10/31/02 23:00	11.5	20,757,124	97015	692,825	30.0	66.0	0.22	0.13
2003	4/1/03 1:00	10/29/03 11:00	2.5	11,190,278	52301	670,419	16.7	35.0	0.50	0.12
2004	4/1/04 1:00	10/31/04 22:00	0.1	8,735,012	40826	456,083	19.2	66.3	0.40	0.08
2005	4/1/05 1:00	10/4/05 10:00	27.6	19,473,731	91016	764,616	25.5	25.5	0.55	0.14
2006	4/10/06 14:00	10/25/06 20:00	15.7	7,257,674	33921	400,214	18.1	44.4	0.20	0.07
2007	4/1/07 1:00	10/30/07 10:00	1.6	9,847,967	46027	483,087	20.4	35.5	0.18	0.09
2008	4/3/08 15:00	10/31/08 22:00	2.7	8,992,278	42028	509,551	17.6	44.9	0.20	0.09
2009	4/2/09 18:00	10/31/09 1:00	2.7	3,849,814	17993	239,809	16.1	45.0	0.11	0.04
2010	4/1/10 1:00	10/31/10 22:00	0.1	16,711,076	78104	677,226	24.7	40.7	0.27	0.13
2011	4/6/11 17:00	10/31/11 23:00	5.7	20,453,719	95597	1,236,581	16.5	86.6	0.42	0.23
2012	4/1/12 1:00	10/31/12 23:00	0.0	7,674,918	35871	433,379	17.7	22.3	0.22	0.08
2013	4/16/13 14:00	10/31/13 23:00	15.6	18,634,025	87092	958,983	19.4	67.7	0.36	0.18
2014	4/10/14 17:00	10/29/14 14:00	12.1	25,785,709	120517	983,511	26.2	69.8	0.44	0.18

	TP			TSS			Cl		
Year	Load (lb)	Rate (lb/d)	Yld (lb/in)	Load (lb)	Rate (lb/d)	Yld (lb/in)	Load (lb)	Rate (lb/d)	Yld (lb/in)
2001	159	0.742	6.2	54,064	252.7	2108.0	92,519	432.4	3,607
2002	1,079	5.042	36.0	924,087	4319.0	30843.9	43,089	201.4	1,438
2003	388	1.813	23.2	395,049	1846.4	23667.7	25,864	120.9	1,550
2004	201	0.939	10.5	218,815	1022.7	11425.0	18,425	86.1	962
2005	524	2.448	20.6	458,779	2144.2	18013.5	39,086	182.7	1,535
2006	185	0.863	10.2	60,415	282.4	3331.5	25,343	118.4	1,397
2007	142	0.662	6.9	43,546	203.5	2136.1	32,354	151.2	1,587
2008	118	0.553	6.7	35,705	166.9	2023.2	46,936	219.4	2,660
2009	40	0.185	2.5	12,593	58.9	784.4	7,426	34.7	463
2010	231	1.079	9.4	92,629	432.9	3753.9	27,806	130.0	1,127
2011	228	1.064	13.8	97,223	454.4	5877.9	52,001	243.0	3,144
2012	69	0.322	3.9	21,723	101.5	1226.6	24,727	115.6	1,396
2013	653	3.052	33.6	245,578	1147.8	12638.4	83,968	392.5	4,321
2014	490	2.289	18.7	517,138	2417.0	19724.5	103,294	482.8	3,940

A-1.2 Year-to-year Variability in Nutrient Concentrations

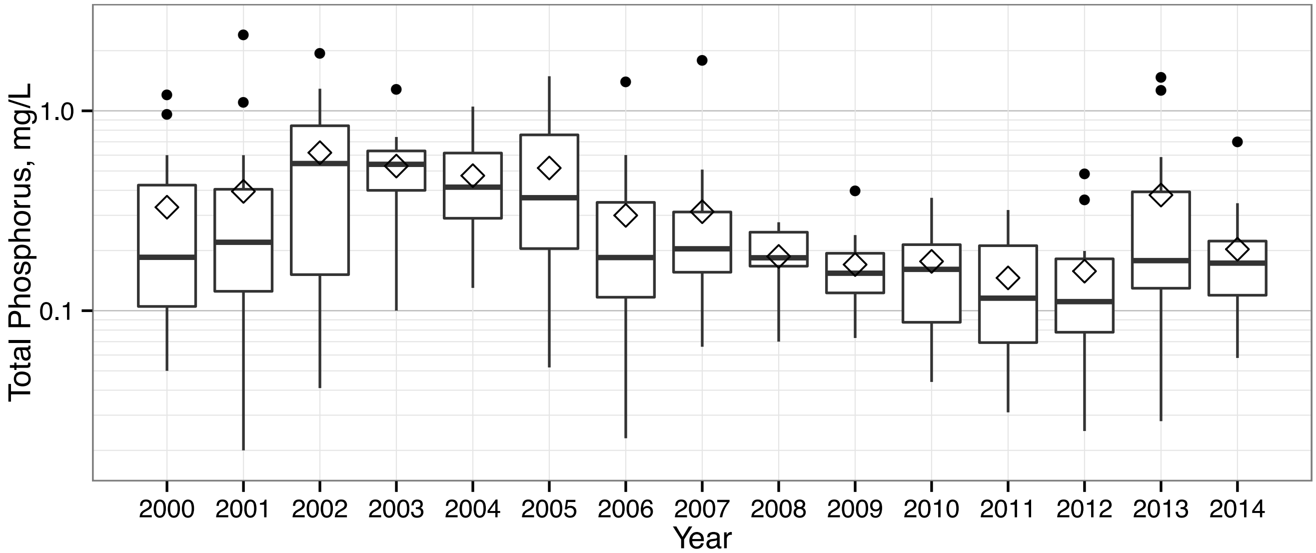
TP, TSS, and Cl concentration data are summarized by year in Figure A-1.1, and by year and flow regime in the table below (Table A-1.2).

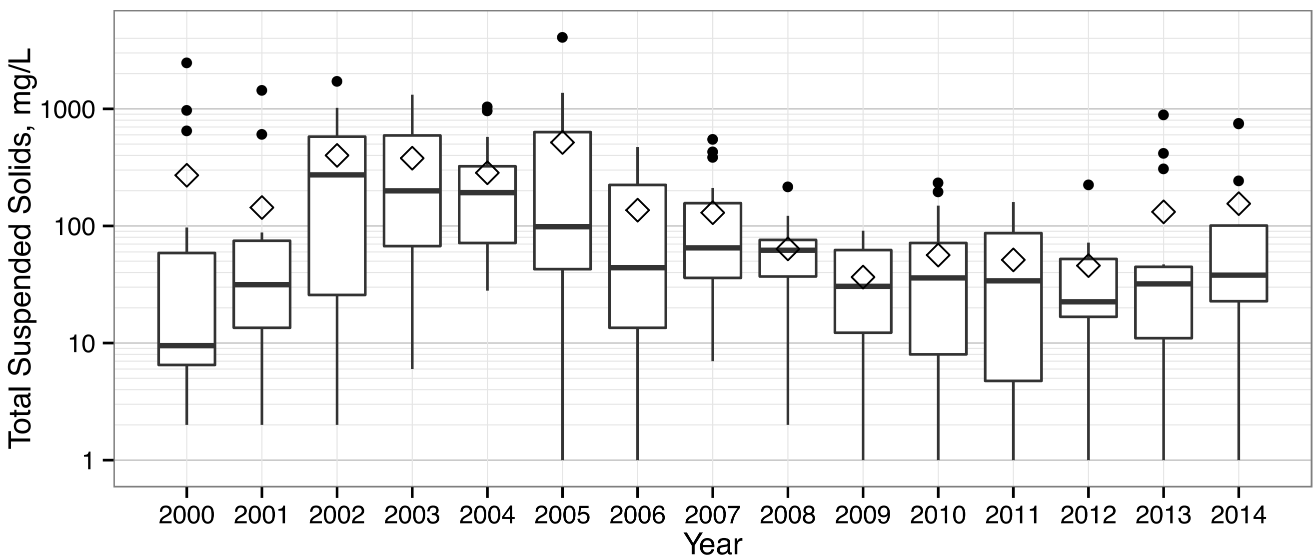
- Both TP and TSS show peaks in concentration during wet years around the beginning of the record (2002 and 2003), and the decreases in TP and TSS concentration from year to year are significant ($p < 0.001$ for TP, $p < 0.05$ for TSS; Table A-1.4);
- Cl concentration increased slightly over time, and is significant at $p < 0.05$;
- Taken together, these results may indicate the effect of increased watershed development and wet years early in the record (e.g. disturbed soils) followed by establishment of vegetation and increased impervious area (higher road salt inputs, less erosion) as the pace of development slowed.

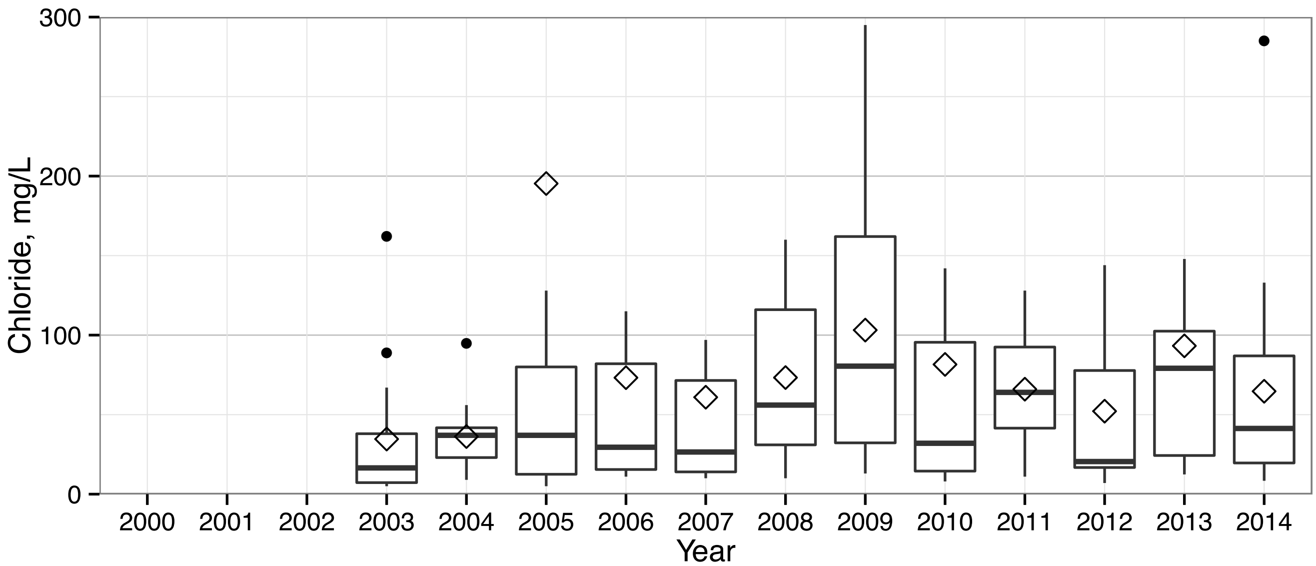
Table A-1.2. Statistical summary of TP, TSS, and Cl concentration data at MS-1.

	Total Phosphorus Concentration (mg/L)							Total Suspended Solids Concentration (mg/L)							Chloride Concentration (mg/L)						
Year	**n**	**Min**	**1st Qtile**	**Median**	**3rd Qtile**	**Max**	**Mean**	**n**	**Min**	**1st Qtile**	**Median**	**3rd Qtile**	**Max**	**Mean**	**n**	**Min**	**1st Qtile**	**Median**	**3rd Qtile**	**Max**	**Mean**
2000	*16*	0.050	0.100	0.185	0.430	1.200	0.329	*16*	2	6	10	72	2460	271	*0*	NA	NA	NA	NA	NA	NA
2001	*19*	0.020	0.125	0.220	0.405	2.400	0.395	*18*	2	13	32	83	1440	144	*0*	NA	NA	NA	NA	NA	NA
2002	*16*	0.041	0.137	0.545	0.918	1.940	0.617	*16*	2	24	273	586	1720	400	*0*	NA	NA	NA	NA	NA	NA
2003	*14*	0.100	0.400	0.540	0.640	1.280	0.529	*14*	6	54	200	636	1320	379	*14*	5	7	17	42	162	35
2004	*18*	0.130	0.290	0.415	0.630	1.050	0.474	*18*	28	60	193	335	1040	284	*18*	9	22	37	42	95	36
2005	*16*	0.052	0.200	0.368	0.801	1.490	0.518	*16*	1	36	99	658	4100	516	*15*	5	13	37	80	2278	195
2006	*16*	0.023	0.116	0.185	0.363	1.400	0.300	*16*	1	12	44	248	472	136	*16*	11	15	30	82	527	73
2007	*20*	0.066	0.155	0.204	0.338	1.790	0.313	*20*	7	34	65	162	547	130	*20*	10	14	27	73	508	61
2008	*13*	0.070	0.167	0.184	0.247	0.277	0.187	*13*	2	37	62	76	215	64	*13*	10	31	56	116	160	73
2009	*12*	0.073	0.121	0.154	0.195	0.398	0.170	*12*	1	12	31	63	91	37	*12*	13	31	81	162	295	103
2010	*19*	0.044	0.088	0.161	0.214	0.367	0.176	*19*	1	8	36	72	233	56	*19*	8	15	32	96	615	82
2011	*14*	0.031	0.068	0.116	0.213	0.319	0.146	*14*	1	3	34	97	160	51	*14*	11	41	64	94	128	66
2012	*12*	0.025	0.074	0.111	0.188	0.485	0.158	*12*	1	17	23	58	224	46	*12*	7	16	21	84	144	52
2013	*14*	0.028	0.125	0.178	0.407	1.470	0.379	*14*	1	10	32	47	888	132	*14*	12	22	79	106	422	93
2014	*15*	0.058	0.120	0.173	0.223	0.700	0.203	*14*	1	22	38	103	750	155	*15*	8	20	41	87	285	65
snowmelt	*24*	0.098	0.225	0.340	0.484	0.715	0.369	*24*	3	14	40	76	547	83	*17*	40	88	128	162	2278	287
baseflow	*34*	0.020	0.052	0.073	0.100	0.350	0.092	*34*	1	1	3	6	76	8	*30*	11	39	92	115	615	103
stormflow	*160*	0.040	0.149	0.232	0.435	2.400	0.380	*158*	2	33	78	243	4100	239	*135*	5	14	24	54	508	45
all data	***234***	**0.020**	**0.120**	**0.198**	**0.400**	**2.400**	**0.334**	***232***	**1**	**15**	**47**	**167**	**4100**	**191**	***182***	**5**	**16**	**39**	**88**	**2278**	**77**

Figure A-1.1. Boxplots of nutrient concentrations of all sampled **events** at MS-1, by year. Diamonds are mean concentrations and dots are outliers. Note log scale on vertical axes for TP and TSS.







A-1.3 Year-to-year Variability in Seasonal (April - October) Loading

Linear regression was used to investigate general patterns between the seasonal loading and precipitation parameters from Table A-1.1 above; results are shown in Table A-1.3.

- Volume was a significant predictor for the nutrient loads, suggesting hydrologic control of nutrient loading, though precipitation was a significant predictor only of TP and TSS load rates, potentially evidence of large storage/infiltration capacity of the watershed (supported also by the generally low runoff coefficients);
- Load rate and yield of water volume were positively and significantly correlated with antecedent snowfall (and with baseflow ratio), suggesting that snowmelt may be crucial for setting initial (Spring) water levels in surface water or shallow groundwater (if present) in the watershed;
- Chloride yield was significantly related to antecedent snowfall, which may indicate that salt application in the watershed is roughly proportional to snowfall and that Cl has a relatively short residence time in surface water;
- TP loading was strongly related to TSS loading but not to Cl, suggesting the importance of particulate forms of P;
- Loading rates of water and nutrients generally decreased year-to-year over the study period, though none of the relationships were significant; water yield (runoff volume per inch of rainfall) increased slightly over the period, perhaps the result of increased impervious area.

Table A-1.3. Summary of Pearson *r* values from regression of annual flow and nutrient concentrations vs. several precipitation and flow parameters. * indicates significance at $p < 0.05$, ** indicates significance at $p < 0.001$.

Parameter	**Year**	**Total Volume**		**Precip**	**Ant Snow**	**Baseflow** Ratio	**TP**		**TSS**		**Cl**	
		Rate	*Yield*				*Load Rate*	*Yield*	*Load Rate*	*Yield*	*Load Rate*	*Yield*
Vol, Rate	-0.07		0.86**	0.64*	0.56*	0.54*	0.66*	0.61*	0.61*	0.56*	0.75*	0.64*
Vol, Yield	0.21	0.86**		0.20	0.60*	0.64*	0.45	0.55*	0.34	0.39	0.64*	0.71*
Precip	-0.49	0.64*	0.20		0.26	0.02	0.56*	0.31	0.59*	0.42	0.47	0.18
Ant Snow	-0.05	0.56*	0.60*	0.26		0.16	0.32	0.31	0.23	0.19	0.57*	0.59*
BF Ratio	-0.19	0.54*	0.64*	0.02	0.16		0.30	0.45	0.37	0.55*	0.30	0.32
TP Load Rate	-0.27	0.66*	0.45	0.56*	0.32	0.30		0.94**	0.93**	0.88**	0.33	0.23
TP Yield	-0.15	0.61*	0.55*	0.31	0.31	0.45	0.94**		0.82**	0.86**	0.33	0.32
TSS Load Rate	-0.48	0.61*	0.34	0.59*	0.23	0.37	0.93**	0.82**		0.96**	0.24	0.06
TSS Yield	-0.47	0.56*	0.39	0.42	0.19	0.55*	0.88**	0.86**	0.96**		0.20	0.07
Cl Load Rate	-0.05	0.75*	0.64*	0.47	0.57*	0.30	0.33	0.33	0.24	0.20		0.93**
Cl Yield	0.19	0.64*	0.71*	0.18	0.59*	0.32	0.23	0.32	0.06	0.07	0.93**	

A-1.4 Seasonal and Monthly Variability in Event Nutrient Loads and Concentrations

Monthly event loading rates (cfs or lb/d) of water, TP, TSS, and Cl are summarized in the box-plots below (Figure A-1.2). Several general patterns are apparent in the loading rate data:

- Loading of water, TP, and TSS generally peaked in early summer (June) and decreased through Fall, suggesting hydrologic control for loading rates and the potential importance of erosional or sediment sources for phosphorus;
- Higher and more variable flow rates in early summer may be evidence of larger or more intense storms occurring while water retention is relatively low in the watershed (e.g. from high water levels in lakes and ponds from spring rain and snowmelt, or from relatively low evapotranspiration rates by aquatic and terrestrial vegetation);
- Cl loading rates decrease throughout the season, likely indicating a flushing of winter road de-icer applications.

Event concentration data are summarized by month in Figure A-1.3 and by season in Figure A-1.4. These are intended to illustrate the strong seasonality of the nutrient data. Several results are worth noting:

- TP and TSS concentrations peak in early summer (June), and in the case of TSS this summer concentration is significantly higher than in spring and fall; these June peaks also coincide with the highest flow rates and therefore of loading rates;
- Cl concentrations were significantly different across seasons, and the decrease of Cl from spring to fall was significant (r = -0.48; Table A-1.4);
- While data are somewhat limited in the early season, TP concentrations were nearly as high in Feb and March as in mid-summer; this trend may be evidence of export in snowmelt and early spring rains of P from over-winter decomposition of vegetation in lakes and on lawns and streets;
- Baseflow ratio (not shown) was significantly higher in spring than in the other seasons.

Figure A-1.2. Boxplots of flow and nutrient **loading rates** of all sampled **events** at MS-1, by month. Diamonds are mean concentrations and dots are outliers. Note log scale on the vertical axes.

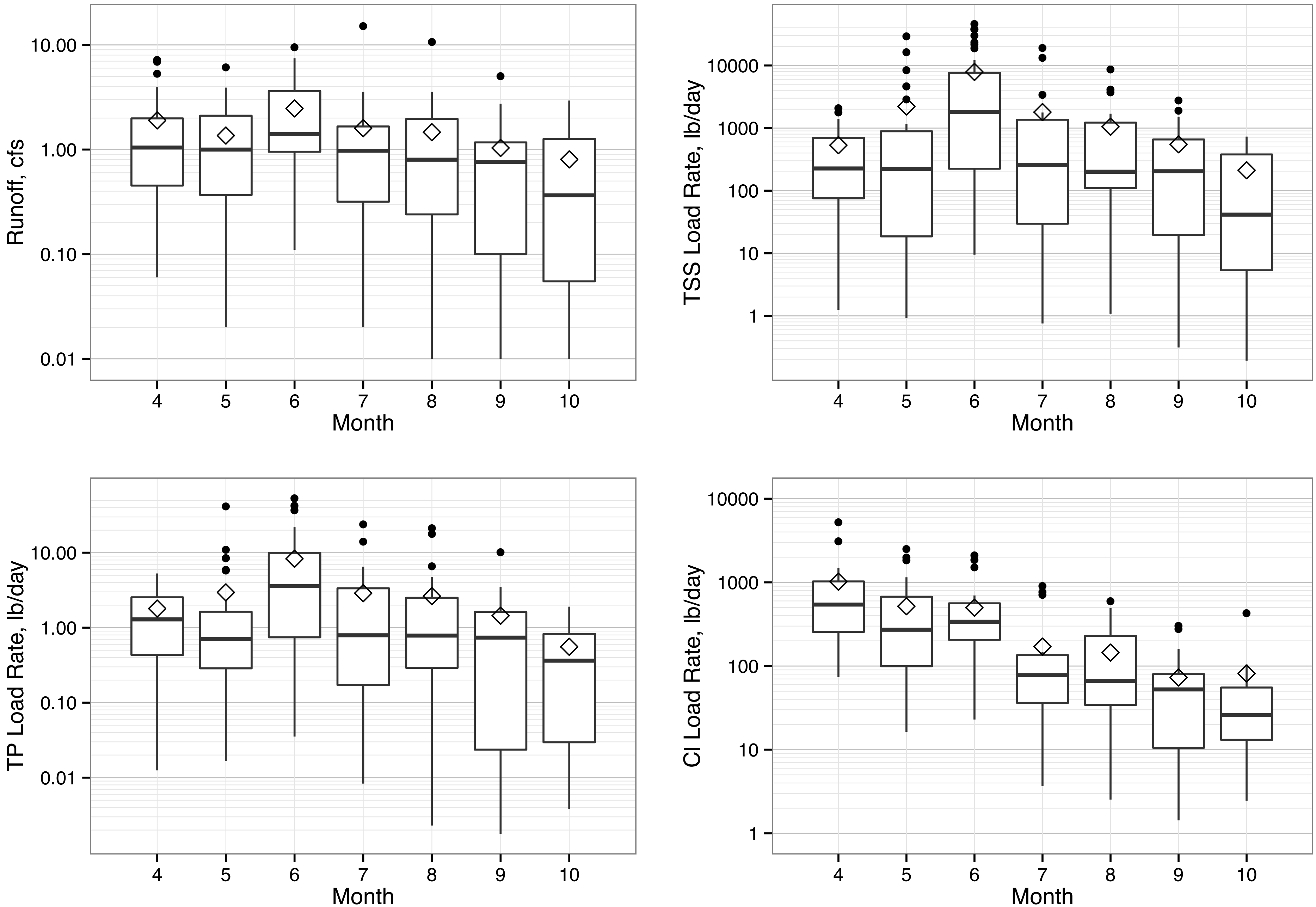


Figure A-1.3. Boxplots of monthly nutrient **concentrations** of all sampled **events** at MS-1. Diamonds are mean concentrations and dots are outliers. Note log scale on the vertical axes.

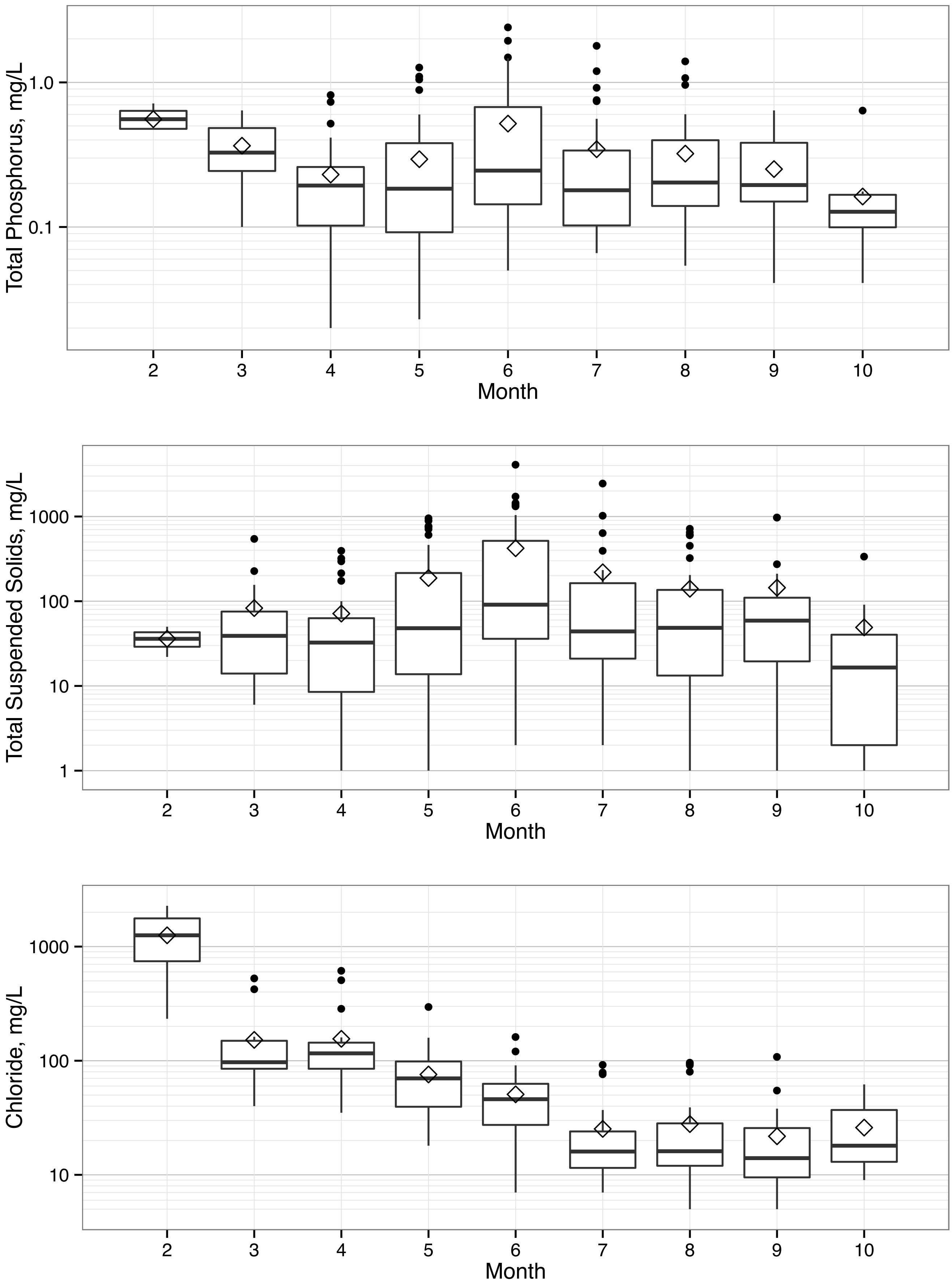
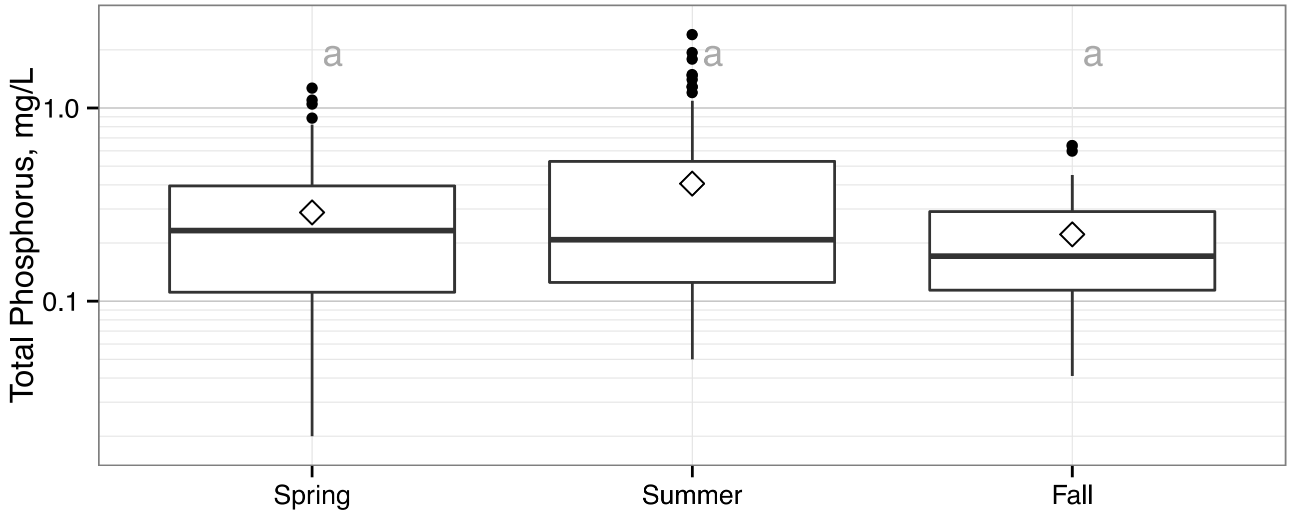
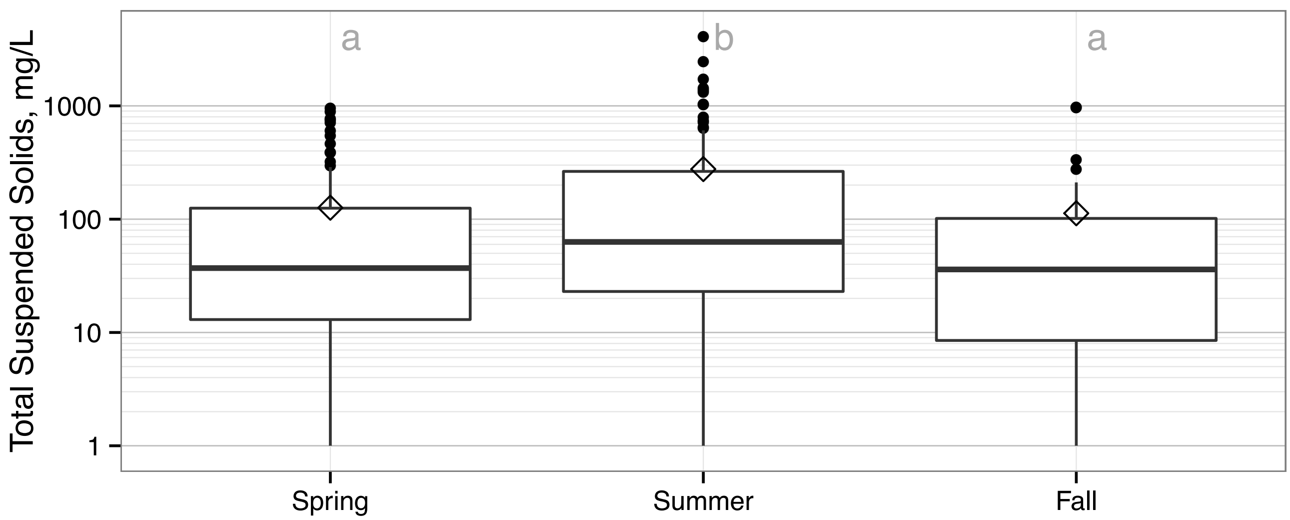
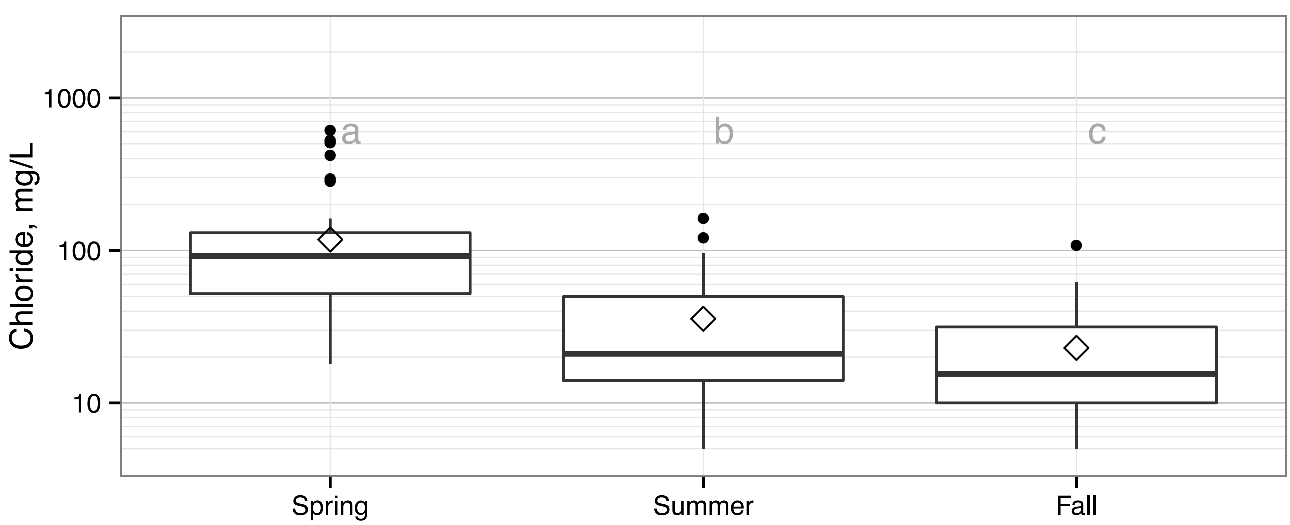


Figure A-1.4. Boxplots of seasonal nutrient **concentrations** of all sampled **events** at MS-1. Diamonds are mean concentrations and dots are outliers; seasons with different letters are significantly different at $p < 0.05$ by Mann-Whitney-Wilcoxon rank sum test. Note log scale on vertical axes.







A-1.5 Influence of Antecedent Precipitation and Flow on Event Nutrient Loads and Concentrations

Simple linear regression was used to investigate the effect of several precipitation and flow parameters on observed volumes and observed nutrient loads and concentrations, as well as to illustrate any relationships between the parameters themselves. Results considering concentration data only are shown in Table A-1.4, while results for event loading data are shown in Table A-1.5. Note that the concentration data set has more samples than the loading data set because some samples were collected when flow was not monitored. Pearson *r* are shown in the tables along with significance of the regressions: * indicates significance at $p < 0.05$, ** indicates significance at $p < 0.001$.

Table A-1.4. Results of regression of event flow and nutrient concentrations vs. several temporal and antecedent precipitation and flow parameters.

Param	Year	Month	Flow Rate	BF Ratio	Antecedent Precip			Ant. Stage		TP	TSS	Cl
					28 Days	*14 Days*	*7 Days*	*6 Hr*	*7 Days*	Conc	Conc	Conc
Flow Rate	0.18 *	0.03		0.07	0.21 *	0.10	0.15 *	0.27 **	0.12	0.35 **	0.23 *	-0.18 *
BF Ratio	0.00	-0.23 *	0.07		0.40 **	0.45 **	0.33 **	0.37 **	0.63 **	0.03	0.07	0.03
TP Conc	-0.28 **	-0.05	0.35 **	0.03	-0.01	0.00	0.00	-0.06	-0.10		0.66 **	-0.20 *
TSS Conc	-0.22 *	-0.04	0.23 *	0.07	0.11	0.08	0.06	-0.05	-0.03	0.66 **		-0.16 *
Cl Conc	0.16 *	-0.48 **	-0.18 *	0.03	-0.11	-0.11	-0.08	-0.02	0.09	-0.20 *	-0.16 *	

Table A-1.5. Results of regression of event flow and nutrient loading vs. antecedent precipitation and flow parameters.

Param.	Flow	Volume			BF	Precip		Antecedent Precip			Ant. Stage	
	Rate	Total	Baseflow	Storm	Ratio	Depth	Intensity	*28 Days*	*14 Days*	*7 Days*	*6 Hr*	*7 Days*
Flow Rate		0.84**	0.72**	0.83**	0.26**	0.69**	0.20*	0.29**	0.27**	0.32**	0.55**	0.34**
Vol, Total	0.84**		0.92**	0.95**	0.35**	0.76**	0.05	0.37**	0.36**	0.39**	0.56**	0.44**
Vol, Base	0.72**	0.92**		0.75**	0.52**	0.60**	-0.04	0.38**	0.43**	0.44**	0.58**	0.57**
Vol, Storm	0.83**	0.95**	0.75**		0.16*	0.80**	0.11	0.33**	0.27**	0.33**	0.50**	0.30**
BF Ratio	0.26**	0.35**	0.52**	0.16*		0.10	-0.21*	0.43**	0.47**	0.35**	0.40**	0.64**
TP Conc	0.24*	0.29**	0.18*	0.34**	0.04	0.41**	0.23*	0.00	-0.01	-0.02	-0.02	-0.08
TP Load	0.46**	0.70**	0.56**	0.72**	0.12	0.52**	0.06	0.18*	0.11	0.11	0.13	0.14
TSS Conc	0.21*	0.26**	0.20*	0.27**	0.08	0.29**	0.11	0.12	0.06	0.02	-0.01	0.00
TSS Load	0.38**	0.63**	0.51**	0.64**	0.13	0.45**	0.05	0.22*	0.14	0.14	0.11	0.15*
Cl Conc	-0.13	-0.08	-0.02	-0.12	0.05	-0.25*	-0.30**	-0.09	-0.10	-0.08	-0.01	0.08
Cl Load	0.50**	0.70**	0.78**	0.56**	0.42**	0.49**	-0.11	0.25*	0.36**	0.34**	0.54**	0.50**

Several results of the regression analyses are worth noting:

- TP (and to a lesser extent TSS) was significantly and positively correlated with flow rate and with volumes;
- Cl was negatively and significantly correlated with month, suggesting dilution and flushing of road de-icer application during winter months;
- Flow rate was strongly correlated with event precipitation, antecedent precipitation and antecedent stage, illustrating the logical linkage between precipitation and hydrology at this watershed;
- As was the case with the annual loads, event loading was strongly controlled by hydrology, with TP, TSS, and Cl loads well-correlated with flow rate and total, storm, and baseflow volumes;
- Rainfall intensity was not well-correlated with many parameters but was significant with increased TP concentration and decreased Cl concentration.

A-2 Analysis Summary: MS-2

A-2.1 Seasonal (April – October) Loading by Year

Estimated loads are shown in Table A-2.1 below for the monitoring period (April – October) of each year. Absolute load (ft^3 or lb), loading rate (ft^3/d or lb/d), and yield (ft^3 or lb per in. of precipitation) are shown by year along with baseflow ratio and runoff coefficient. Precipitation totals are for April 1 – October 31 of each year; volumes and loads have been scaled proportional to the amount of rainfall during data gaps. Note that 2005, 2007 and 2011 involved extensive reconstruction of intervals (10/4 to 10/31 in 2005, 9/26 to 10/31 in 2007, and 8/5 to 10/31 in 2011).

Table A-2.1. Seasonal (Apr – Oct) volumes and nutrient loads, precipitation depth, antecedent snowfall, and flow characteristics for all monitored years at the MS-2 site. Loads have been scaled by precipitation depth for gaps in the data record.

Year	Monitoring Start	Monitoring End	Gaps (d)	Volume Load (ft^3)	Volume Rate (ft^3/d)	Volume Yld (ft^3/in)	Precip in	Ant. Snow in	Base Ratio	Runoff Coeff
2001	4/1/01 1:00	11/6/01 15:30	0.0	28,429,495	132874	1,104,630	25.7	66.4	0.74	0.03
2002	4/13/02 17:15	11/2/02 5:15	11.5	263,893,810	1233389	9,382,045	28.1	66.0	0.65	0.26
2003	4/1/03 1:00	10/29/03 10:00	2.6	64,922,278	303434	3,938,415	16.5	35.0	0.69	0.11
2005	4/5/05 15:15	10/4/05 18:15	31.8	47,367,835	221388	1,791,879	26.4	25.5	0.49	0.05
2006	4/5/06 11:15	10/25/06 13:15	10.9	31,829,294	148764	1,767,534	18.0	44.4	0.49	0.05
2007	4/11/07 15:45	10/31/07 23:45	45.6	6,727,682	31444	325,922	20.6	35.5	0.33	0.01
2008	4/8/08 16:00	11/5/08 15:00	3.0	37,952,522	177383	2,266,208	16.7	44.9	0.44	0.06
2009	4/8/09 12:30	11/3/09 13:30	4.9	25,351,557	118488	1,404,842	18.0	45.0	0.40	0.04
2010	4/1/10 1:00	11/1/10 10:30	0.0	83,191,181	388820	3,285,519	25.3	40.7	0.54	0.09
2011	4/8/11 10:30	10/31/11 23:00	94.4	91,926,673	429648	4,797,905	19.2	86.6	0.60	0.13
2012	4/4/12 15:30	11/6/12 12:00	0.0	32,481,348	151812	1,796,250	18.1	22.3	0.50	0.05
2013	4/9/13 16:15	10/22/13 8:15	18.3	50,156,438	234422	2,518,861	19.9	67.7	0.56	0.07
2014	4/9/14 13:00	10/29/14 13:00	11.0	112,061,264	523753	4,196,087	26.7	68.7	0.69	0.11

Year	TP Load (lb)	TP Rate (lb/d)	TP Yld (lb/in)	TSS Load (lb)	TSS Rate (lb/d)	TSS Yld (lb/in)	Cl Load (lb)	Cl Rate (lb/d)	Cl Yld (lb/in)
2001	239	1.115	9.3	28,752	134.4	1117.2	126,838	592.8	4,928
2002	2,492	11.649	88.6	264,928	1238.2	9418.8	938,712	4387.4	33,373
2003	618	2.887	37.5	68,442	319.9	4152.0	183,991	859.9	11,162
2005	558	2.607	21.1	120,220	561.9	4547.8	177,321	828.8	6,708
2006	305	1.425	16.9	23,563	110.1	1308.5	124,485	581.8	6,913
2007	72	0.335	3.5	5,481	25.6	265.5	17,859	83.5	865
2008	289	1.352	17.3	30,163	141.0	1801.1	203,505	951.1	12,152
2009	282	1.319	15.6	33,416	156.2	1851.7	99,590	465.5	5,519
2010	696	3.254	27.5	86,541	404.5	3417.8	274,735	1284.1	10,850
2011	766	3.580	40.0	86,091	402.4	4493.3	438,108	2047.6	22,866
2012	243	1.137	13.5	32,204	150.5	1780.9	135,327	632.5	7,484
2013	424	1.981	21.3	35,756	167.1	1795.7	290,827	1359.3	14,605
2014	717	3.353	26.9	61,870	289.2	2316.7	576,925	2696.4	21,603

A-2.2 Year-to-year Variability in Nutrient Concentrations

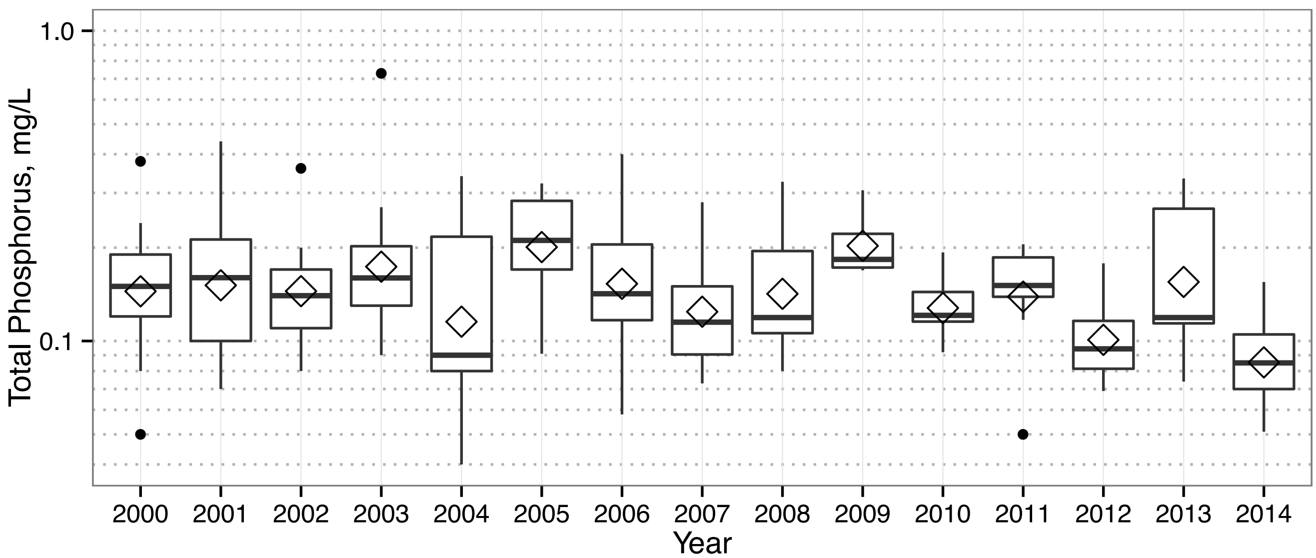
TP, TSS, and Cl concentration data are summarized by year in Figure A-2.1, and by year and flow regime in the tables below (Table A-2.2).

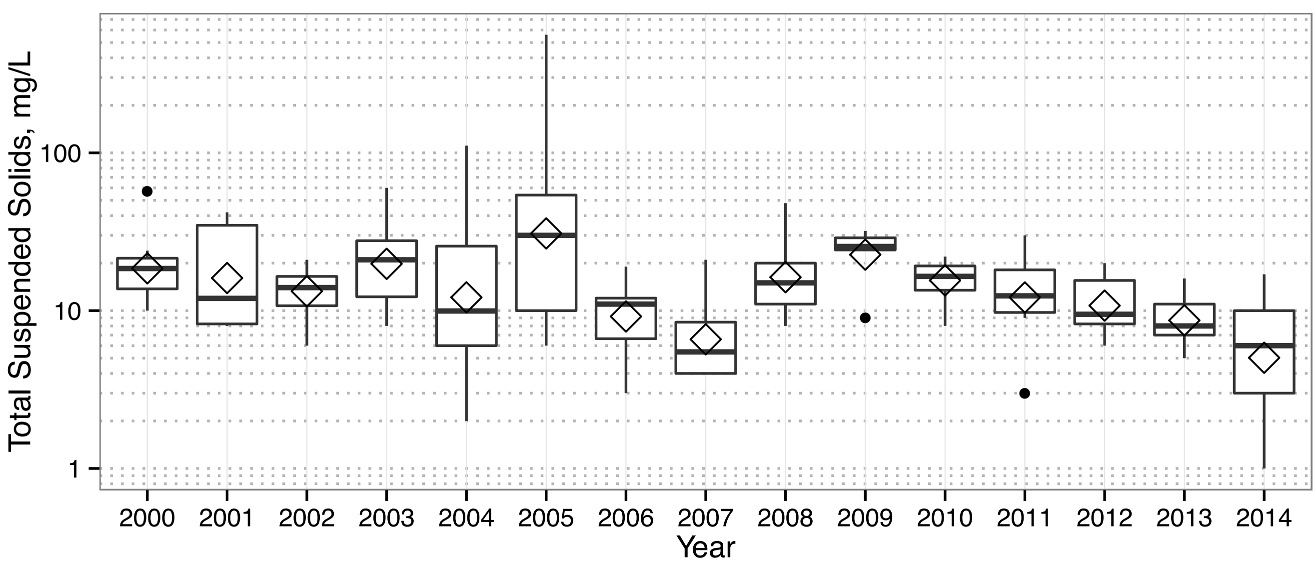
- Both TP and TSS show peaks in concentration around 2004 and 2005 with decreasing trends in recent years, though none are significant at $p < 0.05$ over the length of the record (Table A-2.3);
- Cl concentration increased substantially from year to year ($r = 0.50$), and was significant at $p < 0.001$;
- Taken together, these results may indicate the effect of increased watershed development (e.g. disturbed soils) and wet years early in the record, followed by establishment of vegetation and increased impervious area (higher road salt inputs, less erosion) as the pace of development slowed or BMPs were implemented.

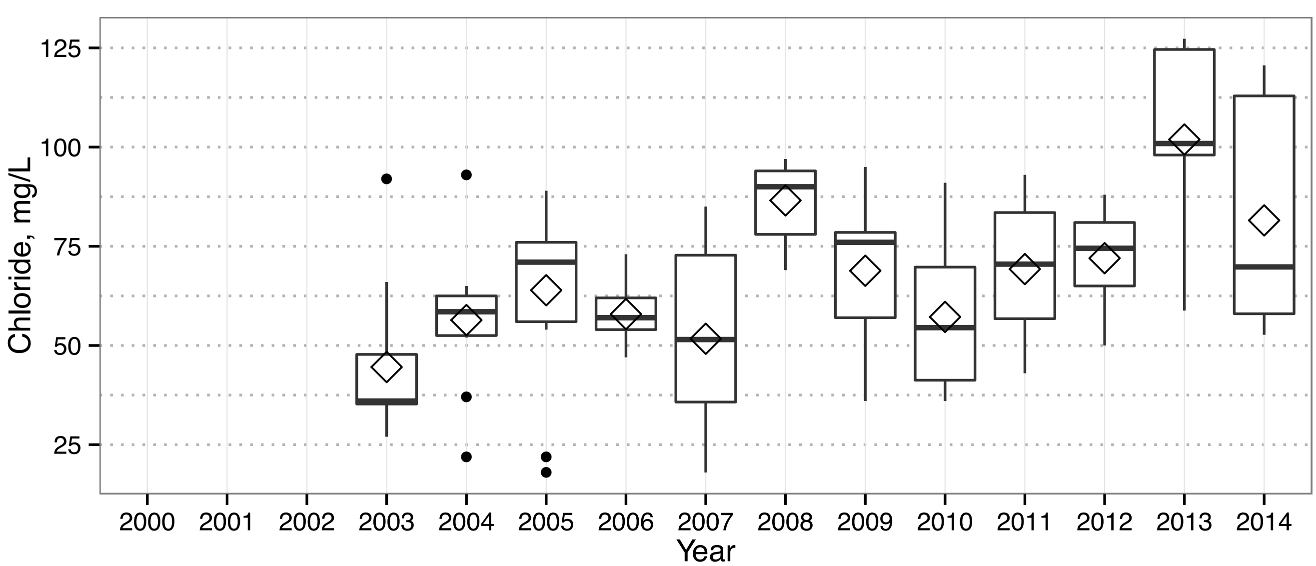
Table A-2.2. Statistical summary of TP, TSS, and Cl concentration data at MS-2.

	Total Phosphorus Concentration (mg/L)							Total Suspended Solids Concentration (mg/L)							Chloride Concentration (mg/L)						
Year	**n**	**Min**	**1st Qtile**	**Median**	**3rd Qtile**	**Max**	**Mean**	**n**	**Min**	**1st Qtile**	**Median**	**3rd Qtile**	**Max**	**Mean**	**n**	**Min**	**1st Qtile**	**Median**	**3rd Qtile**	**Max**	**Mean**
2000	*17*	0.050	0.120	0.150	0.190	0.380	0.159	*16*	10	14	19	22	57	20	*NA*	NA	NA	NA	NA	NA	NA
2001	*20*	0.070	0.100	0.160	0.215	0.440	0.176	*18*	8	8	12	35	42	20	*NA*	NA	NA	NA	NA	NA	NA
2002	*17*	0.080	0.110	0.140	0.170	0.360	0.154	*16*	6	11	14	17	21	14	*NA*	NA	NA	NA	NA	NA	NA
2003	*14*	0.090	0.130	0.160	0.210	0.730	0.203	*14*	8	12	21	28	60	23	*14*	27	35	36	49	92	45
2004	*10*	0.040	0.080	0.090	0.240	0.340	0.148	*10*	2	6	10	33	111	23	*10*	22	52	59	63	93	56
2005	*13*	0.091	0.170	0.211	0.283	0.322	0.215	*13*	6	10	30	54	560	79	*13*	18	56	71	76	89	64
2006	*11*	0.058	0.118	0.142	0.205	0.400	0.176	*10*	3	6	11	12	19	10	*11*	47	54	57	62	73	58
2007	*10*	0.073	0.090	0.115	0.159	0.280	0.136	*10*	4	4	6	9	21	8	*10*	18	35	52	73	85	52
2008	*9*	0.080	0.106	0.119	0.195	0.326	0.158	*9*	8	11	15	20	48	20	*9*	69	78	90	94	97	87
2009	*6*	0.169	0.172	0.184	0.232	0.306	0.208	*6*	9	24	26	30	32	24	*6*	36	51	76	79	95	69
2010	*10*	0.092	0.115	0.121	0.147	0.193	0.131	*10*	8	13	17	20	22	16	*10*	36	41	55	71	91	57
2011	*8*	0.050	0.132	0.151	0.186	0.205	0.149	*8*	3	10	13	20	30	15	*8*	43	54	71	85	93	69
2012	*6*	0.069	0.079	0.095	0.122	0.178	0.106	*6*	6	8	10	18	20	12	*6*	50	63	75	82	88	72
2013	*5*	0.074	0.114	0.119	0.267	0.334	0.182	*5*	5	7	8	11	16	9	*5*	59	98	101	125	127	102
2014	*9*	0.051	0.070	0.085	0.105	0.155	0.090	*9*	1	3	6	10	17	7	*9*	53	58	70	113	121	82
snowmelt	*12*	0.110	0.184	0.307	0.390	0.730	0.313	*12*	6	7	8	10	14	9	*6*	48	59	69	92	93	72
baseflow	*35*	0.050	0.090	0.130	0.175	0.400	0.151	*35*	3	9	17	27	59	20	*27*	22	45	60	76	125	62
stormflow	*95*	0.040	0.110	0.140	0.193	0.326	0.151	*91*	1	9	13	22	560	25	*72*	18	48	62	78	127	64
all data	***165***	**0.040**	**0.104**	**0.140**	**0.196**	**0.730**	**0.162**	***160***	**1**	**9**	**14**	**21**	**560**	**22**	***111***	**18**	**49**	**63**	**78**	**127**	**65**

Figure A-2.1. Boxplots of nutrient concentrations of all sampled **events** at MS-2, by year. Diamonds are mean concentrations and dots are outliers. Note log scale on vertical axes for TP and TSS.







A-2.3 Year-to-year Variability in Seasonal (April - October) Loading

Linear regression was used to investigate general patterns between the seasonal loading and precipitation parameters from Table A-2.1 above; results are shown in Table A-2.3.

- Volume was logically a significant predictor for the nutrient loads, but precipitation was not well correlated with any parameters except volume loading rate and Cl loading rate; the lack of a strong link between precipitation and runoff volume at the seasonal scale could potentially be evidence of large storage/infiltration capacity of the watershed (supported also by the generally low runoff coefficients);
- Chloride yield was significantly related to antecedent snowfall, which may indicate that salt application in the watershed is roughly proportional to snowfall and that it has a relatively short residence time in surface water;
- TP loading was strongly related to loading of TSS, Cl, and volume;
- Loading of water and TP/TSS generally decreased year-to-year over the study period, though none of the relationships were significant;
- Baseflow ratio was a poor predictor for water or nutrients, but all were positively correlated with baseflow ratio (i.e. greater loading in years when baseflow comprises more of the total flow); an explanation for this trend is not apparent but may indicate that baseflow dominance is generally characteristic of wetter years or higher flow (and therefore of greater loading).

Table A-2.3. Summary of Pearson *r* values from regression of annual flow and nutrient concentrations vs. several precipitation and flow parameters. * indicates significance at $p < 0.05$, ** for significance at $p < 0.001$.

Parameter	Year	Total Volume		Precip	Ant	Baseflow	TP		TSS		Cl	
		Rate	*Yield*		Snow	Ratio	*Load Rate*	*Yield*	*Load Rate*	*Yield*	*Load Rate*	*Yield*
Vol, Rate	-0.17		0.98**	0.59*	0.45	0.48	0.99**	0.96**	0.93**	0.89**	0.97**	0.92**
Vol, Yield	-0.15	0.98**		0.44	0.47	0.52	0.96**	0.98**	0.90**	0.91**	0.95**	0.95**
BF Ratio	-0.23	0.48	0.52	0.50	0.53		0.42	0.46	0.37	0.40	0.52	0.52
TP Load Rate	-0.28	0.99**	0.96**	0.54	0.38	0.42		0.98**	0.97**	0.94**	0.92**	0.87**
TP Yield	-0.27	0.96**	0.98**	0.40	0.39	0.46	0.98**		0.94**	0.95**	0.89**	0.89**
TSS Load Rate	-0.35	0.93**	0.90**	0.54	0.25	0.37	0.97**	0.94**		0.98**	0.84**	0.78*
TSS Yield	-0.34	0.89**	0.91**	0.40	0.23	0.40	0.94**	0.95**	0.98**		0.80**	0.79*
Cl Load Rate	0.00	0.97**	0.95**	0.59*	0.59*	0.52	0.92**	0.89**	0.84**	0.80**		0.97**
Cl Yield	0.08	0.92**	0.95**	0.42	0.65*	0.52	0.87**	0.89**	0.78*	0.79*	0.97**	

A-2.4 Seasonal and Monthly Variability in Event Nutrient Loads and Concentrations

Monthly event loading rates (cfs or lb/d) of water, TP, TSS, and Cl are summarized in the box-plots below (Figure A-2.2). Event concentration data are summarized by month in Figure A-2.3 and by season in Figure A-2.4. Several features of these data are worth noting:

- Flow, TP, and TSS loading were more variable in the late spring and summer months, likely the effect of more intense storms occurring while water retention was relatively low in the watershed (e.g. from high water levels in lakes and ponds from spring rain and snowmelt, or from relatively low early-season evapotranspiration rates by aquatic and terrestrial vegetation);
- Mean TP and TSS loading increased from September to October, and both TP and TSS concentrations increased in August and September (and were significantly higher in Summer/Fall than in Spring); these patterns may be the result of autumn leaf litter inputs or decomposition of senescing vegetation in lakes and ponds, with late season storms potentially eroding dormant lawns or re-suspending sediment trapped by macrophytes in shallow surface water during summer;
- While early-season data may be limited, TP concentrations were highest in March, providing evidence of potential export in snowmelt and early spring rains of P from over-winter decomposition of vegetation in lakes and on lawns and streets;
- Cl loading rates (and variability) decreased throughout the season, likely indicating a flushing of winter road de-icer appliations; Cl concentration, which also decreased over the year, was significantly different among seasons.

Figure A-2.2. Boxplots of flow and nutrient **loading rates** of all sampled **events** at MS-2, by month. Diamonds are mean concentrations and dots are outliers.

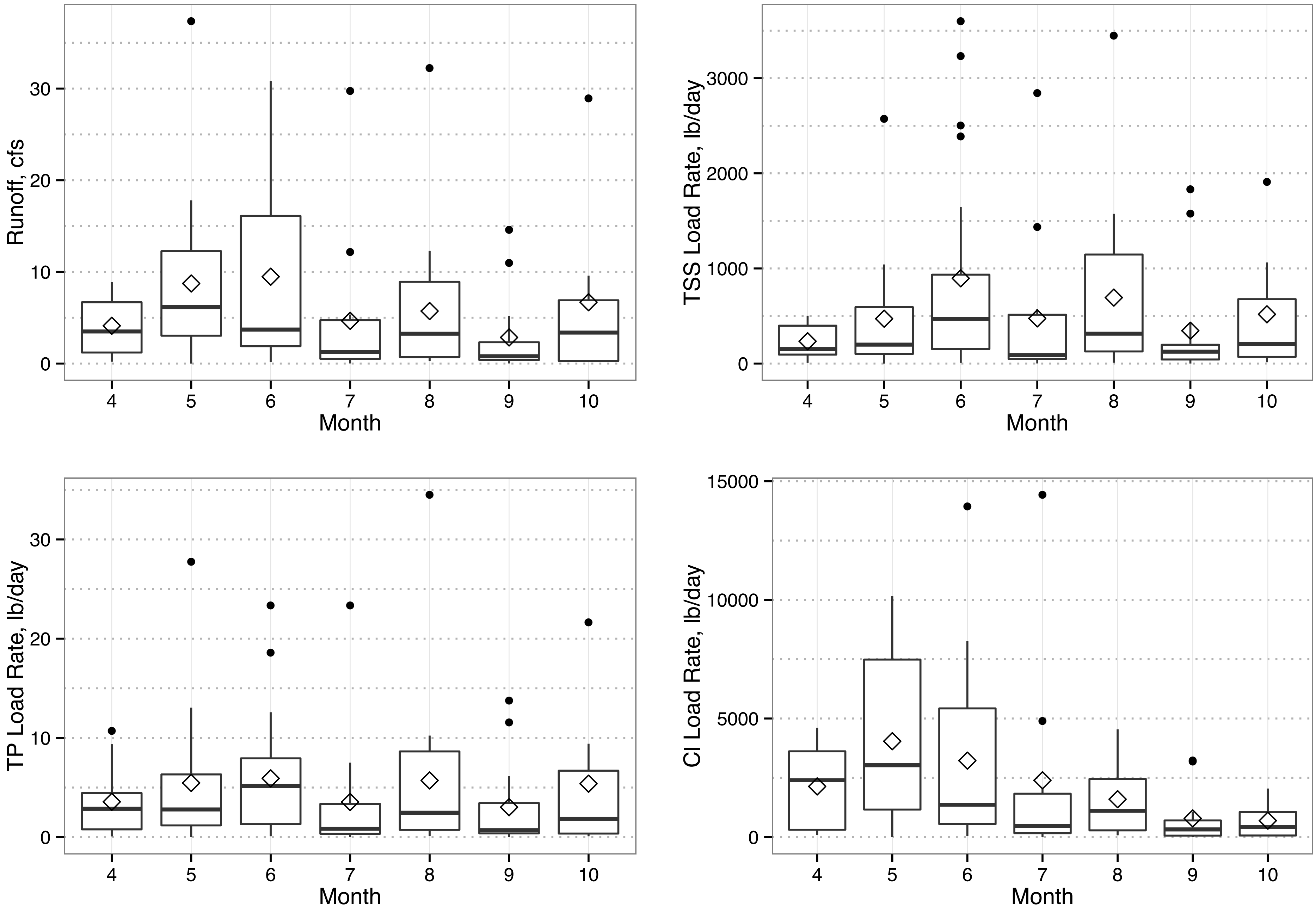


Figure A-2.3. Boxplots of monthly nutrient **concentrations** of all sampled **events** at MS-2. Diamonds are mean concentrations and dots are outliers. Note log scale on the vertical axes for TP and TSS.

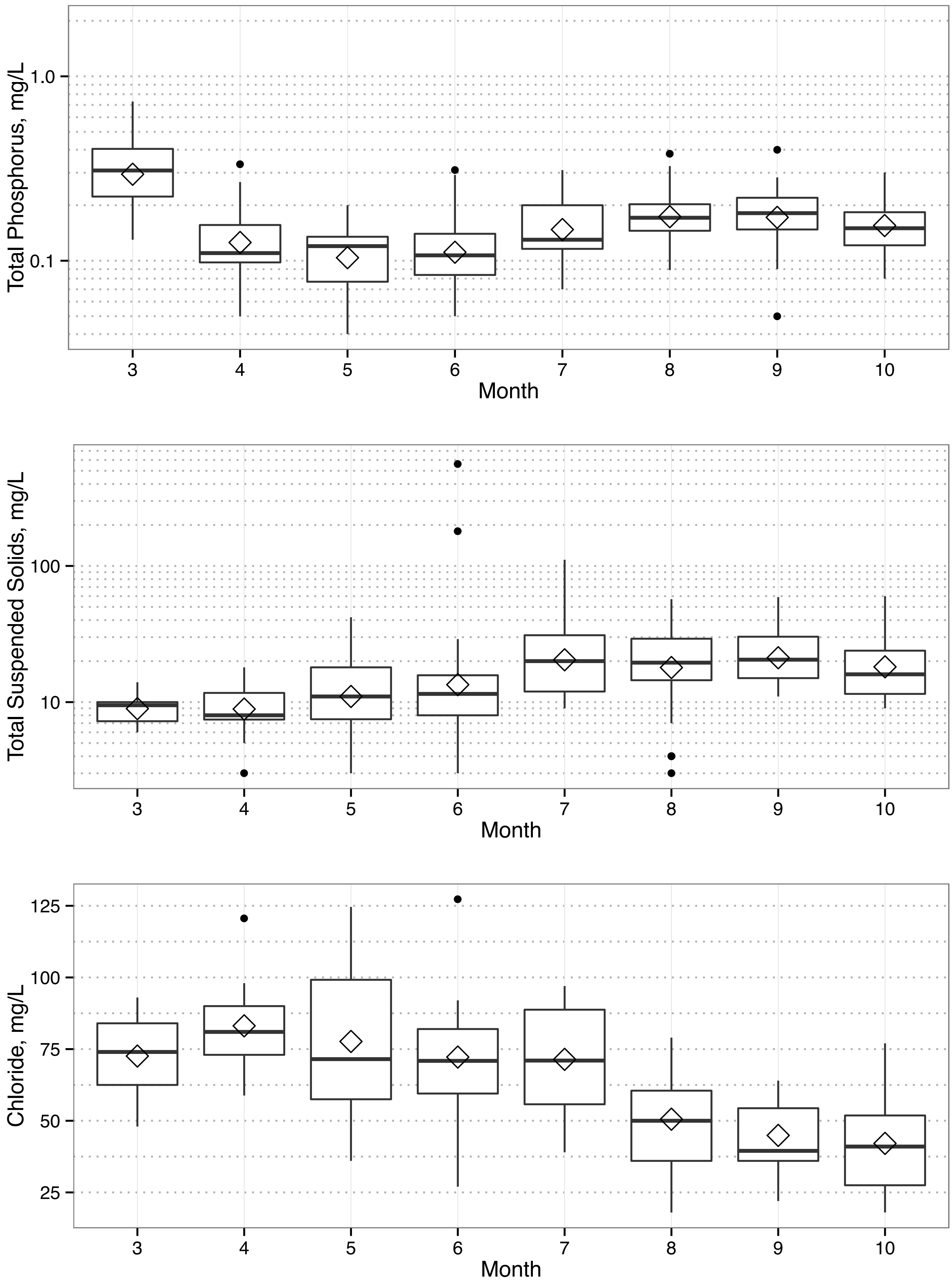
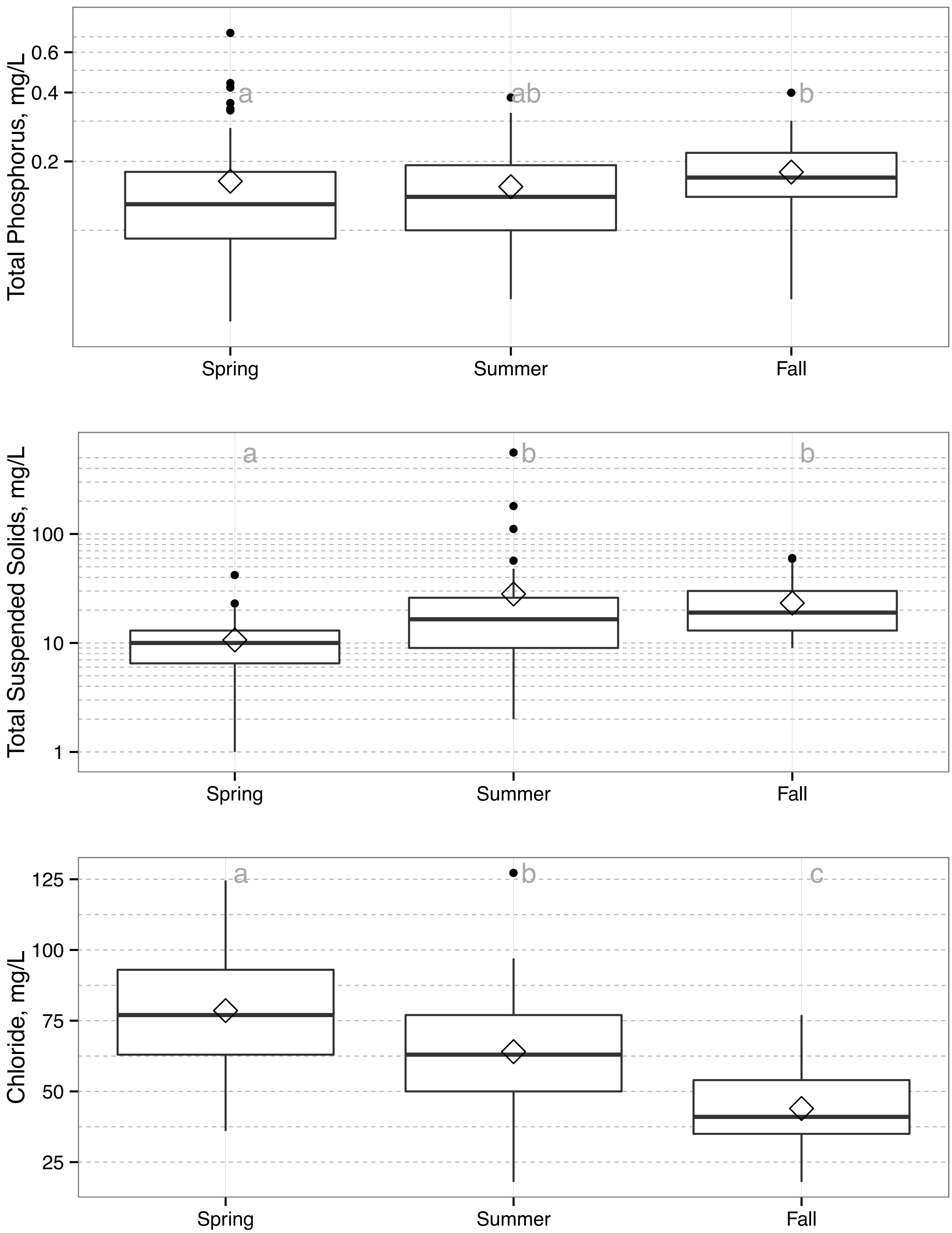


Figure A-2.4. Boxplots of seasonal nutrient **concentrations** of all sampled **events** at MS-2. Diamonds are mean concentrations and dots are outliers; seasons with different letters are significantly different at $p < 0.05$ by Mann-Whitney-Wilcoxon rank sum test. Note log scale on vertical axes for TP and TSS.



A-2.5 Influence of Antecedent Precipitation and Flow on Event Nutrient Loads and Concentrations

Simple linear regression was used to investigate the effect of several precipitation and flow parameters on observed volumes and observed nutrient loads and concentrations, as well as to illustrate any relationships between the parameters themselves. Results considering concentration data only are shown in Table A-2.4, while results for event loading data are shown in Table A-2.5. Note that the concentration data set has more samples than the loading data set because some samples were collected when flow was not monitored. Pearson *r* are shown in the tables along with significance of the regressions: * indicates significance at $p < 0.05$, ** indicates significance at $p < 0.001$.

Table A-2.4. Results of regression of event flow and nutrient concentrations vs. several temporal and antecedent precipitation and flow parameters.

Param	Year	Month	Flow Rate	BF Ratio	Antecedent Precip			Ant. Stage		TP	TSS	Cl
					28 Days	*14 Days*	*7 Days*	*6 Hr*	*7 Days*	Conc	Conc	Conc
Flow Rate	0.04	0.04		0.02	0.41 **	0.53 **	0.54 **	0.72 **	0.58 **	-0.04	-0.07	-0.01
BF Ratio	-0.18	-0.07	0.02		0.02	-0.07	-0.16	0.21 *	0.29 *	-0.20 *	-0.14	0.06
TP Conc	-0.12	0.33 **	-0.04	-0.20 *	-0.23 *	-0.23 *	-0.17 *	-0.13	-0.16		0.25 *	-0.18
TSS Conc	-0.09	0.07	-0.07	-0.14	-0.06	-0.09	-0.05	-0.08	-0.11	0.25 *		0.00
Cl Conc	0.50 **	-0.58 **	-0.01	0.06	0.04	0.10	0.01	0.08	0.16	-0.18	0.00	

Table A-2.5. Results of regression of event flow and nutrient loading vs. antecedent precipitation and flow parameters.

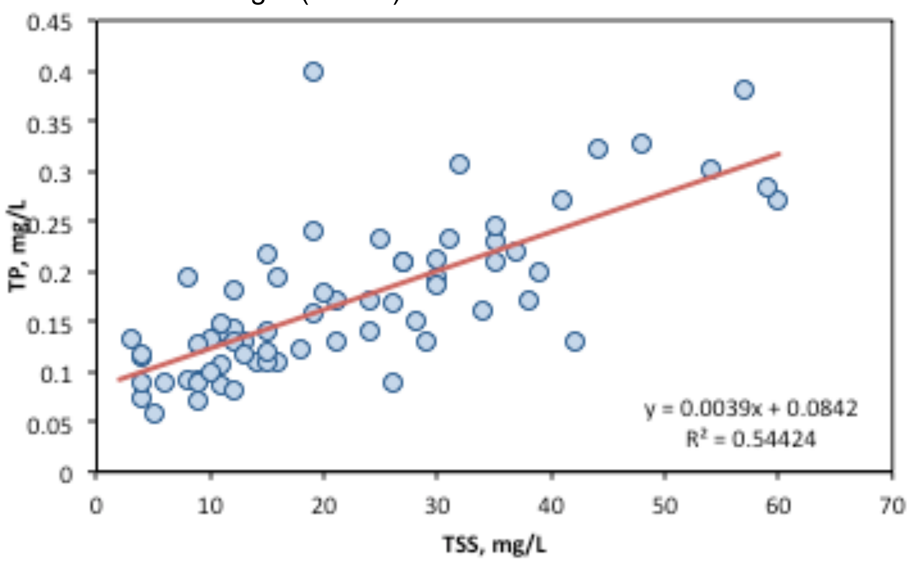
Param.	Flow	Volume			BF	Precip		Antecedent Precip			Ant. Stage	
	Rate	Total	Baseflow	Storm	Ratio	Depth	Intensity	*28 Days*	*14 Days*	*7 Days*	*6 Hr*	*7 Days*
Flow Rate		0.85**	0.79**	0.90**	0.07	0.56**	0.09	0.53**	0.59**	0.56**	0.75**	0.62**
Vol, Total	0.85**		0.99**	0.95**	0.11	0.59**	-0.01	0.36**	0.42**	0.44**	0.74**	0.64**
Vol, Base	0.79**	0.99**		0.89**	0.16	0.54**	-0.03	0.34**	0.38**	0.39**	0.74**	0.67**
Vol, Storm	0.90**	0.95**	0.89**		0.02	0.64**	0.03	0.39**	0.47**	0.49**	0.67**	0.53**
BF Ratio	0.07	0.11	0.16	0.02		-0.06	-0.37**	0.02	-0.06	-0.19	0.25*	0.35**
TP Conc	-0.13	-0.12	-0.12	-0.11	-0.18	-0.09	0.25*	-0.21*	-0.22*	-0.16	-0.19	-0.19
TP Load	0.82**	0.97**	0.95**	0.93**	0.09	0.57**	0.00	0.30*	0.35**	0.38**	0.67**	0.58**
TSS Conc	-0.11	-0.10	-0.09	-0.10	-0.14	-0.09	-0.03	-0.04	-0.09	-0.06	-0.11	-0.14
TSS Load	0.74**	0.89**	0.87**	0.87**	0.07	0.55**	0.02	0.32*	0.35**	0.33**	0.58**	0.52**
Cl Conc	0.13	0.04	0.06	0.00	0.03	0.06	-0.06	0.12	0.15	0.02	0.10	0.17
Cl Load	0.87**	0.90**	0.90**	0.86**	0.23*	0.71**	0.01	0.46**	0.56**	0.53**	0.71**	0.56**

Several results of the regression analyses are worth noting:

- TP concentration was significantly and positively correlated with month (i.e. increased over the season);
- Higher TP and TSS loading were significantly correlated ($p < 0.001$) with higher flow rates and volumes;
- Cl was negatively and significantly correlated with month, suggesting dilution and flushing of road de-icer application during winter months;
- TP and TSS were weakly but significantly correlated, and this relationship improved with the removal of samples for which TSS > 100 mg/L (see plot below);
- Baseflow ratio was negatively correlated with precipitation intensity ($p < 0.001$) and with antecedent rainfall (not significant), logically suggesting that more intense events and drier antecedent periods result in more baseflow in a watershed with a large time of concentration;
- At this smaller time scale, precipitation depth had a significant, positive effect on volumes and flow rates (unlike at the annual scale), and the strong correlations of precipitation with nutrient loads is likely explained by a strong tie between precipitation and hydrology;

- Antecedent precipitation (especially 7-day and 14-day) as well as antecedent stage were well-correlated with event volumes and loading of all constituents, again highlighting the importance of wetter conditions for increased nutrient loading;
- A dilution effect was weakly present for TP and TSS, with negative (but mostly insignificant) correlations between concentrations of TP/TSS and antecedent precipitation, antecedent stage, and flow volumes.

TP concentration vs. TSS concentration for all composite samples at MS-2, using a subset of data for which TSS < 100 mg/L (n = 78) to remove the influence of outliers.



A-2.6 Comparison to Previous Loading Estimates

A comparison to previous loading estimates for MS-2 from two different sources/methods (FLUX32, and a previous loading table method similar to the one in this analysis) is shown in Table A-2.6 below.

Table A-2.6. Comparison of loading at MS-2 as estimated in this study and in previous work, for select years.

	TP (lb)			TSS (lb)			
Year	Previous	This Report	Diff (%)	Previous	This Report	Diff (%)	**Source for Previous Estimate (Method)**
2001	391	239	-39	46,697	28,752	-38	SWWD MS2 Summary (FLUX32)
2002	4313	2492	-42	434,355	264,928	-39	SWWD MS2 Summary (FLUX32)
2003	985	618	-37	103,276	68,442	-34	SWWD MS2 Summary (FLUX32)
2005	1193	558	-53	292,473	120,220	-59	SWWD MS2 Summary (FLUX32)
2006	321.6	305	-5	22,225	23,563	6	2006 Monitoring Report (Loading Table)
2006	501	305	-39	36,634	23,563	-36	SWWD MS2 Summary (FLUX32)
2007	109	72	-34	6,189	5,481	-11	SWWD MS2 Summary (FLUX32)
2007	33.9	72	112	2,057	5,481	166	2007 Monitoring Report (Loading Table)
2008	470	289	-39	58,840	30,163	-49	SWWD MS2 Summary (FLUX32)
2008	260.5	289	11	31,921	30,163	-6	2008 Monitoring Report (Loading Table)
2009	565	282	-50	68,888	33,416	-51	SWWD MS2 Summary (FLUX32)
2010	607	696	15	76,856	86,541	13	SWWD MS2 Summary (FLUX32)
2011	1614	766	-53	153,940	86,091	-44	SWWD MS2 Summary (FLUX32)

The aggregate seasonal means over 2001-2013 were 583 lb for TP and 72,426 lb based on the current method; this compares to mean projected loads of 1288 lb and 160,944 lb, respectively, as determined using a stochastic method and the 2000-2004 monitoring data in the SWWD Watershed Management Plan (HEI, 2011). Median loads were 352 lb TP and 40,368 lb TSS in the current study, compared to 166 lb TP and 18,648 lb TSS in the SWWD WMP.

A-3 Analysis Summary: Central Ravine

A-3.1 Seasonal (April – October) Loading by Year

Estimated loads are shown in Table A-3.1 below for the monitoring period (April – October) of each year. Absolute load (ft^3 or lb), loading rate (ft^3/d or lb/d), and yield (ft^3 or lb per in. of precipitation) are shown by year along with baseflow ratio and runoff coefficient. Precipitation totals are for April 1 – October 31 of each year; volumes and loads have been scaled proportional to the amount of rainfall during data gaps.

Table A-3.1. Seasonal (Apr – Oct) volumes and nutrient loads, precipitation depth, antecedent snowfall, and flow characteristics for all monitored years at the Central Ravine site. Loads have been scaled by precipitation depth for gaps in the data record.

	Monitoring	Monitoring	Gaps	Volume			Precip	Ant. Snow	Base	Runoff
Year	Start	End	(d)	Load (ft^3)	Rate (ft^3/d)	Yld (ft^3/in)	in	in	Ratio	Coeff
2009	4/29/09 13:00	10/25/09 10:00	0.0	63.5	11,471,046	53613	417,139	27.5	45.0	0.17
2010	4/5/10 13:00	11/1/10 0:00	11.5	51.5	25,324,080	118360	810,750	31.2	40.7	0.13
2011	4/7/11 13:00	10/29/11 0:45	2.5	77.3	9,371,639	43801	376,330	24.9	86.6	0.27
2012	4/1/12 1:00	10/31/12 23:00	0.1	5.2	10,956,118	51207	600,861	18.2	22.3	0.16
2013	4/16/13 12:00	10/31/13 2:00	27.6	42.8	10,206,614	47704	518,856	19.7	67.7	0.15
2014	4/10/14 18:00	10/29/14 9:15	15.7	58.6	26,842,968	125459	762,277	35.2	69.8	0.34

	TP			TSS			Cl		
Year	Load (lb)	Rate (lb/d)	Yld (lb/in)	Load (lb)	Rate (lb/d)	Yld (lb/in)	Load (lb)	Rate (lb/d)	Yld (lb/in)
2009	110	0.516	4.0	63,894	298.6	2323.5	7,207	33.7	262
2010	277	1.295	8.9	247,972	1159.0	7938.8	10,018	46.8	321
2011	100	0.468	4.0	424,834	1985.6	17059.8	6,883	32.2	276
2012	154	0.722	8.5	290,641	1358.4	15939.5	4,232	19.8	232
2013	182	0.853	9.3	356,516	1666.3	18123.6	5,311	24.8	270
2014	409	1.913	11.6	269,077	1257.6	7641.1	21,554	100.7	612

A-3.2 Year-to-year Variability in Nutrient Concentrations

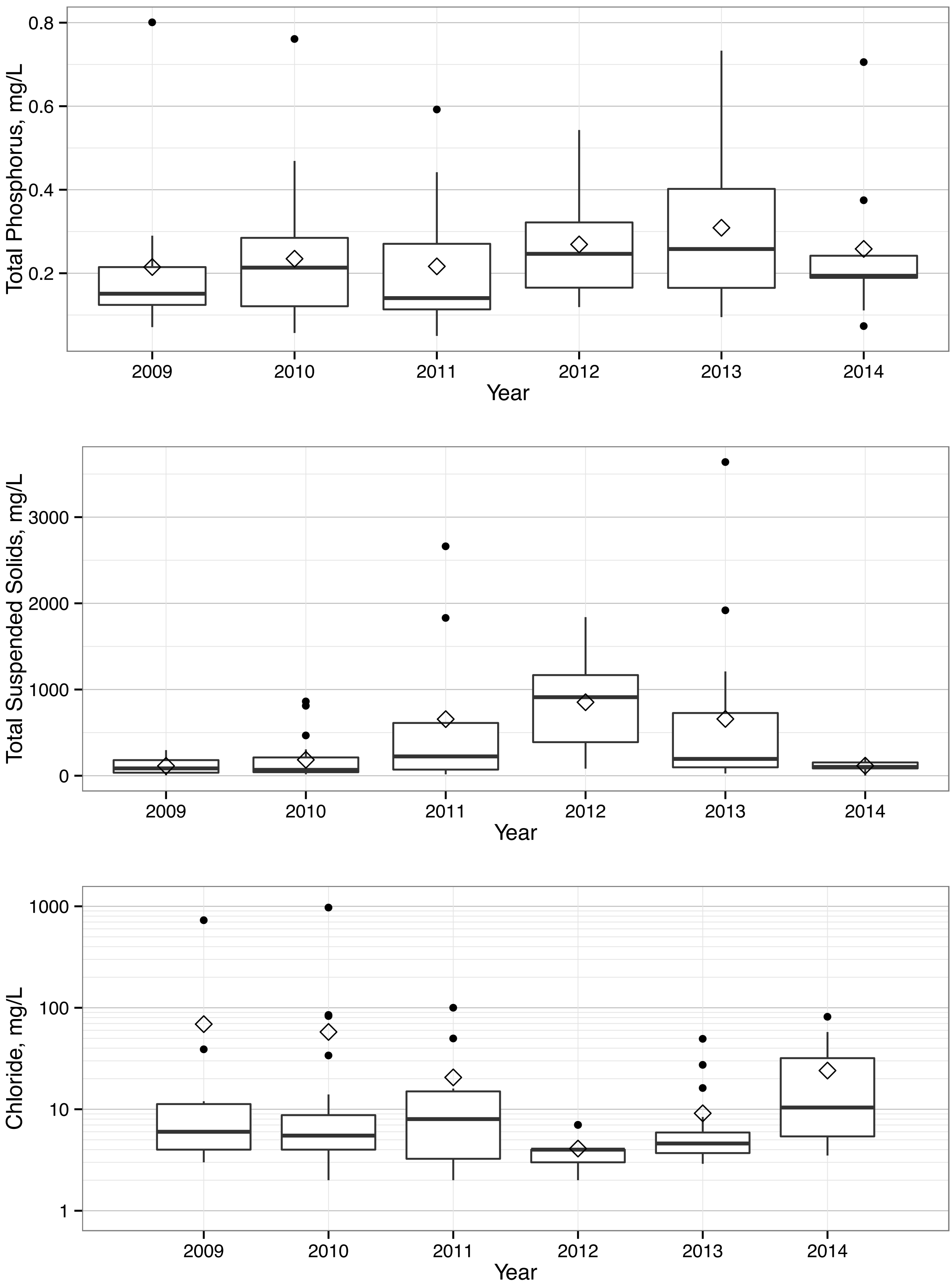
TP, TSS, and Cl concentration data are summarized by year in Figure A-3.1, and by year and flow regime in the tables below (Table A-3.2).

- The data record at this site is relatively short (6 years) and no year-to-year trends are readily apparent.
- TP and TSS appeared to be highest in 2012 and 2013, which were both relatively dry years.

Table A-3.2. Statistical summary of TP, TSS, and Cl concentration data at Central Ravine.

	Total Phosphorus Concentration (mg/L)							Total Suspended Solids Concentration (mg/L)							Chloride Concentration (mg/L)						
Year	**n**	**Min**	**1st Qtile**	**Median**	**3rd Qtile**	**Max**	**Mean**	**n**	**Min**	**1st Qtile**	**Median**	**3rd Qtile**	**Max**	**Mean**	**n**	**Min**	**1st Qtile**	**Median**	**3rd Qtile**	**Max**	**Mean**
2009	*12*	0.071	0.124	0.151	0.223	0.801	0.215	*12*	4	33	85	198	297	114	*12*	3	4	6	12	728	69
2010	*22*	0.057	0.121	0.214	0.292	0.761	0.235	*21*	16	41	68	212	864	185	*22*	2	4	6	9	970	58
2011	*10*	0.050	0.113	0.141	0.310	0.592	0.217	*9*	16	71	224	612	2660	656	*10*	2	3	8	16	100	21
2012	*10*	0.119	0.155	0.247	0.322	0.543	0.269	*8*	82	313	911	1225	1840	852	*10*	2	3	4	4	7	4
2013	*17*	0.095	0.165	0.258	0.402	0.733	0.309	*15*	26	98	195	728	3640	659	*17*	3	4	5	6	49	9
2014	*9*	0.074	0.189	0.194	0.242	0.706	0.258	*9*	1	85	102	154	212	116	*9*	4	5	10	32	82	24
snowmelt	*2*	0.359	0.359	0.560	0.761	0.761	0.560	*2*	103	103	191	279	279	191	*2*	83	83	527	970	970	527
baseflow	*0*	NA	NA	NA	NA	NA	NA	*0*	NA	NA	NA	NA	NA	NA	*0*	NA	NA	NA	NA	NA	NA
stormflow	*78*	0.050	0.125	0.196	0.310	0.801	0.244	*72*	1	51	141	419	3640	396	*78*	2	4	5	10	728	21
all data	***80***	**0.050**	**0.127**	**0.197**	**0.322**	**0.801**	**0.252**	***74***	**1**	**55**	**141**	**372**	**3640**	**390**	***80***	**2**	**4**	**5**	**11**	**970**	**34**

Figure A-3.1. Boxplots of nutrient concentrations of all sampled **events** at Central Ravine, by year. Diamonds are mean concentrations and dots are outliers. Note log scale on vertical axis for Cl.



A-3.3 Year-to-year Variability in Seasonal (April - October) Loading

Linear regression was used to investigate general patterns between the seasonal loading and precipitation parameters from Table A-3.1 above; results are shown in Table A-3.3.

- Precipitation was very strongly related to volume load rate ($r = 0.99$, $p < 0.001$) as well as to loading of TP and Cl; accordingly, TP and Cl loading were both well-correlated with volume rate (and to a lesser extent, water yield), consistent with expectations for a completely sewered watershed;
- No correlations were present between TSS and rainfall, water volume, or TP, a relatively surprising result given that this site's TSS load rates / yields were higher than at other sites (e.g. MS-1 and MS-2).

Table A-3.3. Summary of Pearson *r* values from regression of annual flow and nutrient concentrations vs. several precipitation and flow parameters. * indicates significance at $p < 0.05$, ** for significance at $p < 0.001$.

Parameter	**Year**	**Total Volume**		**Precip**	**Ant**	**Baseflow**	**TP**		**TSS**		**Cl**	
		Rate	*Yield*		**Snow**	Ratio	*Load Rate*	*Yield*	*Load Rate*	*Yield*	*Load Rate*	*Yield*
Vol, Rate	0.20		0.88*	0.99**	0.01	0.29	0.91*	0.63	-0.16	-0.47	0.81*	0.76
Vol, Yield	0.31	0.88*		0.80	-0.34	0.02	0.85*	0.82*	-0.16	-0.26	0.57	0.56
BF Ratio	0.51	0.29	0.02	0.37	0.63		0.43	0.15	0.24	-0.06	0.75	0.77
TP Load Rate	0.57	0.91*	0.85*	0.88*	0.12	0.43		0.85*	-0.03	-0.27	0.88*	0.88*
TP Yield	0.76	0.63	0.82*	0.53	-0.13	0.15	0.85*		0.07	0.08	0.54	0.62
TSS Load Rate	0.45	-0.16	-0.16	-0.23	0.61	0.24	-0.03	0.07		0.87*	-0.08	-0.06
TSS Yield	0.46	-0.47	-0.26	-0.57	0.26	-0.06	-0.27	0.08	0.87*		-0.43	-0.35
Cl Load Rate	0.46	0.81*	0.57	0.86*	0.36	0.75	0.88*	0.54	-0.08	-0.43		0.99**
Cl Yield	0.58	0.76	0.56	0.79	0.35	0.77	0.88*	0.62	-0.06	-0.35	0.99**	

A-3.4 Seasonal and Monthly Variability in Event Nutrient Loads and Concentrations

Monthly event loading rates (cfs or lb/d) of water, TP, TSS, and Cl are summarized in the box-plots below (Figure A-3.2). Several general patterns are worth noting:

- Loading of water, TP, and TSS were generally highest in late spring and summer, likely the result of export during larger or more intense summer storms in a flashy system;
- TSS loading rates were very high in the spring as well, which may be the result of erosion before vegetation (lawns especially) have stabilized soils;
- Cl loading rates decreased throughout the season, likely indicating a flushing of winter road salt.

Event concentration data are summarized by month in Figure A-3.3 and by season in Figure A-3.4. These are intended to illustrate the strong seasonality of the nutrient data.

- TSS concentrations are highest in late spring and summer, with several events exceeding 1000 mg/L; Spring and Summer TSS concentrations were significantly higher than in Fall;
- TP concentrations were highest in March, which may be evidence of export in snowmelt and early spring rains of P from over-winter decomposition of leaf litter on lawns and streets;
- High TP in May coincided with high TSS and may be evidence of soil erosion, or flushing of leaf litter deposited in streets during leaf out; a corresponding increase in TP from September to October may also be evidence of vegetative inputs (leaf drop);
- Cl concentrations were significantly different across seasons, though the decrease of Cl from spring to fall was not significant.

Figure A-3.2. Boxplots of flow and nutrient **loading rates** of all sampled **events** at Central Ravine, by month. Diamonds are mean concentrations and dots are outliers. Note log scale on the vertical axes.

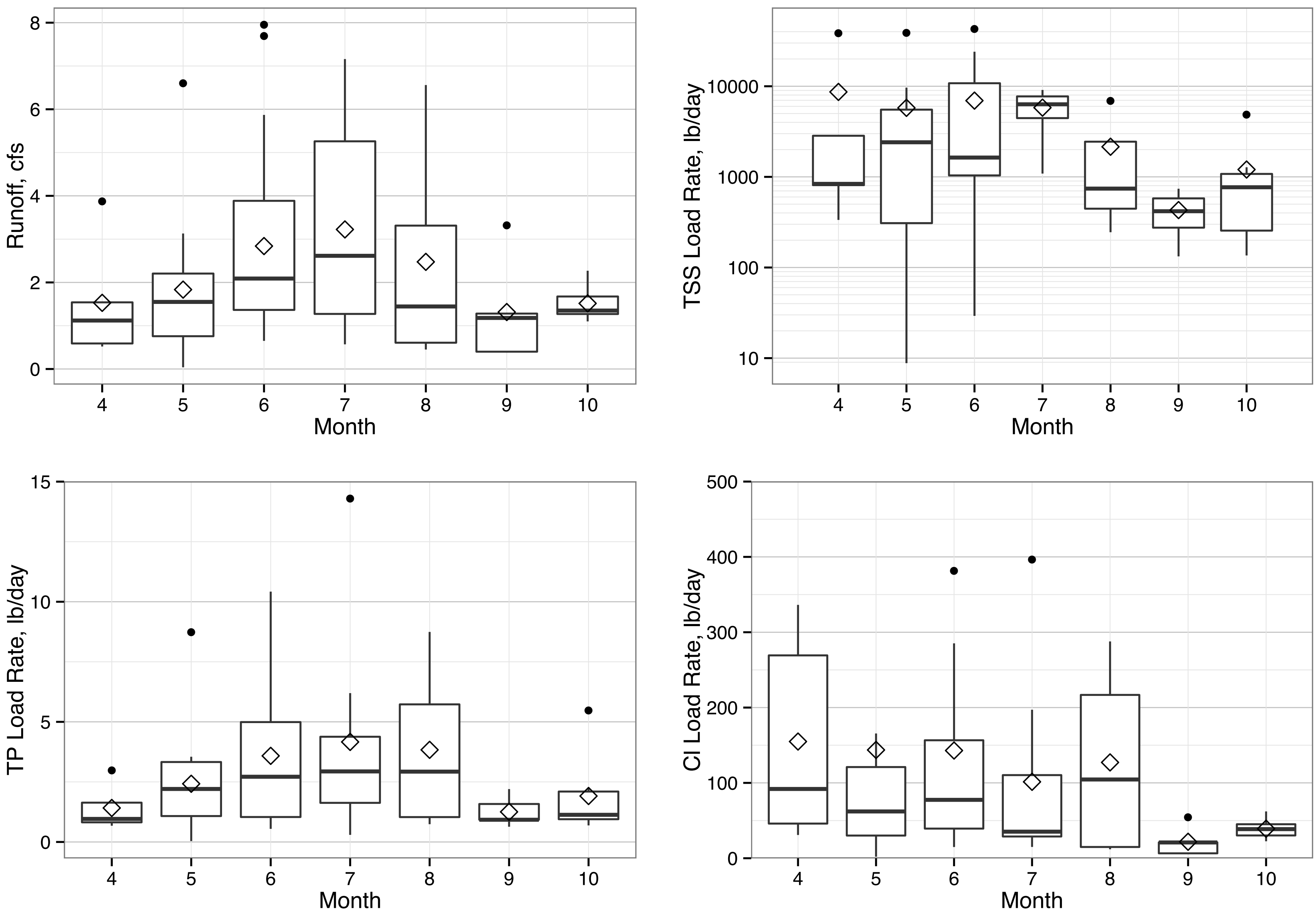


Figure A-3.3. Boxplots of monthly nutrient **concentrations** of all sampled **events** at Central Ravine. Diamonds are mean concentrations and dots are outliers. Note log scale on the vertical axes for Cl.

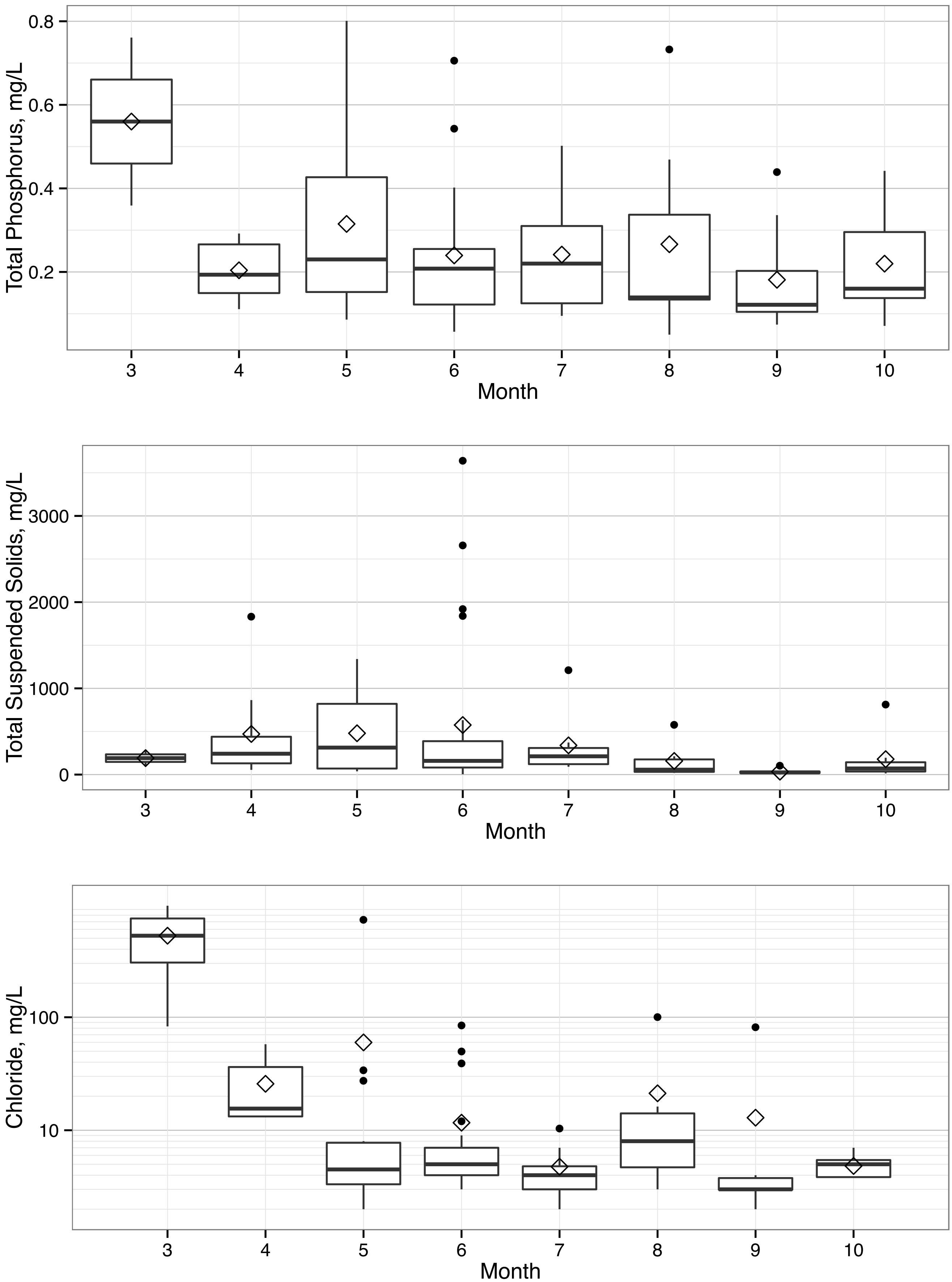
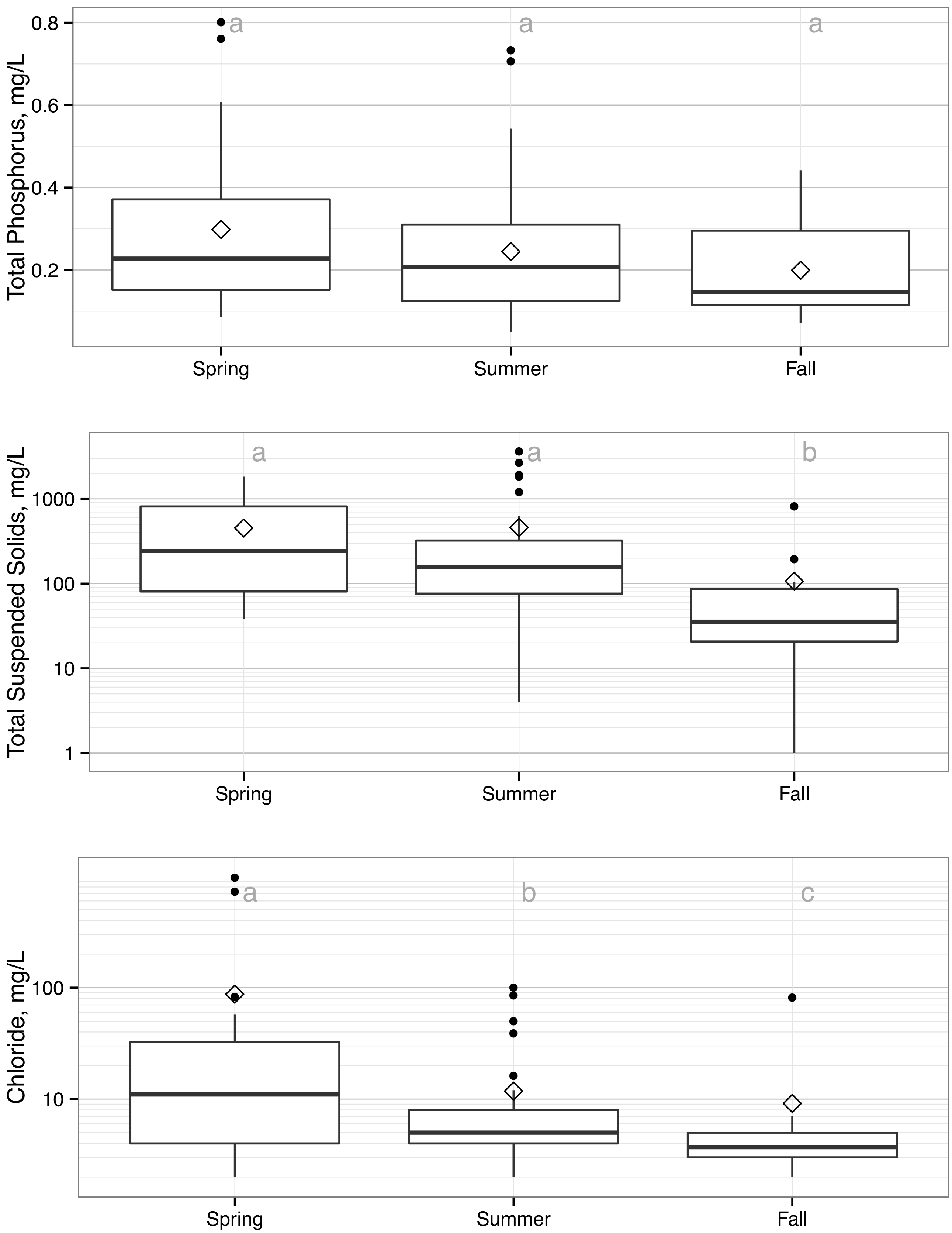


Figure A-3.4. Boxplots of seasonal nutrient **concentrations** of all sampled **events** at Central Ravine. Diamonds are mean concentrations and dots are outliers; seasons with different letters are significantly different at $p < 0.05$ by Mann-Whitney-Wilcoxon rank sum test. Note log scale on vertical axes.



A-3.5 Influence of Antecedent Precipitation and Flow on Event Nutrient Loads and Concentrations

Simple linear regression was used to investigate the effect of several precipitation and flow parameters on observed volumes and observed nutrient loads and concentrations, as well as to illustrate any relationships between the parameters themselves. Results considering concentration data only are shown in Table A-3.4, while results for event loading data are shown in Table A-3.5. Note that the concentration data set has more samples than the loading data set because some samples were collected when flow was not monitored. Pearson *r* are shown in the tables along with significance of the regressions: * indicates significance at $p < 0.05$, ** indicates significance at $p < 0.001$.

Table A-3.4. Results of regression of event flow and nutrient concentrations vs. several temporal and antecedent precipitation and flow parameters.

Param	Year	Month	Flow Rate	BF Ratio	Antecedent Precip			Ant. Stage		TP	TSS	Cl
					28 Days	*14 Days*	*7 Days*	*6 Hr*	*7 Days*	Conc	Conc	Conc
Flow Rate	0.22	-0.01		0.30 *	0.31 *	0.16	0.21	0.15	0.09	0.12	0.23	-0.18
BF Ratio	0.14	-0.10	0.30 *		0.48 **	0.49 **	0.49 **	0.49 **	0.43 **	-0.08	-0.03	0.09
TP Conc	0.21	-0.10	0.12	-0.08	0.05	-0.14	-0.27 *	-0.09	-0.17		0.23 *	0.34 *
TSS Conc	0.19	-0.23	0.23	-0.03	-0.02	-0.18	-0.08	-0.14	-0.19	0.23 *		-0.09
Cl Conc	-0.13	-0.13	-0.18	0.09	-0.09	-0.04	-0.04	-0.09	-0.01	0.34 *	-0.09	

Table A-3.5. Results of regression of event flow and nutrient loading vs. antecedent precipitation and flow parameters.

Param.	Flow	Volume			BF	Precip		Antecedent Precip			Ant. Stage	
	Rate	Total	Baseflow	Storm	Ratio	Depth	Intensity	*28 Days*	*14 Days*	*7 Days*	*6 Hr*	*7 Days*
Flow Rate		0.62**	0.52**	0.64**	0.46**	0.41**	0.44**	0.49**	0.49**	0.46**	0.50**	0.48**
Vol, Total	0.62**		0.92**	0.98**	0.59**	0.75**	0.28*	0.27*	0.27*	0.20	0.27*	0.20
Vol, Base	0.52**	0.92**		0.83**	0.72**	0.71**	0.30*	0.25	0.27*	0.20	0.40*	0.20
Vol, Storm	0.64**	0.98**	0.83**		0.49**	0.83**	0.33*	0.22	0.24	0.15	0.40*	0.17
BF Ratio	0.46**	0.59**	0.72**	0.49**		0.49**	0.30*	0.49**	0.48**	0.46**	0.48**	0.38*
TP Conc	-0.16	-0.14	-0.08	-0.12	-0.14	-0.19	0.16	0.06	-0.11	-0.24*	0.00	-0.15
TP Load	0.60**	0.91**	0.84**	0.89**	0.51**	0.51**	0.37*	0.36*	0.27*	0.15	0.28*	0.16
TSS Conc	-0.04	-0.04	-0.06	-0.04	-0.03	0.00	0.13	-0.03	-0.19	-0.08	-0.09	-0.18
TSS Load	0.34*	0.47**	0.40*	0.49**	0.33*	0.34*	0.31*	0.08	-0.02	0.05	0.02	-0.03
Cl Conc	-0.16	-0.08	0.16	0.16	0.16	-0.10	0.03	-0.09	-0.05	-0.04	-0.10	-0.01
Cl Load	0.15	0.47**	0.49**	0.43**	0.35*	0.40**	-0.08	0.05	0.20	0.18	0.06	0.22

Several results of the regression analyses are worth noting:

- TP loading (and to a lesser extent that of Cl and TSS) were significantly and positively correlated with flow rate and with volumes;
- TP and TSS were weakly but significantly correlated at the event scale;
- TP concentration was significantly and negatively correlated with increased antecedent weekly rainfall, a pattern associated with build up – wash off of P sources (soil, vegetation) from streets;
- Flow rate and volume were generally well-correlated with event precipitation/intensity, antecedent precipitation and antecedent stage, highlighting a strong linkage between precipitation and hydrology;
- Rainfall intensity was significantly correlated with increased TP and TSS load rates, which could indicate that soil erosion is an important mechanism for P and TSS export.

A-4 Analysis Summary: Newport

A-4.1 Seasonal (April – October) Loading by Year

Estimated loads are shown in Table A-4.1 below for the monitoring period (April – October) of each year. Absolute load (ft^3 or lb), loading rate (ft^3/d or lb/d), and yield (ft^3 or lb per in. of precipitation) are shown by year along with baseflow ratio and runoff coefficient. Precipitation totals are for April 1 – October 31 of each year; volumes and loads have been scaled proportional to the amount of rainfall during data gaps.

Table A-4.1. Seasonal (Apr – Oct) volumes and nutrient loads, precipitation depth, antecedent snowfall, and flow characteristics for all monitored years at the Newport site. Loads have been scaled by precipitation depth for gaps in the data record.

	Monitoring	Monitoring	Gaps	Volume			Precip	Ant. Snow	Base	Runoff
Year	Start	End	(d)	Load (ft^3)	Rate (ft^3/d)	Yld (ft^3/in)	in	in	Ratio	Coeff
2006	5/18/06 16:00	10/26/06 10:00	53.2	989,532	4625	54,998	18.0	66.4	0.53	0.05
2007	4/10/07 14:00	10/29/07 9:30	25.3	3,117,900	14572	142,750	21.8	35.5	0.42	0.13
2008	4/9/08 13:00	10/14/08 20:00	43.8	2,490,104	11638	143,775	17.3	44.9	0.55	0.13
2009	4/7/09 11:00	10/30/09 5:00	15.9	1,430,282	6685	72,759	19.7	45.0	0.47	0.07
2010	4/1/10 16:00	10/26/10 21:00	22.3	2,111,903	9871	76,280	27.7	40.7	0.50	0.07
2011	5/24/11 15:00	10/31/11 16:15	83.4	5,583,420	26096	235,551	23.7	86.6	0.80	0.22
2012	4/1/12 0:00	10/31/12 23:00	19.7	5,218,975	24392	267,652	19.5	22.3	0.68	0.25
2013	4/12/13 16:00	10/31/13 13:00	36.2	7,049,946	32950	289,639	24.3	67.7	0.67	0.27
2014	4/10/14 12:00	10/25/14 0:00	27.6	10,793,127	50445	355,080	30.4	69.8	0.74	0.33

	TP			TSS			Cl		
Year	Load (lb)	Rate (lb/d)	Yld (lb/in)	Load (lb)	Rate (lb/d)	Yld (lb/in)	Load (lb)	Rate (lb/d)	Yld (lb/in)
2006	13	0.059	0.7	3,471	16.2	192.9	2,743	12.8	152
2007	56	0.261	2.6	10,032	46.9	459.3	7,939	37.1	363
2008	37	0.171	2.1	16,637	77.8	960.6	15,050	70.3	869
2009	16	0.073	0.8	6,524	30.5	331.9	5,205	24.3	265
2010	31	0.144	1.1	53,745	251.2	1941.2	6,572	30.7	237
2011	60	0.282	2.5	47,681	222.9	2011.5	16,177	75.6	682
2012	52	0.241	2.6	184,192	860.9	9446.2	20,866	97.5	1,070
2013	66	0.306	2.7	50,500	236.0	2074.7	37,906	177.2	1,557
2014	97	0.453	3.2	18,846	88.1	620.0	40,856	191.0	1,344

A-4.2 Year-to-year Variability in Nutrient Concentrations

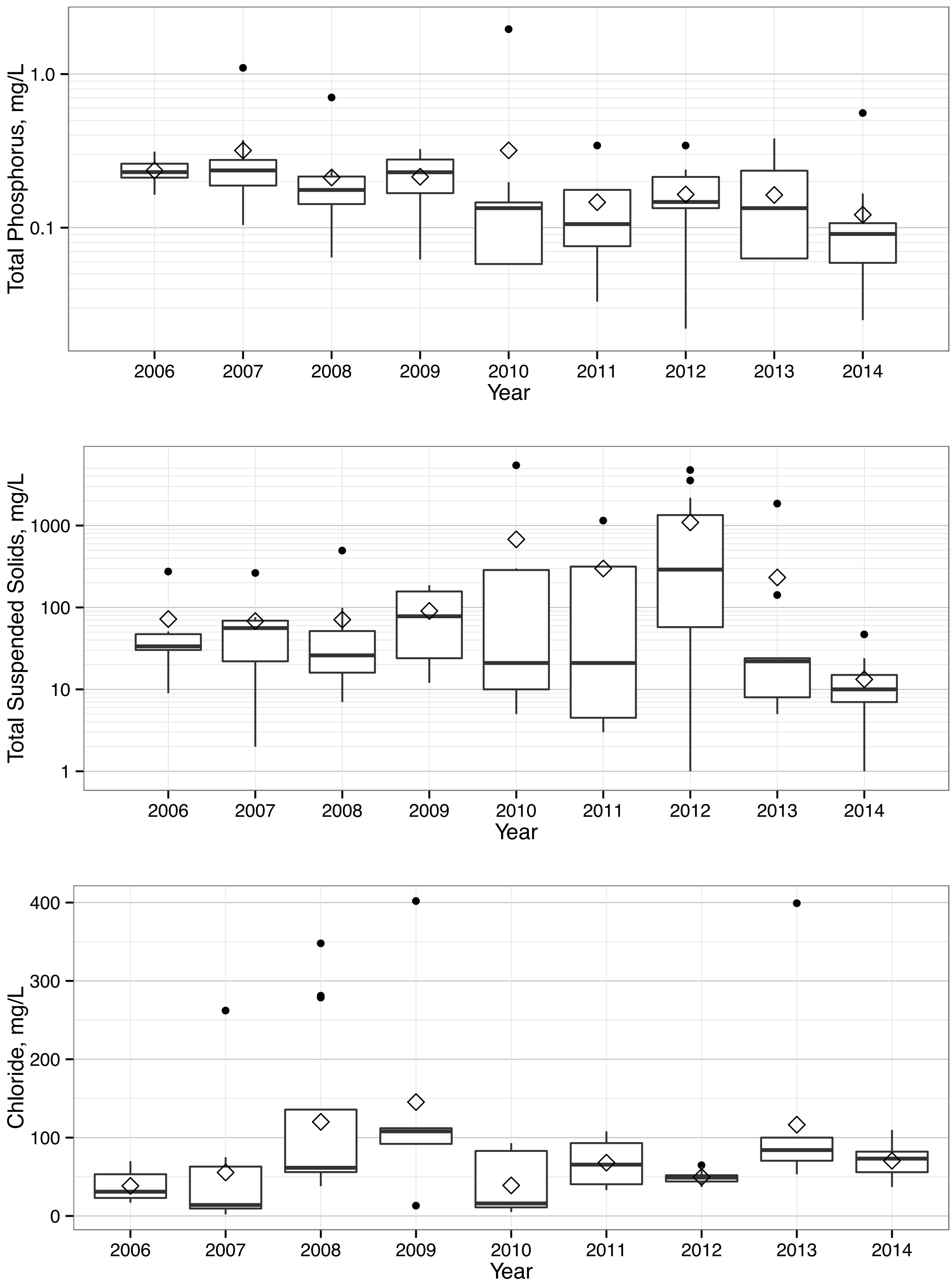
TP, TSS, and Cl concentration data are summarized by year in Figure A-4.1, and by year and flow regime in the tables below (Table A-4.2).

- TP concentration generally decreased during the study period (*r* = -0.22; Table A-4.4) but the decrease was not significant;
- TSS was variable, with peak concentrations in 2012 and substantial declines in the next two years (2013 and 2014);
- Cl concentration was also variable among years and appeared to be slightly elevated relative to the other sites, with mean concentrations in excess of 100 mg/L in 2008, 2009, and 2012.

Table A-4.2. Statistical summary of TP, TSS, and Cl concentration data at Newport.

	Total Phosphorus Concentration (mg/L)							Total Suspended Solids Concentration (mg/L)							Chloride Concentration (mg/L)						
Year	**n**	**Min**	**1st Qtile**	**Median**	**3rd Qtile**	**Max**	**Mean**	**n**	**Min**	**1st Qtile**	**Median**	**3rd Qtile**	**Max**	**Mean**	**n**	**Min**	**1st Qtile**	**Median**	**3rd Qtile**	**Max**	**Mean**
2006	*6*	0.164	0.207	0.230	0.270	0.313	0.236	*6*	9	30	34	51	276	72	*6*	17	23	31	58	70	38
2007	*9*	0.104	0.188	0.236	0.276	1.100	0.318	*9*	2	22	56	69	264	68	*8*	2	9	14	67	262	56
2008	*12*	0.064	0.141	0.176	0.216	0.706	0.212	*12*	7	15	26	54	495	71	*12*	38	56	62	184	348	120
2009	*6*	0.062	0.149	0.230	0.292	0.325	0.215	*6*	12	14	78	175	187	91	*5*	13	92	108	112	402	145
2010	*9*	0.050	0.058	0.134	0.146	1.960	0.319	*9*	5	10	21	286	5430	678	*9*	5	11	16	83	93	39
2011	*4*	0.033	0.062	0.106	0.232	0.342	0.147	*4*	3	4	21	594	1150	299	*4*	33	38	66	98	108	68
2012	*11*	0.022	0.134	0.147	0.214	0.342	0.165	*11*	1	58	290	1342	4760	1091	*9*	37	44	49	52	65	50
2013	*9*	0.054	0.063	0.134	0.235	0.381	0.163	*9*	5	8	22	24	1850	232	*9*	53	71	84	100	399	116
2014	*13*	0.025	0.059	0.091	0.107	0.558	0.121	*12*	1	7	10	15	47	13	*13*	37	56	73	82	110	70
snowmelt	*5*	0.144	0.224	0.240	0.292	0.381	0.256	*5*	7	12	13	14	20	13	*5*	108	279	348	399	402	307
baseflow	*12*	0.022	0.054	0.097	0.132	0.184	0.096	*12*	1	4	8	14	37	10	*11*	23	59	82	88	262	87
stormflow	*62*	0.025	0.100	0.150	0.235	1.960	0.226	*61*	2	15	47	175	5430	390	*59*	2	35	56	74	281	57
all data	***79***	**0.022**	**0.093**	**0.147**	**0.235**	**1.960**	**0.208**	***78***	**1**	**10**	**27**	**99**	**5430**	**308**	***75***	**2**	**39**	**61**	**86**	**402**	**78**

Figure A-4.1. Boxplots of nutrient concentrations of all sampled **events** at Newport, by year. Diamonds are mean concentrations and dots are outliers. Note log scale on vertical axes for TP and TSS.



A-4.3 Year-to-year Variability in Seasonal (April - October) Loading

Linear regression was used to investigate general patterns between the seasonal loading and precipitation parameters from Table A-4.1 above; results are shown in Table A-4.3.

- Volume was a significant predictor for annual loads of water, TP and Cl (but not of TSS), logically suggesting hydrologic control of loading for these consituents; however, precipitation was not significantly related to any variables at the annual scale, including water loading rate or yield;
- Chloride yield was significantly related to volume and to baseflow ratio (but not to antecedent snowfall), potentially indicating flushing of Cl stored in surface water or shallow groundwater in the watershed;
- TP and TSS loading were not well correlated with each other;
- Loading rates of water, TP and Cl increased significantly year-to-year over the study period.

Table A-4.3. Summary of Pearson *r* values from regression of annual flow and nutrient concentrations vs. several precipitation and flow parameters. * indicates significance at $p < 0.05$, ** for significance at $p < 0.001$.

Parameter	Year	Total Volume		Precip	Ant	Baseflow	TP		TSS		Cl	
		Rate	*Yield*		**Snow**	Ratio	*Load Rate*	*Yield*	*Load Rate*	*Yield*	*Load Rate*	*Yield*
Vol, Rate	0.85*		0.95**	0.46	0.36	0.74*	0.94**	0.84*	0.18	0.16	0.93**	0.82*
Vol, Yield	0.86*	0.95**		0.24	0.28	0.81*	0.88*	0.91**	0.39	0.38	0.93**	0.91**
BF Ratio	0.75*	0.74*	0.81*	-0.10	0.59		0.59	0.62	0.36	0.35	0.68*	0.68*
TP Load Rate	0.70*	0.94**	0.88*	0.49	0.24	0.59		0.92**	0.13	0.11	0.84*	0.73*
TP Yield	0.65	0.84*	0.91**	0.21	0.13	0.62	0.92**		0.33	0.33	0.80*	0.80*
TSS Load Rate	0.44	0.18	0.39	-0.04	-0.46	0.36	0.13	0.33		0.99**	0.19	0.35
TSS Yield	0.40	0.16	0.38	-0.11	-0.48	0.35	0.11	0.33	0.99**		0.18	0.35
Cl Load Rate	0.85*	0.93**	0.93**	0.37	0.31	0.68*	0.84*	0.80*	0.19	0.18		0.95**
Cl Yield	0.81*	0.82*	0.91**	0.15	0.20	0.68*	0.73*	0.80*	0.35	0.35	0.95**	

A-4.4 Seasonal and Monthly Variability in Event Nutrient Loads and Concentrations

Monthly event loading rates (cfs or lb/d) of water, TP, TSS, and Cl are summarized in the box-plots below (Figure A-4.2). Event concentration data are summarized by month in Figure A-4.3 and by season in Figure A-4.4. Several general patterns are apparent in the loading rate data:

- Loading of water, TP, and TSS were highest in early summer (May/June) and decreased through October, suggesting hydrologic control for loading rates and the potential importance of erosional or sediment sources for phosphorus;
- TP and TSS concentration peaks were a bit later in the summer (June/July) than their respective peaks in loading rates, and Summer TP and TSS were both significantly higher than in Fall;
- March (snowmelt) TP was also high relative to the rest of the year, consistent with patterns seen at other SWWD sites (e.g. Central Ravine) that potentially indicate over-winter decomposition of vegetation (leaf litter, lawns, or aquatic vegetation) as a source of P;
- Higher and more variable flow rates in early summer may be evidence of larger or more intense storms occurring while water retention is relatively low in the watershed (e.g. from high water levels in upstream ponds from spring rain and snowmelt);
- Cl loading rates and concentrations decreased significantly throughout the season ($r = -0.56$, $p < 0.001$ for concentration; Table A-4.4), indicating flushing of winter road de-icer applications.

Figure A-4.2. Boxplots of flow and nutrient **loading rates** of all sampled **events** at Newport, by month. Diamonds are mean concentrations and dots are outliers. Note log scale on some of the vertical axes.

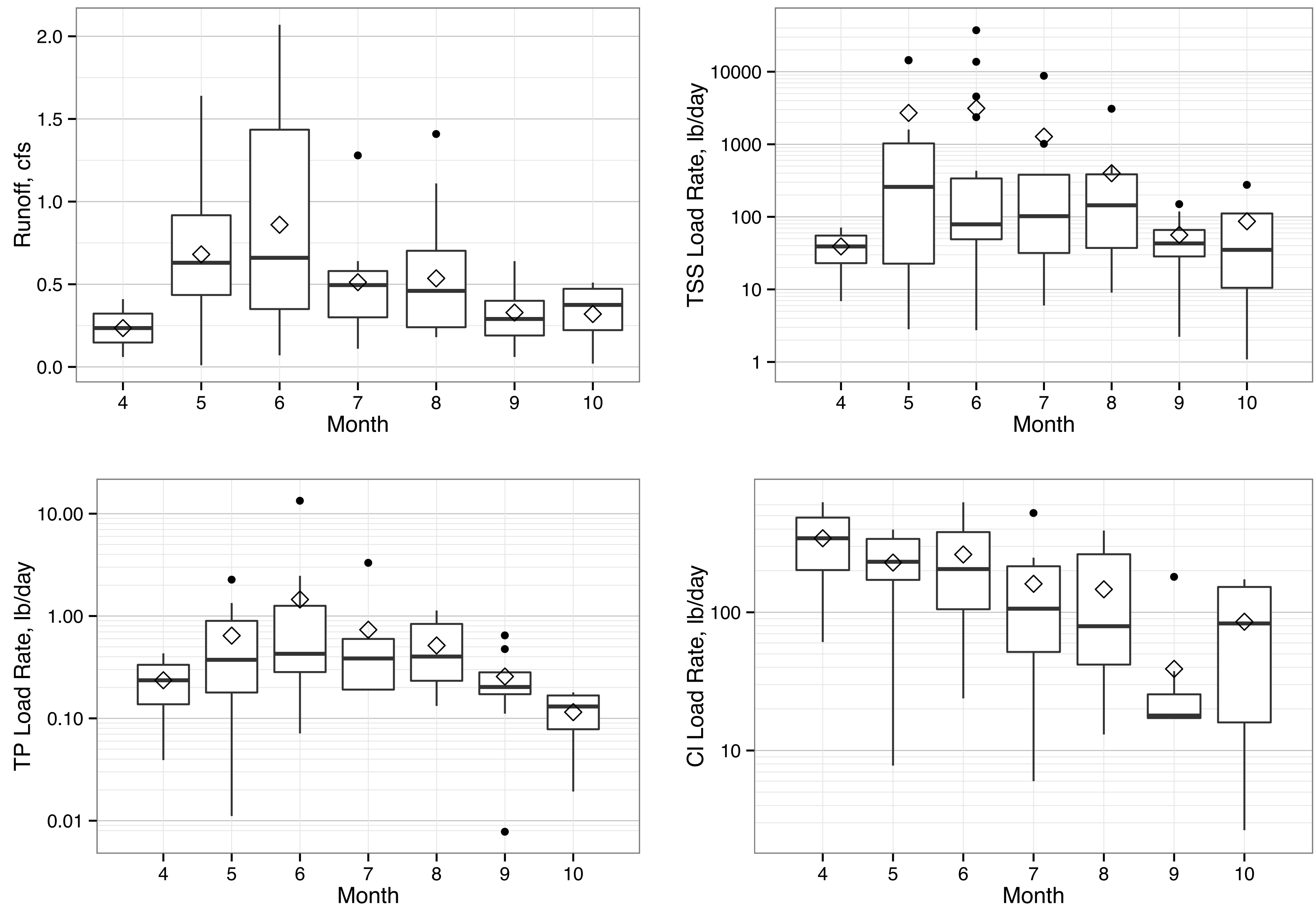


Figure A-4.3. Boxplots of monthly nutrient **concentrations** of all sampled **events** at Newport. Diamonds are mean concentrations and dots are outliers. Note log scale on the vertical axes.

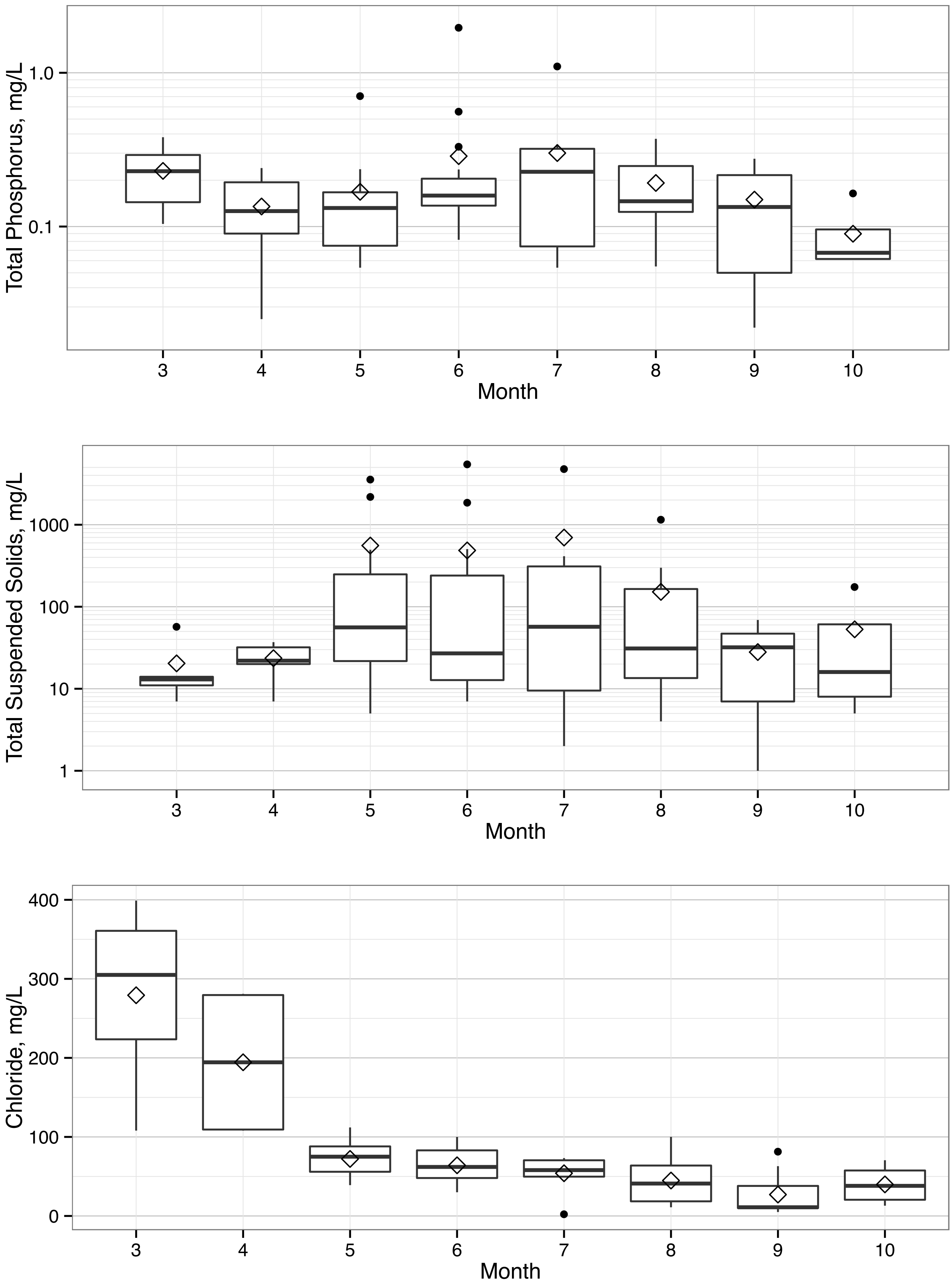
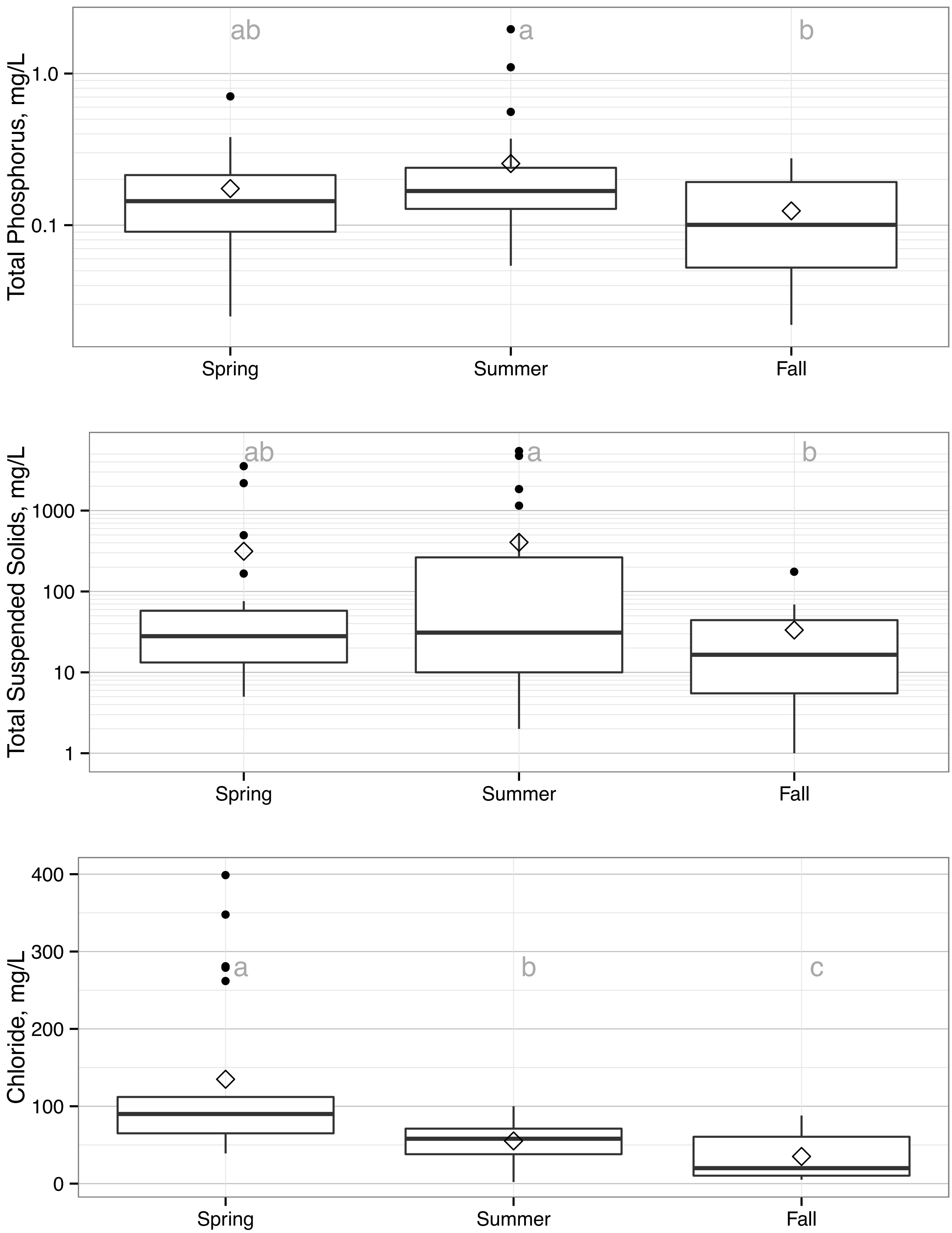


Figure A-4.4. Boxplots of seasonal nutrient **concentrations** of all sampled **events** at Newport. Diamonds are mean concentrations and dots are outliers; seasons with different letters are significantly different at $p < 0.05$ by Mann-Whitney-Wilcoxon rank sum test. Note log scale on vertical axes.



A-4.5 Influence of Antecedent Precipitation and Flow on Nutrient Loads and Concentrations

Simple linear regression was used to investigate the effect of several precipitation and flow parameters on observed volumes and observed nutrient loads and concentrations. Results considering concentration data only are shown in Table A-4.4, while results for event loading data are shown in Table A-4.5. Note that the concentration data set has more samples than the loading data set because some samples were collected when flow was not monitored. Pearson *r* are shown in the tables along with significance of the regressions: * indicates significance at $p < 0.05$, ** indicates significance at $p < 0.001$.

Table A-4.4. Results of regression of flow and nutrient concentrations vs. several temporal and antecedent precipitation and flow parameters.

Param	**Year**	**Month**	**Flow** Rate	**BF Ratio**	**Antecedent Precip** *28 Days*	*14 Days*	*7 Days*	**Ant. Stage** *6 Hr*	*7 Days*	**TP** Conc	**TSS** Conc	**Cl** Conc
Flow Rate	0.33*	-0.08		-0.38*	0.40**	0.36*	0.42**	0.48**	0.41**	0.27*	0.25*	-0.21
BF Ratio	0.34*	-0.20	-0.38*		-0.01	-0.18	-0.20	0.13	0.38*	-0.31*	-0.11	0.35*
TP Conc	-0.22	-0.06	0.27*	-0.31*	-0.03	-0.03	-0.05	-0.23	-0.21		0.56**	-0.17
TSS Conc	0.10	-0.13	0.25*	-0.11	0.01	-0.07	0.00	-0.08	-0.01	0.56**		-0.08
Cl Conc	0.13	-0.56**	-0.21	0.35*	-0.20	-0.21	-0.16	0.01	0.21	-0.17	-0.08	

Table A-4.5. Results of regression of flow and nutrient loading vs. antecedent precipitation and flow parameters.

Param.	**Flow Rate**	**Volume** Total	Baseflow	Storm	**BF Ratio**	**Precip** Depth	Intensity	**Antecedent Precip** *28 Days*	*14 Days*	*7 Days*	**Ant. Stage** *6 Hr*	*7 Days*
Flow Rate		0.69**	0.50**	0.68**	-0.19	0.39**	0.28*	0.54**	0.48**	0.36*	0.61**	0.64**
Vol, Total	0.69**		0.79**	0.95**	-0.10	0.64**	0.12	0.43**	0.48**	0.32*	0.58**	0.51**
Vol, Base	0.50**	0.79**		0.57**	0.44**	0.24	-0.14	0.48**	0.43**	0.28*	0.65**	0.73**
Vol, Storm	0.68**	0.95**	0.57**		-0.36*	0.75**	0.21	0.34*	0.47**	0.31*	0.45**	0.32*
BF Ratio	-0.19	-0.10	0.44**	-0.36*		-0.58**	-0.48**	0.02	-0.17	-0.17	0.16	0.43**
TP Conc	0.08	0.04	-0.15	0.12	-0.33*	0.18	0.49**	-0.04	-0.03	-0.05	-0.24	-0.22
TP Load	0.27*	0.46**	0.21	0.51**	-0.27*	0.34*	0.39**	0.09	0.14	0.08	-0.02	0.00
TSS Conc	0.16	-0.06	-0.10	-0.05	-0.10	0.05	0.34*	-0.01	-0.08	-0.01	-0.09	-0.02
TSS Load	0.18	-0.01	-0.05	-0.02	-0.08	0.06	0.30*	0.00	-0.08	0.00	-0.06	0.02
Cl Conc	-0.09	-0.12	0.11	-0.21	0.39*	-0.24*	-0.36*	-0.14	-0.23	-0.18	-0.05	0.15
Cl Load	0.48**	0.69**	0.74**	0.56**	0.19	0.24*	-0.10	0.23	0.16	0.01	0.41**	0.52**

Several results of the regression analyses are worth noting:

- TP and Cl load rates were significantly and positively correlated with flow rate and with volumes, suggesting stormwater as a primary form of transport; accordingly, TP loading and concentration were significantly and negatively correlated with increased baseflow ratio;
- Cl was negatively and significantly correlated with month, suggesting dilution and flushing of road de-icer application during winter months;
- TSS loading was not well correlated with any variables, though TSS and TP concentration were significantly correlated;
- Flow rate was strongly (and positively) correlated with event precipitation, antecedent precipitation and antecedent stage; this is a logical result as wetter antecedent conditions would mean less storage and infiltration capacity in the watershed;
- Rainfall intensity was strongly correlated with several parameters, including TP and TSS load rates and concentrations, potentially indicating soil erosion or re-suspension of sediment during intense storms as P sources.

A-5 Analysis Summary: St. Paul Park

A-5.1 Seasonal (April – October) Loading by Year

Estimated loads are shown in Table A-5.1 below for the monitoring period (April – October) of each year. Absolute load (ft^3 or lb), loading rate (ft^3/d or lb/d), and yield (ft^3 or lb per in. of precipitation) are shown by year along with baseflow ratio and runoff coefficient. Precipitation totals are for April 1 – October 31 of each year; volumes and loads have been scaled proportional to the amount of rainfall during data gaps.

Very little baseflow is present at this site, and runoff coefficients are quite high in some years, consistent with expectations for a highly developed watershed. The RC for 2011 (1.0) and perhaps 2014 (0.84) might be erroneous, so loading estimates for these years should be considered carefully. Larger and more frequent gaps are present in the monitoring data record at this site than at other SWWD sites, contributing additional uncertainty to the loading estimates.

Table A-5.1. Seasonal (Apr – Oct) volumes and nutrient loads, precipitation depth, antecedent snowfall, and flow characteristics for all monitored years at the St. Paul Park site. Loads have been scaled by precipitation depth for gaps in the data record.

Year	Monitoring Start	Monitoring End	Gaps (d)	Volume Load (ft^3)	Volume Rate (ft^3/d)	Volume Yld (ft^3/in)	Precip in	Ant. Snow in	Base Ratio	Runoff Coeff
2006	5/15/06 15:00	10/26/06 11:00	57.4	655,202	3062	36,505	17.9	66.4	0.05	0.34
2007	4/10/07 17:00	10/19/07 13:00	44.4	1,093,773	5112	48,070	22.8	35.5	0.06	0.44
2008	4/14/08 14:00	11/2/08 6:00	63.2	659,549	3083	32,837	20.1	44.9	0.07	0.30
2009	4/6/09 17:00	10/25/09 9:00	15.2	1,245,816	5823	59,848	20.8	45.0	0.14	0.55
2010	4/1/10 1:00	10/18/10 16:00	42.5	1,867,460	8728	58,015	32.2	40.7	0.10	0.53
2011	4/7/11 13:00	8/18/11 2:00	100.8	2,362,163	11040	108,422	21.8	86.6	0.18	1.00
2012	4/1/12 1:00	11/6/12 2:00	0.0	782,000	3655	43,582	17.9	22.3	0.06	0.40
2013	4/4/13 17:00	11/1/13 0:00	52.1	1,475,830	6898	67,272	21.9	67.7	0.30	0.62
2014	4/10/14 13:00	10/29/14 8:00	15.5	2,606,544	12182	91,226	28.6	69.8	0.16	0.84

Year	TP Load (lb)	TP Rate (lb/d)	TP Yld (lb/in)	TSS Load (lb)	TSS Rate (lb/d)	TSS Yld (lb/in)	Cl Load (lb)	Cl Rate (lb/d)	Cl Yld (lb/in)
2006	8	0.038	0.4	4,691	21.9	261.4	142	0.7	8
2007	13	0.061	0.6	9,111	42.6	400.4	239	1.1	11
2008	9	0.043	0.5	8,686	40.6	432.4	187	0.9	9
2009	14	0.067	0.7	14,279	66.7	685.9	403	1.9	19
2010	22	0.103	0.7	20,372	95.2	632.9	471	2.2	15
2011	25	0.118	1.2	70,171	328.0	3220.8	756	3.5	35
2012	9	0.043	0.5	33,011	154.3	1839.7	289	1.4	16
2013	18	0.085	0.8	18,372	85.9	837.4	670	3.1	31
2014	21	0.096	0.7	13,019	60.8	455.6	1,850	8.6	65

A-5.2 Year-to-year Variability in Nutrient Concentrations

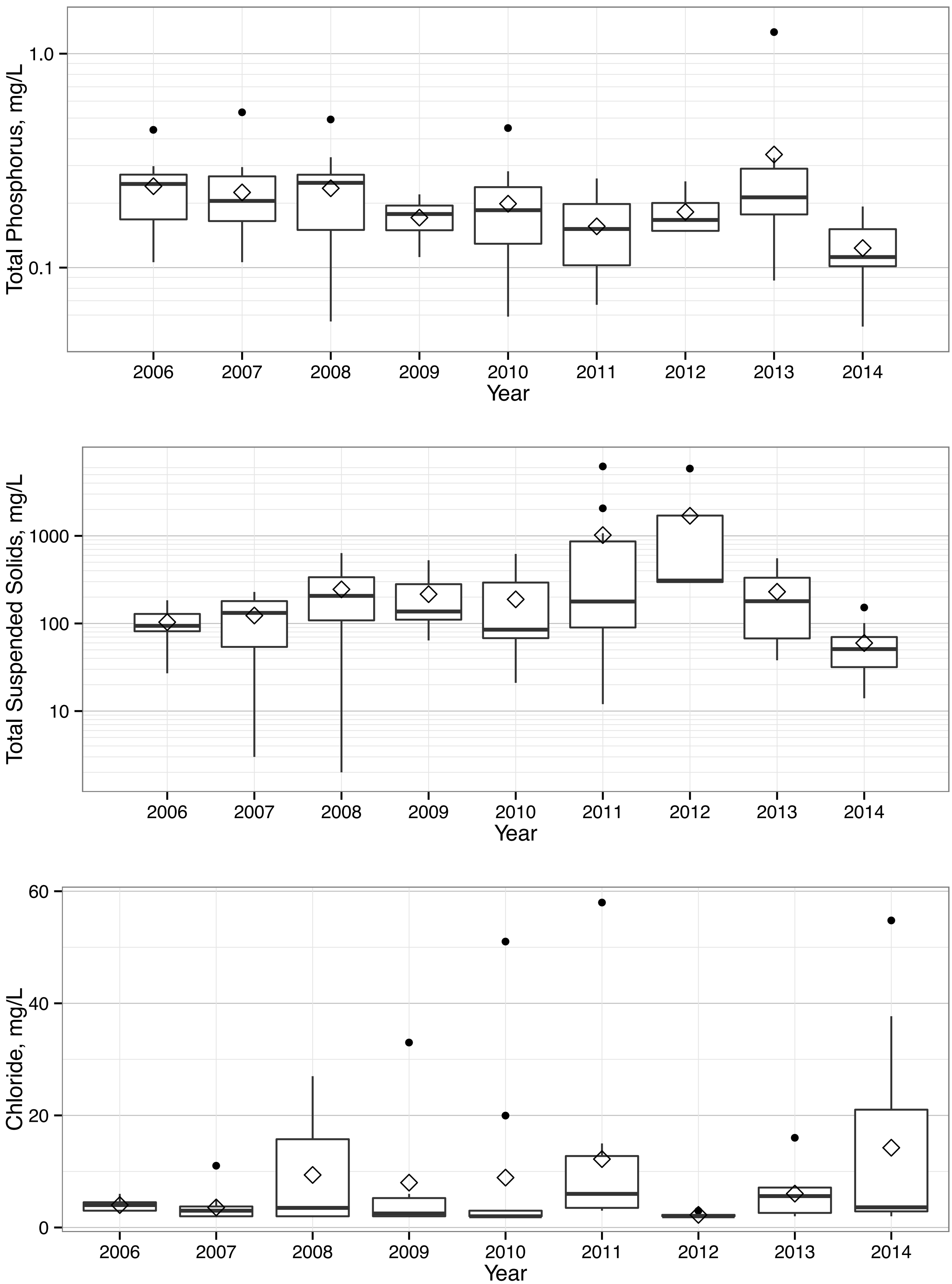
TP, TSS, and Cl concentration data are summarized by year in Figure A-5.1, and by year and flow regime in the tables below (Table A-5.2).

- TP concentration was higher near the beginning of the record (with the exception of 2013), and decreased significantly with year over the record ($r = -0.34$, $p < 0.05$; Table A-5.4);
- TSS concentration was generally highest in 2011 and 2012 but decreased in 2013 and 2014, with no significant trends over the record;
- Cl concentration, while generally low overall, increased slightly with year over the record, and was significant at $p < 0.05$;

Table A-5.2. Statistical summary of TP, TSS, and Cl concentration data at St. Paul Park.

	Total Phosphorus Concentration (mg/L)							Total Suspended Solids Concentration (mg/L)							Chloride Concentration (mg/L)						
Year	**n**	**Min**	**1st Qtile**	**Median**	**3rd Qtile**	**Max**	**Mean**	**n**	**Min**	**1st Qtile**	**Median**	**3rd Qtile**	**Max**	**Mean**	**n**	**Min**	**1st Qtile**	**Median**	**3rd Qtile**	**Max**	**Mean**
2006	*9*	0.106	0.168	0.246	0.272	0.440	0.240	*7*	27	82	94	129	184	104	*7*	3	3	4	5	6	4
2007	*15*	0.106	0.165	0.205	0.267	0.533	0.225	*9*	3	54	132	180	229	123	*14*	2	2	3	4	11	4
2008	*8*	0.056	0.126	0.249	0.291	0.492	0.235	*8*	2	73	207	382	636	245	*8*	2	2	4	18	27	9
2009	*7*	0.112	0.150	0.178	0.195	0.220	0.171	*7*	64	111	137	281	527	216	*6*	2	2	3	6	33	8
2010	*10*	0.059	0.122	0.186	0.254	0.449	0.199	*9*	21	68	85	293	622	188	*10*	2	2	2	3	51	9
2011	*10*	0.067	0.100	0.152	0.202	0.261	0.156	*10*	12	83	178	1070	6200	1021	*10*	3	3	6	14	58	12
2012	*4*	0.141	0.146	0.167	0.218	0.253	0.182	*4*	294	296	309	3090	5860	1693	*4*	2	2	2	3	3	2
2013	*8*	0.087	0.163	0.213	0.302	1.260	0.338	*8*	38	67	180	378	555	230	*8*	2	2	6	7	16	6
2014	*12*	0.053	0.101	0.112	0.159	0.193	0.123	*10*	14	29	51	74	152	60	*12*	2	3	4	24	55	14
snowmelt	*6*	0.056	0.067	0.219	0.295	1.260	0.353	*6*	2	12	72	85	293	89	*6*	11	16	21	51	58	30
baseflow	*3*	0.078	0.142	0.205	0.252	0.298	0.194	*3*	2	3	3	40	77	27	*3*	2	3	4	16	27	11
stormflow	*74*	0.053	0.131	0.183	0.246	0.533	0.194	*63*	14	68	152	291	6200	410	*70*	2	2	3	5	55	6
all data	***83***	**0.053**	**0.127**	**0.183**	**0.248**	**1.260**	**0.206**	***72***	**2**	**62**	**127**	**275**	**6200**	**367**	***79***	**2**	**2**	**3**	**7**	**58**	**8**

Figure A-5.1. Boxplots of nutrient concentrations of all sampled **events** at St. Paul Park, by year. Diamonds are mean concentrations and dots are outliers. Note log scale on vertical axes for TP and TSS.



A-5.3 Year-to-year Variability in Seasonal (April - October) Loading

Linear regression was used to investigate general patterns between the seasonal loading and precipitation parameters from Table A-5.1 above; results are shown in Table A-5.3.

- Volume was a significant predictor for the nutrient loads, but precipitation (which would be expected to correlate well with volume) was not significantly related to any variables at the annual scale;
- Load rate and yield of water volume were positively and significantly correlated with antecedent snowfall, suggesting that snowmelt may be crucial for setting initial (Spring) water levels in shallow groundwater in the watershed, or may simply be contributing supplemental flow early in the season;
- Chloride loading increased significantly with year over the data record;
- TP loading was strongly related to TSS loading but not to that of Cl, suggesting the importance of particulate forms of P;
- Loading rates of water and nutrients generally increased year-to-year over the study period, though none of the relationships (except for Cl) were significant.

Table A-5.3. Summary of Pearson *r* values from regression of annual flow and nutrient concentrations vs. several precipitation and flow parameters. * indicates significance at $p < 0.05$, ** for significance at $p < 0.001$.

Parameter	**Year**	**Total Volume**		**Precip**	**Ant**	**Baseflow**	**TP**		**TSS**		**Cl**	
		Rate	*Yield*		**Snow**	Ratio	*Load Rate*	*Yield*	*Load Rate*	*Yield*	*Load Rate*	*Yield*
Vol, Rate	0.56		0.98**	0.45	0.69*	0.58	0.96**	0.92**	0.73*	0.58	0.81*	0.73*
Vol, Yield	0.63	0.98**		0.42	0.69*	0.62	0.91**	0.92**	0.73*	0.61	0.85*	0.80*
Precip	0.55	0.45	0.42		-0.06	0.29	0.33	0.23	-0.14	-0.21	0.60	0.58
TP Load Rate	0.46	0.96**	0.91**	0.33	0.65	0.62		0.97**	0.81*	0.65	0.63	0.53
TP Yield	0.50	0.92**	0.92**	0.23	0.65	0.69*	0.97**		0.85*	0.73*	0.61	0.53
TSS Load Rate	0.30	0.73*	0.73*	-0.14	0.49	0.32	0.81*	0.85*		0.96**	0.34	0.26
TSS Yield	0.35	0.58	0.61	-0.21	0.30	0.24	0.65	0.73*	0.96**		0.24	0.20
Cl Load Rate	0.76*	0.81*	0.85*	0.60	0.62	0.58	0.63	0.61	0.34	0.24		0.99**
Cl Yield	0.80*	0.73*	0.80*	0.58	0.56	0.57	0.53	0.53	0.26	0.20	0.99**	

A-5.4 Seasonal and Monthly Variability in Event Nutrient Loads and Concentrations

Monthly event loading rates (cfs or lb/d) of water, TP, TSS, and Cl are summarized in the box-plots below (Figure A-5.2). Several results are worth noting:

- Loading of water, TP, TSS, and Cl were generally highest in Spring and early Summer (Apr – June), and decreased over the rest of the season; this pattern suggests hydrologic control for loading rates, and also that soil erosion or sediment may be an important source of P;
- Higher and more variable flow rates in late spring and early summer may be evidence of larger or more intense storms occurring while water retention is relatively low in the watershed (e.g. while evapotranspiration rates are low, or before lawns are established);
- Cl loading rates decreased throughout the season, likely indicating a flushing of winter road de-icer.

Event concentration data are summarized by month in Figure A-5.3 and by season in Figure A-5.4. These are intended to illustrate the strong seasonality of the nutrient data. Several results are worth noting:

- TP, TSS, and Cl concentrations generally decreased from Spring to September, roughly consistent with the pattern seen in the monthly loading data; the summer decreases were statistically significant for all three constituents (Table A-5.4);
- The timing of peak concentrations varied somewhat, with highest TP occurring in March and May, and highest TSS occurring in early summer (potentially indicating early season erosion as a TSS and TP source);
- Cl concentrations were significantly higher in spring than in fall or summer, suggesting relatively rapid flushing from the watershed in spring rains and snowmelt;
- While data are somewhat limited in the early and late season, the high TP concentrations in March and May as well as the increase from September to October may be related to leaf litter inputs to streets, i.e. leaf out in May, leaf fall in October, and flushing in March of over-winter decomposition of leaf litter remaining on the streets and lawns at the onset of winter.

Figure A-5.2. Boxplots of flow and nutrient **loading rates** of all sampled **events** at St. Paul Park, by month. Diamonds are mean concentrations and dots are outliers. Note log scale on the vertical axes.

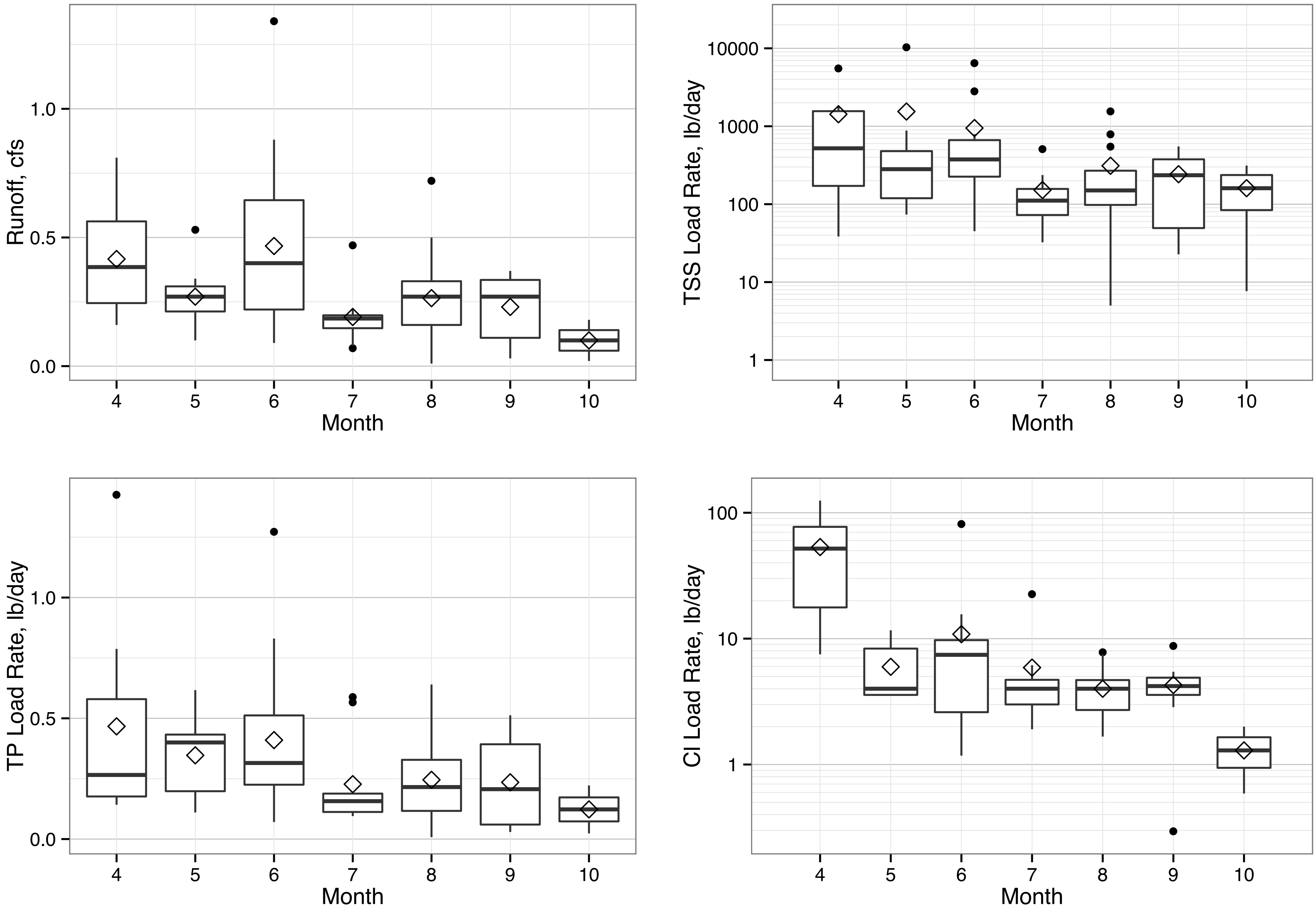
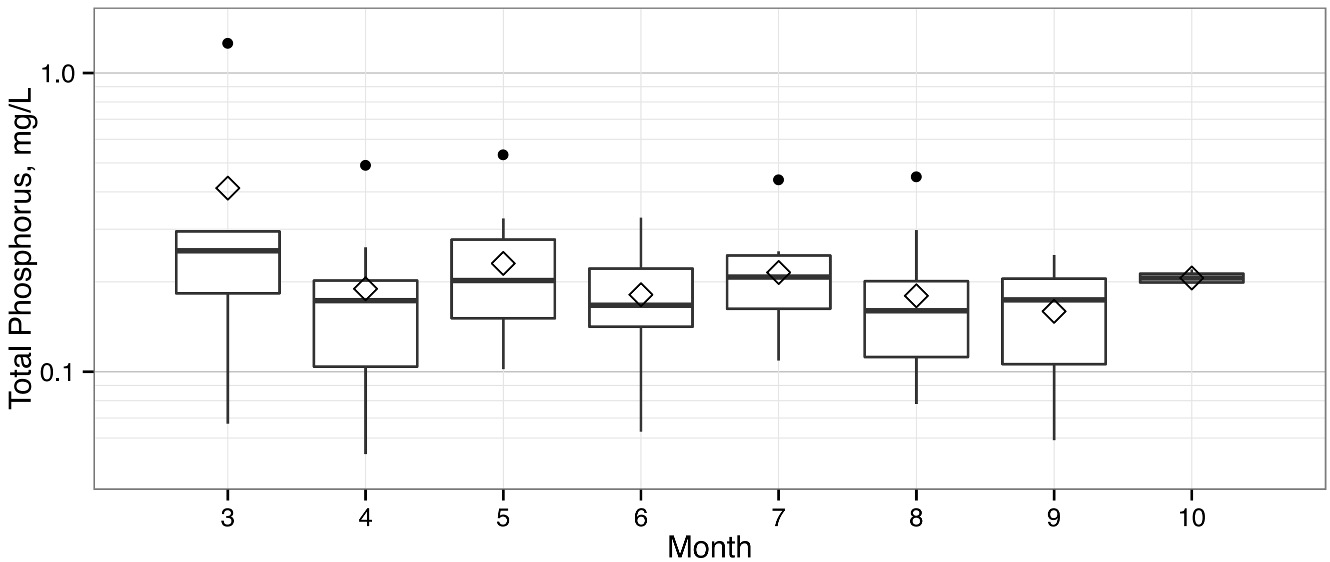
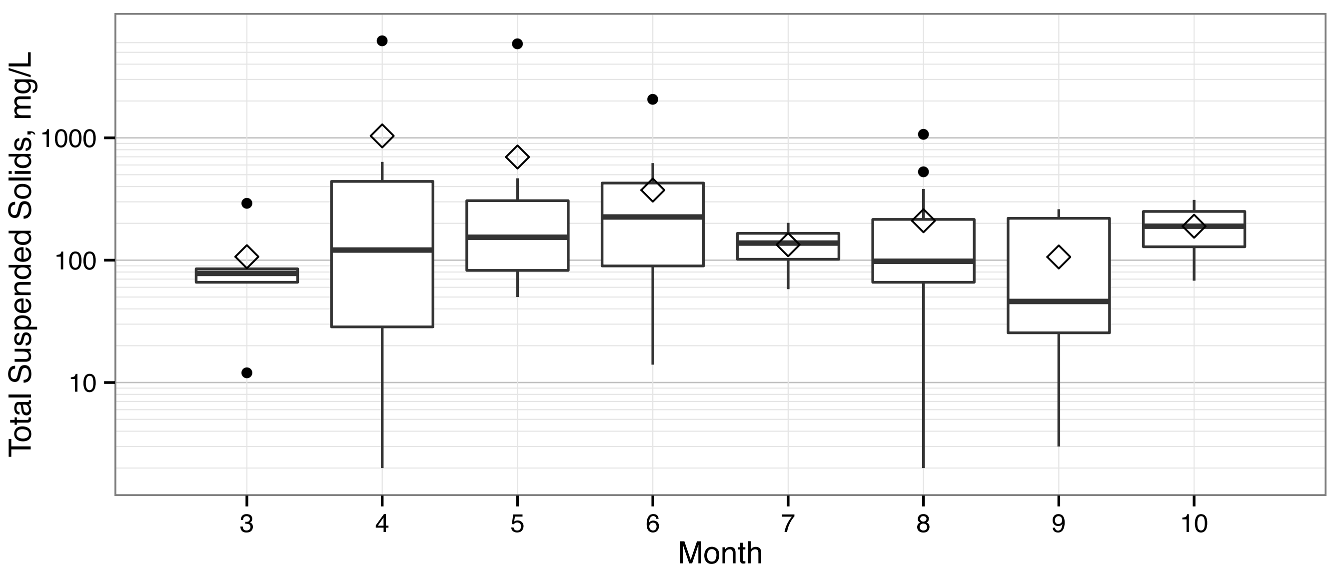


Figure A-5.3. Boxplots of monthly nutrient **concentrations** of all sampled **events** at St. Paul Park. Diamonds are mean concentrations and dots are outliers. Note log scale on the vertical axes.





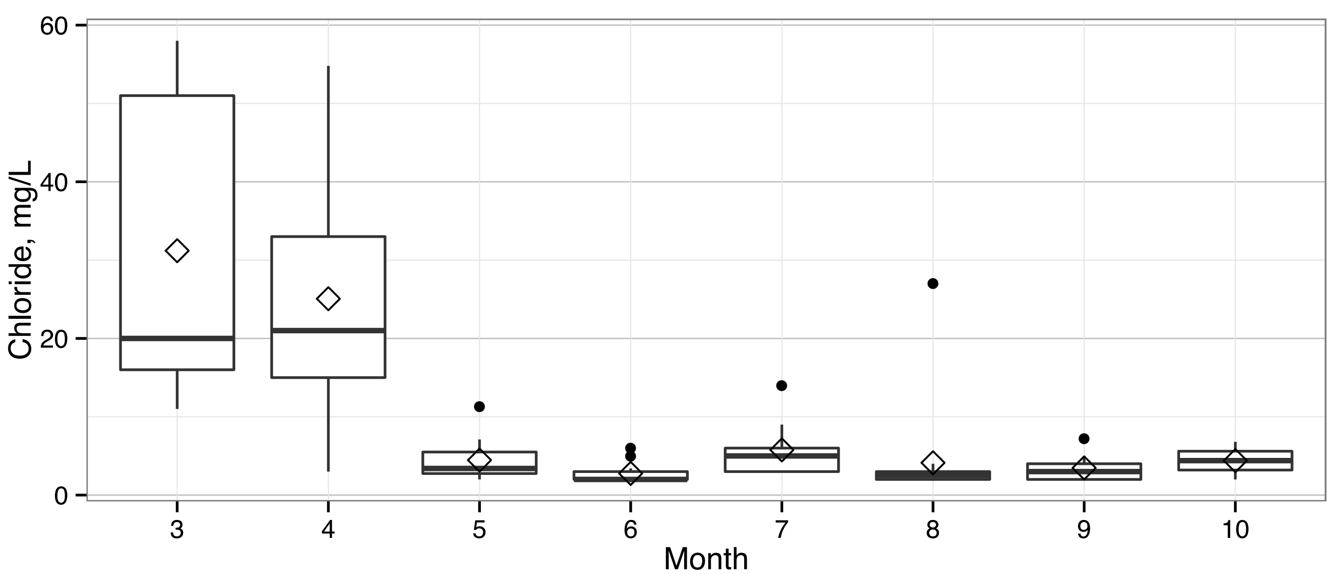
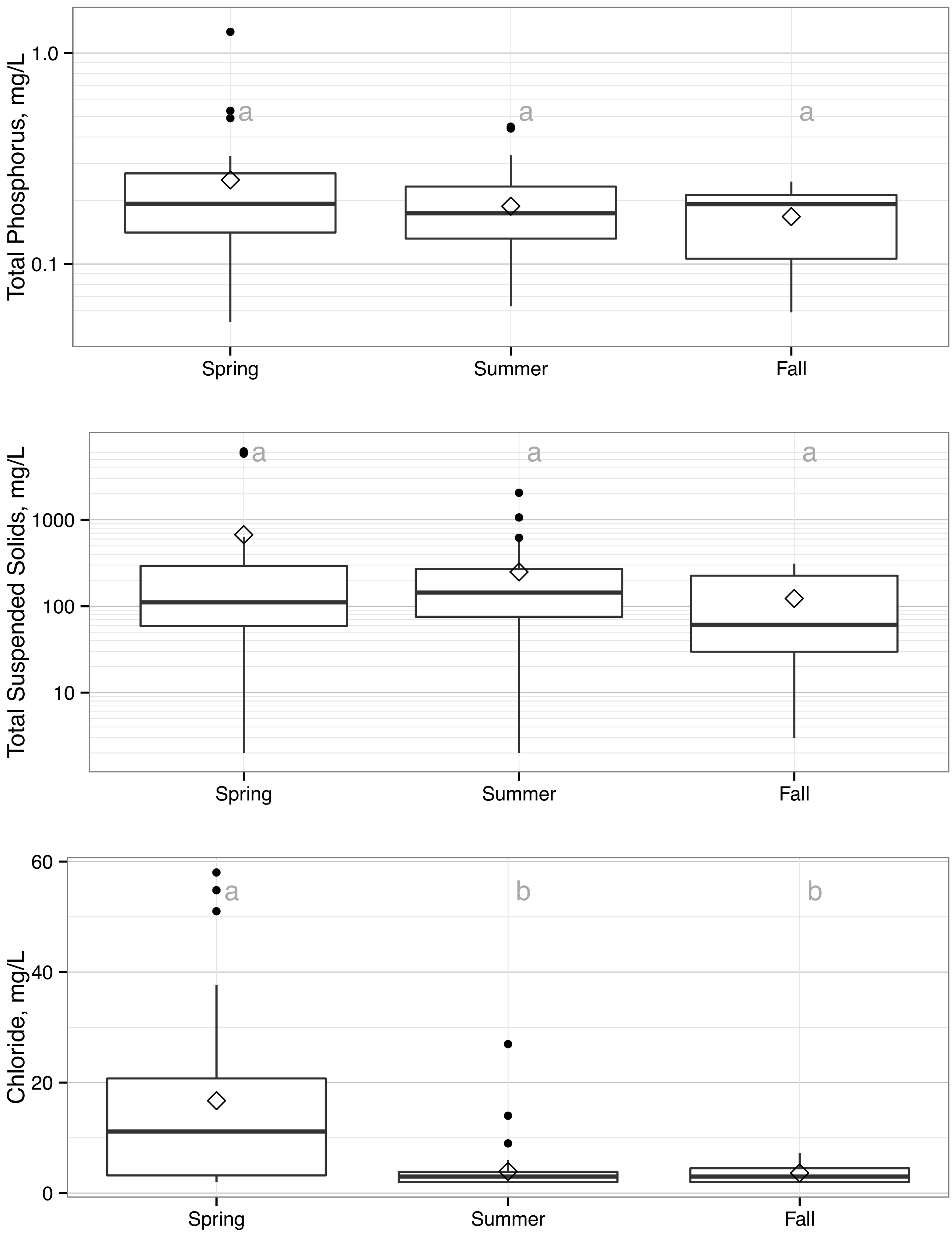


Figure A-5.4. Boxplots of seasonal nutrient **concentrations** of all sampled **events** at St. Paul Park. Diamonds are mean concentrations and dots are outliers; seasons with different letters are significantly different at $p < 0.05$ by Mann-Whitney-Wilcoxon rank sum test. Note log scale on vertical axes.



A-5.5 Influence of Antecedent Precipitation and Flow on Event Nutrient Loads and Concentrations

Simple linear regression was used to investigate the effect of several precipitation and flow parameters on observed event volumes and observed nutrient loads and concentrations, as well as to illustrate any relationships between the parameters themselves. Results considering concentration data only are shown in Table A-5.4, while results for event loading data are shown in Table A-5.5. Note that the concentration data set has more samples than the loading data set because some samples were collected when flow was not monitored. Pearson *r* are shown in the tables along with significance of the regressions: * indicates significance at $p < 0.05$, ** indicates significance at $p < 0.001$.

Table A-5.4. Results of regression of event flow and nutrient concentrations vs. several temporal and antecedent precipitation and flow parameters.

Param	Year	Month	Flow Rate	BF Ratio	Antecedent Precip			Ant. Stage		TP	TSS	Cl
					28 Days	*14 Days*	*7 Days*	*6 Hr*	*7 Days*	Conc	Conc	Conc
Flow Rate	0.15	0.02		-0.17	0.30 *	0.23 *	0.19	-0.01	0.11	0.00	0.02	-0.23
BF Ratio	0.30 *	-0.33 *	-0.17		0.09	0.19	0.22	0.21	0.28 *	-0.22	0.14	0.11
TP Conc	-0.34 *	-0.12	0.00	-0.22	-0.24 *	-0.26 *	-0.16	-0.34 *	-0.27 *		0.10	-0.19
TSS Conc	0.10	-0.25 *	0.02	0.14	-0.01	0.03	0.19	-0.08	0.01	0.10		-0.01
Cl Conc	0.25 *	-0.43 **	-0.23	0.11	-0.29 *	-0.18	-0.10	0.05	0.05	-0.19	-0.01	

Table A-5.5. Results of regression of event flow and nutrient loading vs. antecedent precipitation and flow parameters.

Param.	Flow	Volume			BF	Precip		Antecedent Precip			Ant. Stage	
	Rate	Total	Baseflow	Storm	Ratio	Depth	Intensity	*28 Days*	*14 Days*	*7 Days*	*6 Hr*	*7 Days*
Flow Rate		0.77**	0.47**	0.82**	0.25*	0.54**	0.19	0.28*	0.36*	0.22	0.15	0.25*
Vol, Total	0.77**		0.82**	0.95**	0.48**	0.66**	0.08	0.22	0.23*	0.19	0.19	0.32*
Vol, Base	0.47**	0.82**		0.61**	0.56**	0.48**	-0.12	0.12	0.15	0.18	0.14	0.20
Vol, Storm	0.82**	0.95**	0.61**		0.38**	0.66**	0.17	0.24*	0.24*	0.17	0.19	0.34*
BF Ratio	0.25*	0.48**	0.56**	0.38**		0.42**	-0.21	0.12	0.26*	0.36*	0.41**	0.51**
TP Conc	-0.11	-0.25*	-0.19	-0.25*	-0.31*	-0.28*	0.05	-0.27*	-0.28*	-0.19	-0.34*	-0.28*
TP Load	0.68**	0.87**	0.74**	0.82**	0.42**	0.56**	0.18	0.12	0.07	0.10	0.00	0.17
TSS Conc	-0.02	-0.03	-0.02	-0.03	0.27*	-0.05	0.08	-0.02	0.03	0.18	-0.09	0.00
TSS Load	0.14	0.13	0.09	0.13	0.29*	0.07	0.18	0.03	0.01	0.17	-0.06	0.06
Cl Conc	0.06	0.10	0.14	0.07	0.16	-0.03	-0.28*	-0.27*	-0.16	-0.09	0.05	0.05
Cl Load	0.53**	0.72**	0.64**	0.67**	0.38*	0.48**	-0.12	0.04	0.15	0.19	0.20	0.32*

Several results of the regression analyses are worth noting:

- Event TP and Cl loading were significantly and positively correlated with flow rate and with volumes;
- Wetter antecedent conditions were also correlated with lower TP concentration, a pattern consistent with build up – wash off of particulate P from impervious surfaces;
- Cl was negatively and significantly correlated with month, suggesting dilution and flushing of road de-icer application during winter months;
- Flow rate was correlated with event precipitation, antecedent precipitation and antecedent stage, illustrating a strong linkage between precipitation and hydrology at this watershed; in addition, flow rate and storm volume were more strongly related to antecedent rainfall over the longer time scales than the shorter time scales, perhaps indicating limited infiltration capacity in the watershed (e.g. from a higher water table or more extensive impervious areas);
- As was the case with the annual loads, event loading was strongly controlled by hydrology, with TP and Cl loads well-correlated with precipitation, flow rate, and total, storm, and baseflow volumes.

A-6 Analysis Summary: Trout Brook

A-6.1 Seasonal (April – October) Loading by Year

Estimated loads are shown in Table A-6.1 below for the monitoring period (April – October) of each year. Absolute load (ft^3 or lb), loading rate (ft^3/d or lb/d), and yield (ft^3 or lb per in. of precipitation) are shown by year along with baseflow ratio and runoff coefficient. Precipitation totals are for April 1 – October 31 of each year; volumes and loads have been scaled proportional to the amount of rainfall during data gaps.

Trout Brook has more baseflow than the other SWWD sites because it is a stream, and heavily influenced by groundwater inputs. Therefore the site has high baseflow ratios and low runoff coefficients relative to the other SWWD sites. Yields and loading rates are also high relative to the other sites due to this persistent baseflow.

Table A-6.1. Seasonal (Apr – Oct) volumes and nutrient loads, precipitation depth, antecedent snowfall, and flow characteristics for all monitored years at the Trout Brook site. Loads have been scaled by precipitation depth for gaps in the data record.

Year	Monitoring Start	Monitoring End	Gaps (d)	Volume Load (ft^3)	Volume Rate (ft^3/d)	Volume Yld (ft^3/in)	Precip in	Ant. Snow in	Base Ratio	Runoff Coeff
2011	4/15/11 13:00	10/29/11 15:00	16.9	47,988,083	224287	2,322,476	20.7	86.6	0.94	0.15
2012	4/1/12 1:00	10/31/12 23:00	0.0	32,977,581	154131	1,773,945	18.6	22.3	0.83	0.11
2013	4/23/13 17:00	11/1/13 7:00	22.4	35,892,529	167755	1,709,117	21.0	67.7	0.91	0.11
2014	4/10/14 16:00	11/1/14 0:00	9.6	51,817,282	242184	1,924,290	26.9	69.8	0.85	0.12

Year	TP Load (lb)	TP Rate (lb/d)	TP Yld (lb/in)	TSS Load (lb)	TSS Rate (lb/d)	TSS Yld (lb/in)	Cl Load (lb)	Cl Rate (lb/d)	Cl Yld (lb/in)
2011	705	3.295	34.1	492,878	2303.6	23853.8	128,908	602.5	6,239
2012	386	1.806	20.8	565,245	2641.8	30405.9	88,364	413.0	4,753
2013	531	2.484	25.3	414,204	1935.9	19723.4	102,425	478.7	4,877
2014	1,045	4.883	38.8	1,501,497	7017.7	55759.7	145,366	679.4	5,398

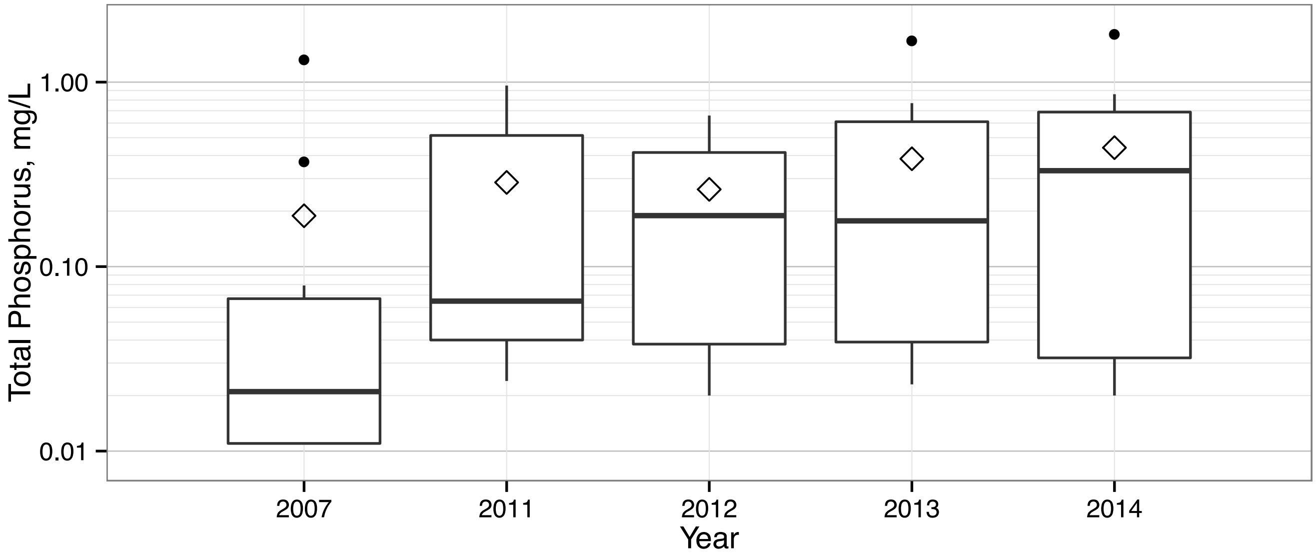
A-6.2 Year-to-year Variability in Nutrient Concentrations

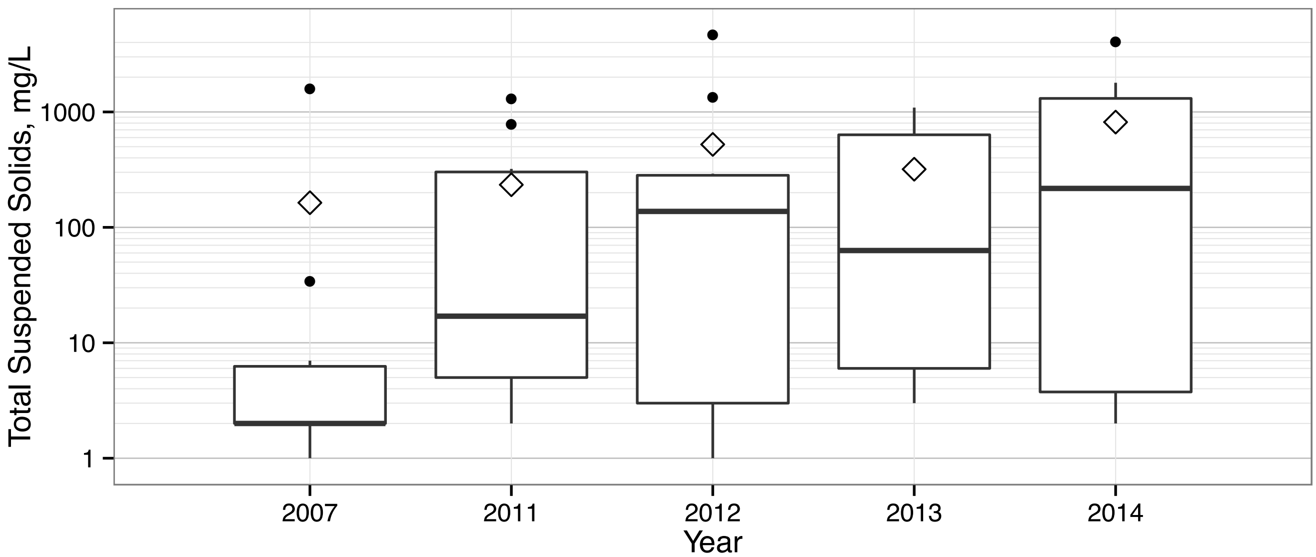
TP, TSS, and Cl concentration data are summarized by year in Figure A-6.1, and by year and flow regime in the tables below (Table A-6.2). A short record overall (5 years) and a lack of data from 2008 – 2010 make year-to-year trends difficult to assess at this site. However, TP, TSS, and Cl concentrations appear to increase slightly over the monitoring period, and the increase in TP was significant ($p < 0.05$; Table A-6.3).

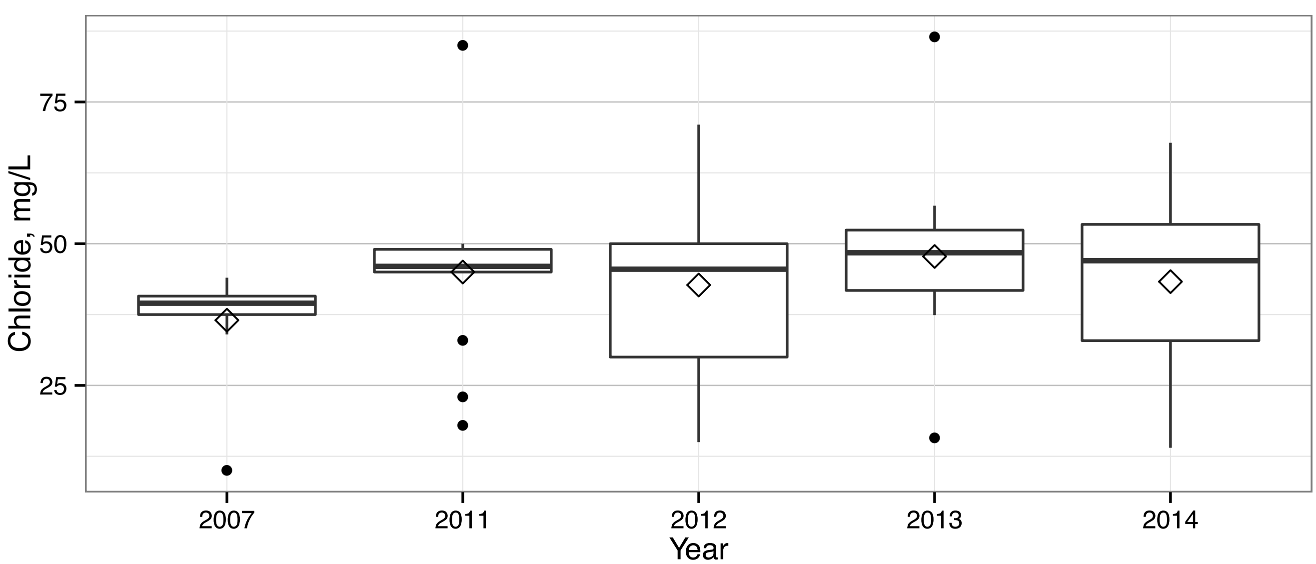
Table A-6.2. Statistical summary of TP, TSS, and Cl concentration data at Trout Brook.

	Total Phosphorus Concentration (mg/L)							Total Suspended Solids Concentration (mg/L)							Chloride Concentration (mg/L)						
Year	n	Min	1st Qtile	Median	3rd Qtile	Max	Mean	n	Min	1st Qtile	Median	3rd Qtile	Max	Mean	n	Min	1st Qtile	Median	3rd Qtile	Max	Mean
2007	*10*	0.010	0.010	0.021	0.079	1.320	0.189	*10*	1	2	2	7	1580	164	*10*	10	37	40	41	44	37
2011	*13*	0.024	0.040	0.065	0.514	0.958	0.286	*13*	2	5	17	302	1300	234	*13*	18	45	46	49	85	45
2012	*15*	0.020	0.038	0.189	0.416	0.659	0.262	*14*	1	3	138	288	4640	523	*14*	15	30	46	50	71	43
2013	*11*	0.023	0.039	0.177	0.610	1.670	0.384	*11*	3	6	63	634	1090	319	*11*	16	42	48	52	87	48
2014	*13*	0.020	0.032	0.331	0.688	1.820	0.441	*12*	2	4	218	1390	4070	817	*13*	14	33	47	53	68	43
snowmelt	*0*	NA	NA	NA	NA	NA	NA	*0*	NA	NA	NA	NA	NA	NA	*0*	NA	NA	NA	NA	NA	NA
baseflow	*16*	0.020	0.024	0.035	0.053	0.958	0.112	*16*	2	3	4	6	292	22	*16*	43	47	49	50	71	50
stormflow	*34*	0.023	0.171	0.413	0.659	1.820	0.463	*32*	1	81	295	1023	4640	727	*33*	14	30	41	52	87	40
all data	***62***	**0.010**	**0.031**	**0.115**	**0.514**	**1.820**	**0.315**	***60***	**1**	**3**	**19**	**329**	**4640**	**422**	***61***	**10**	**36**	**45**	**50**	**87**	**43**

Figure A-6.1. Boxplots of nutrient concentrations of all sampled **events** at Trout Brook, by year. Diamonds are mean concentrations and dots are outliers. Note log scale on vertical axes for TP and TSS.







A-6.3 Year-to-year Variability in Seasonal (April - October) Loading

Only 4 years of loading data were available for the Trout Brook site, which were not enough data points to do a linear regression analysis on the seasonal loads.

A-6.4 Seasonal and Monthly Variability in Event Nutrient Loads and Concentrations

Monthly event loading rates (cfs or lb/d) of water, TP, TSS, and Cl are summarized in the box-plots below (Figure A-6.2). Event concentration data are summarized by month in Figure A-6.3 and by season in Figure A-6.4. Several general patterns are apparent in the loading rate data:

- Flow rate at Trout Brook was relatively consistent from April – October, with the higher flow rates in spring and early summer likely produced by snowmelt, and potentially by higher water tables prior to drawdown by crop evapotranspiration in the watershed, which includes a substantial amount of agriculture;
- Accordingly, TSS loading and concentrations are much higher in spring and early summer than in fall, in some cases by one or two orders of magnitude; this is likely an indication of significant erosion in the early months before crops and vegetation have established;
- TP loading rates and concentrations are highest in May, June, and July, which is consistent with the patterns in TSS and suggests that sediment/particulates are likely the dominant form of P;
- Cl loading rates were roughly consistent through the season, and Cl concentrations were relatively low throughout the year (including spring), an indication of the low level of development in the watershed relative to the other SWWD sites.

Figure A-6.2. Boxplots of flow and nutrient **loading rates** of all sampled **events** at Trout Brook, by month. Diamonds are mean concentrations and dots are outliers. Note log scale on the vertical axis for TSS.

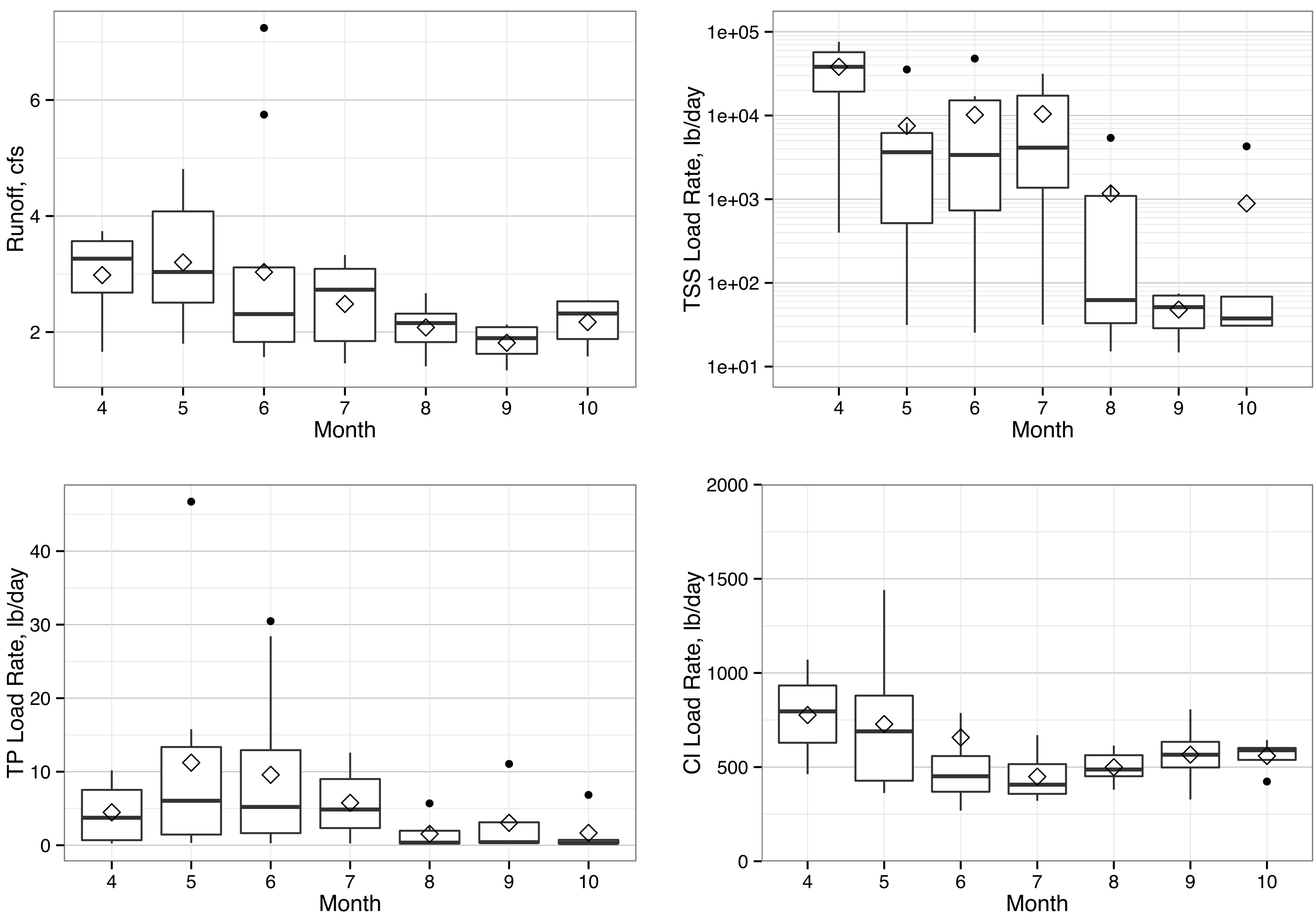


Figure A-6.3. Boxplots of monthly nutrient **concentrations** of all sampled **events** at Trout Brook. Diamonds are mean concentrations and dots are outliers. Note log scale on the vertical axes.

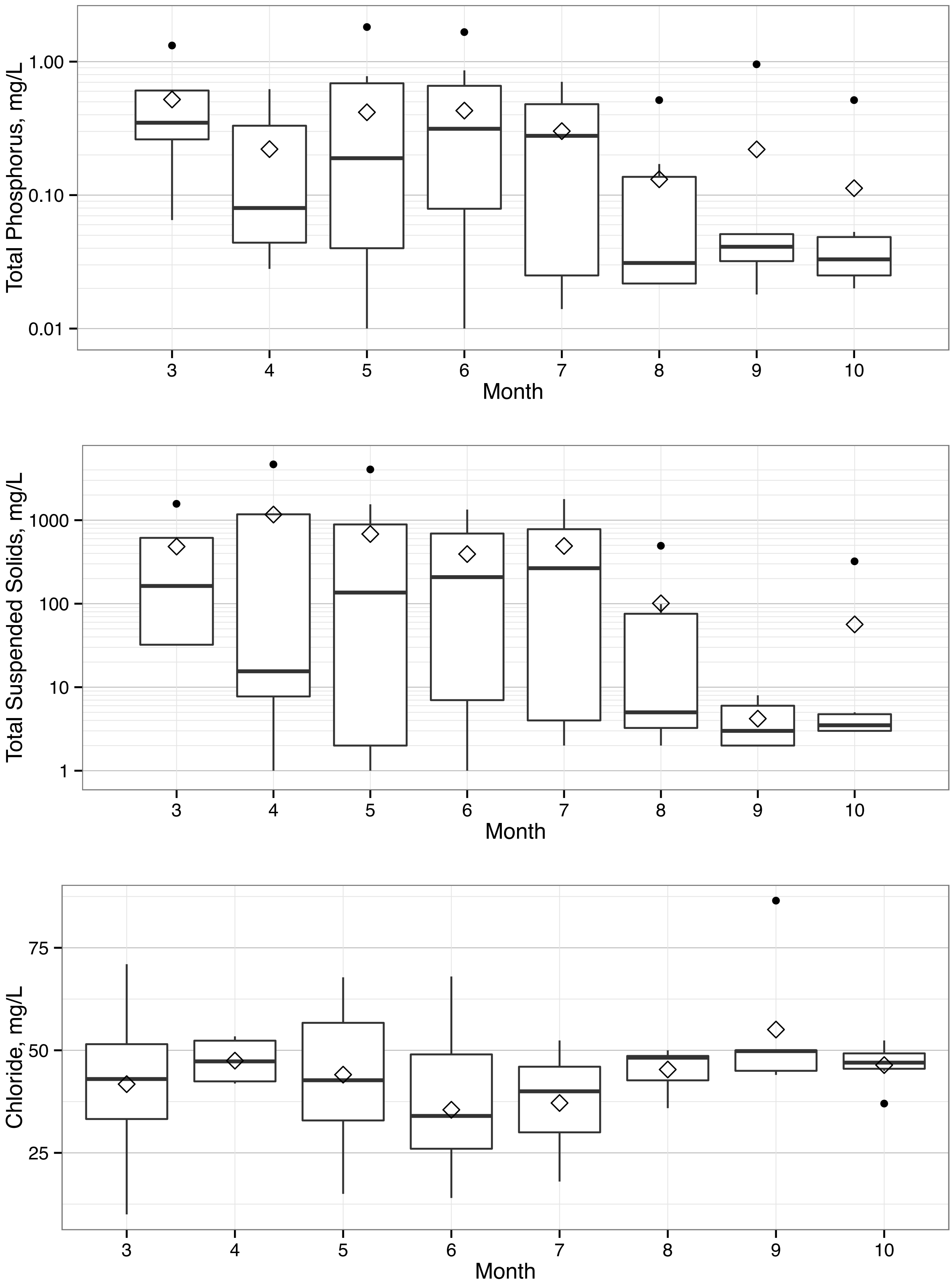
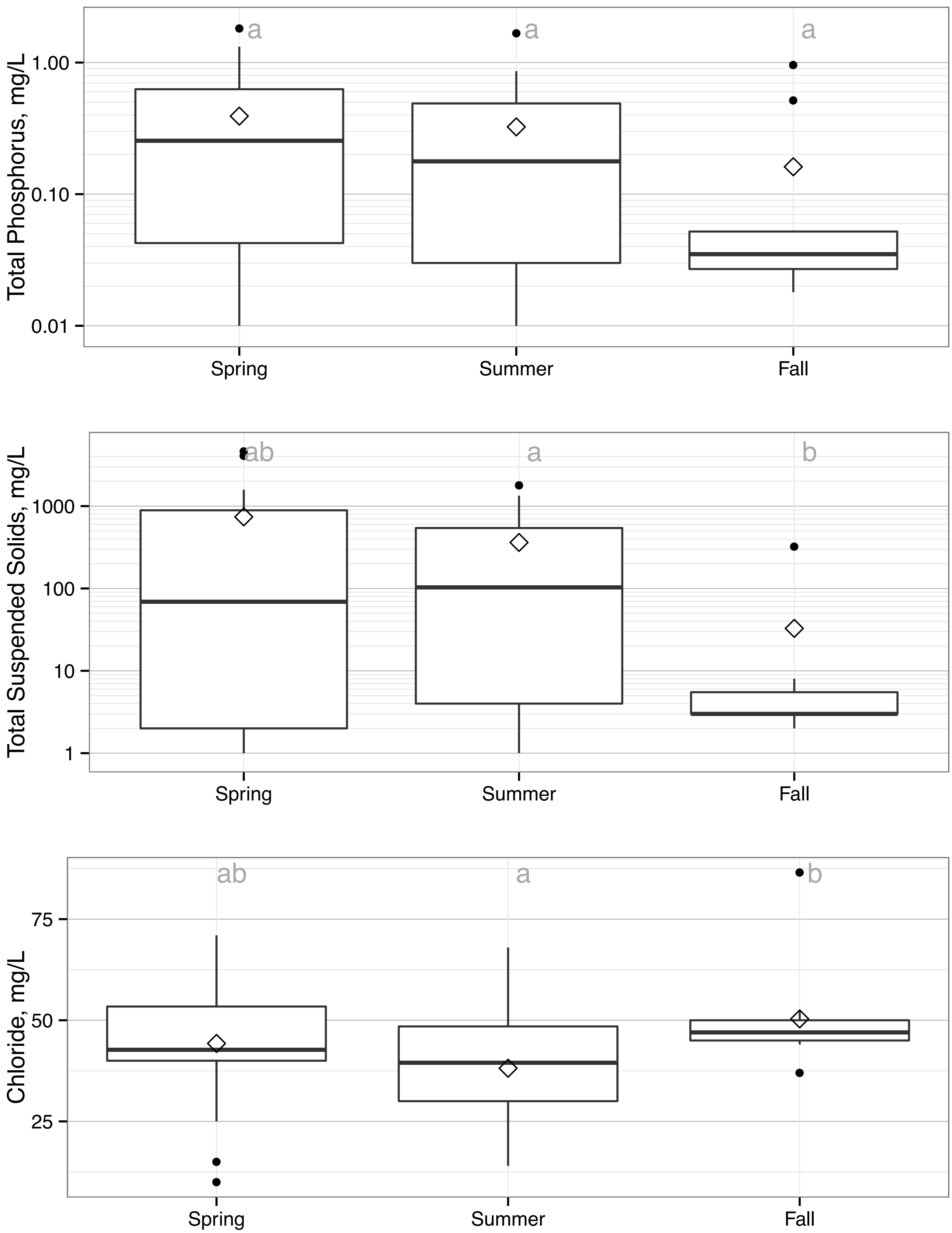


Figure A-6.4. Boxplots of seasonal nutrient **concentrations** of all sampled **events** at Trout Brook. Diamonds are mean concentrations and dots are outliers; seasons with different letters are significantly different at $p < 0.05$ by Mann-Whitney-Wilcoxon rank sum test. Note log scale on vertical axes.



A-6.5 Influence of Antecedent Precipitation and Flow on Event Nutrient Loads and Concentrations

Simple linear regression was used to investigate the effect of several precipitation and flow parameters on observed event volumes and observed nutrient loads and concentrations, as well as to illustrate any relationships between the parameters themselves. Results considering concentration data only are shown in Table A-6.3, while results for event loading data are shown in Table A-6.4. Note that the concentration data set has more samples than the loading data set because some samples were collected when flow was not monitored. Pearson *r* are shown in the tables along with significance of the regressions: * indicates significance at $p < 0.05$, ** indicates significance at $p < 0.001$.

Table A-6.3. Results of regression of event flow and nutrient concentrations vs. several temporal and antecedent precipitation and flow parameters.

Param	**Year**	**Month**	**Flow Rate**	**BF Ratio**	**Antecedent Precip**			**Ant. Stage**		**TP**	**TSS**	**Cl**
					28 Days	*14 Days*	*7 Days*	*6 Hr*	*7 Days*	Conc	Conc	Conc
Flow Rate	0.27	-0.42*		-0.76**	0.59**	0.59**	0.65**	0.51**	0.46*	0.68**	0.69**	-0.59**
BF Ratio	-0.36*	0.52**	-0.76**		-0.48**	-0.55**	-0.58**	-0.57**	-0.53**	-0.57**	-0.50**	0.44*
TP Conc	0.32*	-0.22	0.68**	-0.57**	0.28*	0.28*	0.32*	0.12	0.09		0.69**	-0.36*
TSS Conc	0.25	-0.32*	0.69**	-0.50**	0.27*	0.20	0.18	0.24	0.25	0.69**		-0.25
Cl Conc	0.13	0.15	-0.59**	0.44*	-0.43*	-0.40*	-0.65**	-0.28	-0.15	-0.36*	-0.25	

Table A-6.4. Results of regression of event flow and nutrient loading vs. antecedent precipitation and flow parameters.

Param.	**Flow**	**Volume**			**BF**	**Precip**		**Antecedent Precip**			**Ant. Stage**	
	Rate	Total	Baseflow	Storm	**Ratio**	Depth	Intensity	*28 Days*	*14 Days*	*7 Days*	*6 Hr*	*7 Days*
Flow Rate		0.52**	0.19	0.88**	-0.71**	0.67**	0.33*	0.56**	0.65**	0.54**	0.62**	0.59**
Vol, Total	0.52**		0.92**	0.57**	-0.14	0.20	-0.15	0.09	0.24	0.02	0.28	0.31*
Vol, Base	0.19	0.92**		0.20	0.21	-0.08	-0.32*	-0.08	0.06	-0.13	0.08	0.11
Vol, Storm	0.88**	0.57**	0.20		-0.76**	0.65**	0.26	0.37*	0.45*	0.31*	0.52**	0.52**
BF Ratio	-0.71**	-0.14	0.21	-0.76**		-0.69**	-0.46*	-0.41*	-0.48**	-0.53**	-0.55**	-0.49**
TP Conc	0.49**	0.09	-0.08	0.39*	-0.58**	0.59**	0.52**	0.29	0.28	0.35*	0.10	0.05
TP Load	0.70**	0.49**	0.24	0.72**	-0.57**	0.59**	0.38*	0.29	0.31*	0.23	0.29	0.29
TSS Conc	0.43*	0.05	-0.10	0.34*	-0.52**	0.53**	0.38*	0.31*	0.24	0.23	0.28	0.26
TSS Load	0.64**	0.30*	0.04	0.65**	-0.58**	0.62**	0.35*	0.37*	0.29	0.13	0.37*	0.39*
Cl Conc	-0.20	0.09	0.11	0.01	0.35*	-0.28	-0.16	-0.39*	-0.31*	-0.67**	-0.19	-0.07
Cl Load	0.45*	0.92**	0.82**	0.59**	-0.09	0.16	-0.14	-0.04	0.10	-0.22	0.20	0.26

Several results of the regression analyses are worth noting:

- Loading of TP, TSS, and Cl were well-correlated with total volume and storm volume but not with baseflow volume, while precipitation was strongly correlated with TP and TSS load rates and concentrations; these patterns logically suggest a strong influence of stormflow for export of TSS and TP by Trout Brook;
- Baseflow ratio was positively correlated with month from April – October, suggesting that stormflow was more important for water export early in the season;
- Flow rate was well correlated with event precipitation/intensity, antecedent precipitation and antecedent stage, suggesting a relatively strong link between rainfall and runoff; however, total volume was not well correlated with antecedent parameters, though storm volume logically increased with antecedent stage;
- Rainfall intensity was significantly correlated with increased TP and TSS load rates and concentration, again suggesting soil erosion as a major source of TP and TSS.

A-7 Analysis Summary: Wilmes Lake Outlet

A-7.1 Seasonal (April – October) Loading by Year

Estimated loads are shown in Table A-7.1 below for the monitoring period (April – October) of each year. Absolute load (ft^3 or lb), loading rate (ft^3/d or lb/d), and yield (ft^3 or lb per in. of precipitation) are shown by year along with baseflow ratio and runoff coefficient. Precipitation totals are for April 1 – October 31 of each year; volumes and loads have been scaled proportional to the amount of rainfall during data gaps.

Wilmes Lake Outlet has more baseflow than most other SWWD sites because it is located at a lake outlet that continues to discharge well after the end of rainfall events, due to increased residence time of water in the lake (as well as in hydrologically-connected upstream lakes). Therefore the site has high baseflow ratios and low runoff coefficients relative to most of the other SWWD sites.

Table A-7.1. Seasonal (Apr – Oct) volumes and nutrient loads, precipitation depth, antecedent snowfall, and flow characteristics for all monitored years at the Wilmes Lake Outlet site. Loads have been scaled by precipitation depth for gaps in the data record.

	Monitoring	Monitoring	Gaps	Volume			Precip	Ant. Snow	Base	Runoff
Year	Start	End	(d)	Load (ft^3)	Rate (ft^3/d)	Yld (ft^3/in)	in	in	Ratio	Coeff
2009	4/7/09 16:00	10/31/09 8:00	25.8	20,404,741	95368	1,147,850	17.8	45.0	0.48	0.10
2010	4/1/10 1:00	11/2/10 0:00	14.3	92,981,578	434578	3,502,321	26.5	40.7	0.40	0.30
2011	4/7/11 16:00	11/1/11 13:00	16.4	84,999,842	397273	4,243,335	20.0	86.6	0.68	0.36
2012	4/1/12 1:00	10/31/12 23:00	0.0	32,698,276	152825	1,838,349	17.8	22.3	0.66	0.16
2013	5/8/13 12:00	10/21/13 11:00	48.0	49,075,231	229368	2,340,475	21.0	67.7	0.70	0.20
2014	4/10/14 16:00	10/29/14 10:00	24.6	126,439,994	590956	4,110,375	30.8	69.8	0.62	0.35

	TP			TSS			Cl		
Year	Load (lb)	Rate (lb/d)	Yld (lb/in)	Load (lb)	Rate (lb/d)	Yld (lb/in)	Load (lb)	Rate (lb/d)	Yld (lb/in)
2009	122	0.570	6.9	10,627	49.7	597.8	110,224	515.2	6,201
2010	524	2.449	19.7	50,531	236.2	1903.4	393,380	1838.6	14,817
2011	374	1.750	18.7	35,079	164.0	1751.2	459,921	2149.6	22,960
2012	168	0.784	9.4	15,364	71.8	863.8	195,101	911.9	10,969
2013	230	1.074	11.0	16,718	78.1	797.3	426,642	1994.0	20,347
2014	591	2.761	19.2	50,501	236.0	1641.7	806,399	3769.0	26,215

A-7.2 Year-to-year Variability in Nutrient Concentrations

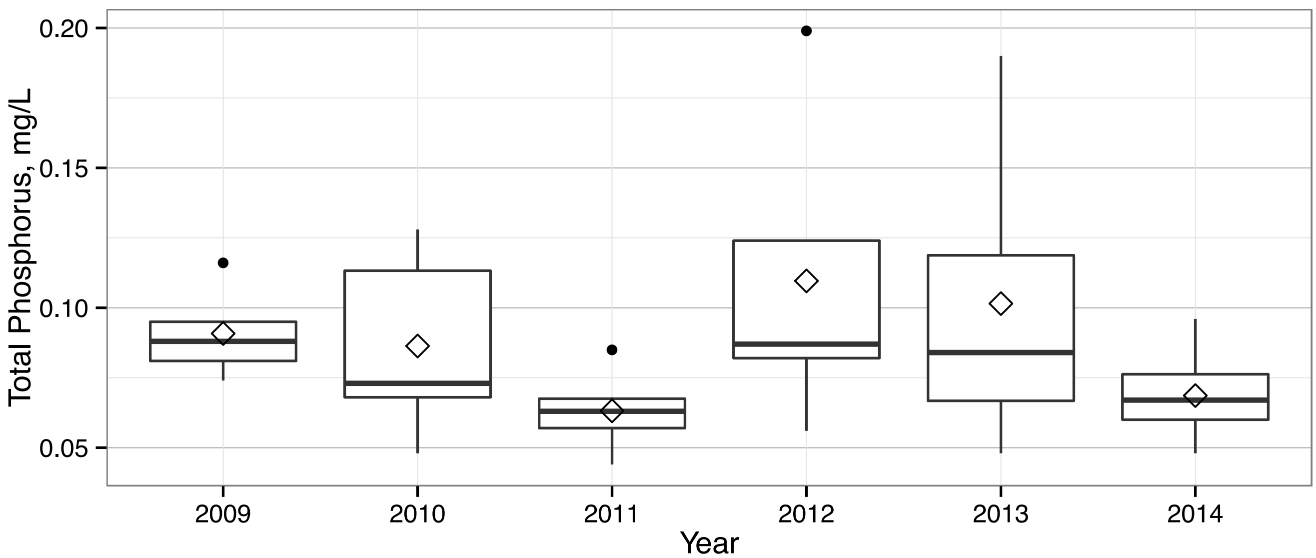
TP, TSS, and Cl concentration data are summarized by year in Figure A-7.1, and by year and flow regime in the tables below (Table A-7.2).

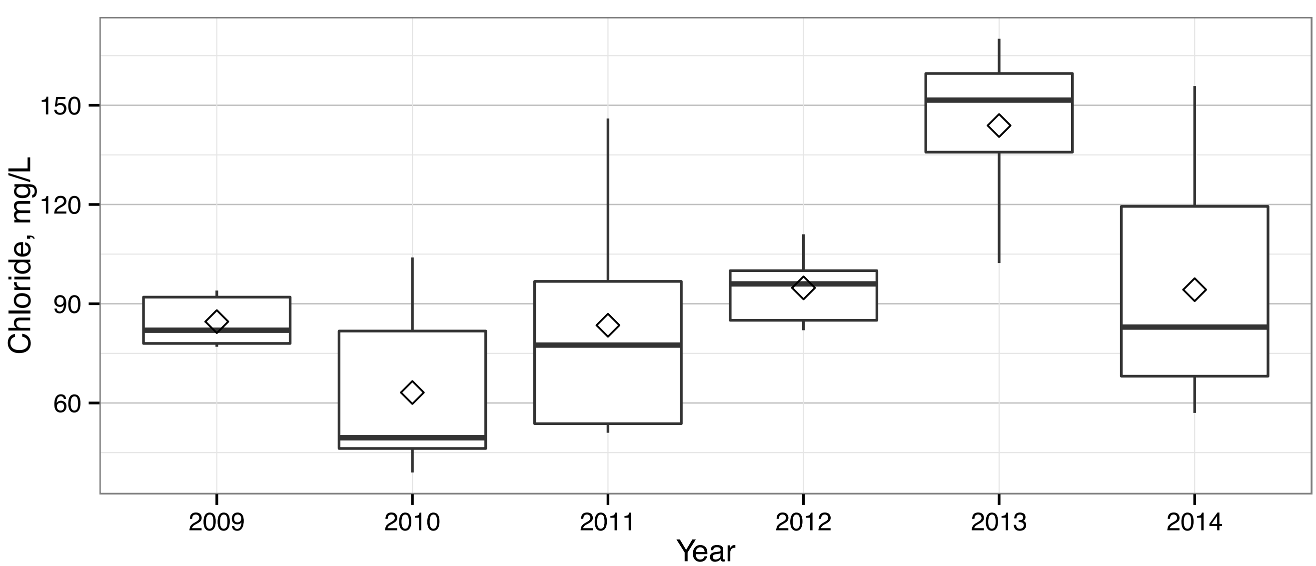
- Both TP and TSS concentrations were highest in 2012, which was a relatively dry year overall with a wet June and several intense storms in July and August;
- Cl concentrations were highest in 2013, a year with a very snowy antecedent winter and colder than average spring; therefore road de-icer inputs may have been higher in this year but appear to flush out over the course of a year;
- Very few trends are apparent year-to-year in volume or concentrations of TP, TSS, or Cl.

Table A-7.2. Statistical summary of TP, TSS, and Cl concentration data at Wilmes Lake Outlet.

	Total Phosphorus Concentration (mg/L)							Total Suspended Solids Concentration (mg/L)							Chloride Concentration (mg/L)						
Year	n	Min	1st Qtile	Median	3rd Qtile	Max	Mean	n	Min	1st Qtile	Median	3rd Qtile	Max	Mean	n	Min	1st Qtile	Median	3rd Qtile	Max	Mean
2009	*5*	0.074	0.081	0.088	0.095	0.116	0.091	*5*	5	6	8	12	13	9	*5*	77	78	82	92	94	85
2010	*12*	0.048	0.068	0.073	0.115	0.128	0.086	*12*	3	5	8	12	14	8	*12*	39	46	50	85	104	63
2011	*6*	0.044	0.056	0.063	0.068	0.085	0.063	*6*	4	5	7	7	11	7	*6*	51	52	78	97	146	84
2012	*5*	0.056	0.082	0.087	0.124	0.199	0.110	*5*	5	8	8	15	16	10	*5*	82	85	96	100	111	95
2013	*4*	0.048	0.061	0.084	0.143	0.190	0.102	*4*	5	5	6	6	6	6	*4*	102	125	152	163	170	144
2014	*8*	0.048	0.059	0.067	0.077	0.096	0.069	*8*	4	5	6	8	8	6	*8*	57	66	83	122	156	94
snowmelt	*0*	NA	NA	NA	NA	NA	NA	*0*	NA	NA	NA	NA	NA	NA	*0*	NA	NA	NA	NA	NA	NA
baseflow	*8*	0.048	0.048	0.063	0.081	0.190	0.078	*8*	3	5	6	7	13	6	*8*	39	48	68	90	156	76
stormflow	*32*	0.044	0.067	0.077	0.096	0.199	0.086	*32*	4	5	7	11	16	8	*32*	44	60	89	102	170	90
all data	***40***	**0.044**	**0.062**	**0.074**	**0.095**	**0.199**	**0.084**	***40***	**3**	**5**	**7**	**9**	**16**	**8**	***40***	**39**	**58**	**84**	**101**	**170**	**87**

Figure A-7.1. Boxplots of nutrient concentrations of all sampled **events** at Wilmes Lake Outlet, by year. Diamonds are mean concentrations and dots are outliers. Note log scale on vertical axes for TP and TSS.





A-7.3 Year-to-year Variability in Seasonal (April - October) Loading

Linear regression was used to investigate general patterns between the seasonal loading and precipitation parameters from Table A-7.1 above; results are shown in Table A-7.3.

- Volume was logically a significant predictor for the nutrient loads;
- TP loading was strongly related to TSS (r = 0.99) and precipitation was strongly correlated with both TP and TSS loads, suggesting that stormflow-transported particulates may be the dominant form of P.

Table A-7.3. Summary of Pearson r values from regression of annual flow and nutrient concentrations vs. several precipitation and flow parameters. * indicates significance at $p < 0.05$, ** for significance at $p < 0.001$.

Parameter	Year	Total Volume		Precip	Ant	Baseflow	TP		TSS		Cl	
		Rate	*Yield*		Snow	Ratio	*Load Rate*	*Yield*	*Load Rate*	*Yield*	*Load Rate*	*Yield*
Vol, Rate	0.45		0.93*	0.89*	0.51	-0.03	0.98**	0.94*	0.95*	0.88*	0.91*	0.81
Vol, Yield	0.36	0.93*		0.69	0.65	0.14	0.88*	0.96*	0.87*	0.92*	0.82*	0.85*
Precip	0.33	0.89*	0.69		0.10	-0.33	0.94*	0.79	0.93*	0.76	0.74	0.50
Ant Snow	0.32	0.51	0.65	0.10		0.43	0.38	0.48	0.31	0.38	0.64	0.79
BF Ratio	0.70	-0.03	0.14	-0.33	0.43		-0.21	-0.10	-0.29	-0.20	0.28	0.52
TP Load Rate	0.33	0.98**	0.88*	0.94*	0.38	-0.21		0.94*	0.99**	0.90*	0.83*	0.69
TP Yield	0.23	0.94*	0.96*	0.79	0.48	-0.10	0.94*		0.96*	0.98**	0.75	0.72
TSS Load Rate	0.21	0.95*	0.87*	0.93*	0.31	-0.29	0.99**	0.96*		0.94*	0.75	0.61
TSS Yield	0.08	0.88*	0.92*	0.76	0.38	-0.20	0.90*	0.98**	0.94*		0.63	0.60
Cl Load Rate	0.73	0.91*	0.82*	0.74	0.64	0.28	0.83*	0.75	0.75	0.63		0.93*
Cl Yield	0.73	0.81	0.85*	0.50	0.79	0.52	0.69	0.72	0.61	0.60	0.93*	

A-7.4 Seasonal and Monthly Variability in Event Nutrient Loads and Concentrations

Monthly event loading rates (cfs or lb/d) of water, TP, TSS, and Cl are summarized in the box-plots below (Figure A-7.2). Event concentration data are summarized by month in Figure A-7.3 and by season in Figure A-7.4. Several general patterns are apparent in the loading rate data:

- Loading of water, TP, TSS, and Cl were generally highest in June and July, though concentrations of TP and TSS in these months were low relative to the rest of the year; hydrology (lake outflow) therefore appears to be the dominant factor for magnitude and timing of nutrient export;
- Both TP and TSS concentration show increases at the end of the season (Sep and Oct), and for TSS the fall concentrations were significantly higher than in the rest of the year; this pattern may be evidence of export of sediment and decomposition products as aquatic vegetation senesces and terrestrial leaf litter inputs enter the lake in the late season; flow rates and lake level are also lower at this time and may be causing higher concentrations as well;
- TSS concentration increased significantly (p<0.05) with month from Apr – Oct; this increase may be the result of accumulated summer sediment inputs flushing out of the lake, which is very shallow in the lower bay near the outlet and therefore may have limited retention capacity near the end of the season;
- Cl decreased significantly (p<0.001) over the season, likely from dilution/flushing of winter road de-icer;
- TP concentrations were highest in April, which suggests that spring snowmelt and storms may be exporting products of over-winter decomposition of organic matter in the lake.

Figure A-7.2. Boxplots of flow and nutrient **loading rates** of all sampled **events** at Wilmes Lake Outlet, by month. Diamonds are mean concentrations and dots are outliers.

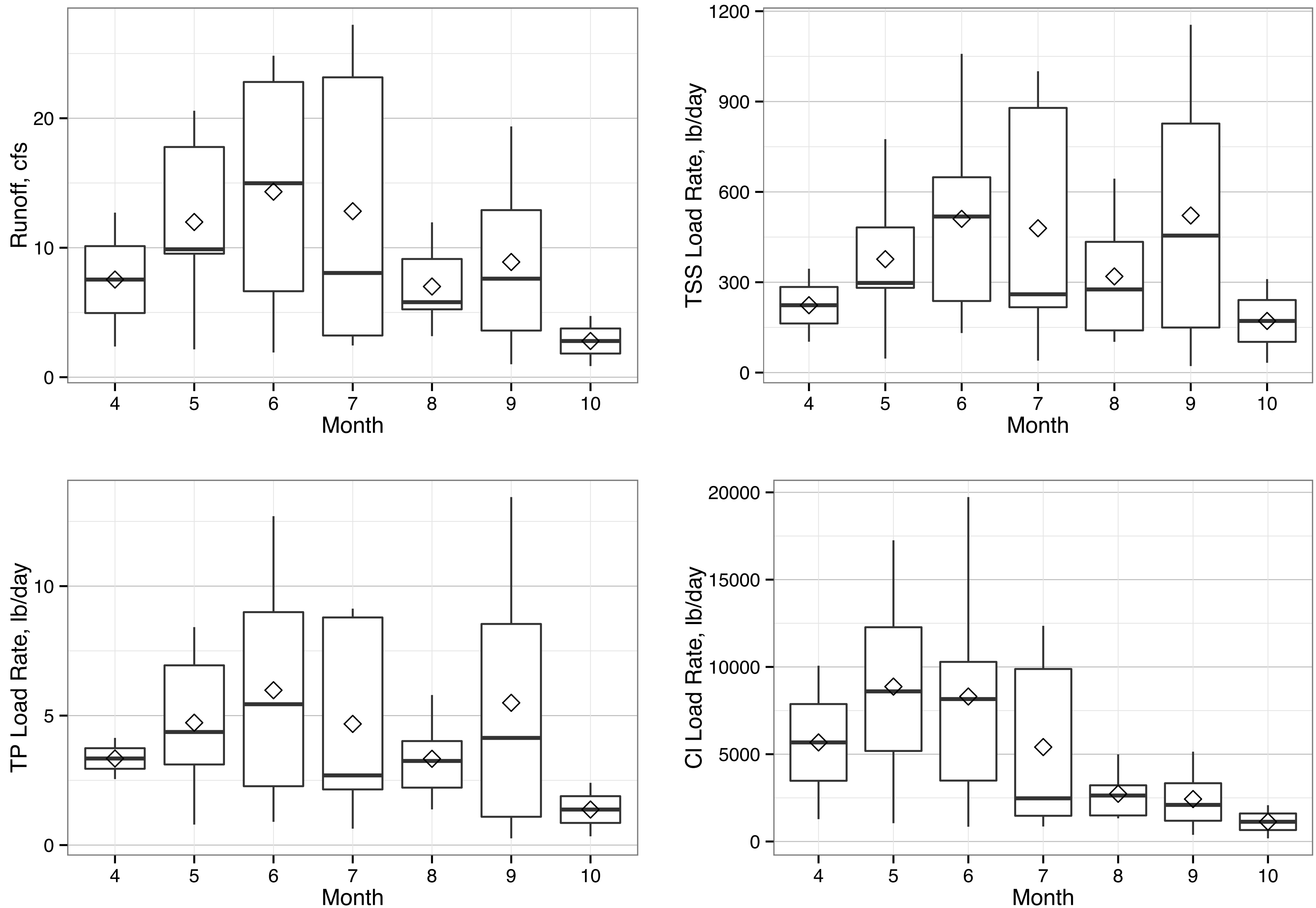
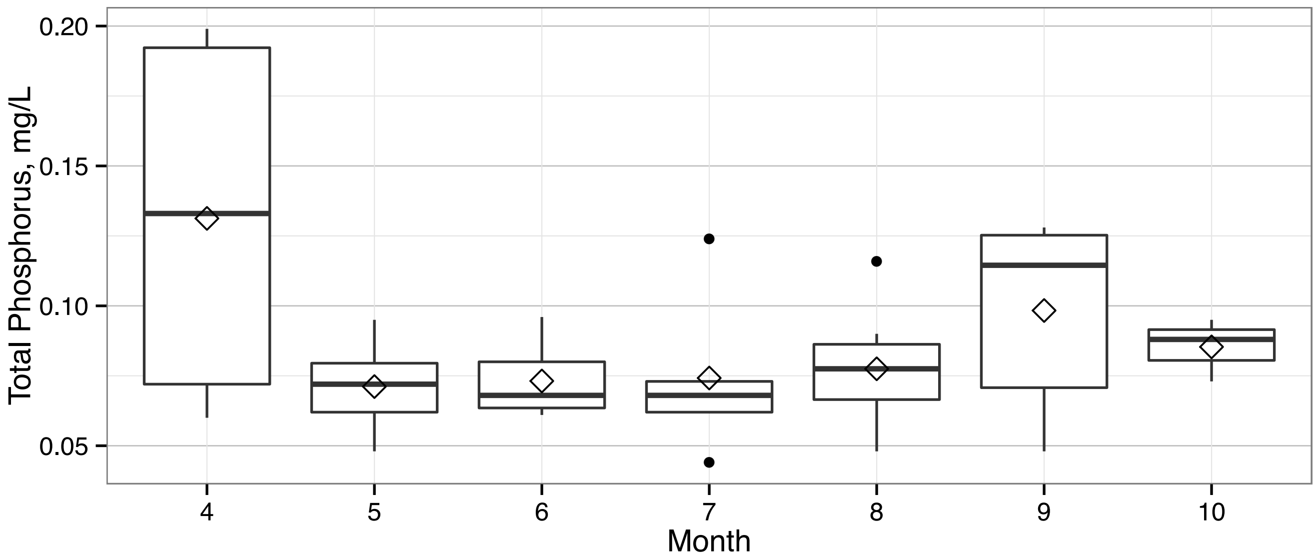
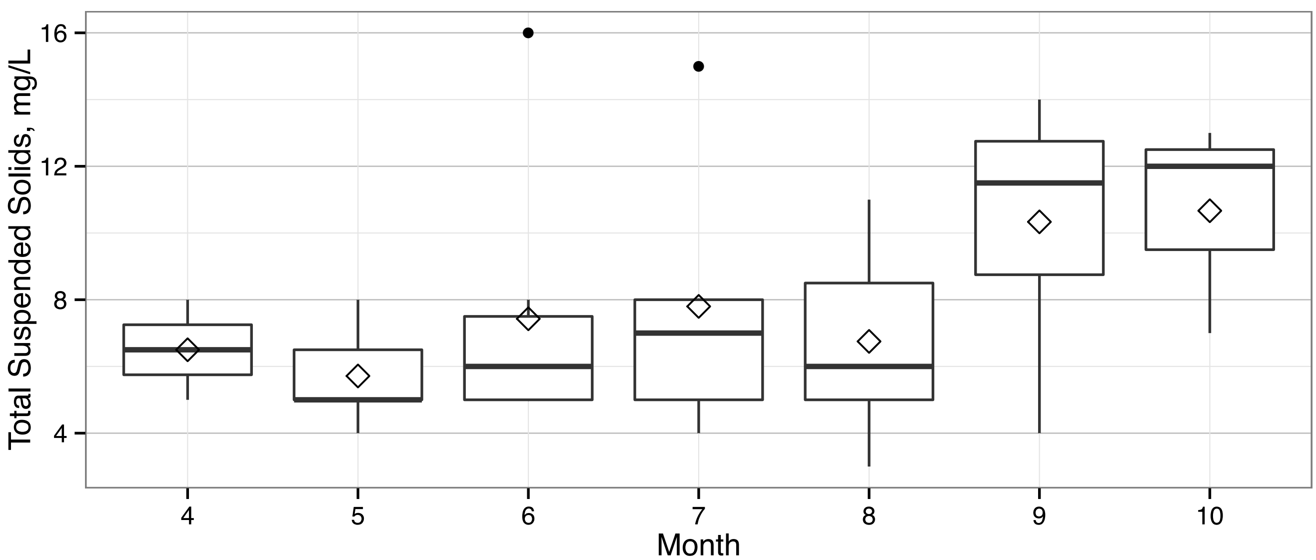


Figure A-7.3. Boxplots of monthly nutrient **concentrations** of all sampled **events** at Wilmes Lake Outlet. Diamonds are mean concentrations and dots are outliers.





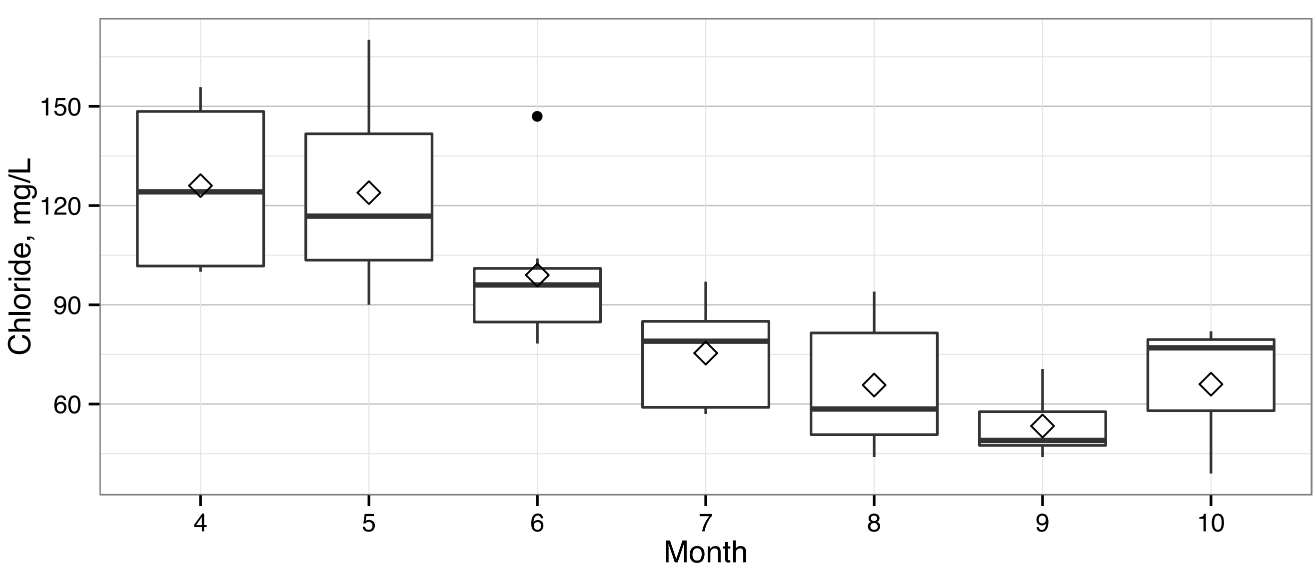
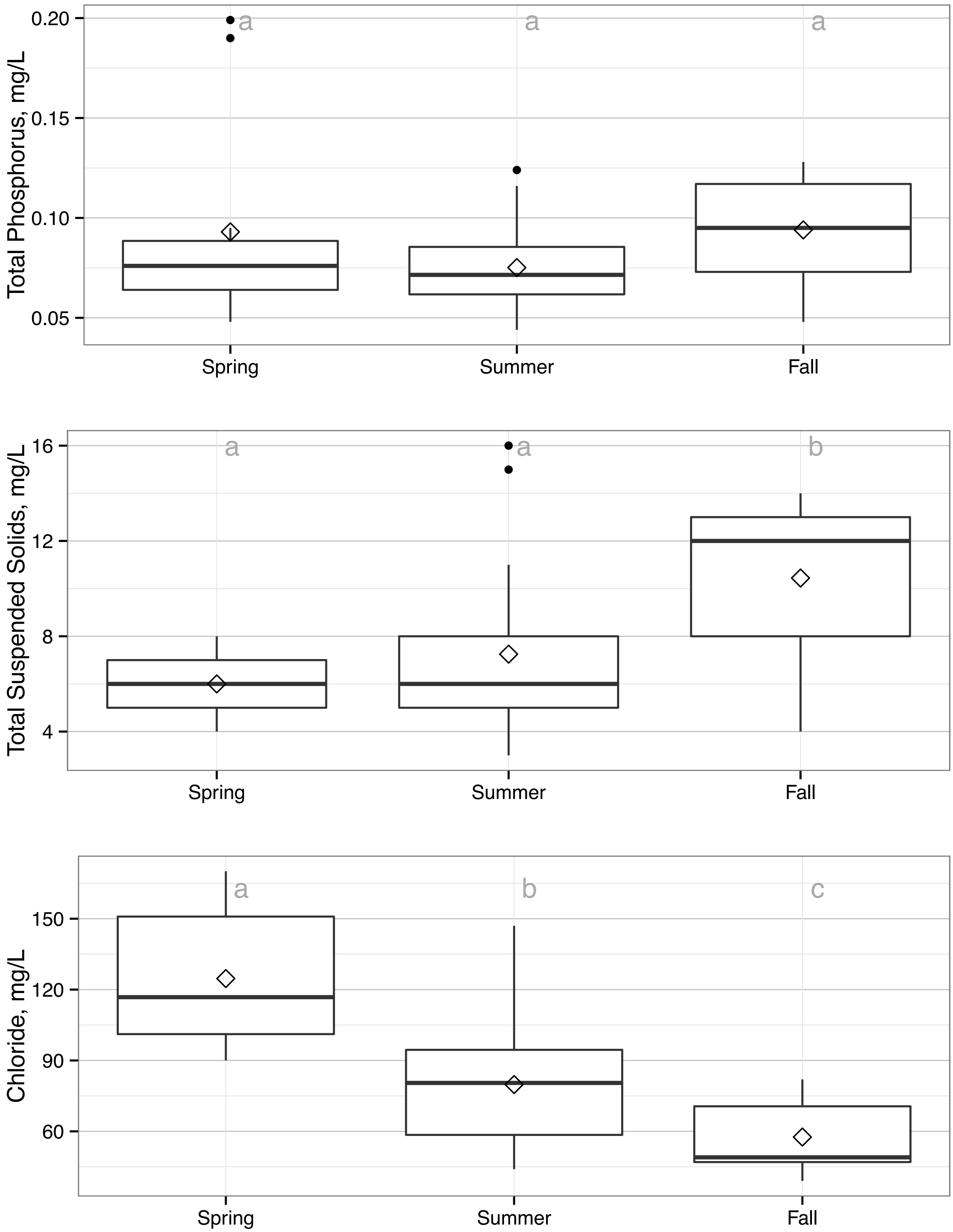


Figure A-7.4. Boxplots of seasonal nutrient **concentrations** of all sampled **events** at Wilmes Lake Outlet. Diamonds are mean concentrations and dots are outliers; seasons with different letters are significantly different at $p < 0.05$ by Mann-Whitney-Wilcoxon rank sum test.



A-7.5 Influence of Antecedent Precipitation and Flow on Event Nutrient Loads and Concentrations

Simple linear regression was used to investigate the effect of several precipitation and flow parameters on observed event volumes and observed nutrient loads and concentrations, as well as to illustrate any relationships between the parameters themselves. Results considering concentration data only are shown in Table A-7.4, while results for event loading data are shown in Table A-7.5. Note that the concentration data set has more samples than the loading data set because some samples were collected when flow was not monitored Pearson *r* are shown in the tables along with significance of the regressions: * indicates significance at $p < 0.05$, ** indicates significance at $p < 0.001$.

Table A-7.4. Results of regression of event flow and nutrient concentrations vs. several temporal and antecedent precipitation and flow parameters.

Param	Year	Month	Flow Rate	BF Ratio	Antecedent Precip			Ant. Stage		TP	TSS	Cl
					28 Days	*14 Days*	*7 Days*	*6 Hr*	*7 Days*	Conc	Conc	Conc
Flow Rate	0.29	-0.21		-0.04	0.55 **	0.32	0.52 *	0.73 **	0.32	-0.07	-0.07	0.13
BF Ratio	0.23	-0.09	-0.04		0.35 *	-0.14	-0.04	-0.12	-0.03	0.24	-0.05	-0.15
TP Conc	-0.09	-0.07	-0.07	0.24	-0.06	-0.04	0.09	-0.08	-0.32 *		0.45 *	-0.07
TSS Conc	-0.25	0.40 *	-0.07	-0.05	0.03	0.08	0.11	-0.01	-0.26	0.45 *		-0.34
Cl Conc	0.42 *	-0.75 **	0.13	-0.15	-0.19	-0.08	-0.02	-0.02	-0.11	-0.07	-0.34 *	

Table A-7.5. Results of regression of event flow and nutrient loading vs. antecedent precipitation and flow parameters.

Param.	Flow	Volume			BF	Precip		Antecedent Precip			Ant. Stage	
	Rate	Total	Baseflow	Storm	Ratio	Depth	Intensity	*28 Days*	*14 Days*	*7 Days*	*6 Hr*	*7 Days*
Flow Rate		0.80**	0.73**	0.82**	-0.04	0.56*	0.38*	0.47*	0.29	0.35	0.41*	0.48*
Vol, Total	0.80**		0.97**	0.93**	0.21	0.73**	0.29	0.39*	0.21	0.40*	0.27	0.31
Vol, Base	0.73**	0.97**		0.83**	0.38*	0.66**	0.26	0.46*	0.12	0.35	0.17	0.25
Vol, Storm	0.82**	0.93**	0.83**		-0.06	0.74**	0.29	0.24	0.20	0.33	0.31	0.36
BF Ratio	-0.04	0.21	0.38*	-0.06		0.13	-0.14	0.34	-0.17	0.03	-0.20	-0.15
TP Conc	-0.10	-0.07	-0.04	-0.22	0.27	0.09	-0.08	0.12	0.13	0.15	-0.21	-0.27
TP Load	0.73**	0.90**	0.94**	0.74**	0.32	0.63**	0.23	0.43*	0.21	0.40*	0.16	0.19
TSS Conc	-0.11	-0.03	-0.05	-0.12	-0.02	0.11	-0.01	0.03	0.11	0.16	-0.07	-0.22
TSS Load	0.67**	0.87**	0.89**	0.75**	0.23	0.60**	0.24	0.36	0.18	0.40*	0.21	0.19
Cl Conc	0.32	0.19	0.07	0.28	-0.20	0.36	0.05	-0.17	0.04	0.06	0.05	-0.05
Cl Load	0.74**	0.84**	0.75**	0.87**	-0.05	0.72**	0.16	0.14	0.15	0.22	0.16	0.20

Several results of the regression analyses are worth noting:

- Event TP, TSS, and Cl loading were significantly and positively correlated with flow rate and with volumes;
- Flow rate was significantly correlated with event precipitation and intensity and with monthly antecedent precipitation, indicating a strong influence of hydrology on nutrient export;
- Antecedent stage, which for this site was likely an indicator of antecedent lake level, was significantly correlated with increased flow rate though not of flow volume;
- Rainfall intensity was not well-correlated with many nutrient loading parameters, nor was antecedent precipitation or antecedent stage.