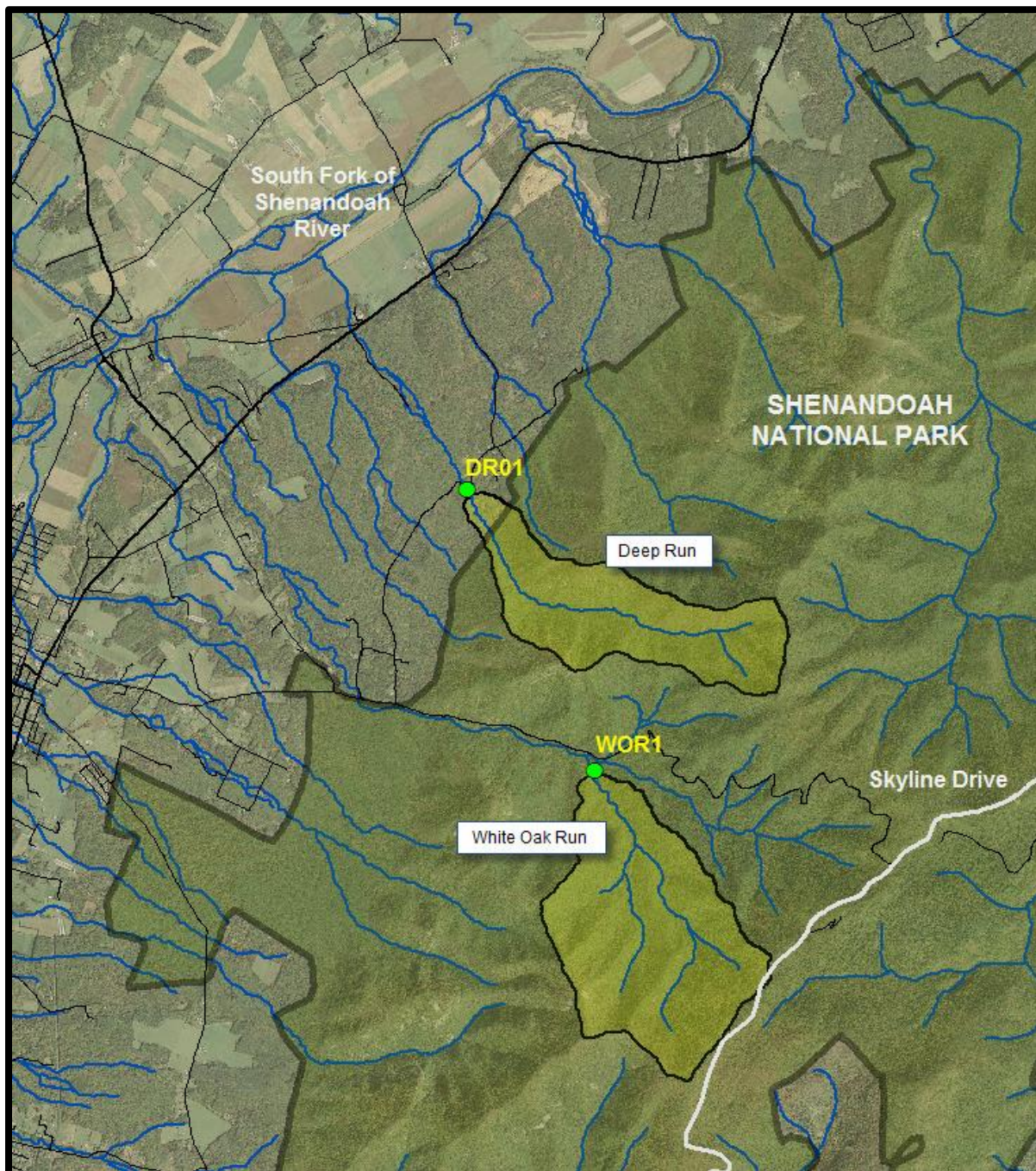


SHENANDOAH WATERSHED STUDY



2009 Report

Shenandoah Watershed Study (SWAS)

2009 Report, 02/01/11

Start and End Dates: ongoing (1979 – present)

Report Period: 01/01/09-12/31/09

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1. Overview

The Department of Environmental Sciences at the University of Virginia maintains the Shenandoah Watershed Study (SWAS) program in cooperation with the National Park Service. Over the 30-year period, 1979-2009, the SWAS program has developed and maintained a monitoring framework designed to account for the spatial and temporal variability of hydrologic and biogeochemical conditions in the watershed ecosystems of the Shenandoah National Park (SHEN). The SWAS monitoring program is a component of the SHEN Natural Resource Inventory and Monitoring Program. The SWAS framework includes 14 primary study watersheds in SHEN (see Figure 1).

Monitoring for the SWAS program study watersheds includes quarterly, weekly, and more-frequent, high-runoff (episodic) sample collection for analysis of stream water composition, and discharge gauging. This data collection allows detection of biogeochemical change in SHEN watersheds and supports research to advance understanding of factors and processes that govern current conditions and determine response to stressors.

This annual interpretive report summarizes water quality data obtained for SHEN during the 2009 calendar year as prescribed by the draft SWAS program standard operation procedure (SOP), **SWAS SOP 8: Interpretive Reporting**. In addition to summary information concerning the number of samples of different types (weekly, episodic, and quarterly) collected for the reporting year, this report provides summary information describing water quality status and

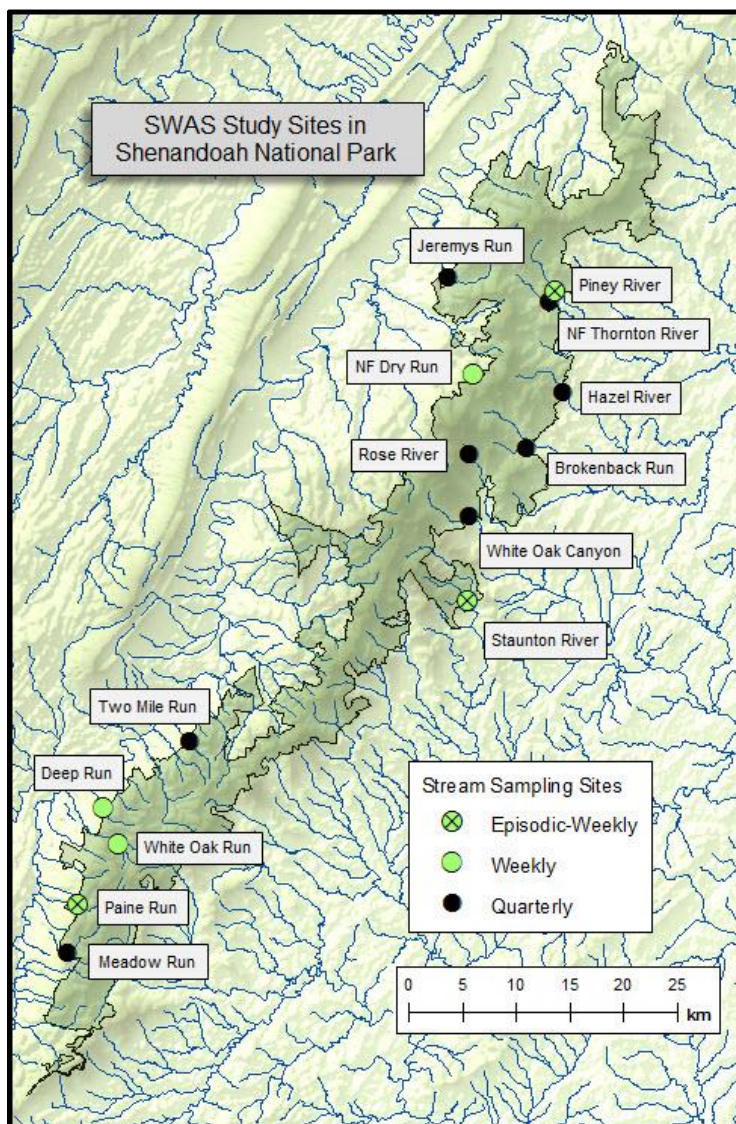


Figure 1 - SWAS monitoring program sites in SHEN.

comparisons with previous years. Comparisons are also made with ecological and regulatory thresholds. Discharge data is described with respect to intra and inter-annual variation. Consistent with the schedule outlined in the draft protocol, statistical analysis of changes in water quality and discharge are reserved for periodic trend analysis reports.

Observations for 2009 include:

- All 14 of the study streams were less acidic in 2009 than in previous years.
- The occurrence of discharge-driven episodic acidification in the three intensively studied streams was less severe in 2009 than in previous years.
- Annual discharge in 2009 was near the long-term mean for the five gauged streams.

This annual report has been prepared for the Natural Resources Division at SHEN, and is submitted together with (1) a Data Quality Assurance Report for sample analysis results obtained by the SWAS program laboratory during the 2009 calendar year, and (2) a data file with SWAS program data in NPSTORET format.

Additional information related to the SWAS monitoring program in SHEN, including program history, design, findings, and procedures is provided in the draft **SWAS Monitoring Program Protocol Narrative** and associated SOP documents and sampling site documentation reports.

2. Number and Type of Samples Collected

Figure 2 indicates the total number of stream water samples analyzed through the SWAS program for each of the years during the period of record, as well as the number of weekly grab samples and episodic (ISCO) samples analyzed for the intensively studied sites established in 1992.

The total number of samples analyzed increased in the late 1980s with initiation of weekly sampling on North Fork Dry Run and quarterly sampling of geologically representative streams throughout SHEN. The number of samples analyzed further increased in the early 1990s with initiation of additional weekly sampling and episodic sampling on three sites selected for intensive study (Paine Run, Piney River, and Staunton River). The lower number of samples analyzed in recent years compared with the early 1990s is due to less-frequent sampling during high-discharge conditions. The number of weekly grab samples has been generally constant. The high number of ISCO samples analyzed in 2003 was due to unusually high discharge. The relatively low number of samples analyzed in 2007 reflects low discharge and the resulting low number of ISCO samples collected in 2007. The somewhat higher number of samples analyzed in 2008 and 2009 reflects higher discharge and the resulting higher number of ISCO samples.

The ISCO samplers are flow-level actuated. Settings for the ISCO samplers have varied during the period of record, 1992–present. In 2009, the samplers were "ON" when the flow level was above the 95th flow percentile. Then samples were taken at 2,4,6,...,12 hours. Samples were chosen for analysis with a 0.2 probability. Approximately 20% of all samples collected were analyzed. Figure 2 indicates the number of samples that were analyzed. Appendix I provides a listing by year for numbers of weekly grab sample and ISCO sample analyses obtained for Paine Run, Piney River, and Staunton River.

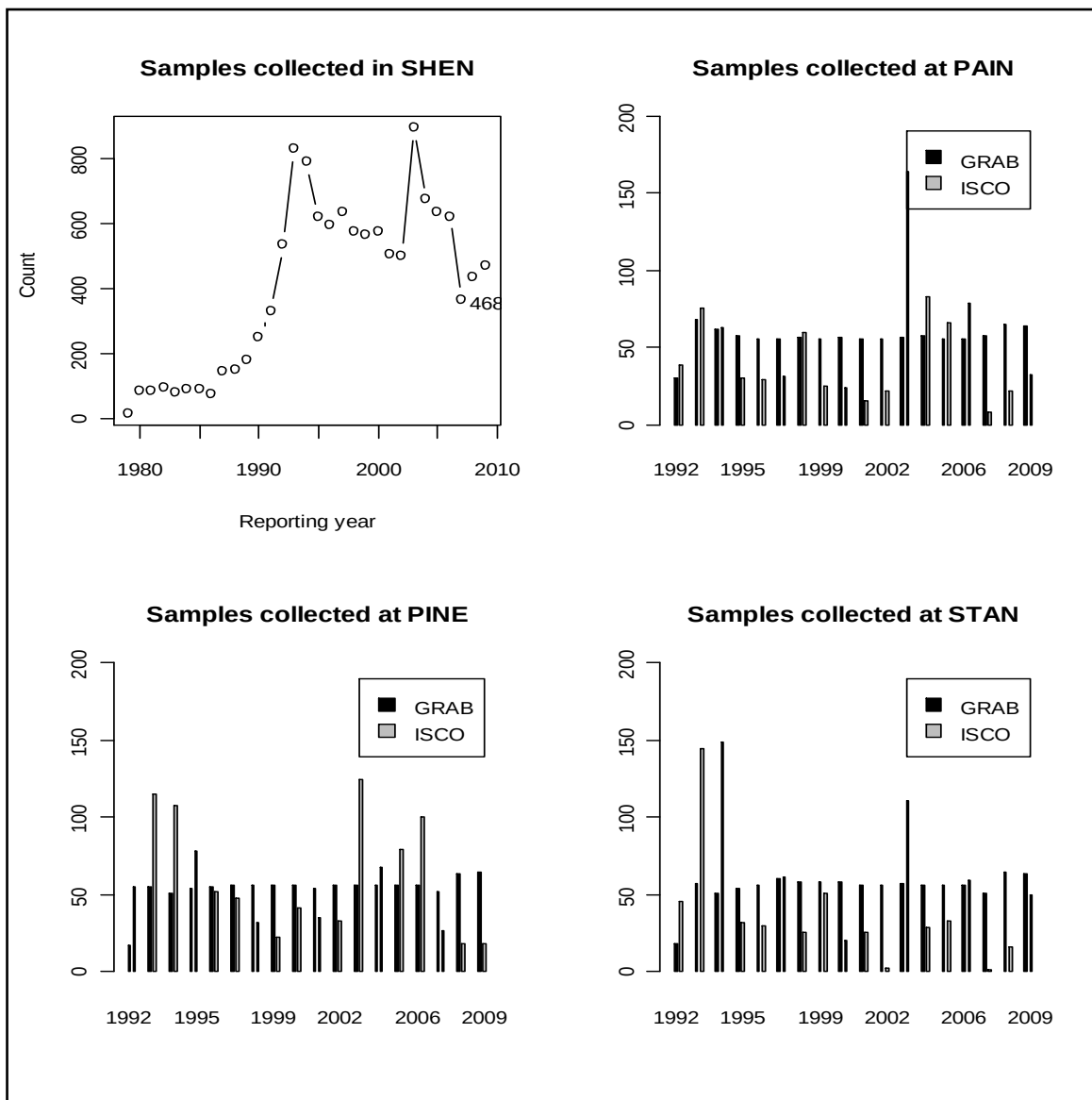


Figure 2 - Stream water sample analyses obtained for SWAS monitoring program sites in SHEN

3. Summary Tables of Sample Analysis Results for 2009

Table 1 provides the site id, stream name, watershed area, bedrock distribution, year of initial data collection, and sampling frequency for the 14 primary study watersheds. Table 2 provides seasonal (quarterly) values for analysis results routinely obtained for the eight quarterly sampling sites in SHEN. Table 3 provides the range, median, and interquartile distribution values for analysis results obtained for weekly grab samples. Table 4 provides the range, median, and interquartile distribution values for analysis results obtained for high-frequency samples collected at Paine Run, Piney River, and Staunton River. The ordering of sites in the presentation of these data is by watershed lithologic class, consistent with the geographic stratification scheme that is central to the SWAS monitoring program design.

Table 1 - SWAS primary watersheds, bedrock distribution, and sampling frequency

SITE ID	STREAM	AREA (km ²)	% OF WATERSHED AREA			START	SAMPLING FREQUENCY
			SILICEOUS	FELSIC	MAFIC		

Predominate Bedrock: Siliceous (Siliciclastic)

PAIN	Paine Run	12.4	100.0	0.0	0.0	1992	Weekly- Episodic
DR01	Deep Run	3.1	100.0	0.0	0.0	1979	Weekly
VT36	Meadow Run	8.9	100.0	0.0	0.0	1987	Quarterly
VT53	Twomile Run	5.6	100.0	0.0	0.0	1987	Quarterly
WOR1	White Oak Run	5.1	100.0	0.0	0.0	1979	Weekly

Predominate Bedrock: Felsic (Granitic)

STAN	Staunton River	10.5	0.0	100.0	0.0	1992	Weekly- Episodic
VT58	Brokenback Run	9.9	0.0	93.4	6.6	1987	Quarterly
VT62	Hazel River	13.2	0.0	100.0	0.0	1987	Quarterly
NFDR	North Fork of Dry Run	2.3	0.0	100.0	0.0	1986	Weekly

Predominate Bedrock: Mafic (Basaltic)

PINE	Piney River	12.6	0.0	31.3	69.7	1992	Weekly- Episodic
VT51	Jeremys Run	22.0	31.0	0.0	69.0	1987	Quarterly
VT61	North Fork Thornton	19.1	5.2	27.0	69.0	1987	Quarterly
VT66	Rose River	23.7	0.0	9.1	90.9	1987	Quarterly
VT75	White Oak Canyon	14.1	0.0	14.1	85.9	1987	Quarterly

Table 2 - Analysis results for seasonal samples collected at quarterly sampling sites in SHEN in 2009

Site	Analyte ¹	Winter	Spring	Summer	Fall
Siliciclastic Bedrock Class					
VT36	Acid neutralizing capacity	2.33	3.24	2.92	6.74
VT36	Calcium	29.32	28.02	24.19	18.43
VT36	Chloride	22.07	22.89	21.78	24.16
VT36	Magnesium	43.06	40.82	33.89	30.22
VT36	pH	5.46	5.38	5.48	5.65
VT36	Potassium	25.45	29.63	28.53	33.72
VT36	Silica	80.58	76.52	96.57	101.11
VT36	Sodium	20.56	21.17	21.54	21.46
VT36	Specific conductance	16.90	17.50	15.70	14.90
VT36	Sulfate	89.85	93.80	73.74	68.88
VT53	Acid neutralizing capacity	13.39	19.29	31.78	31.67
VT53	Calcium	32.51	30.20	29.69	30.93
VT53	Chloride	22.77	23.68	22.61	26.28
VT53	Magnesium	52.49	47.10	44.26	50.30
VT53	pH	5.94	5.93	6.16	6.10
VT53	Potassium	34.16	39.51	38.79	45.90
VT53	Silica	81.35	82.40	114.91	109.39
VT53	Sodium	26.61	26.10	27.95	30.24
VT53	Specific conductance	19.00	18.80	18.20	20.50
VT53	Sulfate	102.95	94.26	72.00	92.84

Site	Analyte ¹	Winter	Spring	Summer	Fall
Granitic Bedrock Class					
VT58	Acid neutralizing capacity	73.51	85.94	132.20	123.65
VT58	Calcium	52.21	58.75	73.94	73.46
VT58	Chloride	22.47	21.96	20.89	32.37
VT58	Magnesium	31.98	34.54	41.96	45.86
VT58	pH	6.60	6.59	6.97	6.80
VT58	Potassium	6.75	9.43	11.08	17.67
VT58	Silica	138.11	146.25	168.41	155.94
VT58	Sodium	57.38	62.05	72.06	69.34
VT58	Specific conductance	16.30	18.00	21.00	22.80
VT58	Sulfate	44.02	46.79	31.26	40.53
VT62	Acid neutralizing capacity	82.95	105.00	140.14	129.09
VT62	Calcium	58.10	62.76	74.11	74.58
VT62	Chloride	26.29	24.87	24.11	34.35
VT62	Magnesium	41.04	42.75	48.49	53.75
VT62	pH	6.62	6.63	7.06	6.88
VT62	Potassium	8.43	12.13	11.75	19.87
VT62	Silica	144.92	155.41	179.67	168.17
VT62	Sodium	60.56	65.40	72.83	70.11
VT62	Specific conductance	18.40	19.60	21.70	23.90
VT62	Sulfate	41.03	42.51	26.41	42.16
Basaltic Bedrock Class					
VT51	Acid neutralizing capacity	151.66	195.27	357.08	339.68

Site	Analyte ¹	Winter	Spring	Summer	Fall
VT51	Calcium	124.09	139.72	192.51	189.82
VT51	Chloride	33.61	32.19	34.18	56.78
VT51	Magnesium	116.29	126.13	161.90	170.88
VT51	pH	6.94	7.11	7.45	7.33
VT51	Potassium	11.72	17.52	19.78	23.84
VT51	Silica	132.68	154.43	187.63	210.42
VT51	Sodium	57.75	68.18	90.94	95.43
VT51	Specific conductance	33.90	38.10	48.20	50.90
VT51	Sulfate	110.48	117.91	75.48	88.61
VT61	Acid neutralizing capacity	211.49	294.80	426.95	390.75
VT61	Calcium	142.85	169.43	213.48	202.03
VT61	Chloride	34.07	32.29	30.54	52.63
VT61	Magnesium	128.14	144.91	172.36	170.31
VT61	pH	6.78	6.91	7.52	7.05
VT61	Potassium	7.28	11.71	12.33	16.29
VT61	Silica	203.80	241.02	282.34	265.56
VT61	Sodium	88.16	102.28	122.15	123.60
VT61	Specific conductance	38.70	44.20	52.60	53.40
VT61	Sulfate	87.02	88.70	56.02	70.46
VT66	Acid neutralizing capacity	126.86	160.71	240.67	219.18
VT66	Calcium	101.64	111.39	138.13	136.49
VT66	Chloride	34.61	32.28	34.55	44.19
VT66	Magnesium	77.76	83.48	101.36	101.00

Site	Analyte ¹	Winter	Spring	Summer	Fall
VT66	pH	6.89	6.82	7.17	7.07
VT66	Potassium	3.38	4.61	4.85	7.49
VT66	Silica	133.06	148.24	167.00	149.45
VT66	Sodium	55.26	61.29	74.01	67.36
VT66	Specific conductance	25.70	28.20	34.00	33.40
VT66	Sulfate	54.96	42.92	36.79	49.79
VT75	Acid neutralizing capacity	112.77	145.38	217.93	170.67
VT75	Calcium	95.15	107.43	133.39	118.86
VT75	Chloride	33.93	30.38	37.24	43.21
VT75	Magnesium	72.49	78.43	96.73	87.41
VT75	pH	6.89	6.94	7.12	6.93
VT75	Potassium	3.22	4.33	4.32	7.50
VT75	Silica	117.18	132.57	148.76	128.87
VT75	Sodium	49.31	54.47	64.90	54.97
VT75	Specific conductance	23.80	26.10	32.30	29.50
VT75	Sulfate	51.27	56.88	34.44	52.93

¹Concentration units: µeq/L for ions and ANC; µm/L for silica; µS/cm for specific conductance

Table 3 - Range, median, and interquartile distribution of analysis results for weekly grab samples collected in 2009

Site ID	Analyte ¹	Max	75th	Median	25th	Min
Siliciclastic Bedrock Class						
DR01	Acid Neutralizing Capacity	16.03	7.87	5.25	4.12	2.10
DR01	Calcium	30.87	25.04	24.22	23.01	20.78
DR01	Chloride	36.80	26.46	25.10	24.01	23.14
DR01	Magnesium	53.44	46.12	44.05	42.01	36.15
DR01	Nitrate	0.71	0.71	0.71	0.71	0.71
DR01	Potassium	46.61	43.94	42.41	40.87	37.22
DR01	Silica	104.91	97.36	91.24	88.58	83.87
DR01	Sodium	28.28	26.55	25.53	24.75	23.52
DR01	Sulfate	110.69	103.99	103.02	100.00	81.40
DR01	pH	5.65	5.55	5.51	5.47	5.33
PAIN	Acid Neutralizing Capacity	22.32	15.64	8.57	6.34	3.24
PAIN	Calcium	32.50	30.79	29.52	28.02	25.26
PAIN	Chloride	28.14	25.03	23.56	23.16	21.83
PAIN	Magnesium	53.38	51.04	48.71	46.57	43.35
PAIN	Nitrate	0.63	0.63	0.63	0.63	0.63
PAIN	Potassium	53.99	48.23	45.39	42.67	37.86
PAIN	Silica	108.13	104.20	89.17	81.87	69.85
PAIN	Sodium	28.52	25.79	24.11	23.15	22.34
PAIN	Sulfate	116.43	113.44	110.49	105.56	88.36
PAIN	pH	6.13	6.00	5.76	5.68	5.24
WOR1	Acid Neutralizing Capacity	96.07	50.32	25.82	22.64	16.98
WOR1	Calcium	45.70	34.73	30.85	28.38	26.45

Site ID	Analyte ¹	Max	75th	Median	25th	Min
WOR1	Chloride	29.14	20.57	19.54	19.08	18.18
WOR1	Magnesium	71.82	53.62	47.59	45.31	43.28
WOR1	Nitrate	5.58	4.61	3.60	1.99	0.69
WOR1	Potassium	75.66	43.01	35.77	33.65	31.49
WOR1	Silica	97.10	85.38	77.33	73.06	69.50
WOR1	Sodium	25.38	22.80	20.72	20.30	18.91
WOR1	Sulfate	84.19	82.44	80.83	75.69	61.31
WOR1	pH	6.69	6.31	6.12	6.06	5.60
Granitic Bedrock Class						
NFDR	Acid Neutralizing Capacity	112.82	95.22	61.79	44.62	39.29
NFDR	Calcium	110.70	95.78	80.04	75.71	66.63
NFDR	Chloride	41.97	33.92	31.27	29.05	25.86
NFDR	Magnesium	59.45	52.93	44.19	42.73	38.25
NFDR	Nitrate	30.13	17.07	14.58	8.75	1.31
NFDR	Potassium	12.88	10.99	9.01	7.89	6.55
NFDR	Silica	207.16	183.25	152.08	145.74	141.65
NFDR	Sodium	96.43	86.88	74.70	71.83	65.53
NFDR	Sulfate	109.20	102.90	98.88	87.30	79.16
NFDR	pH	6.66	6.57	6.51	6.43	6.10
STAN	Acid Neutralizing Capacity	119.82	107.74	82.77	74.44	66.05
STAN	Calcium	75.96	68.18	63.56	61.35	54.34
STAN	Chloride	29.06	22.84	22.17	21.63	20.55
STAN	Magnesium	31.80	28.81	26.41	25.57	23.28
STAN	Nitrate	7.82	7.38	7.37	6.53	0.91
STAN	Potassium	14.53	11.67	9.93	8.76	7.37

Site ID	Analyte ¹	Max	75th	Median	25th	Min
STAN	Silica	153.10	148.01	135.52	131.47	125.07
STAN	Sodium	74.18	69.34	64.13	59.54	54.75
STAN	Sulfate	60.66	47.43	45.10	41.78	37.59
STAN	pH	6.97	6.90	6.79	6.62	6.10
Basaltic Bedrock Class						
PINE	Acid Neutralizing Capacity	408.04	337.97	222.20	177.96	155.51
PINE	Calcium	200.68	177.46	139.11	120.24	109.13
PINE	Chloride	45.78	31.47	29.78	28.03	22.25
PINE	Magnesium	153.24	137.53	110.61	97.89	89.21
PINE	Nitrate	12.11	11.63	8.56	8.30	3.26
PINE	Potassium	10.83	7.20	5.73	4.82	4.01
PINE	Silica	282.19	248.31	198.61	177.35	169.27
PINE	Sodium	113.87	97.56	76.59	68.90	64.27
PINE	Sulfate	82.45	71.21	66.59	49.52	38.57
PINE	pH	7.40	7.25	7.10	7.04	6.76

¹Concentration units: µeq/L for ions and ANC; µm/L for silica

Table 4 - Range, median, and interquartile distribution of analysis results for high-frequency (episodic) samples collected in 2009

Site ID	Analyte ¹	Max	75th	Median	25th	Min
Siliciclastic Bedrock Class						
PAIN	Acid Neutralizing Capacity	18.41	9.58	8.02	6.19	2.25
PAIN	Aluminum, total monomeric	40.80	31.08	28.17	21.05	17.03
PAIN	Calcium	36.24	32.35	31.49	29.48	27.74
PAIN	Carbon, dissolved organic	3.69	2.00	1.54	1.19	1.08
PAIN	Chloride	29.34	26.96	25.69	24.27	29.34
PAIN	Magnesium	57.23	54.30	52.00	50.54	46.63
PAIN	Nitrate	11.13	6.45	3.78	2.20	0.82
PAIN	Ammonium	1.95	1.83	1.26	1.10	1.95
PAIN	Potassium	52.09	46.76	45.75	45.08	44.10
PAIN	Silica	99.69	89.65	88.12	83.83	79.30
PAIN	Sodium	24.42	23.66	23.10	22.29	21.56
PAIN	Sulfate	113.31	111.60	108.54	107.40	97.49
PAIN	pH	5.82	5.74	5.61	5.51	5.40
Granitic Bedrock Class						
STAN	Acid Neutralizing Capacity	100.73	80.85	73.90	68.09	58.20
STAN	Calcium	71.63	65.53	62.23	60.47	49.16
STAN	Carbon, dissolved organic	4.08	1.85	1.12	0.84	0.56
STAN	Chloride	31.00	24.42	23.41	21.81	17.75
STAN	Magnesium	29.51	27.19	26.41	25.66	22.15
STAN	Nitrate	3.29	1.84	1.01	0.67	0.54
STAN	Ammonium	22.27	6.76	3.80	3.11	1.07

Site ID	Analyte ¹	Max	75th	Median	25th	Min
STAN	Potassium	21.17	11.92	10.32	9.65	8.95
STAN	Silica	136.90	130.55	124.82	120.93	105.91
STAN	Sodium	64.42	60.21	57.94	54.70	51.70
STAN	Sulfate	65.30	56.25	50.52	47.20	37.75
STAN	pH	6.87	6.71	6.56	6.43	5.72
Basaltic Bedrock Class						
PINE	Acid Neutralizing Capacity	257.10	214.78	170.59	150.56	136.06
PINE	Calcium	156.93	143.97	130.12	113.27	104.42
PINE	Carbon, dissolved organic	3.23	2.13	1.72	1.26	0.96
PINE	Chloride	46.68	35.55	28.08	27.06	23.26
PINE	Magnesium	122.28	114.70	102.11	91.14	83.10
PINE	Nitrate	16.72	5.44	1.05	0.63	0.60
PINE	Ammonium	8.78	7.56	5.47	1.37	0.92
PINE	Potassium	9.14	7.89	6.45	6.02	5.12
PINE	Silica	231.31	204.03	176.16	167.81	156.99
PINE	Sodium	79.61	75.33	66.01	60.51	54.54
PINE	Sulfate	88.05	79.64	77.63	75.40	65.74
PINE	pH	7.38	7.15	7.09	6.99	6.76

¹Concentration units: µeq/L for ions and ANC; µm/L for silica; mg/L for DOC; µg/L for aluminum

4. Examination of Year-To-Year Change in Stream Water Composition

Context for water quality data obtained in 2009 and summarized in Tables 2-4 is provided by graphical comparison with data obtained in previous years. Site-by-site plots for key acid-base constituents (ANC, pH, nitrate, sulfate, and the sum of base cations) comparing the range, median, and interquartile distribution of values for the current year's data with the same statistics for the previous years' data are provided in Appendix II. Figure 3 compares the mean values for key acid-base constituents for the reporting year with the mean values for all previous years.

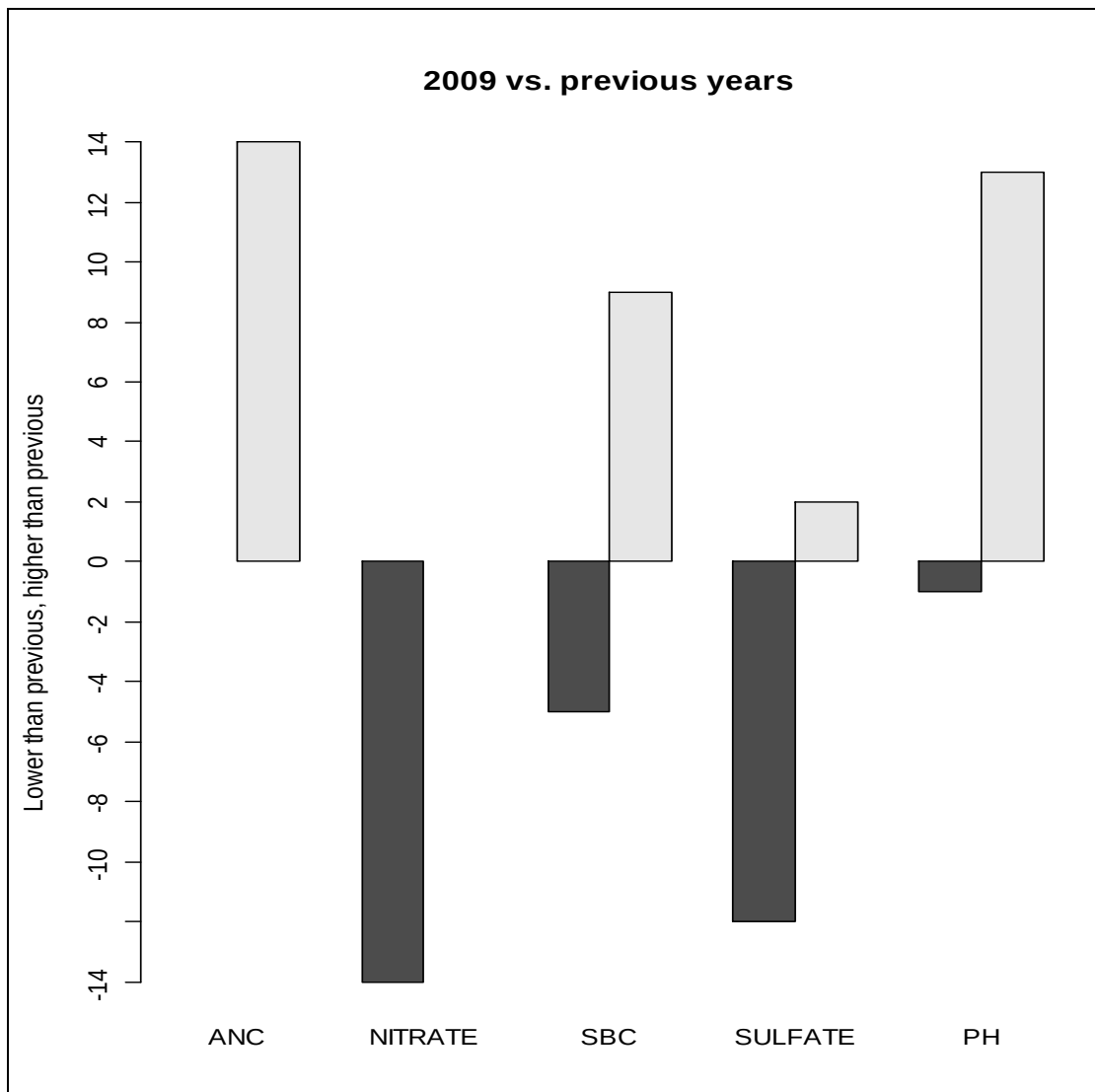


Figure 3 - Comparison of current and previous years' data: summary of differences in mean values of major acid-base constituents. Dark bars indicate the number of sites for which the current year's mean values were lower than for the previous years' means. Light bars indicate the number of sites for which the current year's mean values were higher than the previous years' means.

The differences in mean values evident in Figure 3 between 2009 and pre-2009 are indicative of long-term change associated with acidic deposition.

The comparison of ANC means shows that all of the study streams were less acidic in 2009 than during the prior data collection period. ANC is an integrator of the factors that contribute to the acid-base status of surface waters, and increasing ANC is consistent with recovery from acidification in both stream water and watershed soils. The mean pH values for 13 of the 14 study streams were higher in 2009 than the mean for the previous years. This is consistent with the general increase in ANC and recovery from acidification.

The mean sulfate concentrations were lower in 12 of the 14 streams. This is consistent both with reductions in regional sulfate deposition and with recovery from acidification. It is notable, however, that results for sulfate in 2009 were different than in 2008, when sulfate concentrations for most of the study streams were higher than in previous years. This year-to-year difference highlights the fact that a single year's change does not provide a reliable basis for interpretation. More perspective on SHEN watershed response to reductions in sulfur emissions will be provided when long-term trend analysis is reported.

The change in the mean for the sum of base cation concentrations increased in nine streams and decreased in five streams. This is a mixed result consistent with observations in recent years, suggesting that soils in some areas of SHEN are losing base cations, while others are not. The base cations, including calcium, magnesium, and potassium ion, are mainly derived from watershed soils, and depletion of base cations in watershed soils is a primary aspect of ecosystem harm associated with both acidic deposition and forest disturbance. Again, a single year's change does not provide a strong basis for interpretation.

The comparison of nitrate concentration means shows that mean nitrate concentrations were lower in all of the study stream in 2009 than in the previous years. This is consistent with the previously observed decrease in nitrate concentrations following the transient increase associated with the gypsy moth infestation and forest defoliation in the early 1990s.

Figure 4 breaks down the comparison in mean values between 2009 and pre-2009 by bedrock class. The observed changes are again indicative of recovery from stream acidification.

The pattern for streams associated with basaltic bedrock is uniform. ANC has increased, pH has increased, base cations have increased, and sulfate has decreased in all streams associated with basaltic bedrock. The same general pattern applies to streams associated with felsic and siliceous bedrock. The major difference is that the base cations response is mixed, with base cation concentrations having both increased and decreased among these streams. This difference is consistent with the substantially greater base cation content associated with mafic bedrock and related soils than with felsic and siliceous bedrock and related soils. It suggests that base depletion is mainly associated with the felsic and siliceous areas of SHEN.

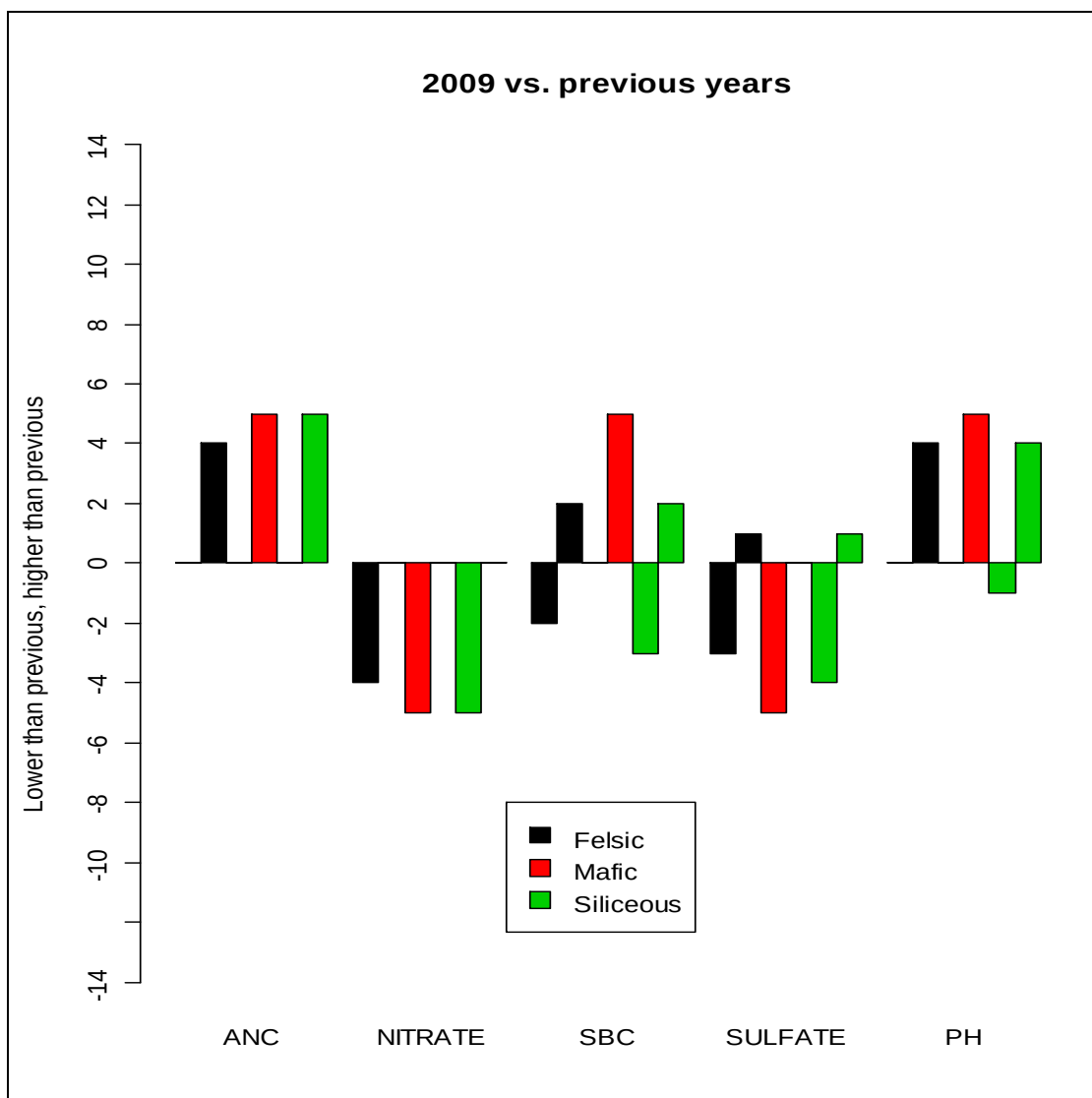


Figure 4 - Comparison of current and previous years' data: summary of differences in mean values of major acid-base constituents. Bars above the zero axis indicate the number of stations for which the current year's mean values were higher than the previous years' means. Bars below the zero axis indicate the number of stations for which the current year's mean values were lower than the previous years' means.

5. Examination of Extreme Conditions

The most extreme conditions, with respect to effects of acid-base chemistry on aquatic biota, occur during episodic high-flow conditions. High-frequency automated sampling at the sites on Paine Run, Piney River, and Staunton River is designed to collect information on episodic chemistry that is missed by less-intensive grab sampling at weekly or quarterly intervals. As described in the draft **SWAS Monitoring Program Protocol Narrative** and in **SOP 2: Field Sampling and Data Collection**, automatic water samplers at the three sampling sites are set to sample at two-hour intervals when discharge levels equal or exceed the 95th flow-percentile value for the season. Different actuator levels are set for cold and warm seasons.

Figure 5 displays ANC values for both weekly grab samples and automated high-flow samples for Paine Run, Piney River, and Staunton River. For all three streams, higher discharge levels occurred in early spring and late fall (see Figure 6), which includes the part of the year (October through March) when sensitive life stages (eggs and fry) of the brook trout (*Salvelinus fontinalis*) are present in SHEN streams. The most severe ANC depressions occurred in Paine Run in the late fall when ANC values approached 0 $\mu\text{eq/L}$. Higher flows in the spring on Paine Run had less effect, and in some cases were associated with increased ANC. Decreased ANC values were also observed during high discharge conditions on Staunton River and Piney River, but ANC levels did not drop below 50 $\mu\text{eq/L}$.

The occurrence of discharge-driven episodic ANC depression in these three streams was less severe in 2009 than in a number of previous years.

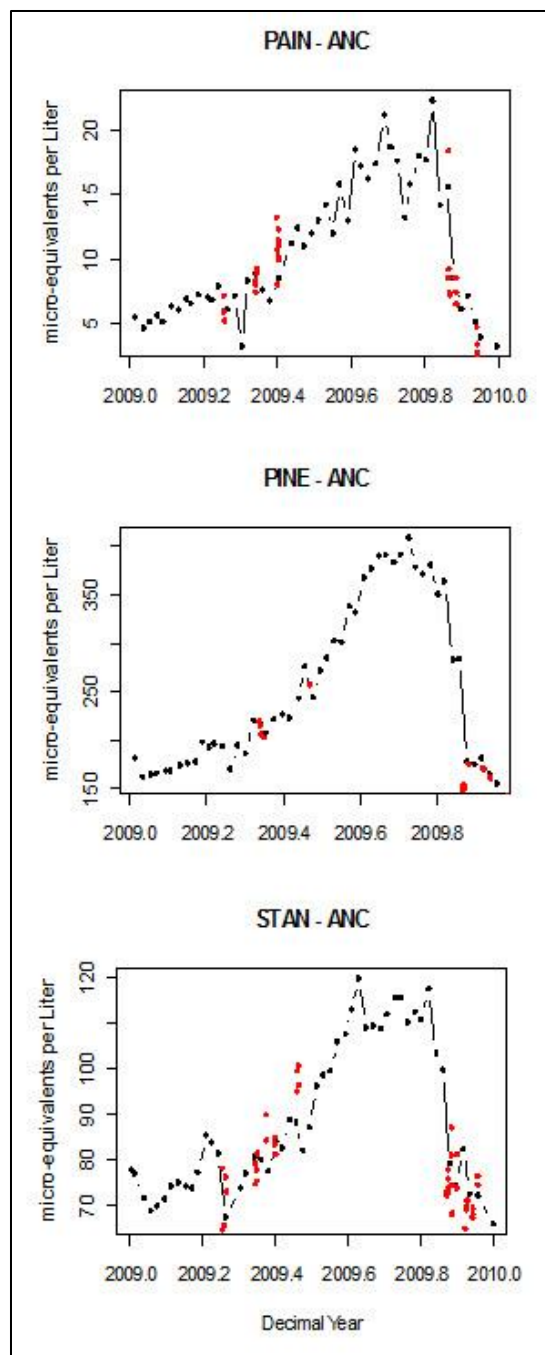


Figure 5 - ANC values for grab (black points) and automated episodic samples (red points) in 2009.

6. Ecological Thresholds

Ecological thresholds for brook trout and other fish species have been established for stream water ANC and pH.

Table 5 indicates ANC thresholds for brook trout response to acidification in forested headwater catchments in western Virginia.

Table 5 - Stream water ANC categories for brook trout response¹

Category	ANC Class	ANC Range (µeq/L)	Brook Trout Response
Suitable	Not acidic	>50	Reproducing brook populations where habitat suitable
Indeterminate	Indeterminate	20-50	Extremely sensitive to acidification; response variable
Marginal	Episodically acidic	0-20	Sub-lethal and/or lethal effects possible
Unsuitable	Chronically acidic	<0	Lethal effects probable

Note: ANC range based on volume-weighted annual means

The following pH ranges have been associated with loss of fish species.²

- pH range less than 6.0-5.5: associated with loss of relatively sensitive fish species such as the blacknose dace (*Rhinichthys atratulus*)
- pH range less than 5.0-4.5: associated with loss of more-tolerant fish species such as the brook trout (*Salvelinus fontinalis*).

Table 6 lists the percentage of analyses obtained in 2009 for each of the 14 primary SWAS study streams in relation to ANC categories for brook trout response indicated in Table 5.

Table 7 lists the percentage of analyses obtained in 2009 for each of the 14 primary SWAS study streams in relation to the above listed pH ranges associated with loss of brook trout and other fish species.

¹ Bulger, A.B., B.J. Cosby, and J.R. Webb, 2000. Current, reconstructed past, and projected future status of brook trout (*Salvelinus fontinalis*) streams in Virginia. Canadian Journal of Fisheries and Aquatic Sciences. 57: 1515.

² Baker, J.P., and S.W. Christensen, 1991. Effects of acidification on biological communities in aquatic ecosystems. In: D.F. Charles (Ed) Acid Deposition and Aquatic Ecosystems: Regional Case Studies. Springer-Verlag, New York.

Table 6 - Percentage of analyses obtained in 2009 in relation to ANC response categories for brook trout (see Table 5).

Site Id	Category	N	%
DR01	Marginal	39	100
NFDR	Indeterminate	20	39.2
NFDR	Suitable	31	60.8
PAIN	Indeterminate	2	2.4
PAIN	Marginal	80	97.6
PINE	Suitable	68	100
STAN	Suitable	101	100
VT36	Marginal	4	100
VT51	Suitable	4	100
VT53	Indeterminate	2	50
VT53	Marginal	2	50
VT58	Suitable	4	100
VT61	Suitable	4	100
VT62	Suitable	4	100
VT66	Suitable	4	100
VT75	Suitable	4	100
WOR1	Indeterminate	28	65.1
WOR1	Marginal	4	9.3
WOR1	Suitable	11	25.6

Table 7 - Percentage of analyses obtained in 2009 in relation to pH ranges associated with fish loss (see text).

Site Id	Category	N	%
DR01	relatively sensitive pH<6	39	100
NFDR	non-sensitive	51	100
PAIN	non-sensitive	13	15.9
PAIN	relatively sensitive pH<6	69	84.1
PINE	non-sensitive	68	100
STAN	non-sensitive	100	99
STAN	relatively sensitive pH<6	1	1
VT36	relatively sensitive pH<6	4	100
VT51	non-sensitive	4	100
VT53	non-sensitive	2	50
VT53	relatively sensitive pH<6	2	50
VT58	non-sensitive	4	100
VT61	non-sensitive	4	100
VT62	non-sensitive	4	100
VT66	non-sensitive	4	100
VT75	non-sensitive	4	100
WOR1	non-sensitive	36	83.7
WOR1	relatively sensitive pH<6	7	16.3

7. Regulatory Thresholds

The Virginia Department of Environmental Quality (DEQ) has established criteria for identification of impaired waters based on pH (Virginia Water Quality Standards, 9 VAC 25-260 et seq.).

The general statewide pH standard is 6.0-9.0. The pH standard for the Shenandoah River basin is 6.5-9.5. Thus, for streams in the James River and Rappahannock River basins on the eastern side of the Blue Ridge Mountains, pH values <6.0 violate the standard. For streams in the Shenandoah River basin on the western side of the Blue Ridge Mountains, pH values <6.5 violate the standard.

Regulatory program use of pH data obtained through the SWAS monitoring program is described in the draft **SWAS Monitoring Program Protocol Narrative** (Section 2.3).

Table 8 lists the percentage of analyses obtained in 2009 for each of the 14 primary SWAS study streams in relation to pH criteria established by the Virginia DEQ.

8. Discharge Status

Discharge gauges are maintained at five SWAS study sites. Gauging methods are described in the draft **SOP 3: Discharge Gauging**.

Figure 6 displays mean daily discharge for the five-year period ending in 2009. Figure 7 displays inter-annual variation in discharge around the long-term mean for each of the five gauging sites. 2009 was not an exceptional year with respect to annual discharge. Annual discharge was near the long-term mean for all five gauged streams.

Table 8 - Percentage of analyses obtained in 2009 in relation to pH criteria established by the Virginia DEQ.

Site Id	category	N	Percentage
DR01	pH<6.5	39	100
NFDR	pH OK	26	51
NFDR	pH<6.5	25	49
PAIN	pH<6.5	82	100
PINE	pH OK	68	100
STAN	pH OK	100	99
STAN	pH<6.0	1	1
VT36	pH<6.5	4	100
VT51	pH OK	4	100
VT53	pH<6.5	4	100
VT58	pH OK	4	100
VT61	pH OK	4	100
VT62	pH OK	4	100
VT66	pH OK	4	100
VT75	pH OK	4	100
WOR1	pH OK	5	11.6
WOR1	pH<6.5	38	88.4

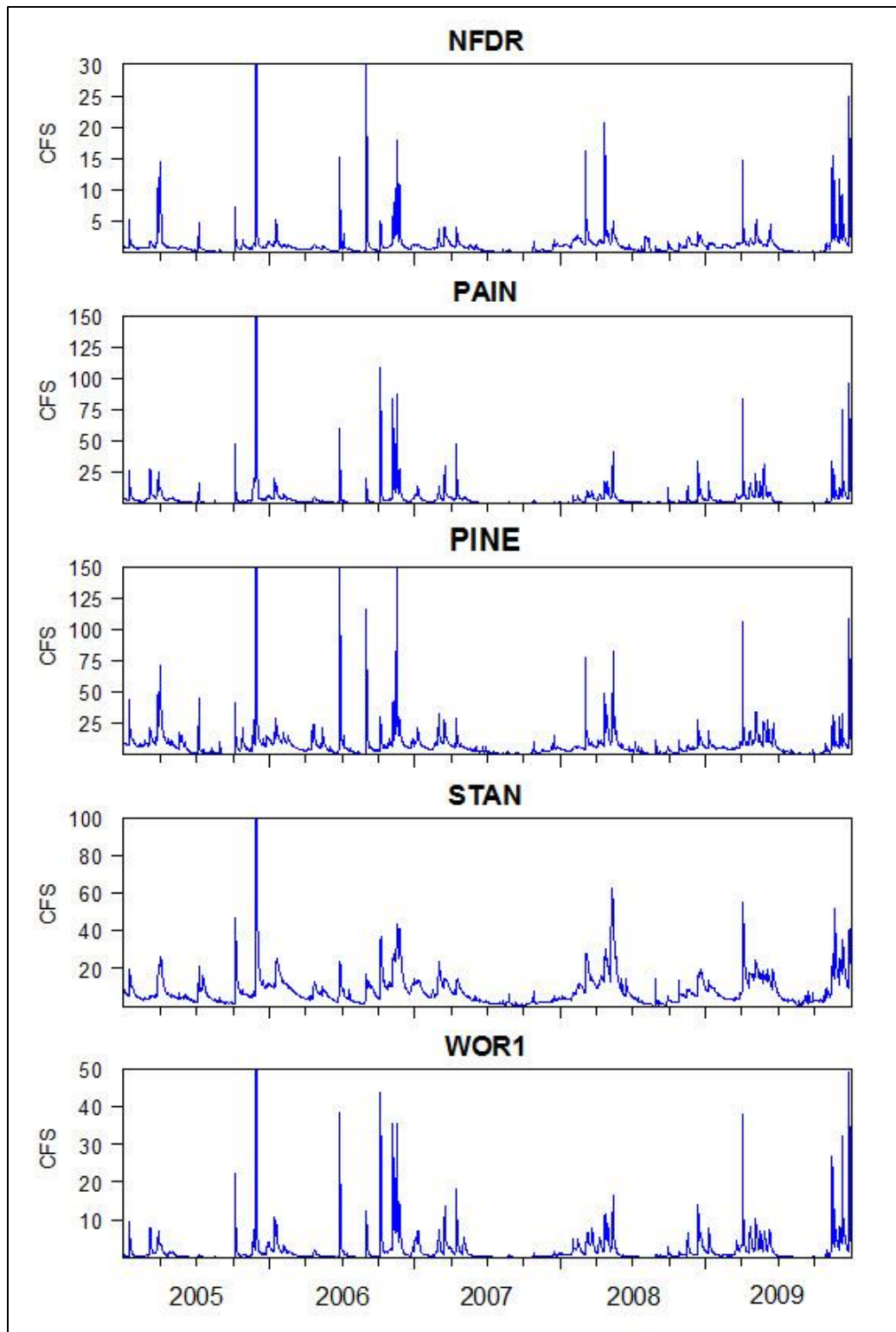


Figure 6 - Mean daily discharge for gauged streams in SHEN. Verticle axes are scaled for 2009. Higher discharge values in previous years are truncated.

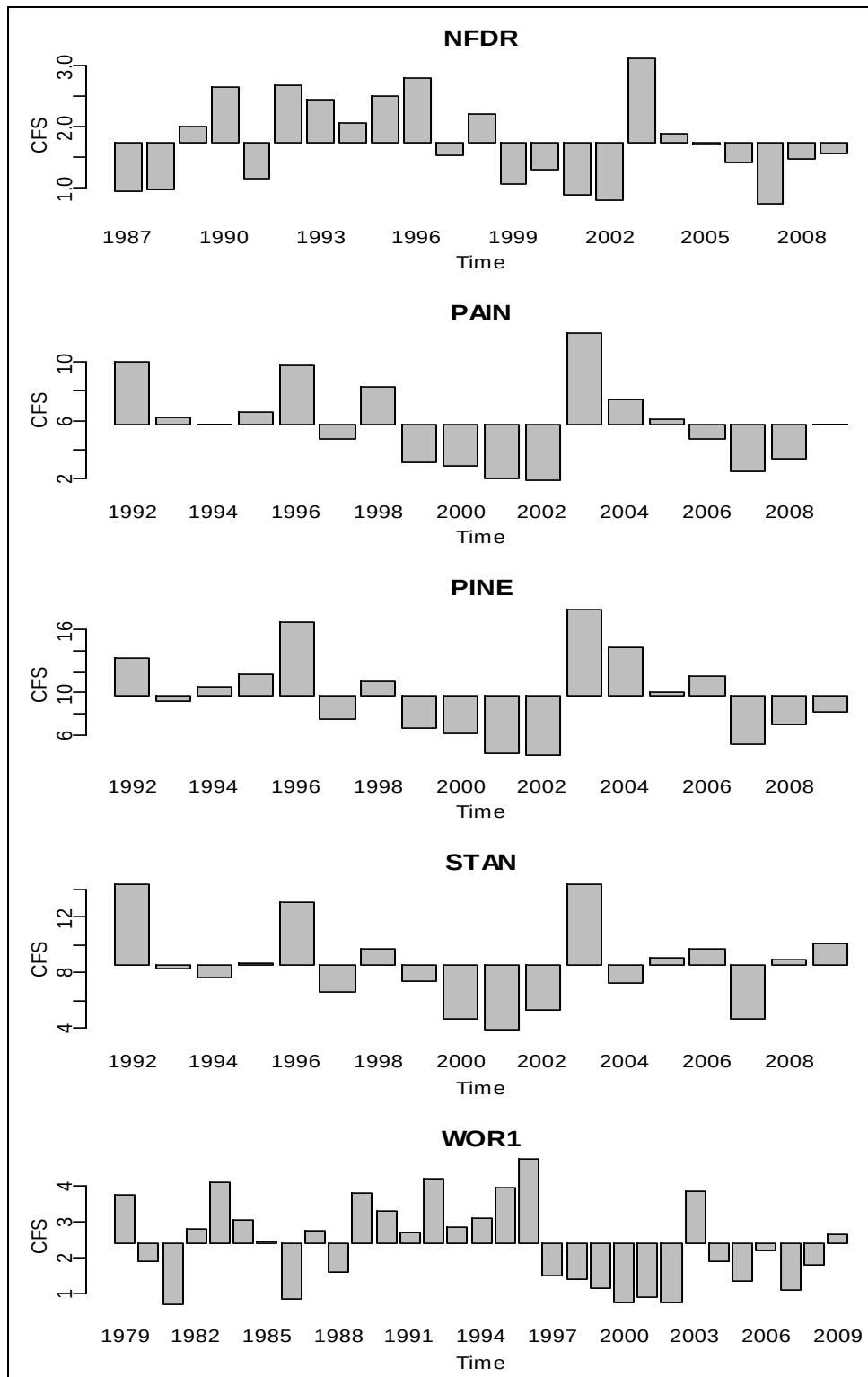


Figure 7 - Inter-annual variation in discharge around the long-term mean annual discharge for gauged streams in SHEN.

Appendix I - Weekly and Episodic Sample Analysis Counts for Paine Run (PAIN), Piney River (PINE), and Staunton River (STAN)

Site Id	Year	Collection_Id	N
PAIN	1987	UVA_SPGRAB	3
PAIN	1988	UVA_SPGRAB	4
PAIN	1989	UVA_SPGRAB	4
PAIN	1990	UVA_SPGRAB	4
PAIN	1991	UVA_SPGRAB	8
PAIN	1992	UVA_SPAUTO	39
PAIN	1992	UVA_SPGRAB	30
PAIN	1993	UVA_SPAUTO	76
PAIN	1993	UVA_SPGRAB	68
PAIN	1994	UVA_SPAUTO	63
PAIN	1994	UVA_SPGRAB	62
PAIN	1995	UVA_SPAUTO	30
PAIN	1995	UVA_SPGRAB	58
PAIN	1996	UVA_SPAUTO	29
PAIN	1996	UVA_SPGRAB	56
PAIN	1997	UVA_SPAUTO	31
PAIN	1997	UVA_SPGRAB	56
PAIN	1998	UVA_SPAUTO	60
PAIN	1998	UVA_SPGRAB	57
PAIN	1999	UVA_SPAUTO	25
PAIN	1999	UVA_SPGRAB	56
PAIN	2000	UVA_SPAUTO	24

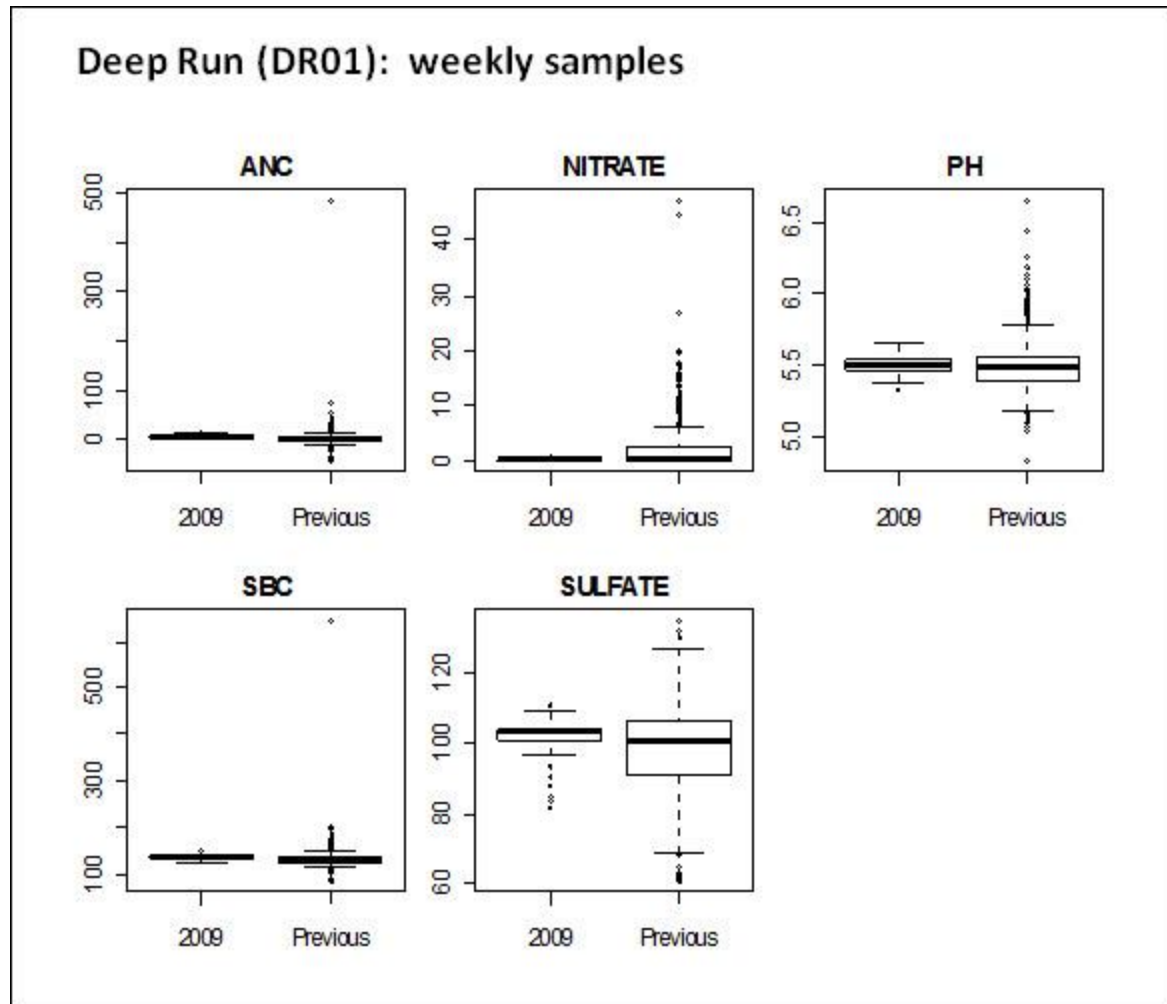
Site Id	Year	Collection_Id	N
PAIN	2000	UVA_SPGRAB	57
PAIN	2001	UVA_SPAUTO	16
PAIN	2001	UVA_SPGRAB	56
PAIN	2002	UVA_SPAUTO	22
PAIN	2002	UVA_SPGRAB	56
PAIN	2003	UVA_SPAUTO	164
PAIN	2003	UVA_SPGRAB	57
PAIN	2004	UVA_SPAUTO	83
PAIN	2004	UVA_SPGRAB	58
PAIN	2005	UVA_SPAUTO	66
PAIN	2005	UVA_SPGRAB	56
PAIN	2006	UVA_SPAUTO	79
PAIN	2006	UVA_SPGRAB	56
PAIN	2007	UVA_SPAUTO	8
PAIN	2007	UVA_SPGRAB	58
PAIN	2008	UVA_SPAUTO	22
PAIN	2008	UVA_SPGRAB	65
PAIN	2009	UVA_SPAUTO	32
PAIN	2009	UVA_SPGRAB	64
PINE	1992	UVA_SPAUTO	55
PINE	1992	UVA_SPGRAB	17
PINE	1993	UVA_SPAUTO	115
PINE	1993	UVA_SPGRAB	55
PINE	1994	UVA_SPAUTO	108

Site Id	Year	Collection_Id	N
PINE	1994	UVA_SPGRAB	51
PINE	1995	UVA_SPAUTO	78
PINE	1995	UVA_SPGRAB	54
PINE	1996	UVA_SPAUTO	52
PINE	1996	UVA_SPGRAB	55
PINE	1997	UVA_SPAUTO	48
PINE	1997	UVA_SPGRAB	56
PINE	1998	UVA_SPAUTO	32
PINE	1998	UVA_SPGRAB	56
PINE	1999	UVA_SPAUTO	22
PINE	1999	UVA_SPGRAB	56
PINE	2000	UVA_SPAUTO	41
PINE	2000	UVA_SPGRAB	56
PINE	2001	UVA_SPAUTO	35
PINE	2001	UVA_SPGRAB	54
PINE	2002	UVA_SPAUTO	33
PINE	2002	UVA_SPGRAB	56
PINE	2003	UVA_SPAUTO	124
PINE	2003	UVA_SPGRAB	56
PINE	2004	UVA_SPAUTO	68
PINE	2004	UVA_SPGRAB	56
PINE	2005	UVA_SPAUTO	79
PINE	2005	UVA_SPGRAB	56
PINE	2006	UVA_SPAUTO	100

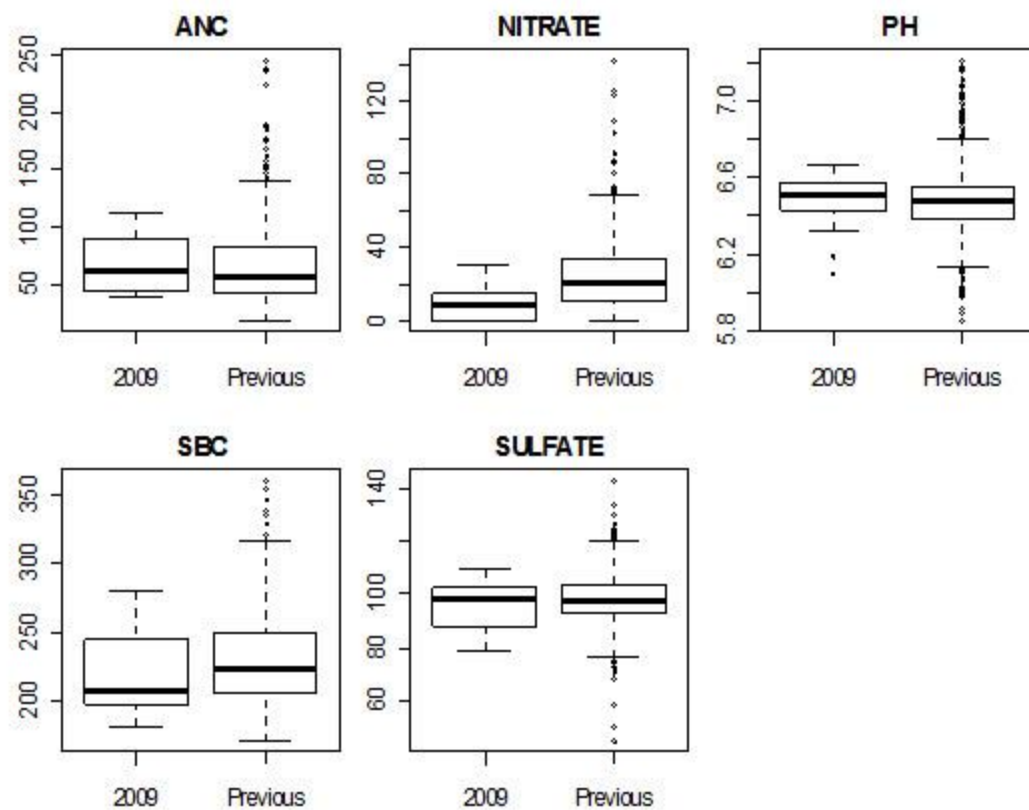
Site Id	Year	Collection_Id	N
PINE	2006	UVA_SPGRAB	56
PINE	2007	UVA_SPAUTO	27
PINE	2007	UVA_SPGRAB	52
PINE	2008	UVA_SPAUTO	18
PINE	2008	UVA_SPGRAB	63
PINE	2009	UVA_SPAUTO	18
PINE	2009	UVA_SPGRAB	65
STAN	1987	UVA_SPGRAB	3
STAN	1988	UVA_SPGRAB	5
STAN	1989	UVA_SPGRAB	4
STAN	1990	UVA_SPGRAB	4
STAN	1991	UVA_SPGRAB	8
STAN	1992	UVA_SPAUTO	46
STAN	1992	UVA_SPGRAB	29
STAN	1993	UVA_SPAUTO	145
STAN	1993	UVA_SPGRAB	67
STAN	1994	UVA_SPAUTO	149
STAN	1994	UVA_SPGRAB	61
STAN	1995	UVA_SPAUTO	32
STAN	1995	UVA_SPGRAB	58
STAN	1996	UVA_SPAUTO	30
STAN	1996	UVA_SPGRAB	56
STAN	1997	UVA_SPAUTO	61
STAN	1997	UVA_SPGRAB	60

Site Id	Year	Collection_Id	N
STAN	1998	UVA_SPAUTO	25
STAN	1998	UVA_SPGRAB	58
STAN	1999	UVA_SPAUTO	51
STAN	1999	UVA_SPGRAB	58
STAN	2000	UVA_SPAUTO	20
STAN	2000	UVA_SPGRAB	58
STAN	2001	UVA_SPAUTO	25
STAN	2001	UVA_SPGRAB	56
STAN	2002	UVA_SPAUTO	2
STAN	2002	UVA_SPGRAB	56
STAN	2003	UVA_SPAUTO	111
STAN	2003	UVA_SPGRAB	57
STAN	2004	UVA_SPAUTO	29
STAN	2004	UVA_SPGRAB	56
STAN	2005	UVA_SPAUTO	33
STAN	2005	UVA_SPGRAB	56
STAN	2006	UVA_SPAUTO	59
STAN	2006	UVA_SPGRAB	56
STAN	2007	UVA_SPAUTO	1
STAN	2007	UVA_SPGRAB	51
STAN	2008	UVA_SPAUTO	16
STAN	2008	UVA_SPGRAB	64
STAN	2009	UVA_SPAUTO	50
STAN	2009	UVA_SPGRAB	63

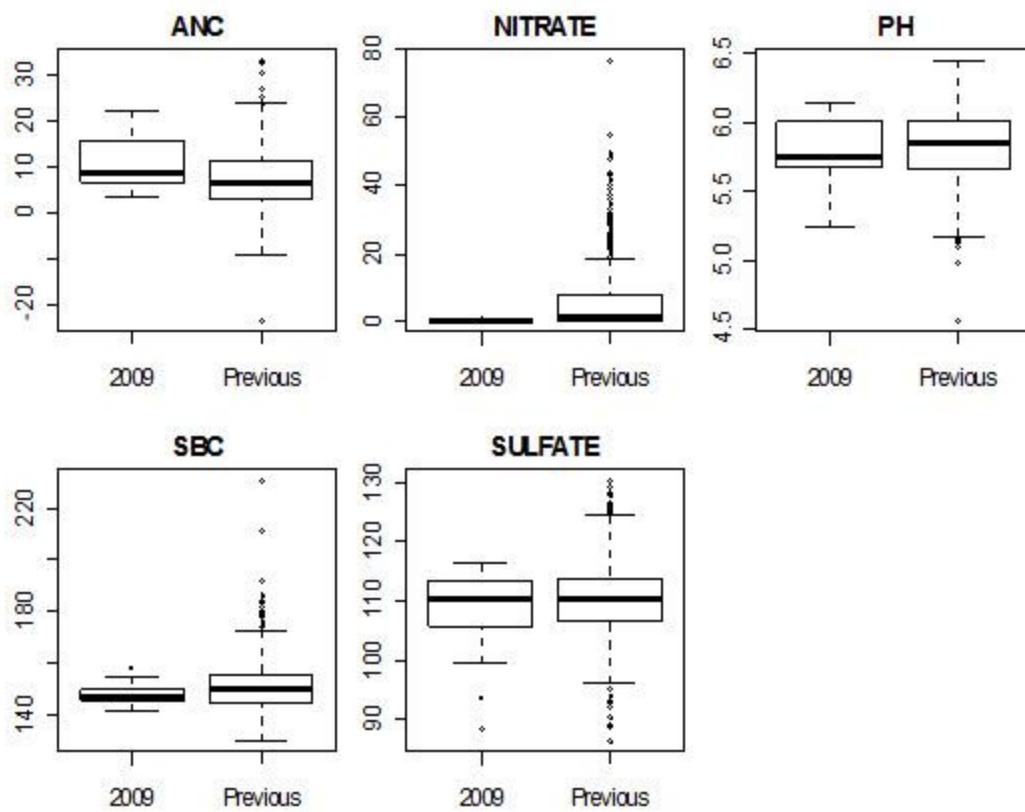
Appendix II - Range, Median, and Distribution of Values for 2009 Sample Analysis Data Compared With Previous Years' Data



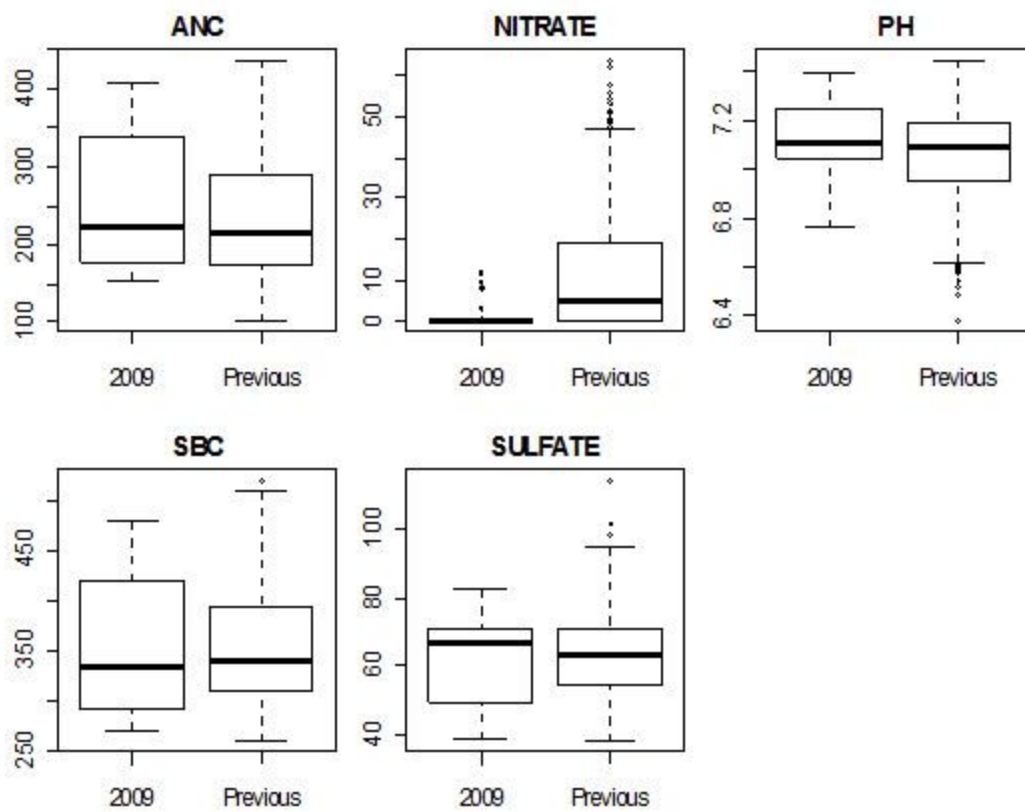
North Fork of Dry Run (NFDR): weekly samples



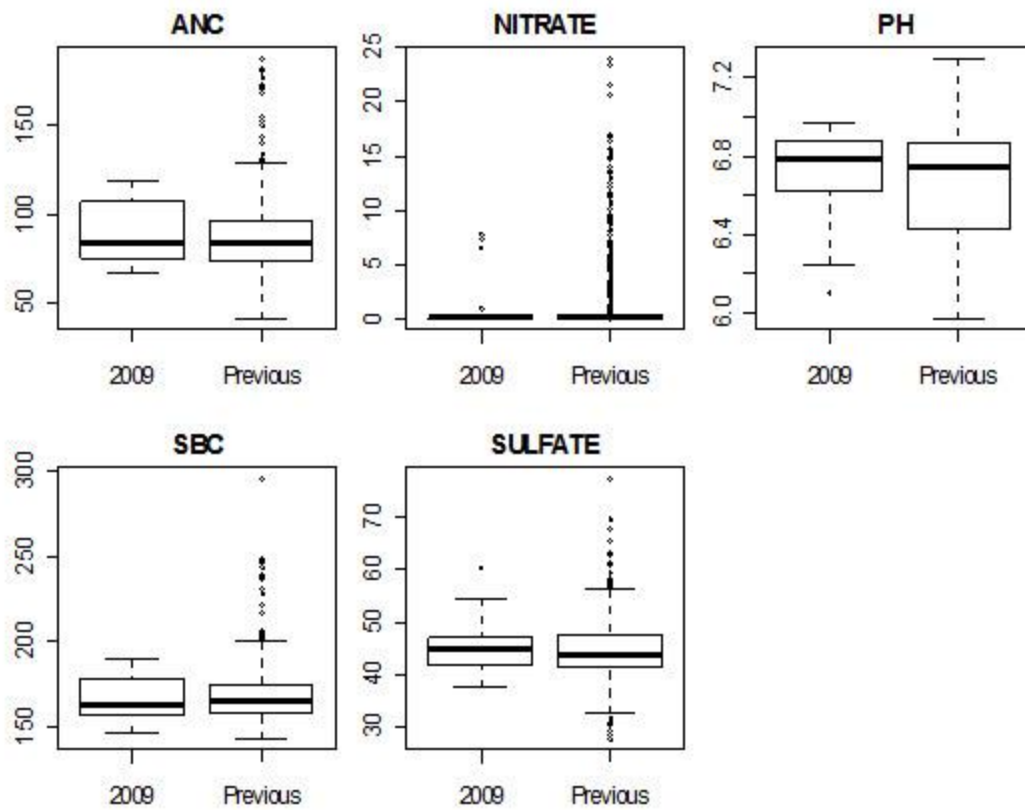
Paine Run (PAIN): weekly samples



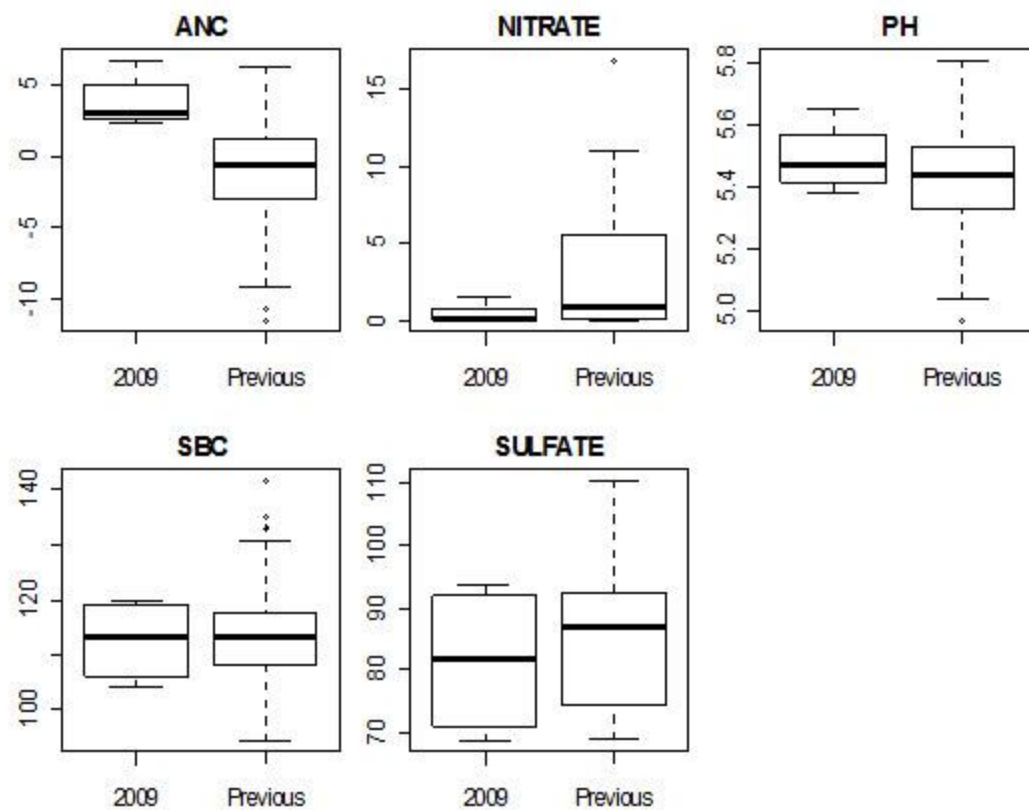
Piney River (PINE): weekly samples



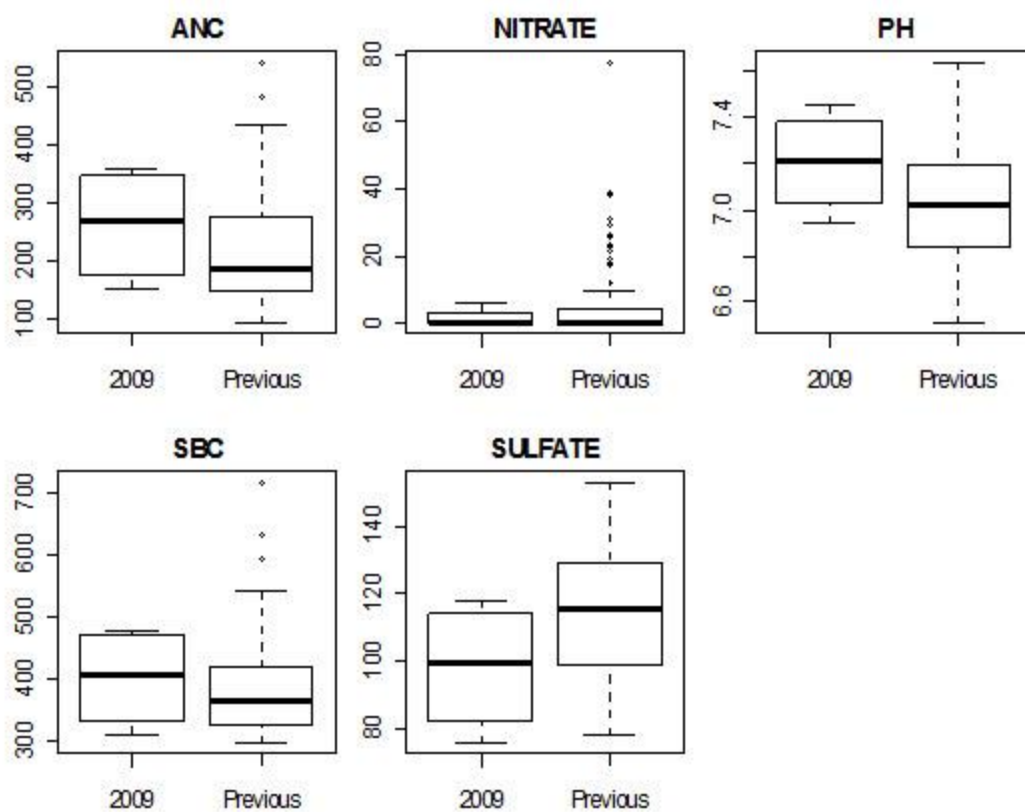
Staunton River (STAN): weekly samples



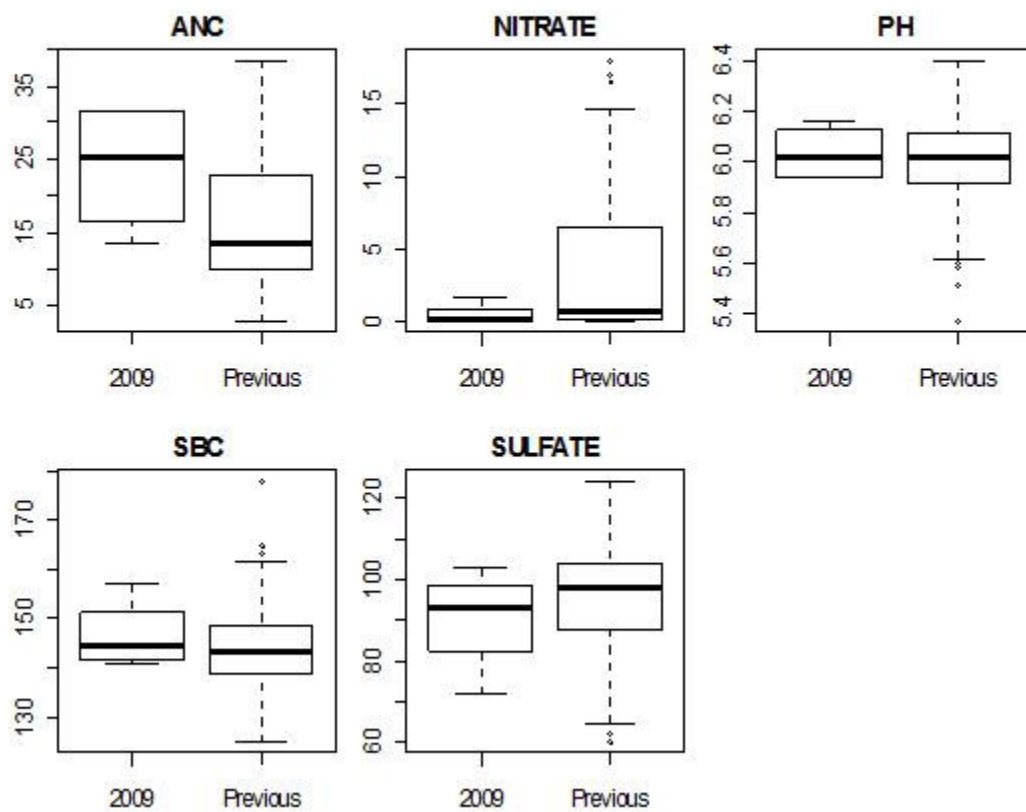
Meadow Run (VT36): quarterly samples



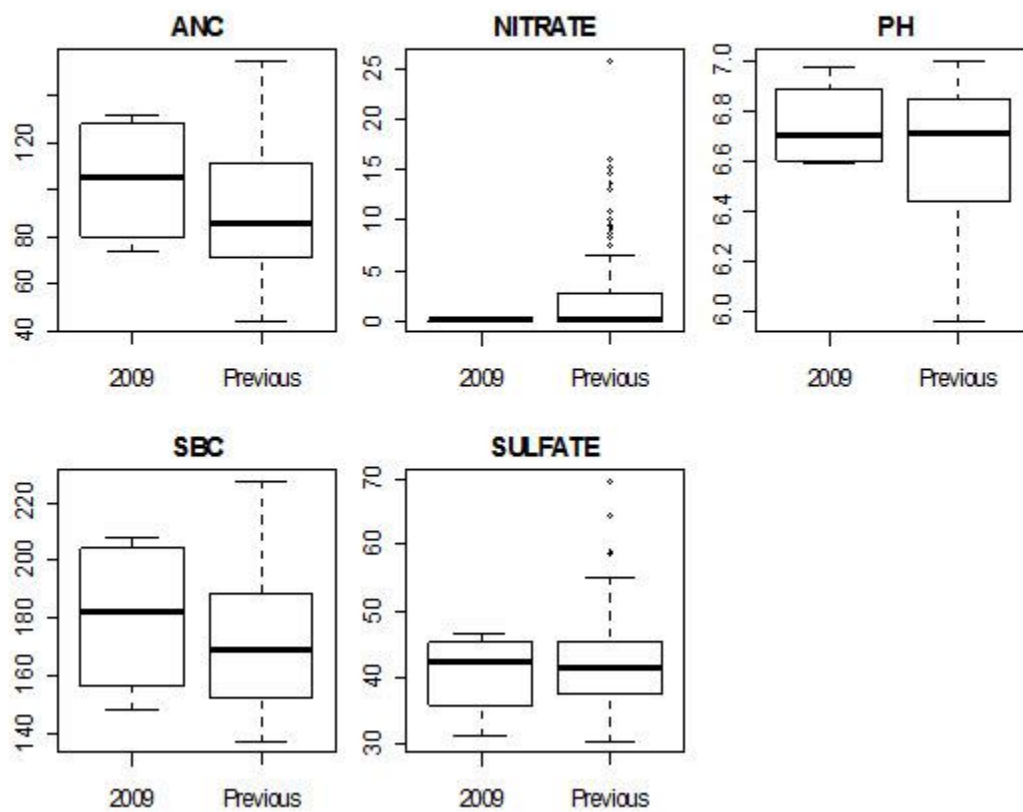
Jeremys Run (VT51): quarterly samples



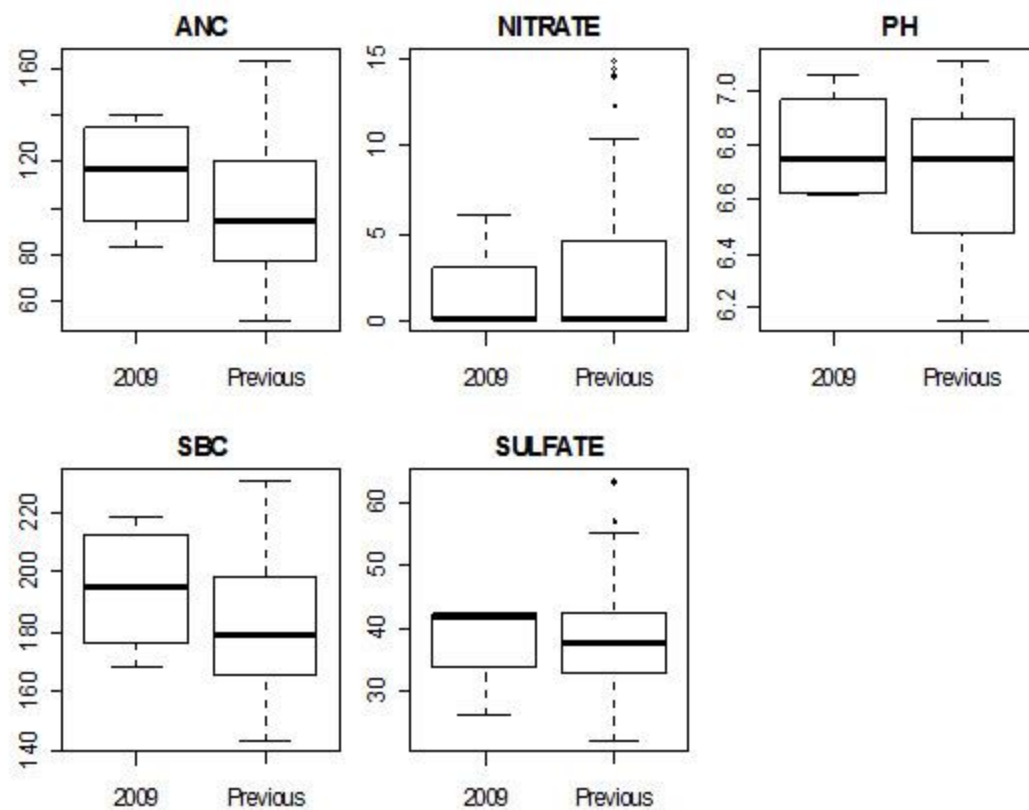
Twomile Run (VT53): quarterly samples



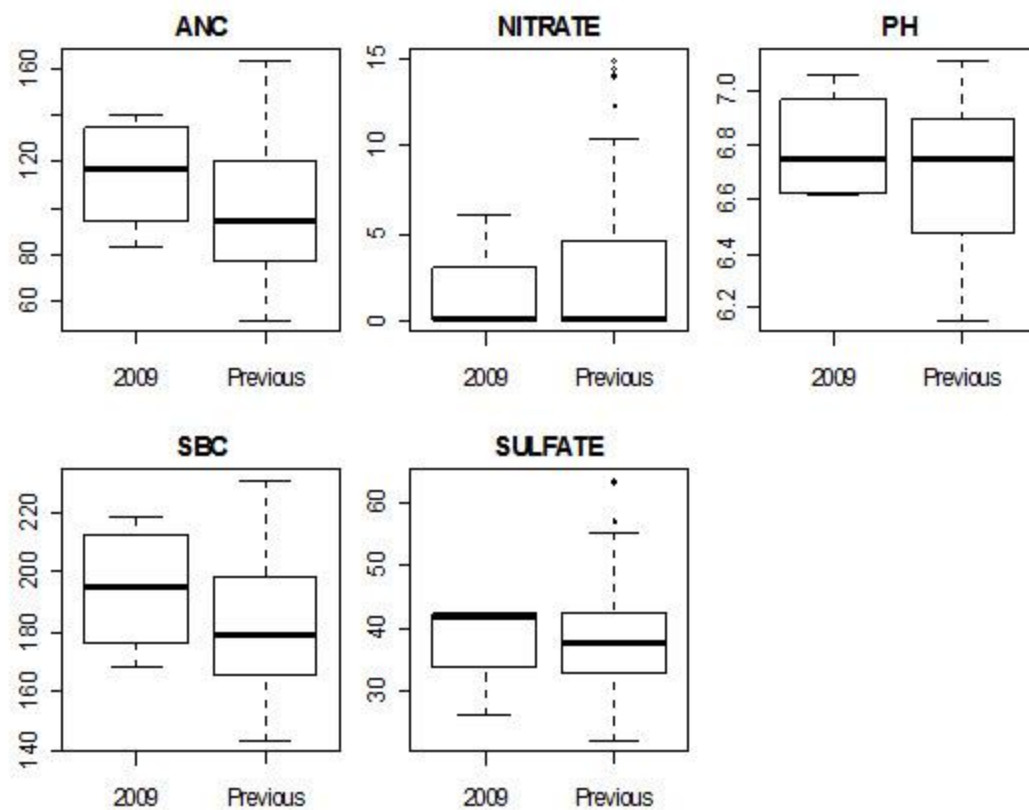
Brokenback Run (VT58): quarterly samples



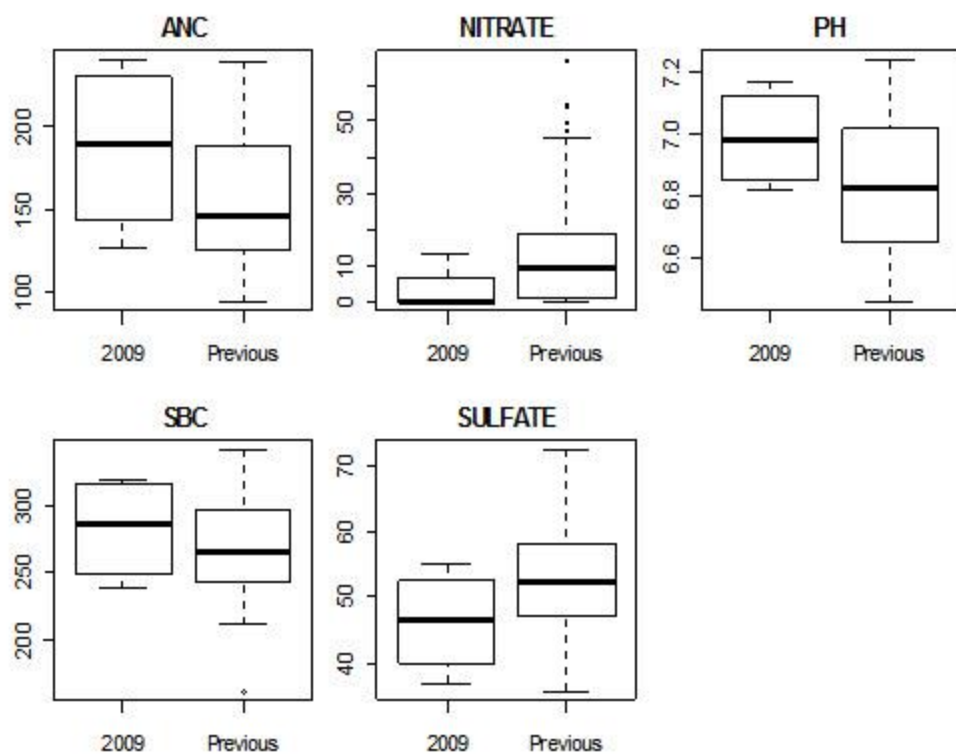
North Fork of Thornton Run (VT61): quarterly samples



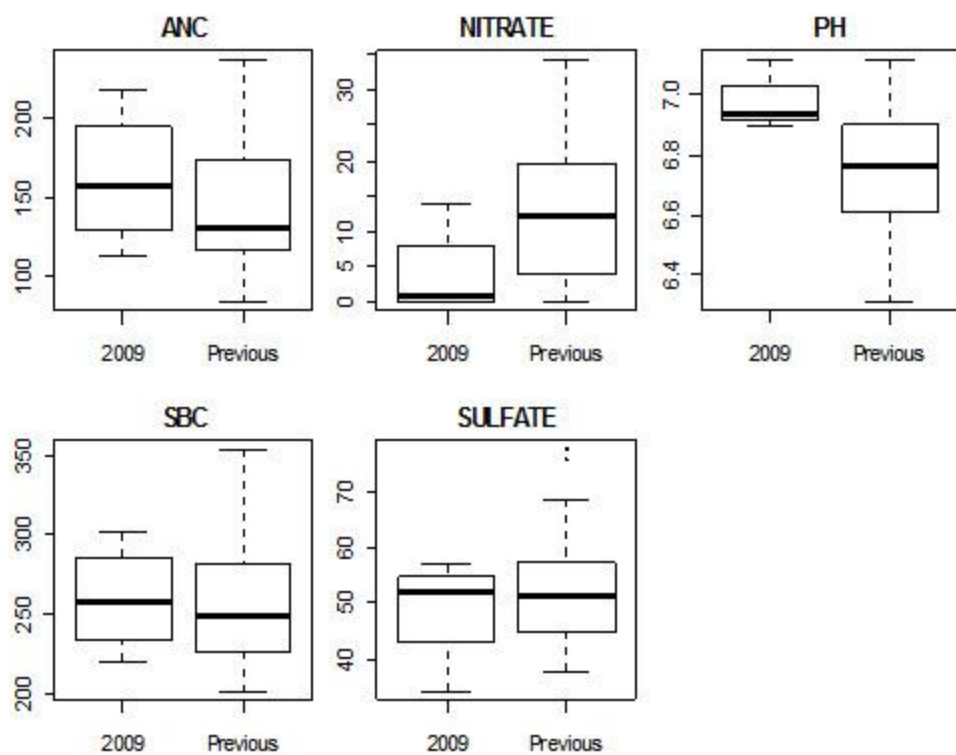
Hazel River (VT62): quarterly samples



Rose River (VT66): quarterly samples



White Oak Canyon (VT75): quarterly samples



White Oak Run (WOR1): weekly samples

