

SHENANDOAH WATERSHED STUDY



2010 Report

Shenandoah Watershed Study (SWAS)

2010 Report, 03/15/12

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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 31-year period, 1979-2010, 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 2010 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

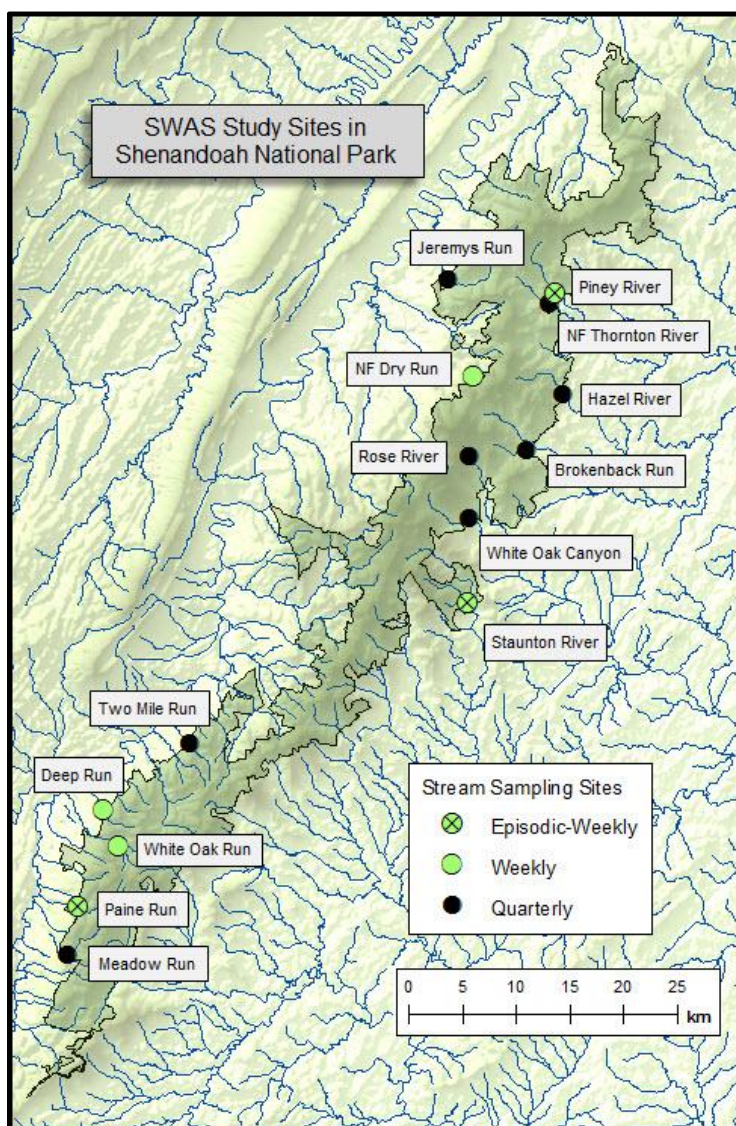


Figure 1 - SWAS monitoring program sites in SHEN.

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 2010 include:

- All 14 of the study streams were less acidic (based on acid neutralizing capacity concentrations) in 2010 than in previous years.
- Annual discharge in 2010 was near the long-term mean for the five gauged streams.

This annual report has been prepared for the Natural Resources Division at SHEN. SWAS program data (water quality and discharge data) through the end of 2010 have been posted on an online data warehouse (UVA Collab site: SHEN Data Submission) for access by the Natural Resources Division at SHEN. In addition, a separate report has been submitted that describes the results of the Virginia Trout Stream Sensitivity Study 2010 Survey for the SHEN area.¹

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. Figure 3 indicates the number of weekly grab samples and episodic (ISCO) samples analyzed for the three 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 both quarterly and weekly grab samples has been generally constant since the early 1990s. The high number of ISCO samples analyzed in 2003 was due to unusually high discharge (see Figure 8). The relatively low number of samples

¹ Webb, 2012. The Virginia Trout Stream Sensitivity Study 2010 Survey: Results for Shenandoah National Park. Submitted to the National Park Service.

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 2010, 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 3 indicates the number of samples that were analyzed.

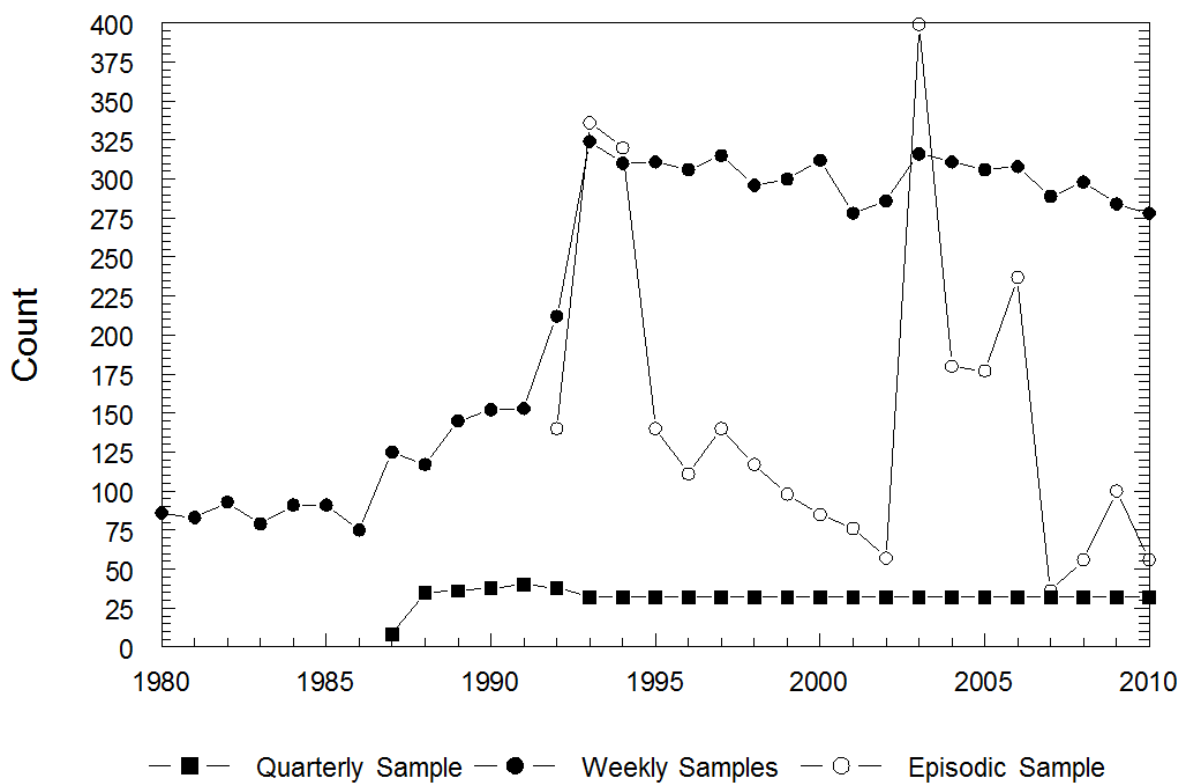


Figure 2 - Stream water sample analyses obtained for SWAS monitoring program sites in SHEN.

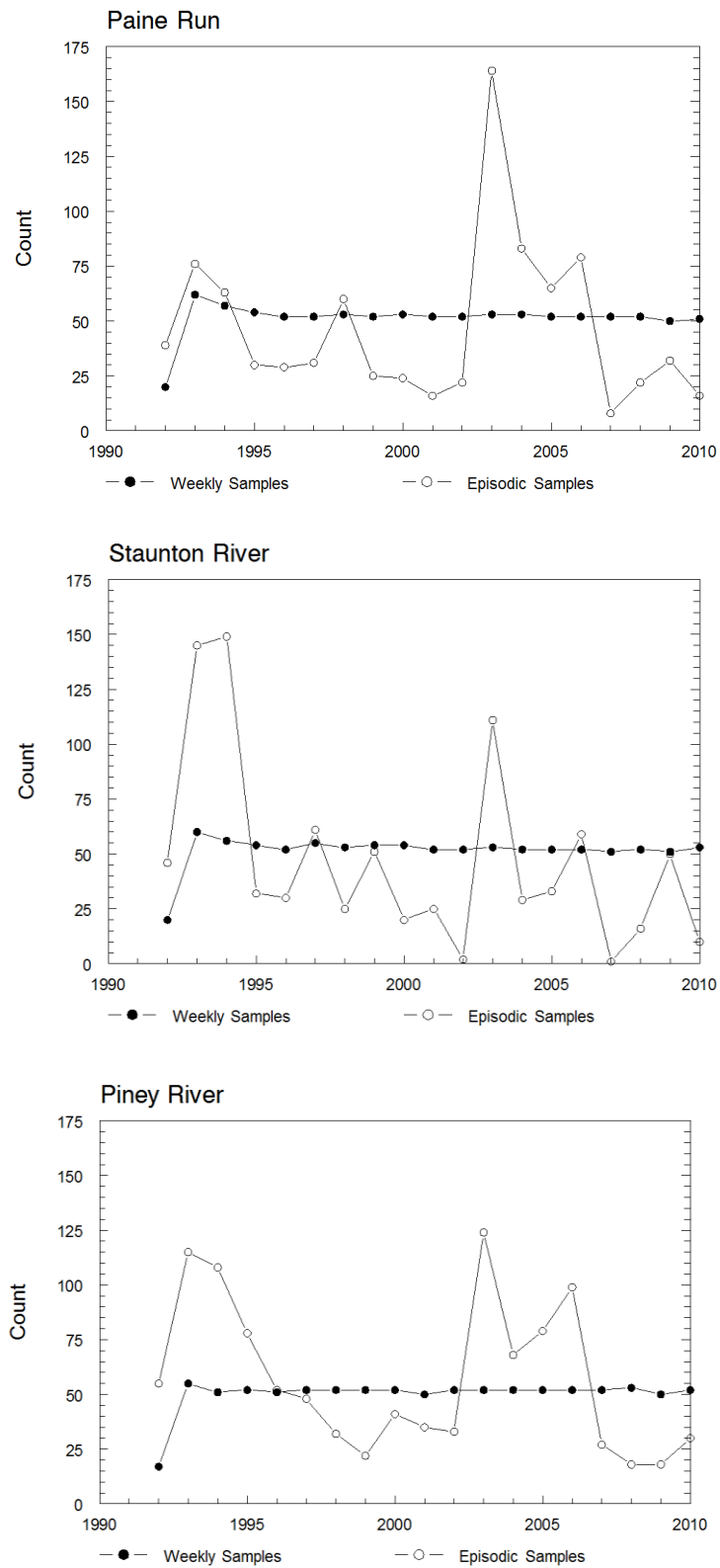


Figure 3 - Stream water sample analyses obtained for the intensively studied monitoring sites established in 1992.

3. Summary Tables of Sample Analysis Results for 2010

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. 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 2010.

Site	Analyte ¹	Winter	Spring	Summer	Fall
Silicious (Siliciclastic) bedrock					
VT36	Acid Neutralizing Capacity	-4.53	-2.29	-0.55	5.89
VT36	pH	5.01	5.1	5.35	5.56
VT36	Specific Conductance	21.1	18.3	15.8	15.4
VT36	Calcium Ion	31.62	26.4	23.28	19.65
VT36	Magnesium Ion	43.76	37.14	31.09	30.02
VT36	Potassium Ion	26.59	27.06	28.33	33.78
VT36	Sodium Ion	19.1	20.64	23.86	21.95
VT36	Ammonium Ion	0	0	0	0
VT36	Sulfate	104.51	89.73	70.54	73.85
VT36	Chloride	22.07	21.55	22.49	23.95
VT36	Nitrate	0	0	0.29	0
VT36	Silica	71.48	80.08	114.53	103.8
VT36	Total Monomeric Aluminum	79.8	34.77	22.5	25.06
VT36	Organic Monomeric Aluminum	23.07			
VT53	Acid Neutralizing Capacity	3.26	11.74	37.68	30.23
VT53	pH	5.42	5.37	6.05	6.09
VT53	Specific Conductance	19.2	19.3	16.3	20.8
VT53	Calcium Ion	30.26	26.59	24.52	33.01
VT53	Magnesium Ion	47.55	43.16	36.92	50.56
VT53	Potassium Ion	35.72	37.34	38.42	48.05

Site	Analyte ¹	Winter	Spring	Summer	Fall
VT53	Sodium Ion	23.21	26.76	29.13	31.29
VT53	Ammonium Ion	0	0	0	0
VT53	Sulfate	101.5	92.55	59.14	98.14
VT53	Chloride	23.85	23.15	21.86	27.34
VT53	Nitrate	0.84	0	0	0
VT53	Silica	81.28	89.48	127.88	116.46
VT53	Total Monomeric Aluminum	27.05	12.95		
Felsic (Granitic) bedrock					
VT58	Acid Neutralizing Capacity	41.58	88.26	160.54	118.42
VT58	pH	5.63	6.43	6.63	6.89
VT58	Specific Conductance	16.6	17.1	23	21.3
VT58	Calcium Ion	46.51	51.41	81.04	72.93
VT58	Magnesium Ion	28.78	31.29	47.08	44.75
VT58	Potassium Ion	8.83	9.68	13.88	14.25
VT58	Sodium Ion	47.77	60.29	77.95	65.92
VT58	Ammonium Ion	0	0	0	0
VT58	Sulfate	55.39	34.73	27.15	39.69
VT58	Chloride	23.17	22.14	21.48	29.3
VT58	Nitrate	0	0	0	0.32
VT58	Silica	121.44	145.4	172.56	161.34
VT62	Acid Neutralizing Capacity	50.15	106.18	164.64	127.24
VT62	pH	5.89	6.59	6.57	6.94
VT62	Specific Conductance	16.5	18.2	23.7	23.6

Site	Analyte ¹	Winter	Spring	Summer	Fall
VT62	Calcium Ion	41.77	52.97	78.77	73.94
VT62	Magnesium Ion	31.32	37.2	54.51	52.24
VT62	Potassium Ion	9.64	11.04	13.49	19.59
VT62	Sodium Ion	50.63	62.86	81.67	71.51
VT62	Ammonium Ion	0	0	0	0
VT62	Sulfate	50.39	30.48	24.43	39.57
VT62	Chloride	25.92	23.94	23.54	37.26
VT62	Nitrate	0	0	0	0
VT62	Silica	132.41	157.39	180.9	174.24
Mafic (Basaltic) bedrock					
VT51	Acid Neutralizing Capacity	108.86	214.82	437.4	247.35
VT51	pH	6.44	7.18	7.19	7.16
VT51	Specific Conductance	33.3	38.4	55.7	42.1
VT51	Calcium Ion	114.66	136.35	217.56	152.81
VT51	Magnesium Ion	105.09	121.24	189.34	140.34
VT51	Potassium Ion	15	18.3	26.66	17.93
VT51	Sodium Ion	53.92	68.51	120.39	82.09
VT51	Ammonium Ion	0	0	0	0
VT51	Sulfate	124.36	102.28	79.29	98.59
VT51	Chloride	32.35	33.11	31.09	45.44
VT51	Nitrate	0	0	0	0
VT51	Silica	145.8	157.27	232.09	201.59
VT61	Acid Neutralizing Capacity	162.98	297.26	489.54	373

Site	Analyte ¹	Winter	Spring	Summer	Fall
VT61	pH	6.61	6.84	6.98	7.38
VT61	Specific Conductance	36.6	40.9	56	51.3
VT61	Calcium Ion	123	151.33	223.59	196.13
VT61	Magnesium Ion	111.96	125.81	180.23	167.78
VT61	Potassium Ion	9.67	10.86	16.13	16.8
VT61	Sodium Ion	73.98	100.78	152	120.08
VT61	Ammonium Ion	3.93	0	0	0
VT61	Sulfate	106.06	66.16	44.82	77.74
VT61	Chloride	32.32	30.37	30.55	45.31
VT61	Nitrate	1.7	0	0	0
VT61	Silica	198.5	250.83	322.95	278.94
VT66	Acid Neutralizing Capacity	93.44	174.95	242.7	191.89
VT66	pH	6.37	6.8	6.77	7.13
VT66	Specific Conductance	23.2	27.6	33.7	30
VT66	Calcium Ion	86.85	107.1	142.53	122.28
VT66	Magnesium Ion	66.31	78.58	103.34	90.62
VT66	Potassium Ion	4.74	5.36	5.73	6.85
VT66	Sodium Ion	45	61.49	76.92	62.21
VT66	Ammonium Ion	0	0	0.31	0
VT66	Sulfate	62.81	45.25	34.96	48.82
VT66	Chloride	28.56	32.27	32.67	37.42
VT66	Nitrate	0	3.71	0	0
VT66	Silica	121.44	143.85	171.57	151.88

Site	Analyte ¹	Winter	Spring	Summer	Fall
VT75	Acid Neutralizing Capacity	84.18	152.31	238.44	173.08
VT75	pH	6.53	6.9	6.92	7.04
VT75	Specific Conductance	22	26	33.9	28.4
VT75	Calcium Ion	80.11	104.51	149.49	119.04
VT75	Magnesium Ion	60.94	74.48	106.01	86.23
VT75	Potassium Ion	4.6	5.31	5.27	7.15
VT75	Sodium Ion	41.33	56.14	66.75	53.8
VT75	Ammonium Ion	0	0	0	0
VT75	Sulfate	56.47	45.34	32.66	46.2
VT75	Chloride	28.16	33.74	37.27	41.11
VT75	Nitrate	0	7.38	1	0.32
VT75	Silica	110.32	130.37	154.95	131.6

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

Table 3 - Range, median, and interquartile distribution of analysis results for weekly grab samples collected in 2010.

Site ID	Analyte ¹	Min	25th	Median	75th	Max
Silicious (Siliciclastic) bedrock						
DR01	Acid Neutralizing Capacity	-0.86	0.95	3.61	6.76	22.21

Site ID	Analyte ¹	Min	25th	Median	75th	Max
DR01	pH	5.22	5.3	5.36	5.41	5.52
DR01	Specific Conductance	18.1	19.2	19.7	21.2	23.1
DR01	Calcium Ion	21.03	23.95	24.55	28.46	35.95
DR01	Magnesium Ion	37.59	40.68	43.26	49.32	56.82
DR01	Potassium Ion	33.74	36.84	38.56	41.72	48.23
DR01	Sodium Ion	21.53	26.67	28.52	30.08	33.12
DR01	Sulfate	82.13	93.79	103.01	107.87	113.15
DR01	Chloride	23.96	25.61	27.35	32.8	50.17
DR01	Nitrate	0	0	0	0.31	5.18
DR01	Ammonium Ion	0	0	0	0	0.6
DR01	Silica	71.75	83.89	91.91	99.63	113.4
PAIN	Acid Neutralizing Capacity	2.76	5.92	10.44	15.9	31.35
PAIN	pH	5.29	5.59	5.83	5.98	6.16
PAIN	Specific Conductance	18.9	19.8	20.1	20.7	22.3
PAIN	Calcium Ion	23.53	27.89	28.85	31.12	41.08
PAIN	Magnesium Ion	42.07	45.42	48.61	51.62	53.91
PAIN	Potassium Ion	37.78	42.9	46.86	50.84	55.45
PAIN	Sodium Ion	19.3	23.36	24.71	26.66	29.33
PAIN	Sulfate	97.17	103.56	108.59	113.48	118.44
PAIN	Chloride	22.19	23.39	23.96	24.46	27.84

Site ID	Analyte ¹	Min	25th	Median	75th	Max
PAIN	Nitrate	0	0	0	0	7.38
PAIN	Ammonium Ion	0	0	0	0	7.65
PAIN	Silica	70.54	81.95	94.02	110.44	117.42
WOR1	Acid Neutralizing Capacity	15.02	20.34	32.31	52.92	82.19
WOR1	pH	5.36	5.94	6.01	6.1	6.29
WOR1	Specific Conductance	16.3	17.2	18.2	20.3	28.3
WOR1	Calcium Ion	25.86	28.21	30.86	36.25	53.92
WOR1	Magnesium Ion	42.08	45.98	48.43	54.76	81.98
WOR1	Potassium Ion	31.58	35.04	37.92	46.47	65.14
WOR1	Sodium Ion	18.32	20.44	22.48	23.82	27.48
WOR1	Sulfate	70.48	81.93	83.36	85.23	87.41
WOR1	Chloride	18.83	19.58	20.53	21.14	23.04
WOR1	Nitrate	0	0	0	1.7	56.02
WOR1	Ammonium Ion	0	0	0	0	2.01
WOR1	Silica	68.88	73.06	80.88	88.48	106.74
Felsic (Granitic) bedrock						
NFDR	Acid Neutralizing Capacity	37.77	50.43	75.82	101.58	134.11
NFDR	pH	6.1	6.4	6.51	6.55	6.61
NFDR	Specific Conductance	21.1	22	24.4	29	32.3

Site ID	Analyte ¹	Min	25th	Median	75th	Max
NFDR	Calcium Ion	60.17	67.2	78.02	100.77	113.63
NFDR	Magnesium Ion	34.74	37.98	43.1	53.77	60.72
NFDR	Potassium Ion	6.99	8.94	10.32	12.94	14.51
NFDR	Sodium Ion	60.18	71.58	75.88	85.3	94.46
NFDR	Sulfate	69.41	87.61	90.45	98.56	106.29
NFDR	Chloride	23.14	27.82	30.03	32.09	36.6
NFDR	Nitrate	0	0	5.13	12.91	38.41
NFDR	Ammonium Ion	0	0	0	0	3.99
NFDR	Silica	132.2	151.8	164.25	183.03	208.23
STAN	Acid Neutralizing Capacity	63.55	74.97	97.79	109.46	151.86
STAN	pH	5.94	6.52	6.71	6.87	7.04
STAN	Specific Conductance	16.7	17.8	18.8	20	23.3
STAN	Calcium Ion	52.66	59.36	65.65	70.15	88.54
STAN	Magnesium Ion	22.75	25.02	27.35	29.88	46.01
STAN	Potassium Ion	7.68	9.33	11.26	12.81	15.35
STAN	Sodium Ion	53.94	59.73	63.53	68.12	76.71
STAN	Sulfate	32.37	41.65	43.41	46.66	56.94
STAN	Chloride	19.34	22.16	22.77	23.15	24.56
STAN	Nitrate	0	0	0	0	0.13
STAN	Ammonium Ion	0	0	0	0	1.38

Site ID	Analyte ¹	Min	25th	Median	75th	Max
STAN	Silica	118.75	130.93	137.3	148.07	160.44
Mafic (Basaltic) bedrock						
PINE	Acid Neutralizing Capacity	131.4	172.92	244.13	360.81	445.56
PINE	pH	6.65	6.96	7.05	7.19	7.29
PINE	Specific Conductance	27.3	30.8	35.2	43.5	51.7
PINE	Calcium Ion	103.27	114.11	139.32	182.18	218.65
PINE	Magnesium Ion	84.87	93.97	110.29	135.64	163.61
PINE	Potassium Ion	4.09	4.95	6.63	8.43	10.61
PINE	Sodium Ion	58.14	67.55	80.05	106.06	124.91
PINE	Sulfate	33.62	45.65	62.11	68.78	81.36
PINE	Chloride	26.29	28.19	29.77	30.69	37.18
PINE	Nitrate	0	0	0.17	1.53	32.26
PINE	Ammonium Ion	0	0	0	0	2.15
PINE	Silica	165.88	188.45	222.49	276.71	306.48

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

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

Context for water quality data obtained in 2010 and summarized in Tables 2-3 is provided by graphical comparison with data obtained in previous years. Site-by-site box 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 I. Figure 4 compares the mean values for key acid-base constituents for the reporting year with the mean values for all previous years.

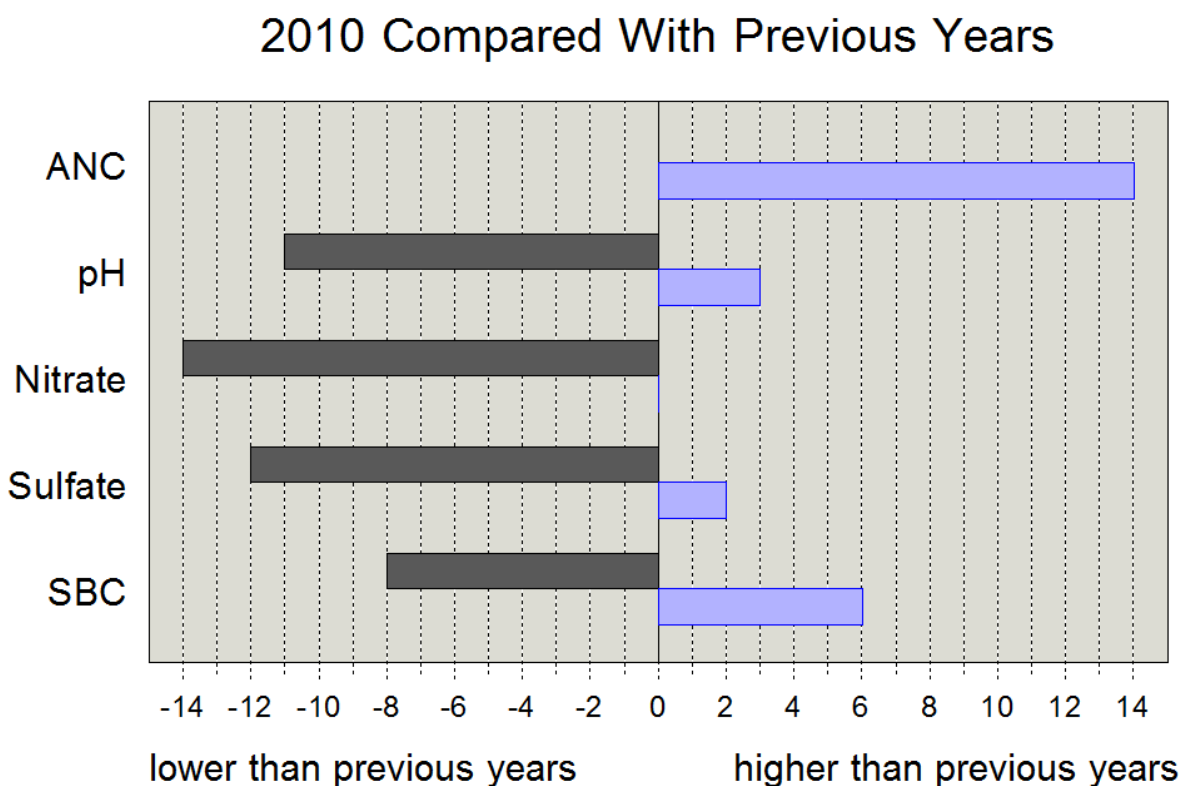


Figure 4 - Comparison of current and previous years' data. Dark gray bars indicate the number of sites for which the current year's mean values were lower than for the previous years' means. Light blue bars indicate the number of sites for which the current year's mean values were higher than the previous years' means.

The differences in mean values evident in Figure 4 between 2010 and pre-2010 are generally 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 2010 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 12 of the 14 study streams were lower in 2010 than the mean for the previous years. This is inconsistent 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. The change in the mean for the sum of base cation concentrations increased in six streams and decreased in eight 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. Other factors may also be involved.

The comparison of nitrate concentration means shows that mean nitrate concentrations were lower in all of the study stream in 2010 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 5 breaks down the comparison in mean values between 2010 and pre-2010 by watershed bedrock class. The evident strong relationship between ANC, pH, and base cations and bedrock class is consistent with previous observations. The lowest values are associated with siliceous (siliciclastic) bedrock, intermediate values are associated with felsic (granitic) bedrock, and the highest values are associated with mafic (basaltic) bedrock. The relationship between watershed bedrock and sulfate concentrations is not as strong. It also appears that the streams with the least recovery or increase in ANC (as well as the most increase in free acidity or decrease in pH) are associated with siliceous bedrock. This is consistent with expectations for streams draining watersheds underlain by this base-poor bedrock type. Previous modeling exercises have indicated that recovery from acidification would be least for this class of streams.²

The observed patterns of change in acid-base chemistry, based on a simple comparison of means for the reporting year with means of preceding years, raise unanswered questions concerning, for example, the mixed responses of base cations and the inverse relationship between ANC and pH. More comprehensive analysis of temporal changes in stream water chemistry related to these questions will be addressed in the context of periodic trend analysis.

² Sullivan, T.J., B.J. Cosby, J.R. Webb, R.L. Dennis, A.J. Bulger, F.A. Deviney, Jr., 2008. Stream water acid-base chemistry and critical loads of atmospheric sulfur deposition in Shenandoah National Park, Virginia. *Environmental Monitoring and Assessment*, 137:85.

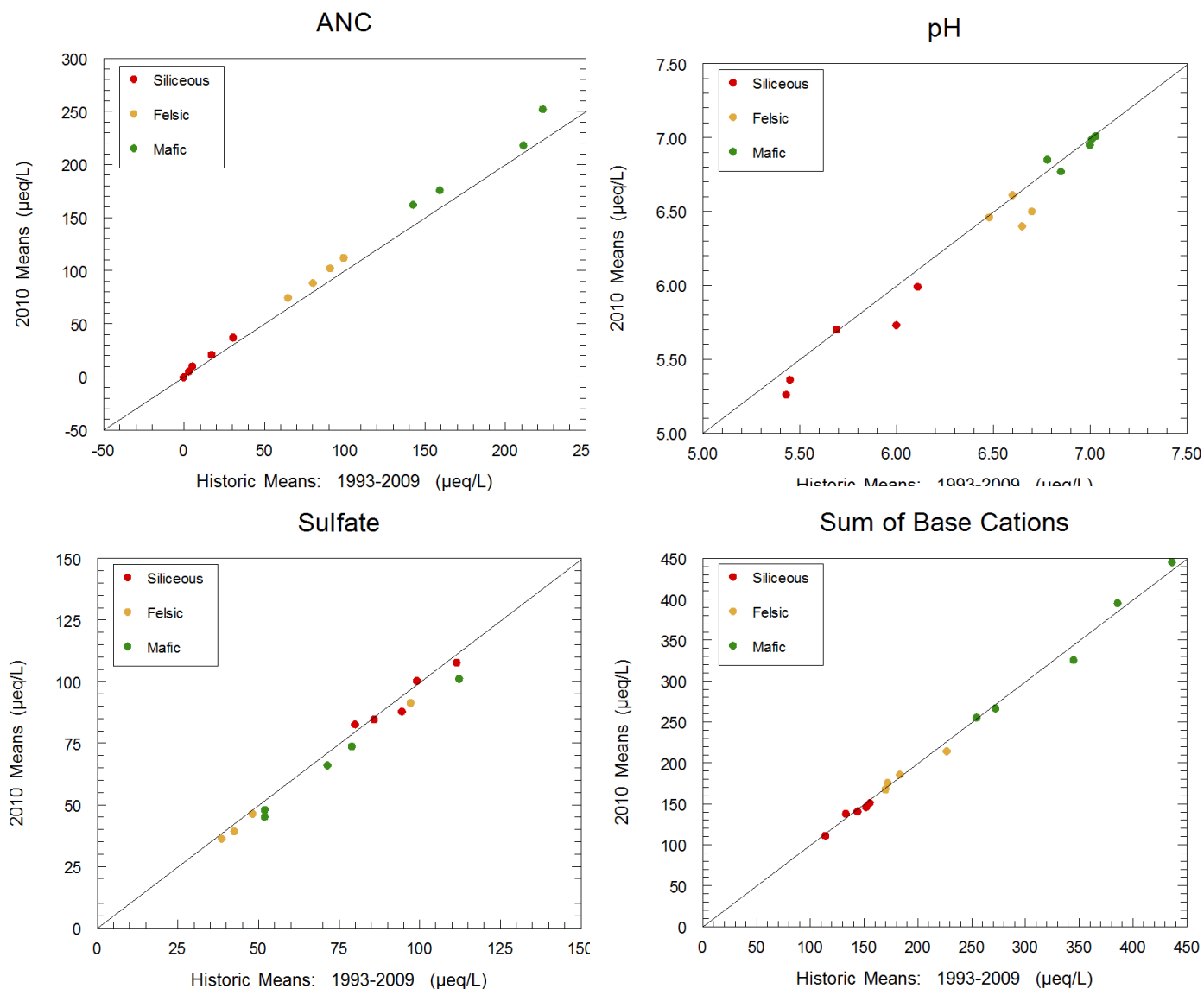


Figure 5 - Comparison of current and previous years' data for SWAS study streams. Points above the 1:1 line indicate streams for which the current year's mean values were higher than the previous years' means. Points below the line indicate streams for which the current year's mean values were lower 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 6 displays five years of ANC values for both weekly grab samples and automated high-flow samples for Paine Run, Piney River, and Staunton River. For all three streams, lower ANC levels occur late fall through early spring, which is 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 occur in Paine Run. Episodically decreased ANC values are also observed on Staunton River and Piney River, but ANC levels, except occasionally for Staunton River, do not drop below 50 $\mu\text{eq/L}$.

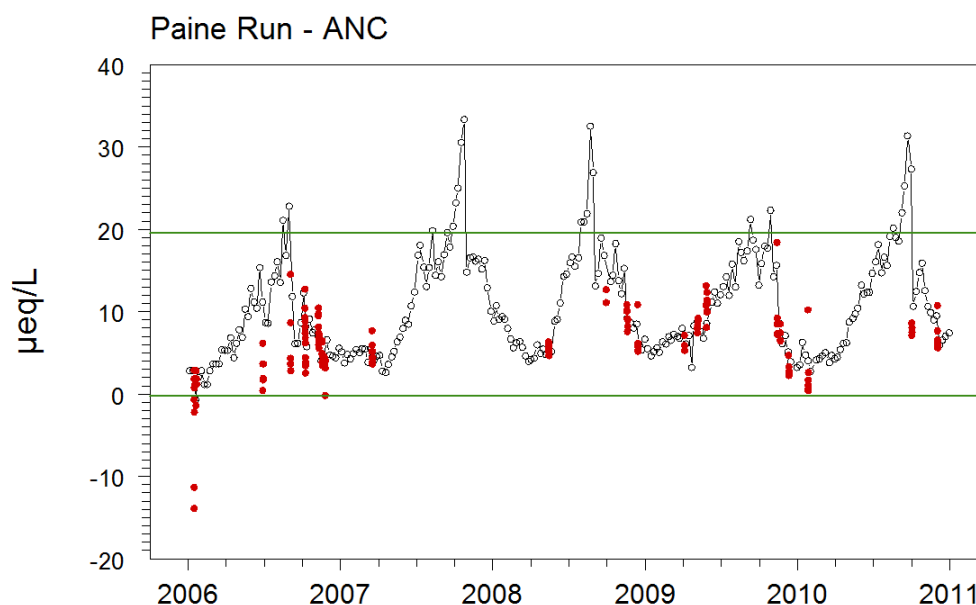


Figure 6 - ANC values for grab (black points) and automated episodic samples (red points) in 2006-2010. Green lines indicate ecological thresholds discussed in Section 6.

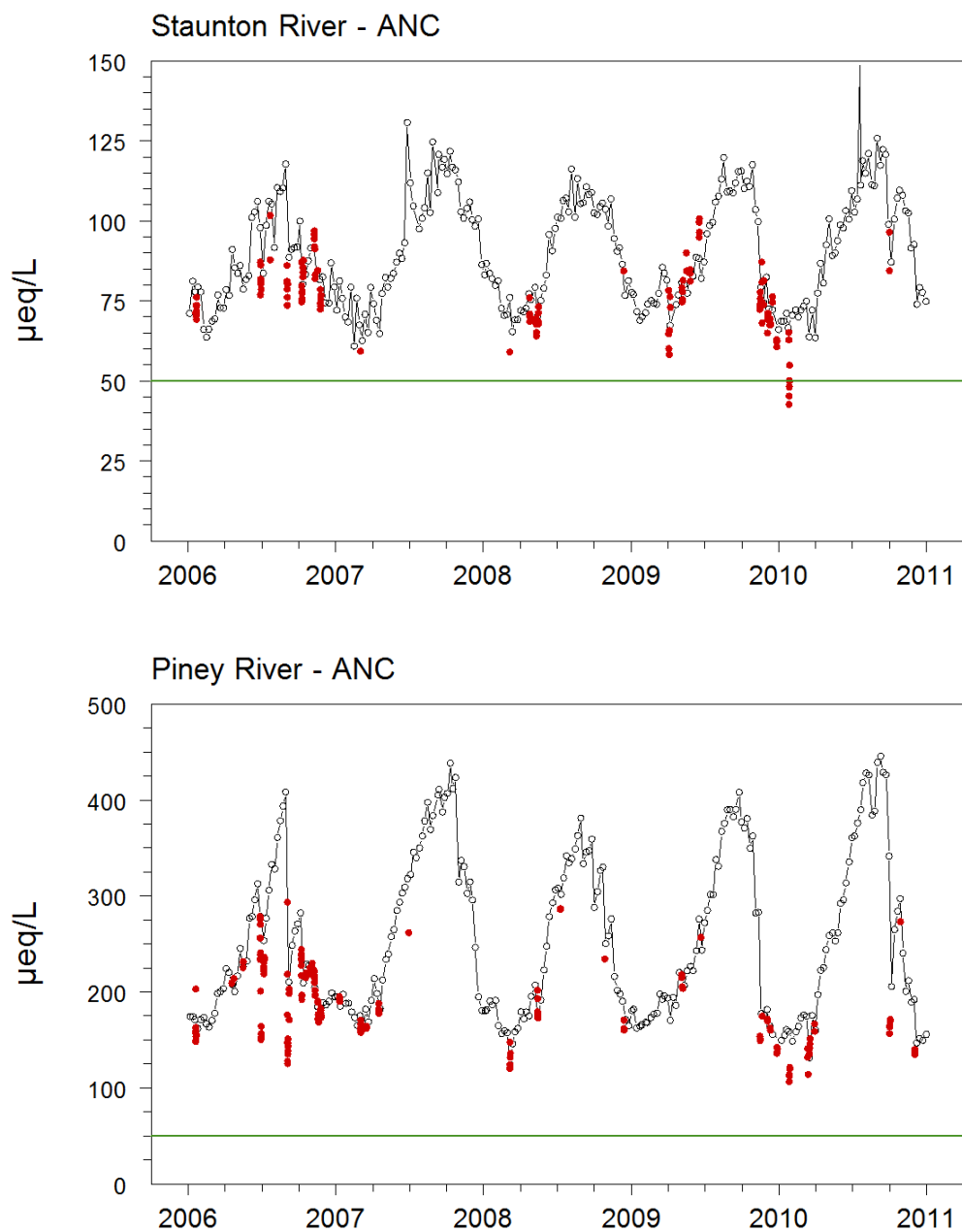


Figure 6 (*continued*) - ANC values for grab (black points) and automated episodic samples (red points) in 2006-2010. Green lines indicate ecological thresholds discussed in Section 6.

6. Ecological and Regulatory Thresholds

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

Table 4 indicates ANC thresholds for brook trout response to acidification in forested headwater catchments in western Virginia.

Table 4 - Stream water ANC categories for brook trout response³

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

Table 5 lists the percentage of analyses obtained in 2010 for each of the 14 primary SWAS study streams in relation to ANC categories for brook trout response indicated in Table 4.

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 6 lists the percentage of analyses obtained in 2010 for each of the 14 primary SWAS study streams in relation to pH criteria established by the Virginia DEQ.

³ 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.

Table 5 - Numbers and percentages of analyses obtained in 2010 in relation to ANC response categories for brook trout (see Table 4).

Site ID	Count < 0 µeq/L	% < 0 µeq/L	Count 0-20 µeq/L	% 0-20 µeq/L	Count > 20-50 µeq/L	% > 20-50 µeq/L
DR01 Deep Run	3	8.3	32	88.9	1	2.8
NFDR North Fork of Dry Run	0	0.0	0	0.0	13	26.5
PAIN Paine Run	0	0.0	62	92.5	5	7.5
PINE Piney River	0	0.0	0	0.0	0	0.0
STAN Staunton River	0	0.0	0	0.0	3	4.8
WOR1 White Oak Run	0	0.0	9	24.3	17	46.0
VT36 Meadow Run	3	75.0	1	25.0	0	0.0
VT51 Jeremys Run	0	0.0	0	0.0	0	0.0
VT53 Twomile Run	0	0.0	2	50.0	2	50.0
VT58 Brokenback Run	0	0.0	0	0.0	1	25.0
VT61 North Fork Thornton River	0	0.0	0	0.0	0	0.0
VT62 Hazel River	0	0.0	0	0.0	0	0.0
VT66 Rose River	0	0.0	0	0.0	0	0.0
VT75 White Oak Canyon	0	0.0	0	0.0	0	0.0

Table 6 - Numbers and percentage of analyses obtained in 2010 in relation to pH criteria established by the Virginia DEQ.

Site Id	Count < 6.0	% < 6.0	Count < 6.5	% < 6.5
DR01 Deep Run			36	100.0
NFDR North Fork of Dry Run			23	46.9
PAIN Paine Run			67	100.0
VT53 Twomile Run			4	100.0
WOR1 White Oak Run			37	100.0
VT36 Meadow Run			4	100.0
VT51 Jeremys Run			1	25.0
PINE Piney River	0	0.0		
STAN Staunton River	1	1.6		
VT58 Brokenback Run	1	25.0		
VT61 North Fork Thornton River	0	0.0		
VT62 Hazel River	1	25.0		
VT66 Rose River	0	0.0		
VT75 White Oak Canyon	0	0.0		

7. Discharge Status

Discharge gauges are maintained at five SWAS study sites. Gauging methods are described in the draft **SOP 3: Discharge Gauging**. Figure 7 displays mean daily discharge for the five-year period ending in 2010.

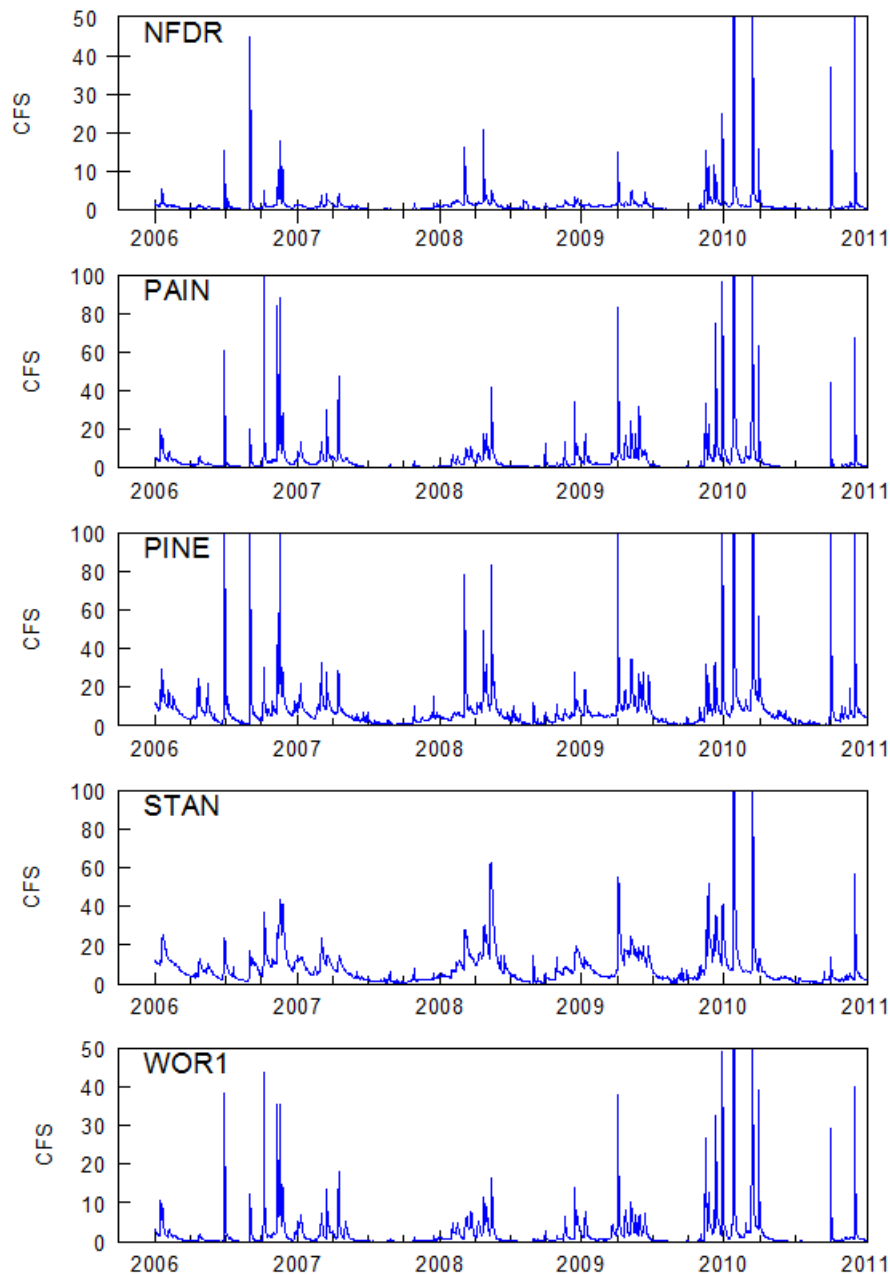


Figure 7 - Mean daily discharge for gauged streams in SHEN. Some of the higher discharge values are truncated.

Figure 8 displays inter-annual variation in discharge around the long-term mean for each of the five gauging sites. Discharge in 2010 was higher than the long-term mean for all five gauged streams.

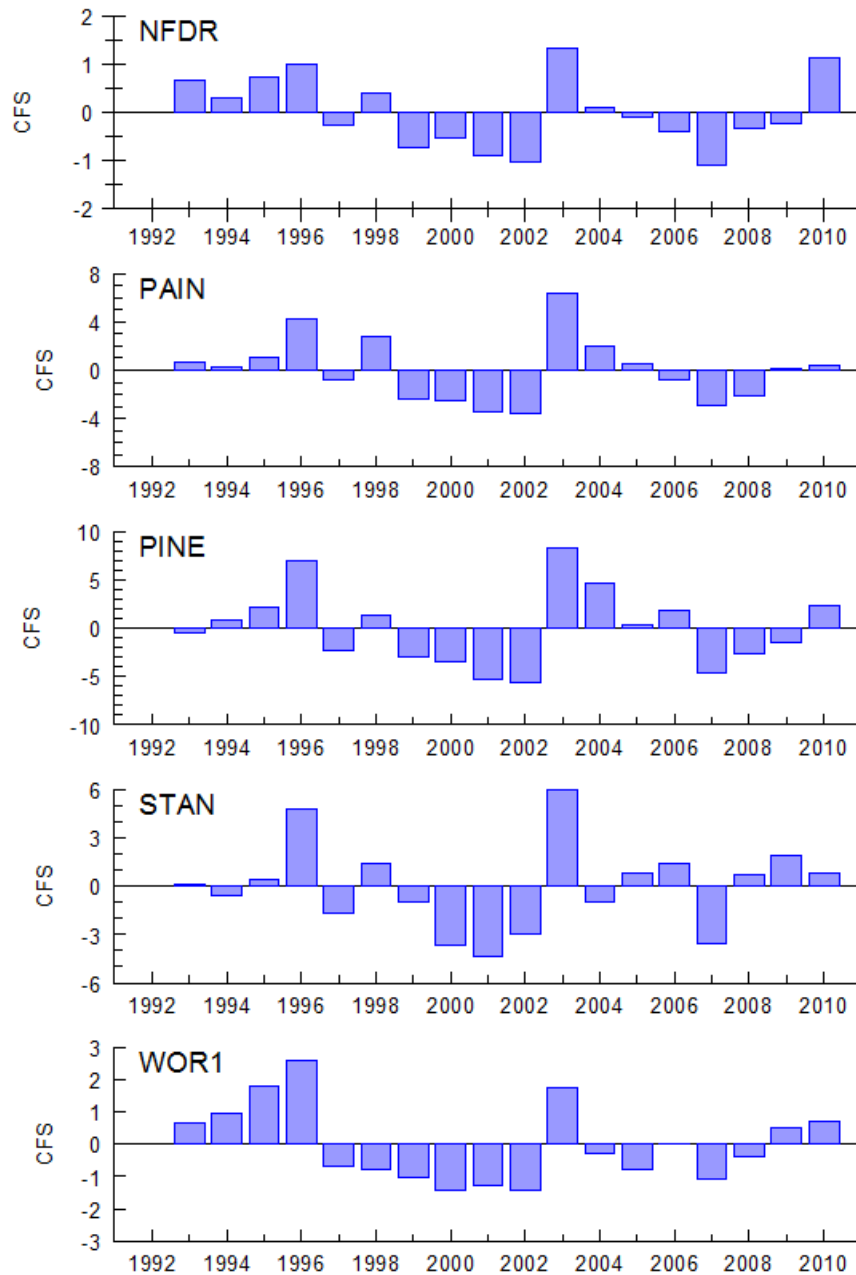
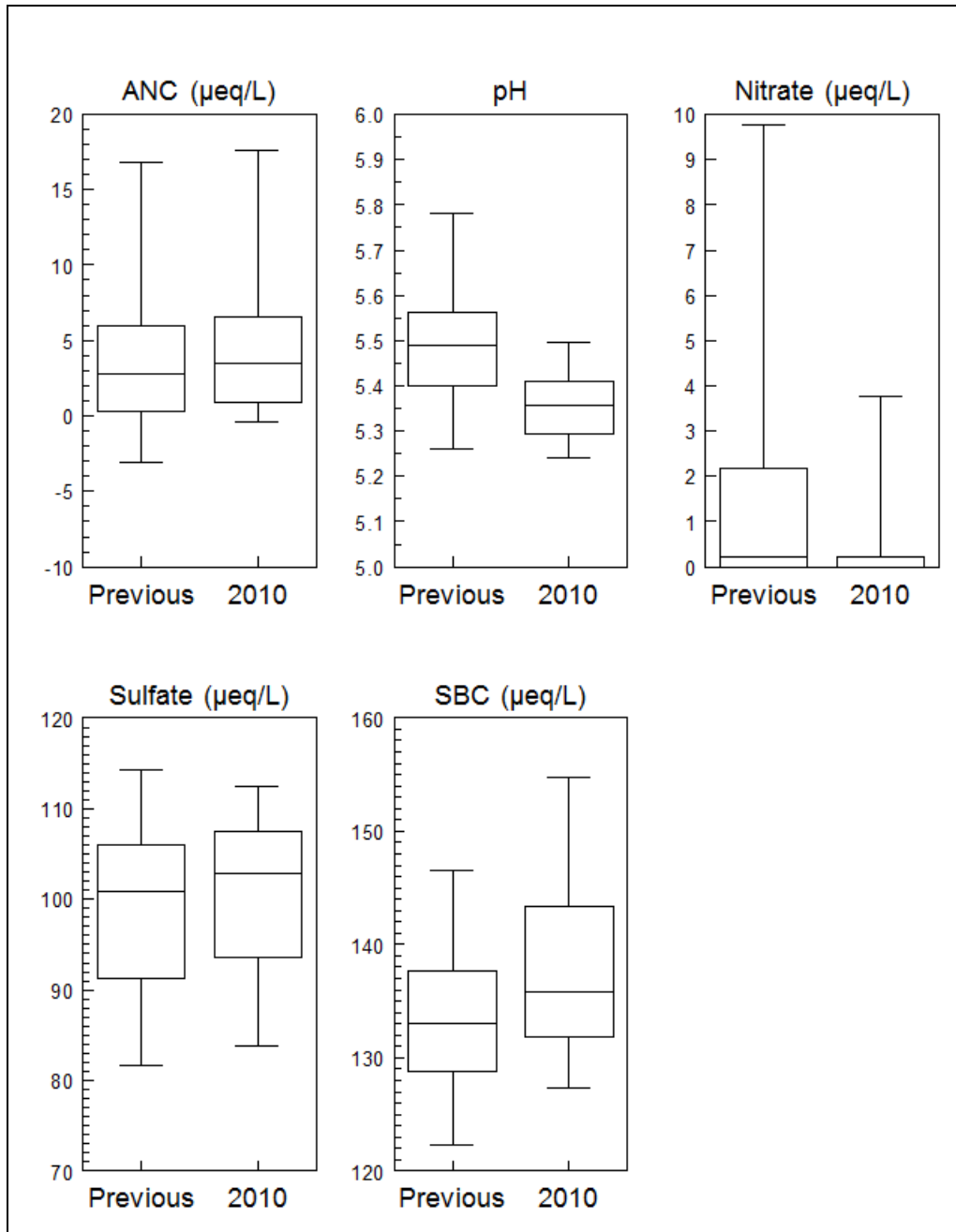


Figure 8 - Inter-annual variation in discharge around the long-term mean annual discharge for gauged streams in SHEN.

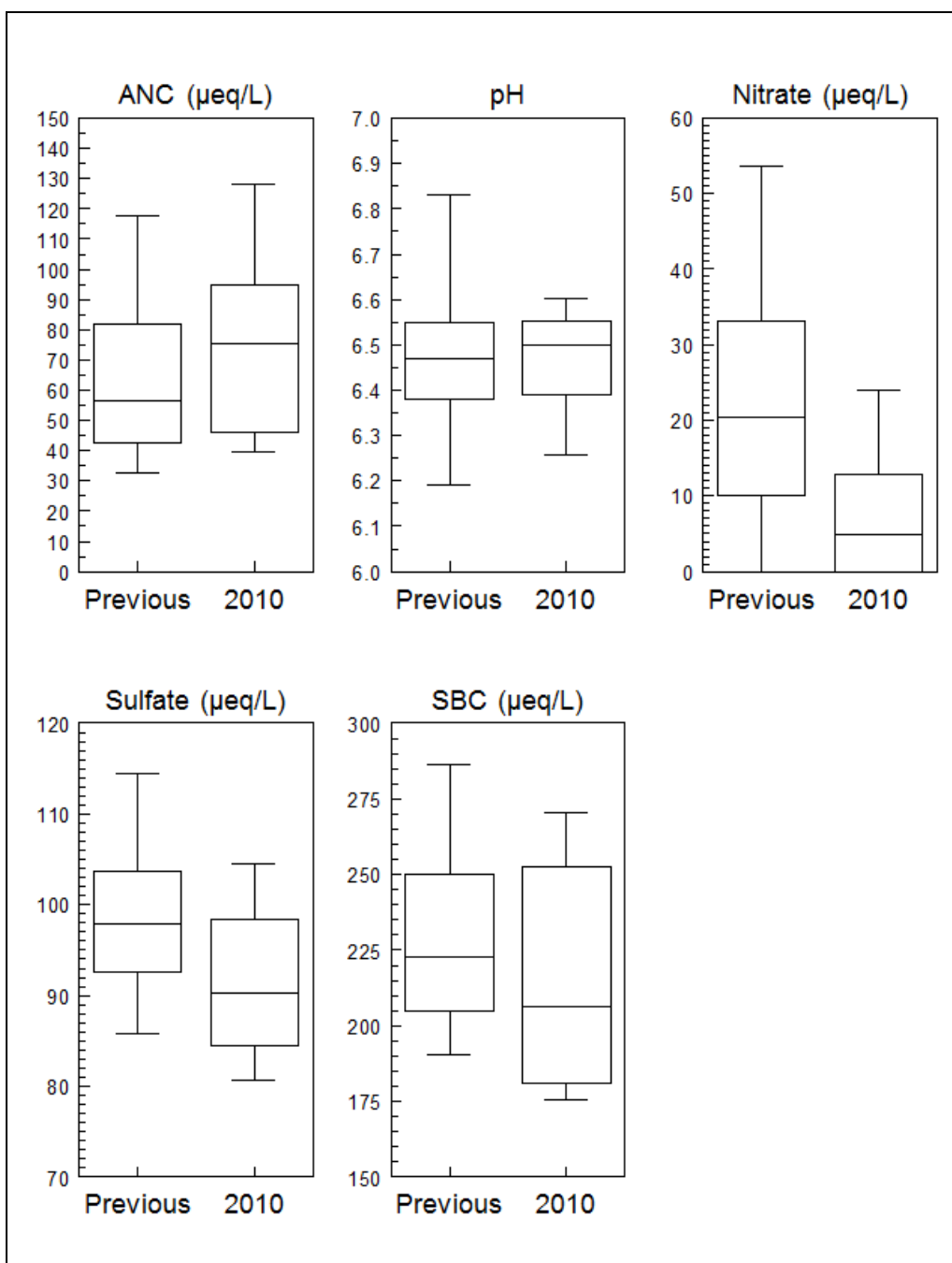
Appendix I - Distribution of Values for 2010 Sample Analysis Data Compared With Previous Years' Data⁴

DEEP RUN

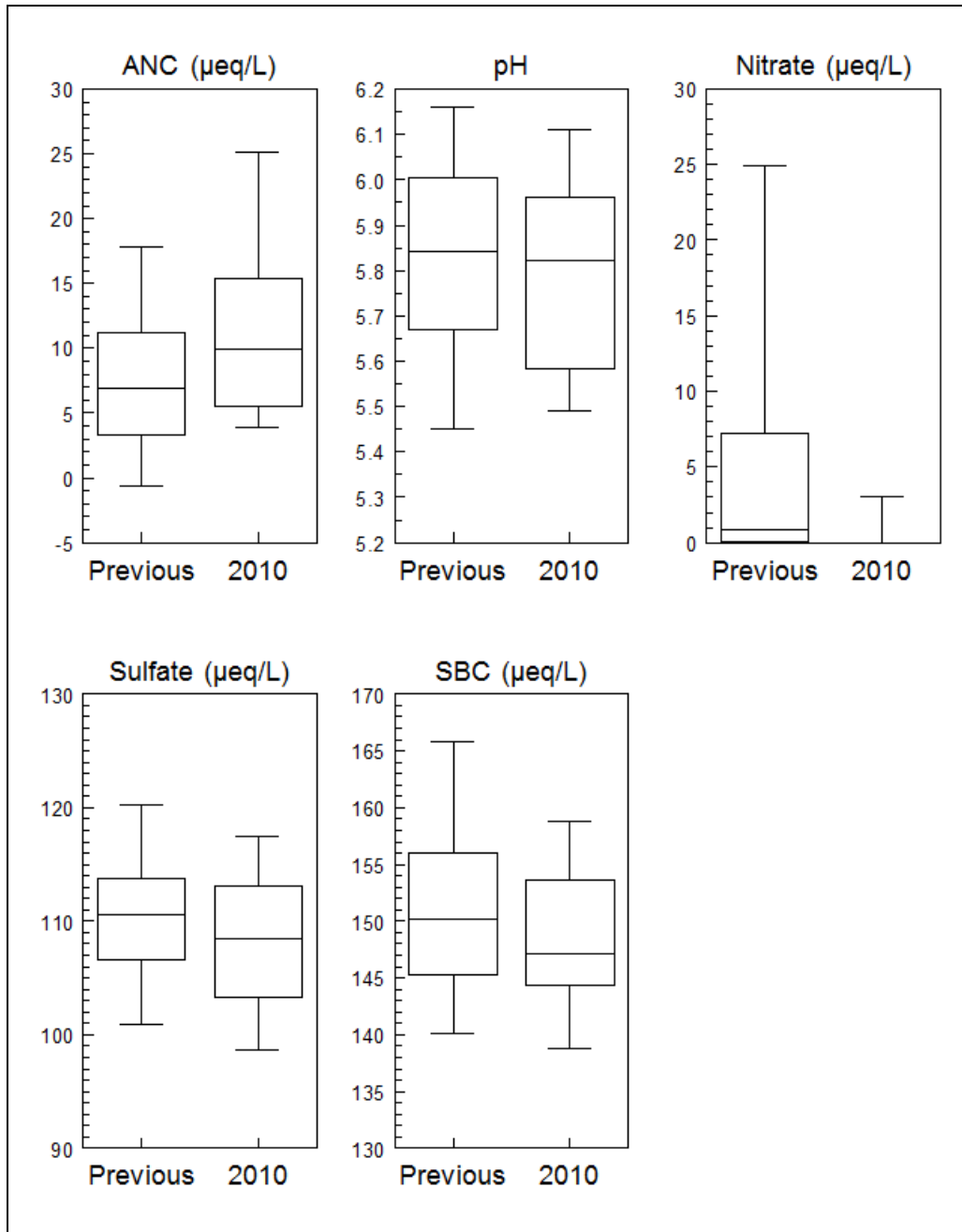


⁴ Distributions for weekly sites do not include episodic data (ISCO samples). Distributions for 2010 quarterly sites represent only four points. The box plots indicate 5th, 25th, 50th, 75th and 95th percentile values.

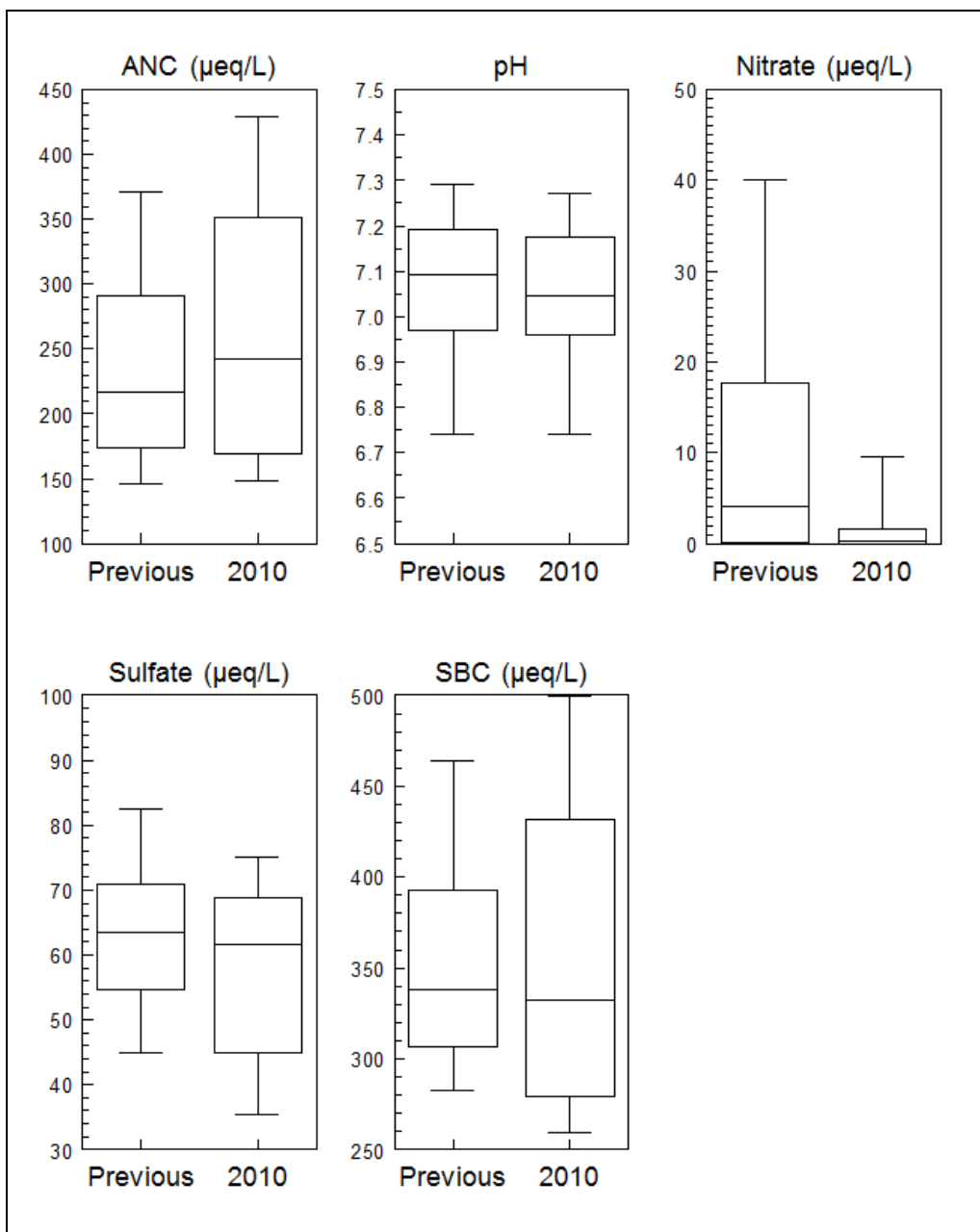
NORTH FORK OF DRY RUN



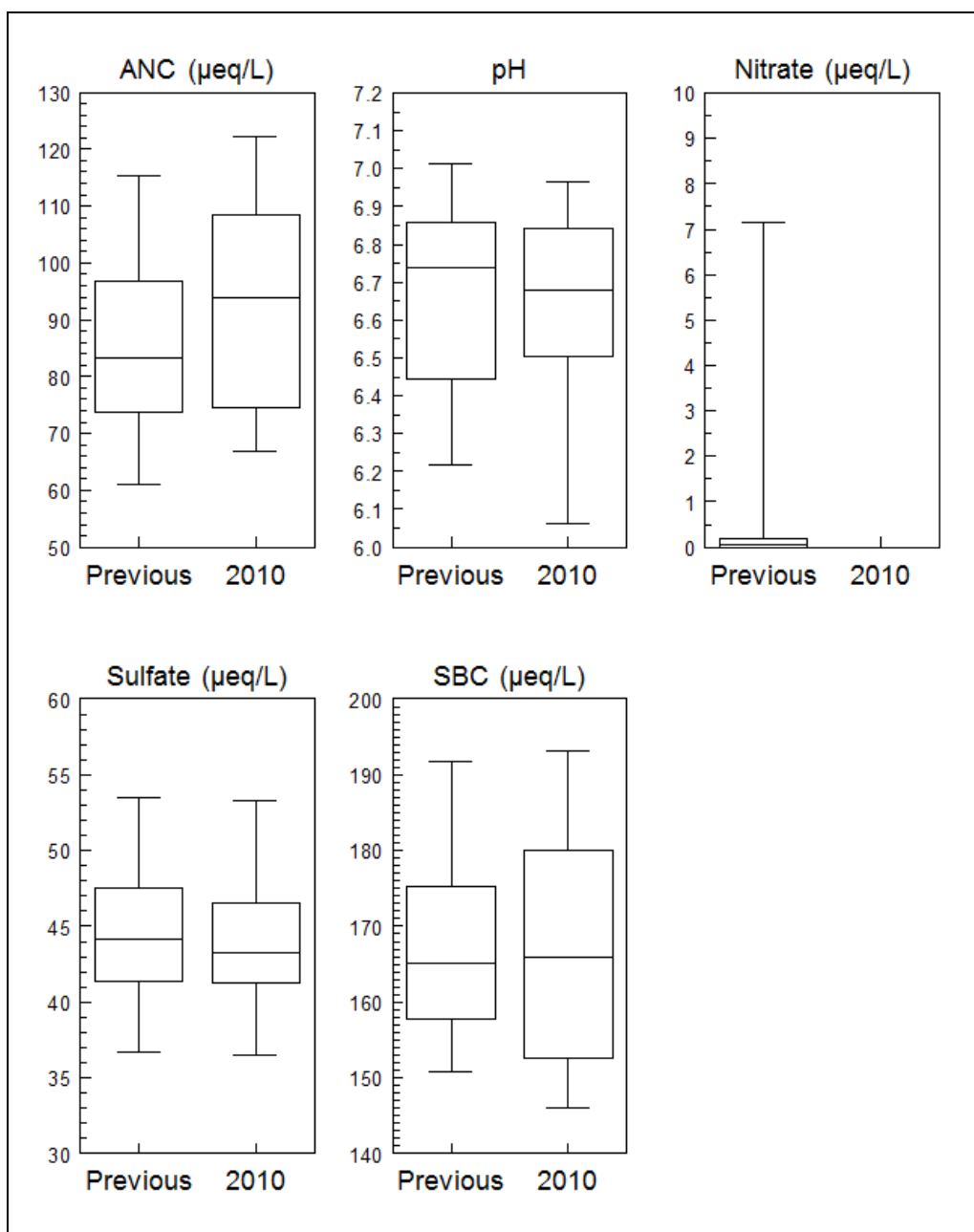
PAINE RUN



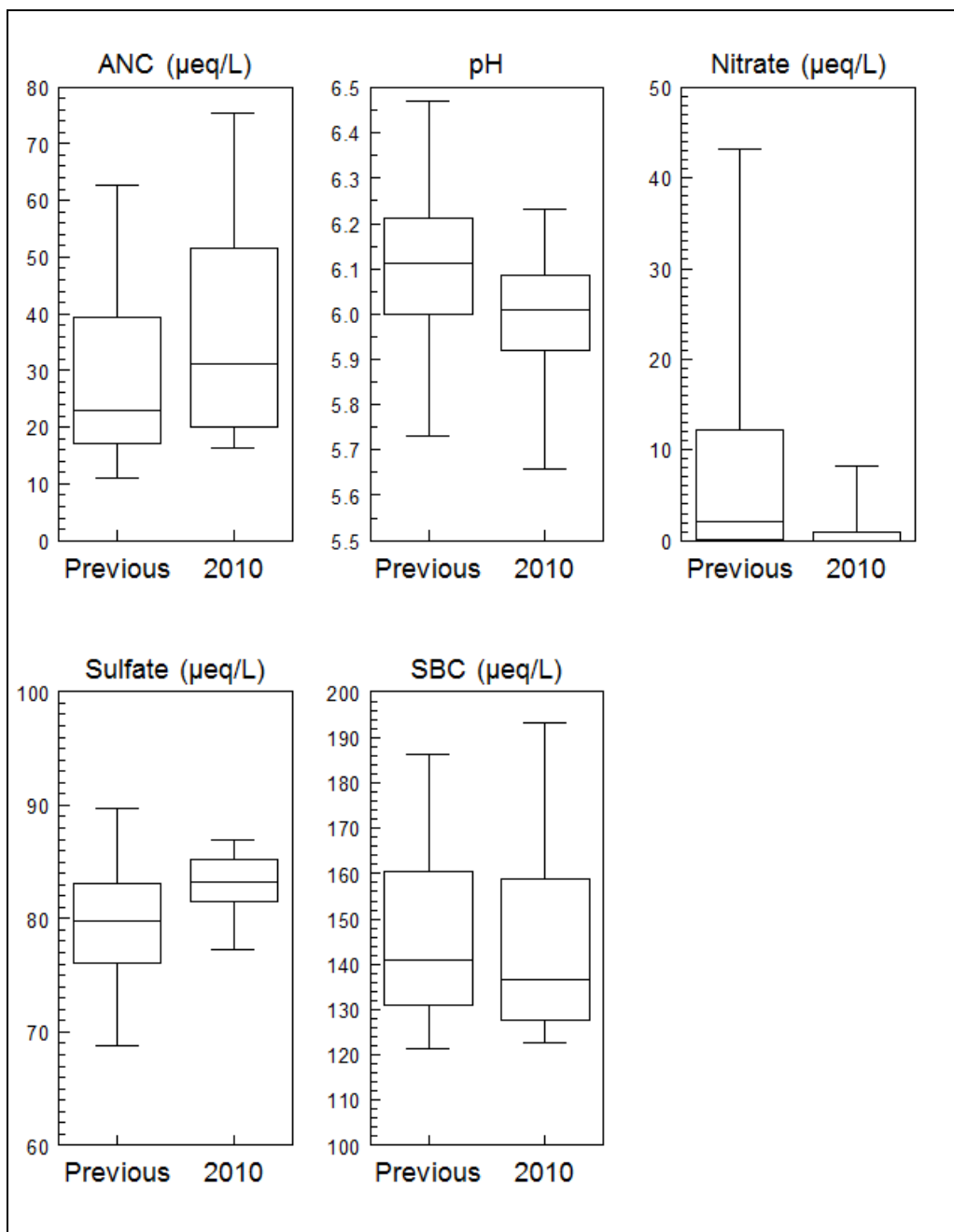
PINEY RIVER



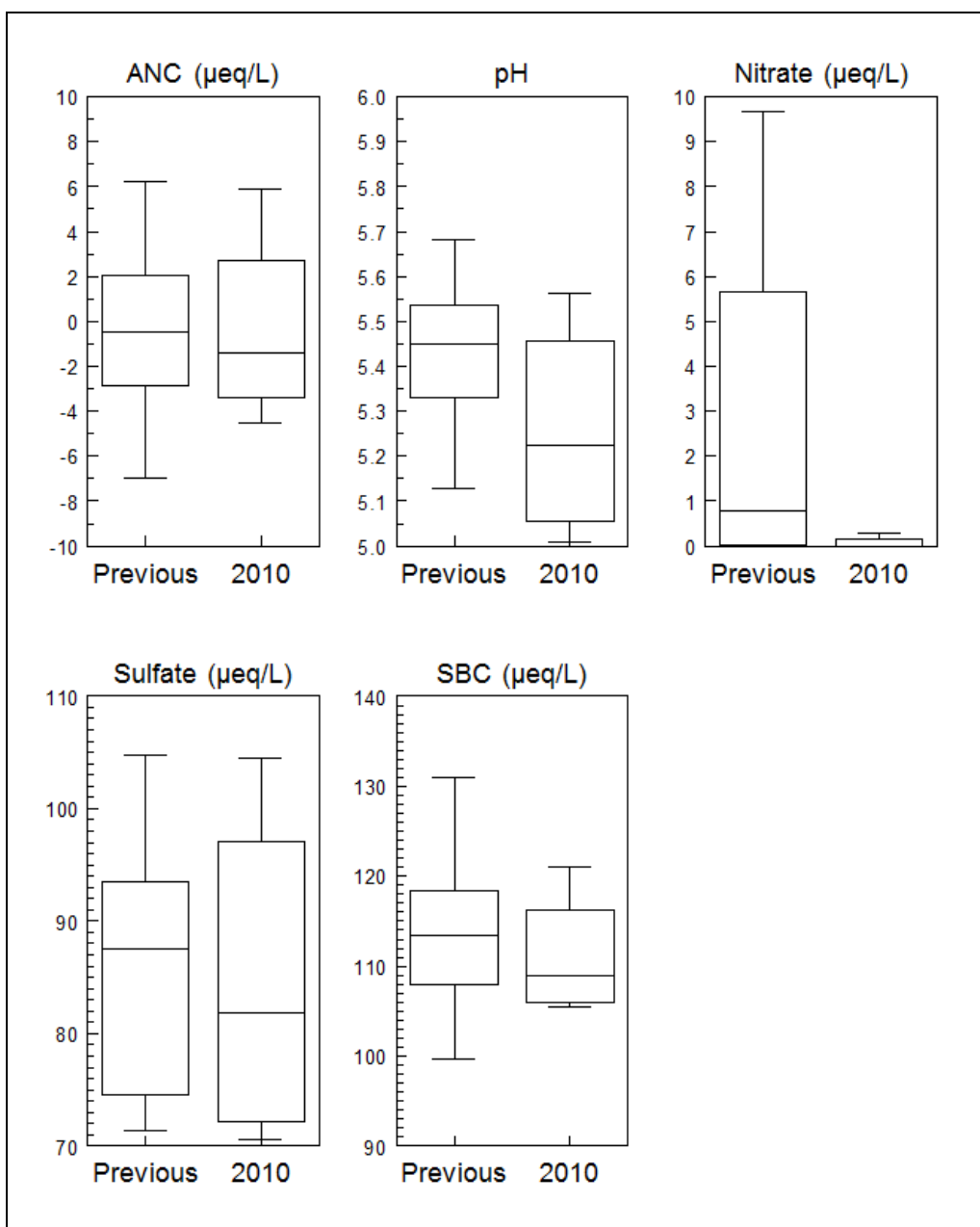
STAUNTON RIVER



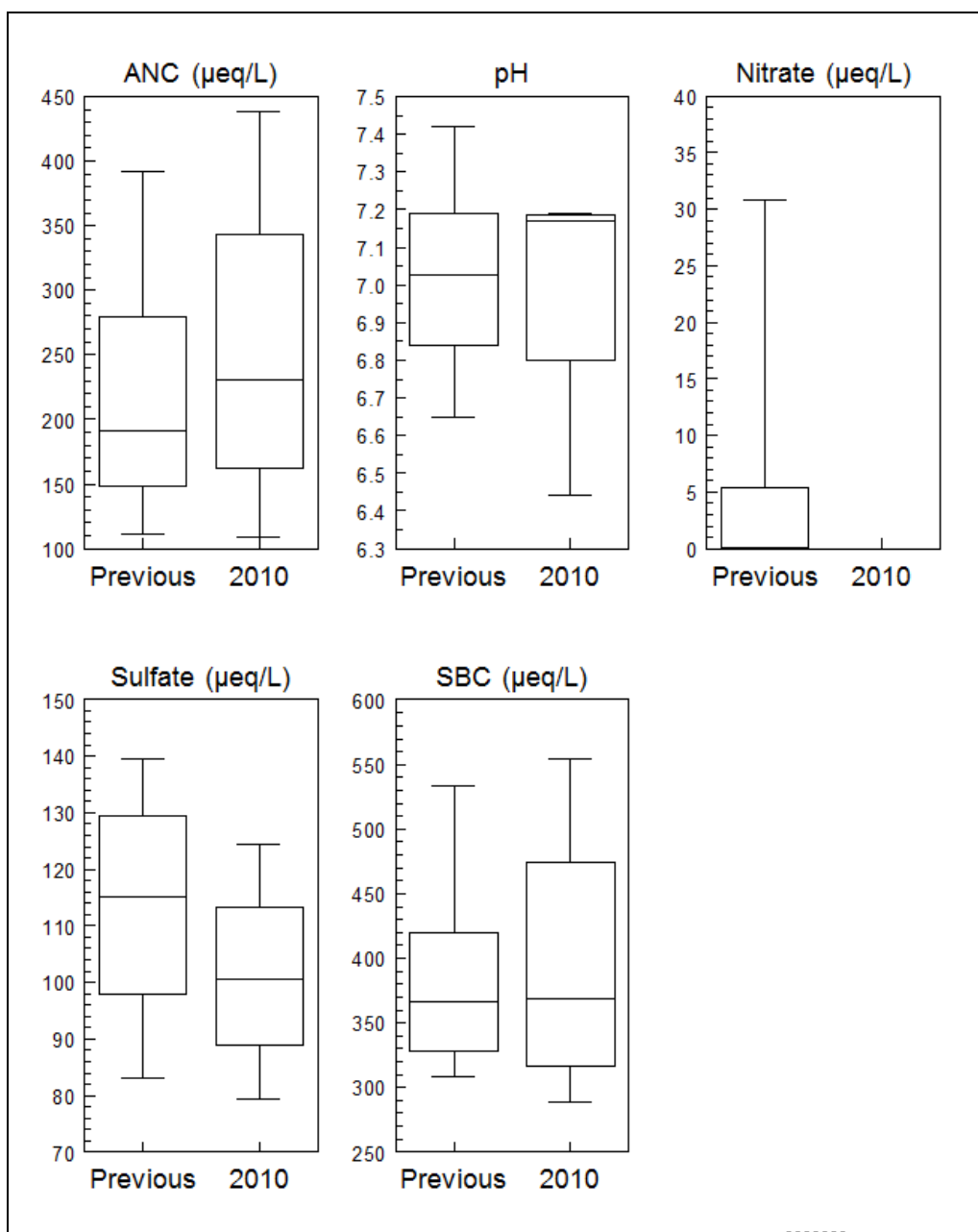
WHITE OAK RUN



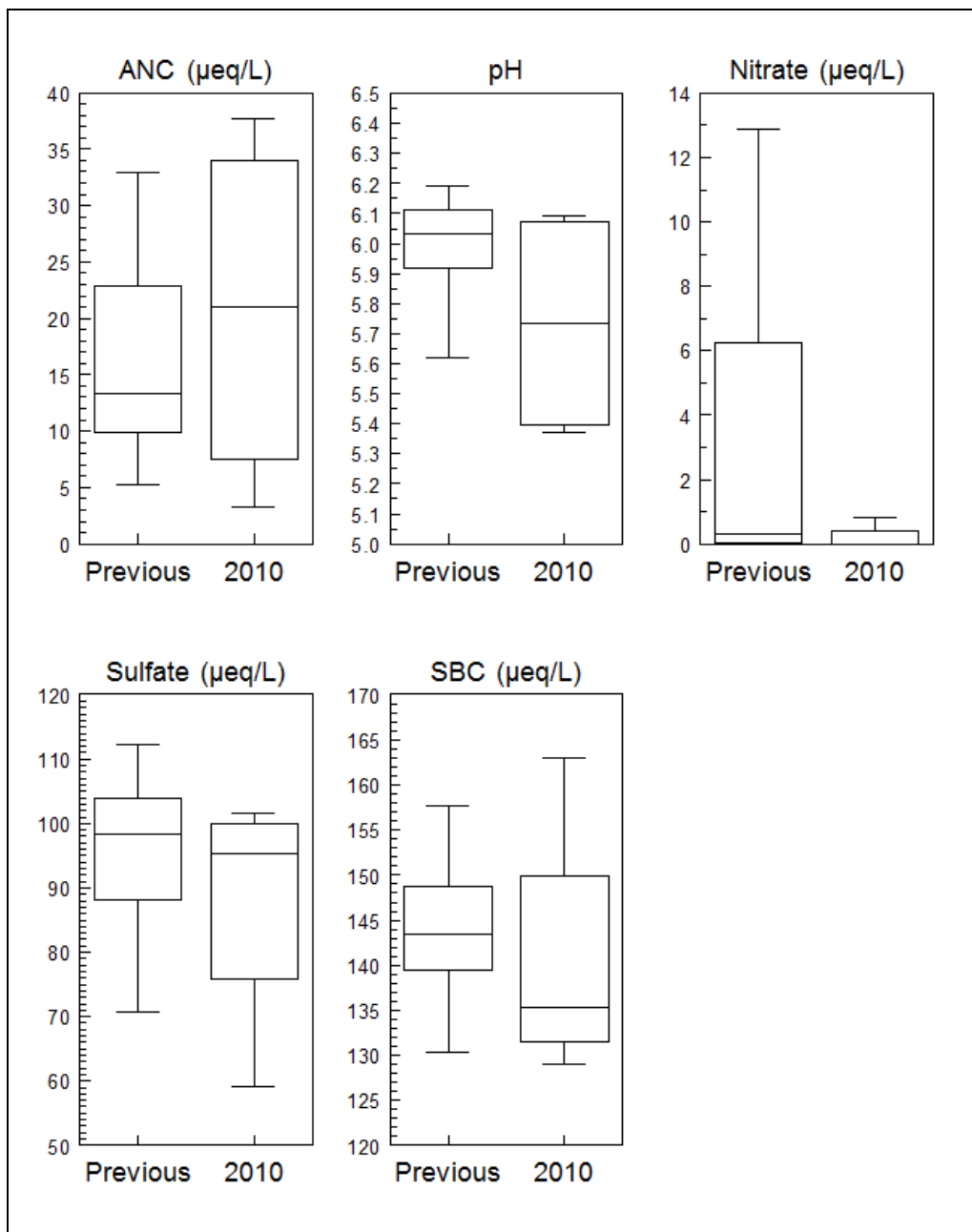
MEADOW RUN



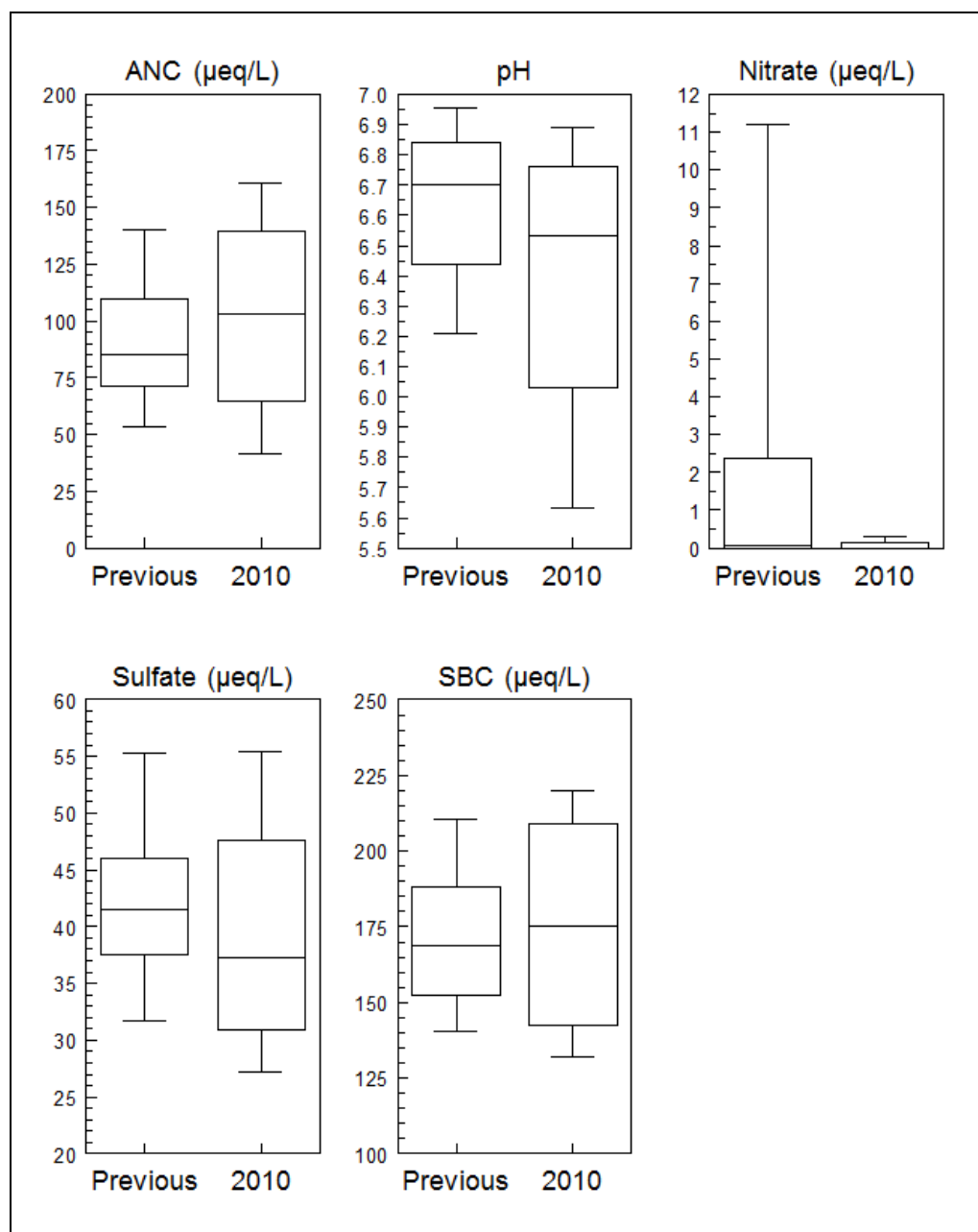
JEREMYS RUN



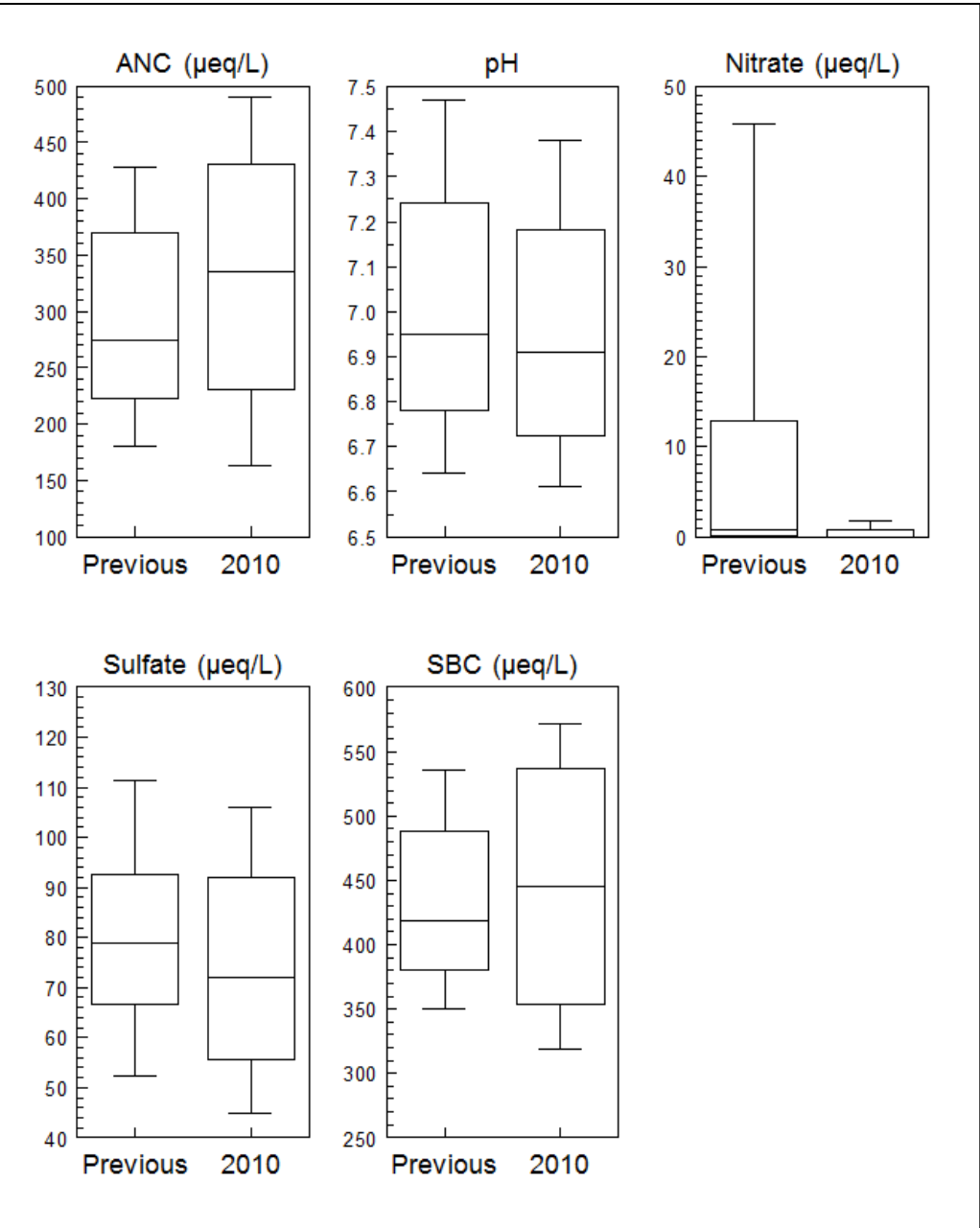
TWOMILE RUN



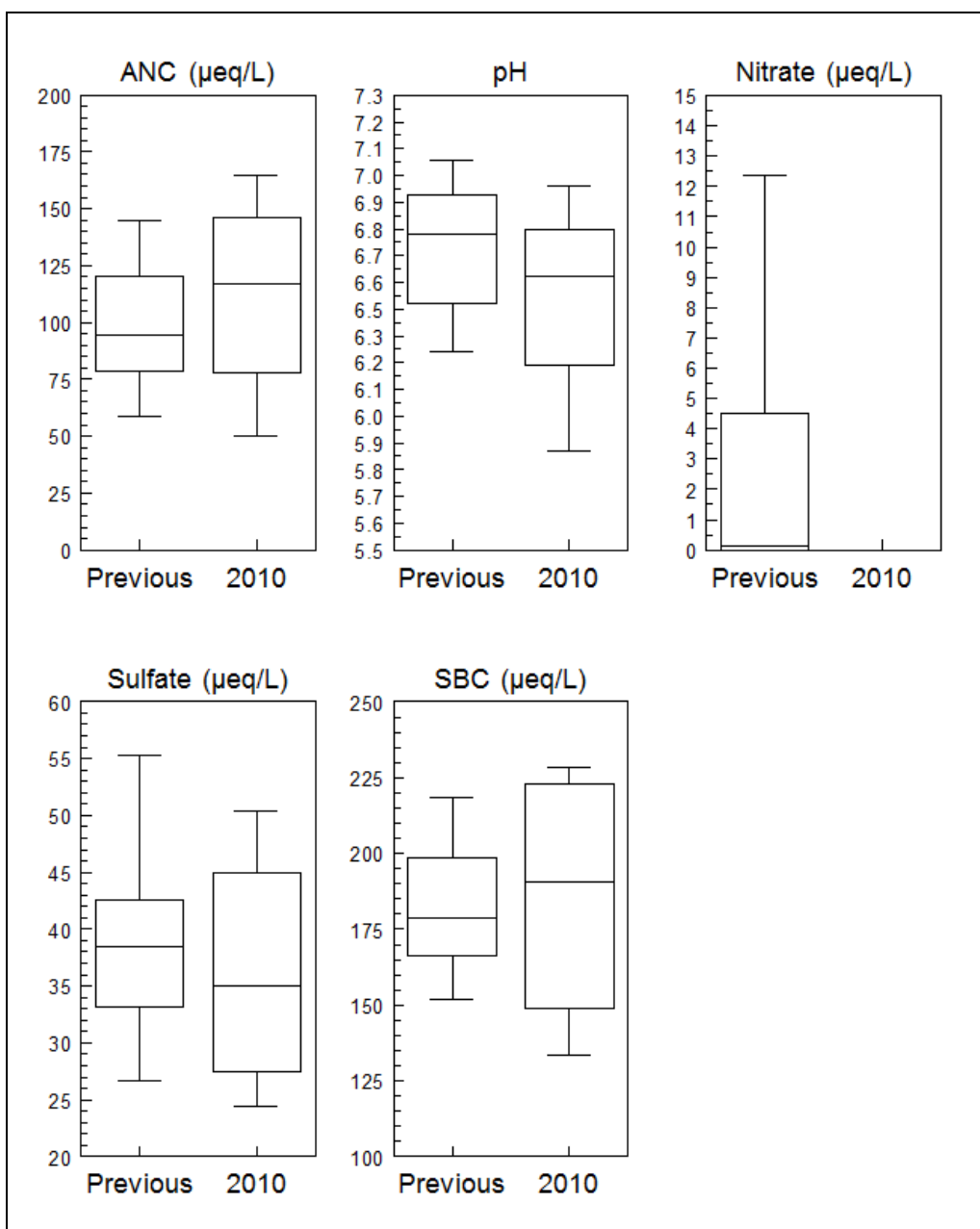
BROKENBACK RUN



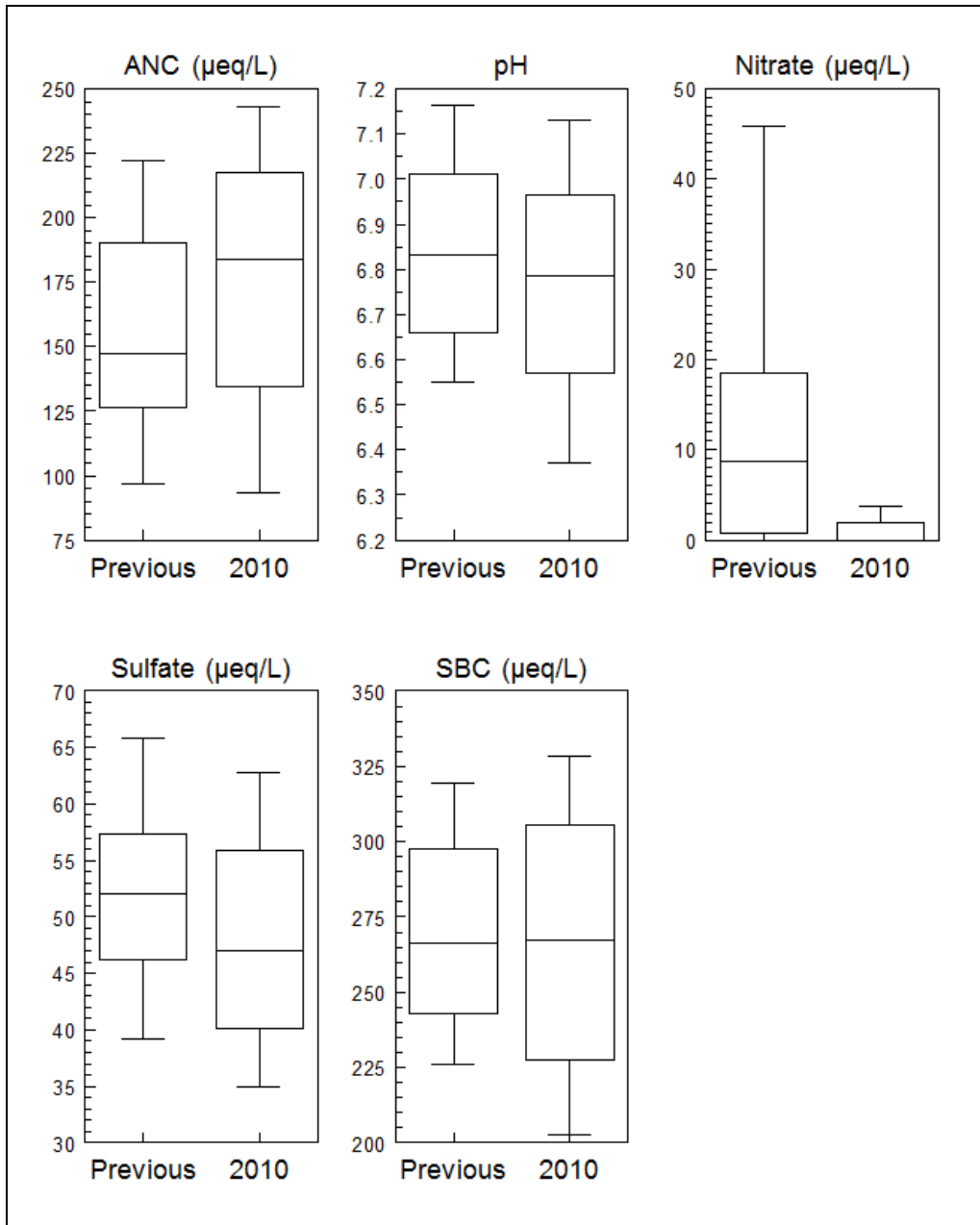
NORTH FORK OF THORNTON RIVER



HAZEL RIVER



ROSE RIVER



WHITE OAK CANYON

