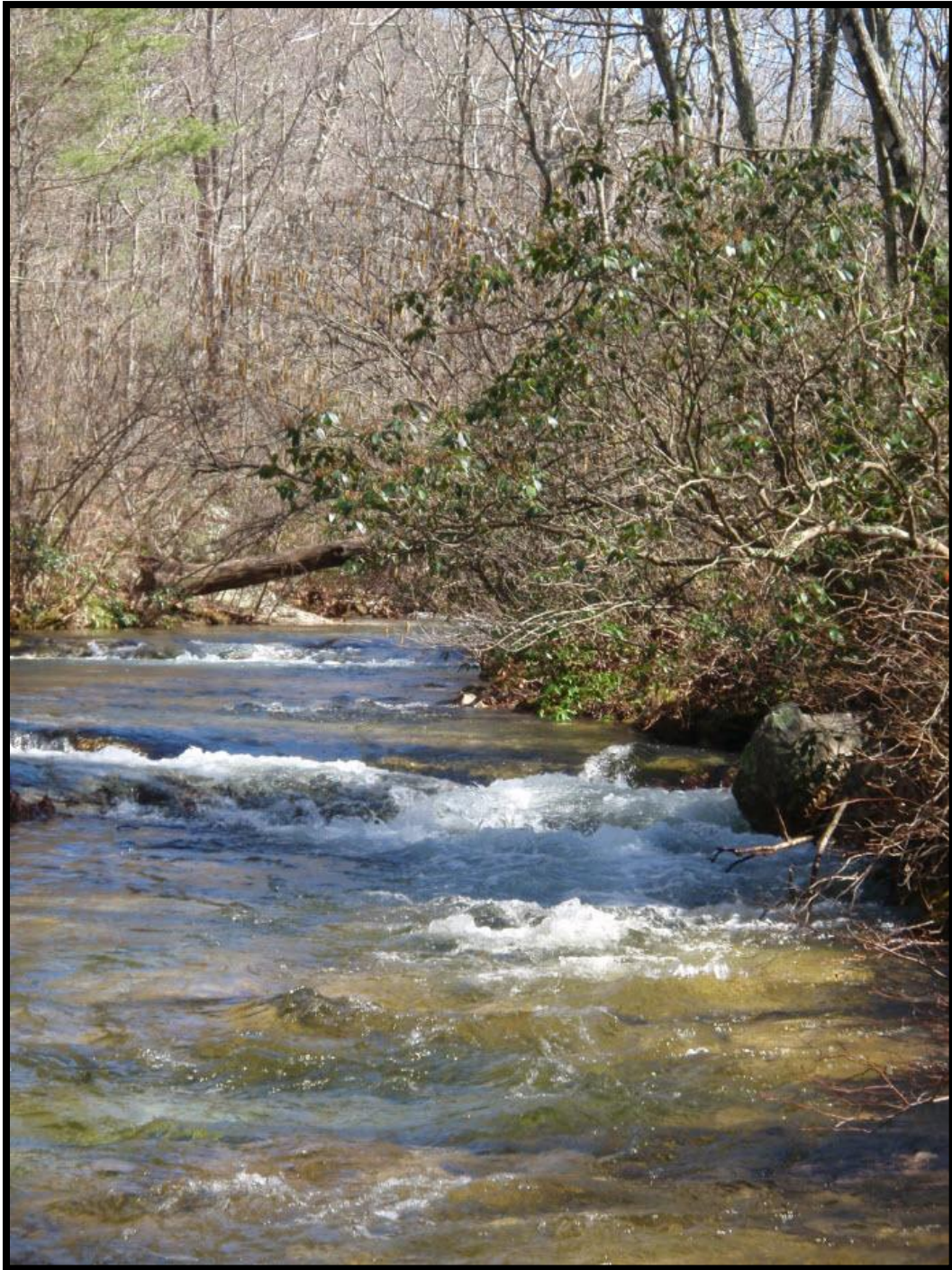


SHENANDOAH WATERSHED STUDY



2011 Report

Shenandoah Watershed Study (SWAS)

2011 Report, 04/02/13

Start and End Dates: ongoing (1979 – present)

Data Report Period: 01/01/11–12/31/11

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APPENDIX 1 - Contents Description for the SWAS-VTSSS Agency Access Site

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 32-year period, 1979-2011, 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. Coordination with the Virginia Trout Stream Sensitivity Study (VTSSS), which conducts water sampling and analysis for mountain streams throughout western Virginia, provides regional context for SWAS program data and interpretive analysis.

This annual report describes water quality sampling and analysis obtained for SWAS study streams during the 2011 calendar year. In addition to a listing of sample analysis results for 2011, this report provides information concerning the number of samples of different types

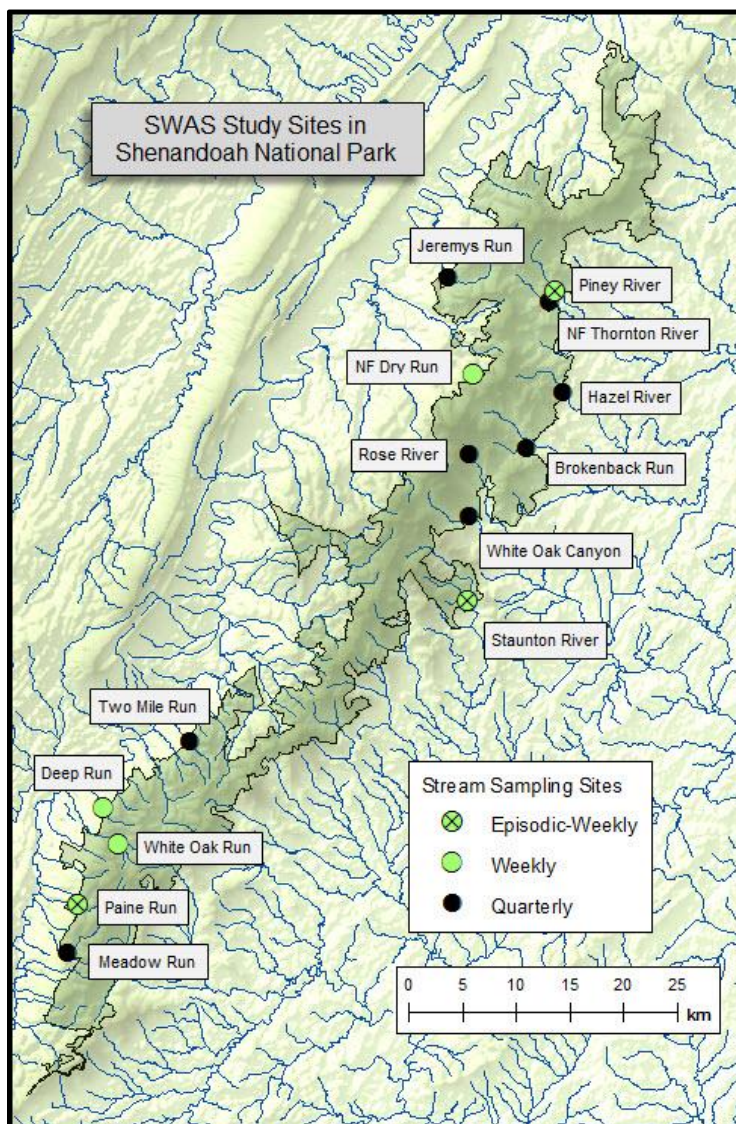


Figure 1 - SWAS monitoring program sites in SHEN.

(weekly, episodic, and quarterly) in 2011 and in previous years, comparisons of mean concentrations of key acid-base constituents in 2011 and previous years, plots of base flow and episodic acid neutralizing capacity for intensively studied streams, and plots of inter-annual variation in stream discharge. Statistical analysis of changes in water quality and discharge are reserved for periodic trend analysis reports.

Observations for 2011 include:

- Most of the primary study streams were less acidic (based on mean acid neutralizing capacity concentrations for quarterly, weekly, and episodic sampling sets) in 2011 than in previous years.
- Annual discharge in 2011 was 41–45% greater than the long-term mean for three currently gauged streams.
- The most acidic (lowest ANC) conditions continue to occur mainly during episodic high-flow conditions, mainly during the late fall, winter, and early spring.

Program changes for 2011 include:

- Sampling frequency on Deep Run and North Fork of Dry Run was reduced from weekly to quarterly in July of 2011.
- Discharge gauging on North Fork of Dry Run was discontinued in September of 2011.

This annual report has been prepared for the Natural Resources Division at SHEN. 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. Program Design

The SWAS monitoring program is designed to obtain information concerning the status and trends of the acid-base chemistry of SHEN watersheds with a stratification scheme, or monitoring framework, that involves extensive and intensive components to account for both spatial and temporal variation. The SWAS monitoring program accounts for spatial variation through a site-selection strategy based on lithologic classification, and temporal variation through collection of data at different frequencies (seasonal, weekly, and episodic or hourly). Sample analysis includes pH, acid neutralizing capacity, specific conductance, sulfate, nitrate, chloride, calcium ion, magnesium ion, sodium ion, potassium ion, ammonium ion, silica, organic

and inorganic monomeric aluminum, and dissolved organic carbon.¹ Additional information concerning the SWAS monitoring program design, including development history and water resource issues in SHEN is provided in the draft **SWAS Monitoring Program Protocol Narrative**. 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 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	Quarterly ¹
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	Quarterly ²
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

¹ Deep Run was sampled weekly until 6/6/2011.

² North Fork of Dry Run was sampled weekly until 6/7/2011.

¹ Analysis of aluminum fractions and dissolved organic carbon is conducted for a subset of samples.

3. Number and Type of Samples Collected

Table 2 indicates the total number of SHEN stream water samples collected and analyzed through the SWAS program for each of the years during the period of record, 1979–2011. Annual totals are provided for all samples, quarterly samples, weekly samples, and episodic samples (high-flow samples collected with ISCO automated samplers). The totals for all samples includes samples collected in regional synoptic surveys conducted in 1987, 2000, and 2010.

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. In July of 2011, however, weekly sampling on North Fork of Dry Run and Deep Run was discontinued (sampling continued on a quarterly basis at these two sites). The relatively low number of samples analyzed in 2007 reflects low discharge and the resulting low number of episodic, high-flow samples collected in 2007. The somewhat higher number of total samples analyzed in 2010 reflects additional sampling conducted during the VTSSS 2010 survey.

The ISCO samplers are flow-level actuated. Settings for the ISCO samplers have varied during the period of record, 1992–present. In 2011, samples were collected when the flow level was above the 95th flow percentile. Then samples were taken every two hours. Samples were chosen for analysis with a 0.2 probability. About 20% of all samples collected were analyzed.

4. Sample Analysis Results

Complete analysis results for SWAS program samples collected in SHEN are posted on the University of Virginia Collab site, SWAS-VTSSS Agency Access, for access by the National Park Service and other supporting and collaborating natural resource management agencies. The SWAS-VTSSS Agency Access site also includes stream water quality data collected through the VTSSS program in the western Virginia mountain region. Additional information provided on the SWAS-VTSSS Agency Access site includes sampling and analysis methods, other metadata, site documentation, and data quality assurance reports. Discharge data for sites in SHEN are also provided. Appendix 1 provides a detailed description of data and information provided on the SWAS-VTSSS Agency Access site.

Table 2 - Number of Samples Collected and Analyzed in SHEN

Year	Total Samples	Quarterly Samples	Weekly Samples	Episodic Samples
1979	15	0	15	0
1980	86	0	86	0
1981	108	0	108	0
1982	120	0	120	0
1983	107	0	107	0
1984	158	0	158	0
1985	116	0	116	0
1986	241	0	241	0
1987	420	9	350	0
1988	388	39	346	0
1989	419	40	379	0
1990	452	42	410	0
1991	456	44	412	0
1992	664	42	471	140
1993	913	36	531	336
1994	809	37	448	320
1995	560	34	386	140
1996	452	35	306	111
1997	492	36	315	140
1998	450	36	296	117
1999	434	36	300	98
2000	489	36	312	85
2001	390	36	278	76
2002	381	36	286	57
2003	751	36	316	399
2004	538	36	311	180
2005	519	36	306	177
2006	581	36	308	237
2007	361	36	289	36
2008	390	36	298	56
2009	420	36	284	100
2010	421	35	278	56
2011	406	39	247	120

5. Comparison of 2011 Sample Analysis Results With Previous Years

Context for water quality data obtained in 2011 is provided by comparison with data obtained in previous years. Tables 3–5 compare the 2011 means for key acid-base constituents with the means for previous years' data. Separate comparisons are made for quarterly, weekly, and episodic sample sets. The ordering of sites in the presentation of these data is by watershed lithologic class.

The differences in mean values evident in Tables 3–5 between 2011 and pre-2011 samples are generally indicative of long-term change associated with acidic deposition. It should be noted though that, with the exception of nitrate, the differences between 2011 and previous years are generally small. More comprehensive analysis of temporal changes in stream water chemistry will be addressed in the context of periodic trend analysis.

Comparison of ANC means for quarterly samples indicates that 13 of the 14 of the study streams were less acidic in 2011 than during the prior data collection period. The results are similar for both weekly and episodic samples. 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.

Comparison of mean pH values for 2011 with the means for previous years indicates a mix of both higher and lower values.

Comparison of mean sulfate concentrations for 2011 with the means for previous years indicates a mix of both higher and lower values.

Comparison of mean nitrate concentrations for 2011 with the means for previous years indicates that 2011 means were consistently lower than in 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.

Comparison of the mean sum of base cation (SBC) concentration for 2011 with the means for previous years indicates that 2011 means were, with one exception, lower than in previous years. This result is 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.

6. 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

Table 3 - Mean Values for Key Acid-Base Constituents in SHEN Study Streams: Quarterly Samples¹

Lithology	Site_ID	ANC_2011	ANC_PRE	pH_2011	pH_PRE	SO4_2011	SO4_PRE	NO3_2011	NO3_PRE	SBC_2011	SBC_PRE
Siliciclastic	DR01	6.04	3.50	5.46	5.45	98.88	98.50	0.16	1.85	133.46	133.21
Siliciclastic	PAIN	11.17	8.00	5.77	5.85	109.72	110.79	0.05	4.53	147.74	151.04
Siliciclastic	VT36	3.20	-0.53	5.46	5.43	80.41	86.19	0.06	2.85	107.66	113.85
Siliciclastic	VT53	21.49	16.72	5.95	5.98	93.58	94.98	0.13	2.95	142.53	144.09
Siliciclastic	WOR1	28.43	35.14	6.05	6.12	83.64	78.88	0.15	10.44	133.51	156.84
Granitic	NFDR	72.64	64.89	6.52	6.48	88.53	97.30	0.57	23.06	206.20	228.04
Granitic	STAN	88.80	87.72	6.66	6.63	44.17	43.87	0.00	1.21	163.26	168.45
Granitic	VT58	96.44	90.83	6.79	6.63	38.92	42.19	0.15	2.17	166.65	171.72
Granitic	VT62	105.29	99.34	6.85	6.69	33.57	38.51	0.06	2.45	174.77	182.47
Basaltic	PINE	233.19	238.47	7.05	7.08	57.18	62.26	0.14	9.53	327.06	354.86
Basaltic	VT51	246.19	224.01	7.21	7.02	96.79	113.42	0.14	5.88	382.40	389.48
Basaltic	VT61	300.31	296.63	7.35	7.01	69.67	79.23	0.13	9.85	413.77	434.29
Basaltic	VT66	165.66	157.04	7.07	6.84	43.21	51.63	0.16	12.88	254.92	269.84
Basaltic	VT75	156.77	143.40	6.93	6.77	46.59	51.39	0.64	11.83	250.55	254.94

¹ Mean values are given for samples collected in 2011 and samples collected in the period, 1988–2010. Quarterly values are provided for weekly sample sites by selecting results for the quarterly sampling windows. Concentration units are µeq/L and pH units.

Table 4 - Mean Values for Key Acid-Base Constituents in SHEN Study Streams: Weekly Samples¹

Lithology	Site_ID	ANC_2011	ANC_PRE	pH_2011	pH_PRE	SO4_2011	SO4_PRE	NO3_2011	NO3_PRE	SBC_2011	SBC_PRE
Siliciclastic	PAIN	10.38	7.74	5.74	5.83	109.31	110.03	0.16	4.94	147.08	151.22
Siliciclastic	WOR1	34.30	29.76	6.05	6.11	81.55	79.31	0.99	10.75	140.99	151.35
Granitic	STAN	87.14	86.48	6.64	6.67	45.21	44.64	0.10	0.95	163.83	168.02
Basaltic	PINE	232.60	236.68	7.05	7.06	60.16	63.10	0.65	10.10	331.65	353.45

¹ Mean values are given for samples collected in 2011 and samples collected in the period, 1988–2010. Weekly sampling began in 1992 for PAIN, STAN, and PINE. Concentration units are µeq/L and pH units.

Table 5 - Mean Values for Key Acid-Base Constituents in SHEN Study Streams: Episodic Samples¹

Lithology	Site_ID	ANC_2011	ANC_PRE	pH_2011	pH_PRE	SO4_2011	SO4_PRE	NO3_2011	NO3_PRE	SBC_2011	SBC_PRE
Siliciclastic	PAIN	6.29	2.27	5.50	5.52	105.46	112.34	2.23	11.98	147.99	160.34
Granitic	STAN	73.56	73.41	6.70	6.49	52.34	51.67	2.51	5.51	161.68	171.99
Basaltic	PINE	191.02	187.60	7.05	7.00	71.78	78.48	3.07	18.23	312.35	335.29

¹ Mean values are given for samples collected in 2011 and samples collected in the period, 1992–2010. Concentration units are µeq/L and pH units.

episodic chemistry that is missed by less-intensive grab sampling at weekly or quarterly intervals. 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 2 displays six 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-extreme or critically low ANC depressions occur in Paine Run. Episodically depressed ANC values are also observed on Staunton River and Piney River, but ANC levels, except occasionally for Staunton River, do not drop below 50 $\mu\text{eq/L}$.

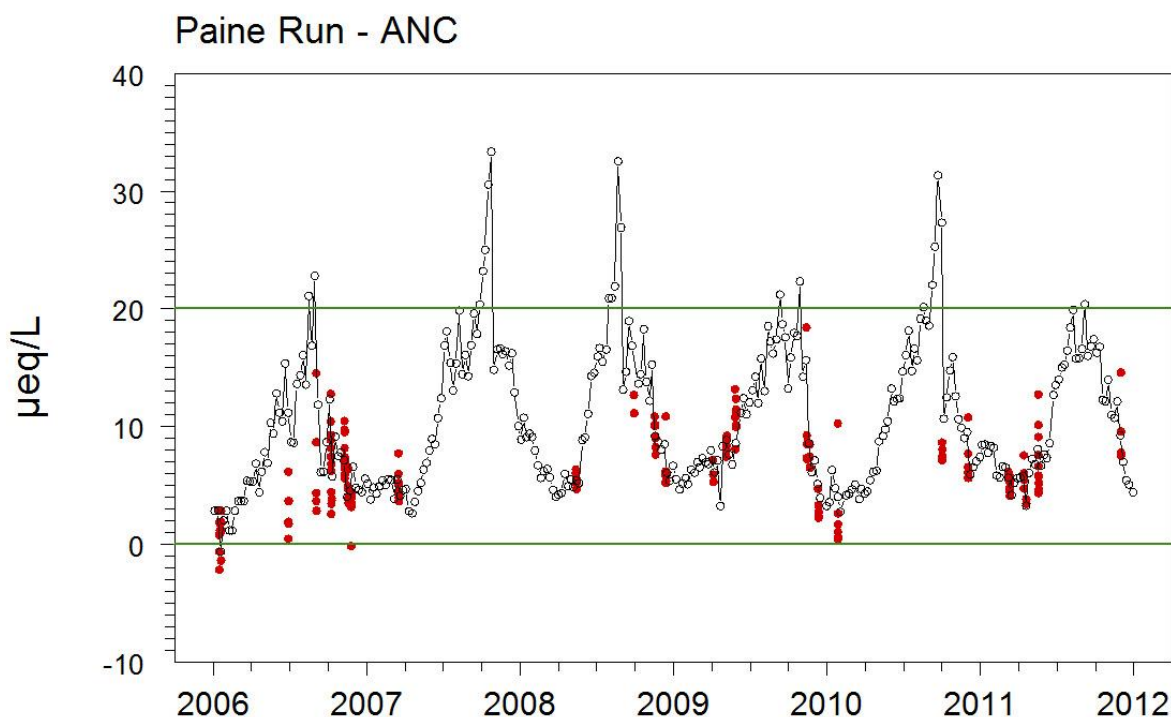


Figure 2 - ANC values for grab (black points) and automated episodic samples (red points) in 2006-2010. Green lines indicate ecological thresholds for brook trout and other fish species that have been cited for stream water ANC (Bulger, A.B., B.J. Cosby, and J.R. Webb, 2000. Current, reconstructed past, and projected future status of brook trout (*Salvelinus fontinalis*) streams in Virginia. Canadian Journal of Fisheries and Aquatic Sciences. 57: 1515).

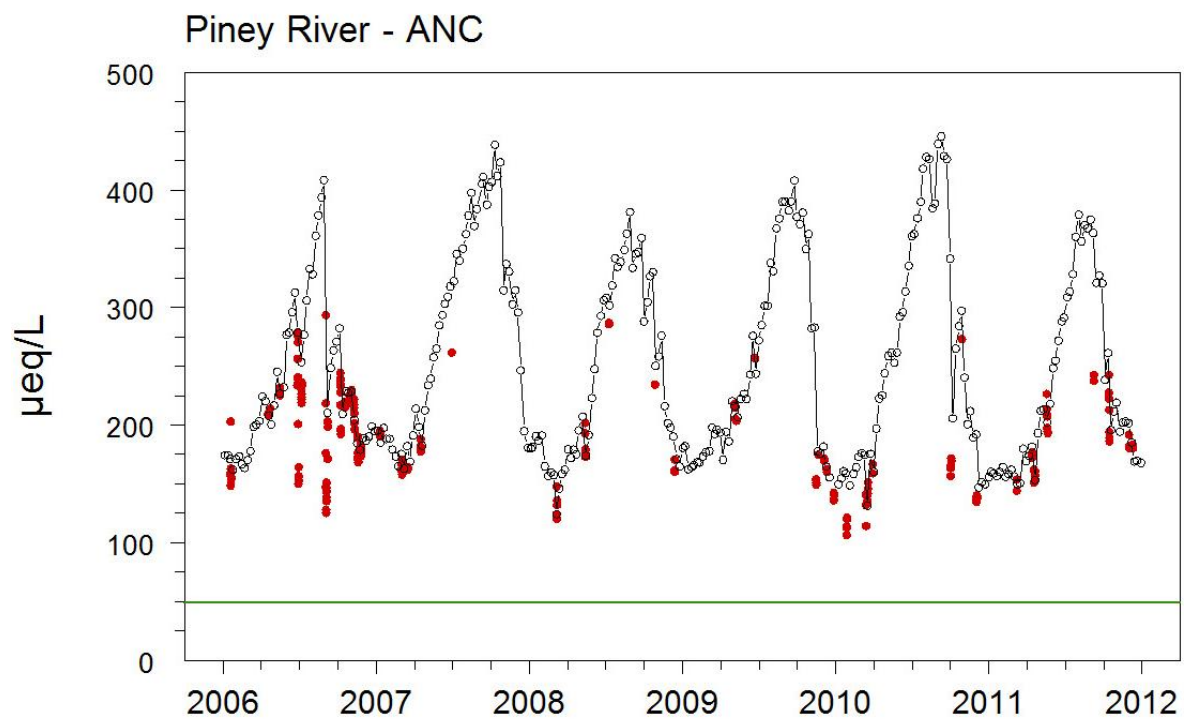
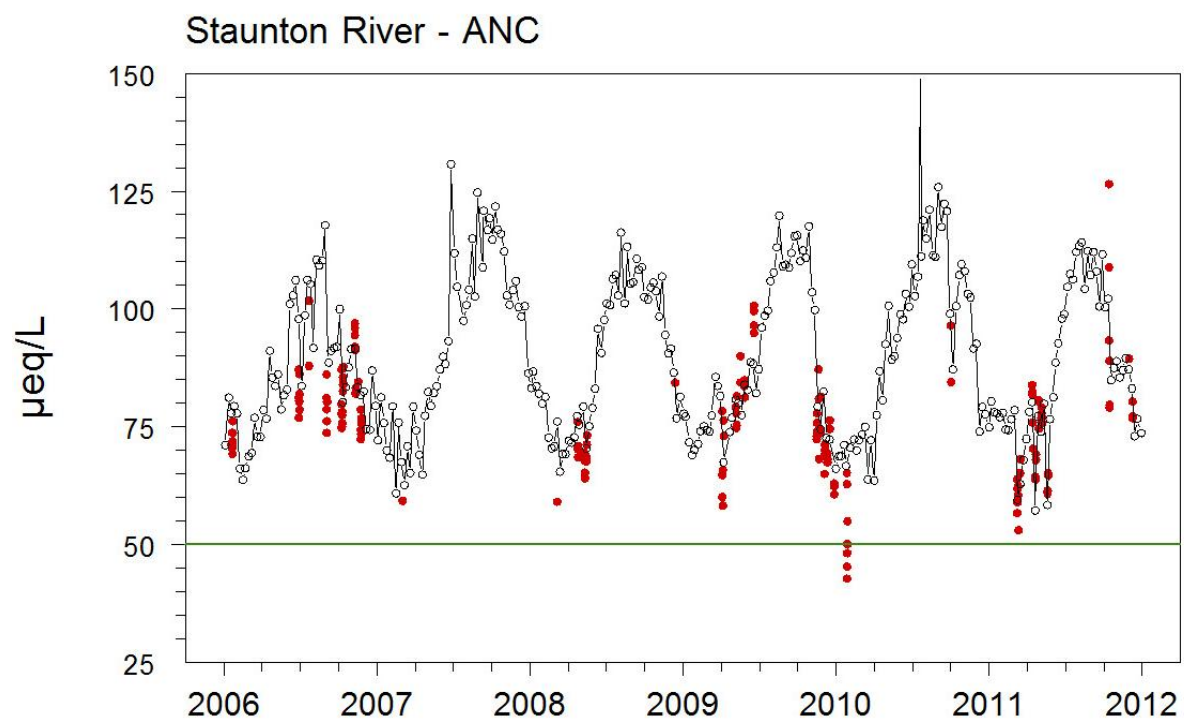


Figure 2 (continued) - ANC values for grab (black points) and automated episodic samples (red points) in 2006-2010.

7. Discharge Status

Discharge gauges were maintained at four SWAS study sites through the end of 2011. Figure 3 displays mean daily discharge for the five-year period ending in 2011. Discharge data processing for Staunton River is not complete, and results are provided only through the end of 2010. Gauging on North Fork of Dry Run, was discontinued in September of 2011.

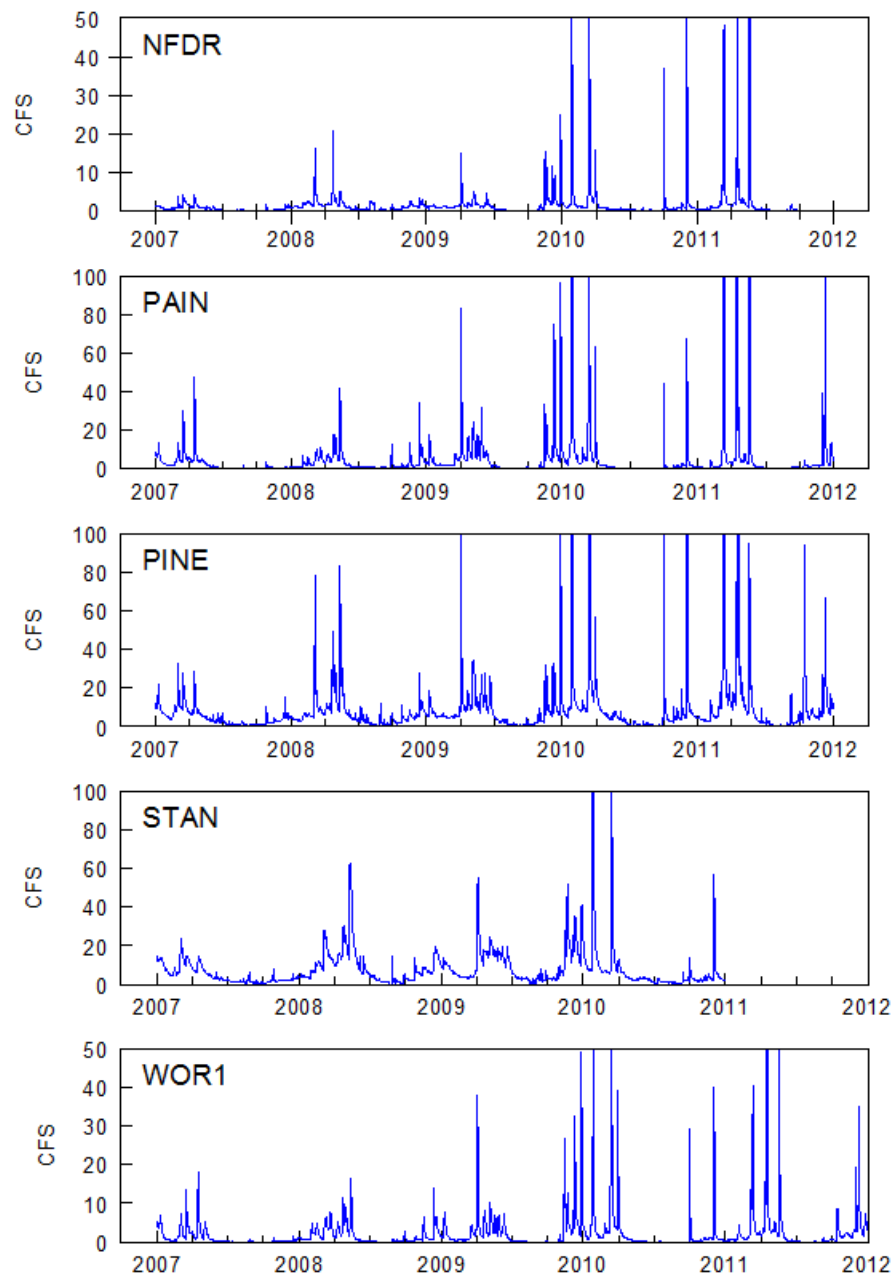


Figure 3 - Mean daily discharge for gauged streams in SHEN. Some of the higher discharge values are truncated.

Figure 4 displays inter-annual variation in discharge around the long-term (1993–2010) mean discharge for each of the five gauging sites in SHEN. Discharge data processing for Staunton River is not complete, and results are provided only through the end of 2010. Gauging on North Fork of Dry Run was discontinued in September of 2011, and results are provided only through the end of 2010. For Paine Run (PAIN), Piney River (PINE), and White Oak Run (WOR1), mean discharge in 2011 ranged between 41% and 45% higher than long-term means.

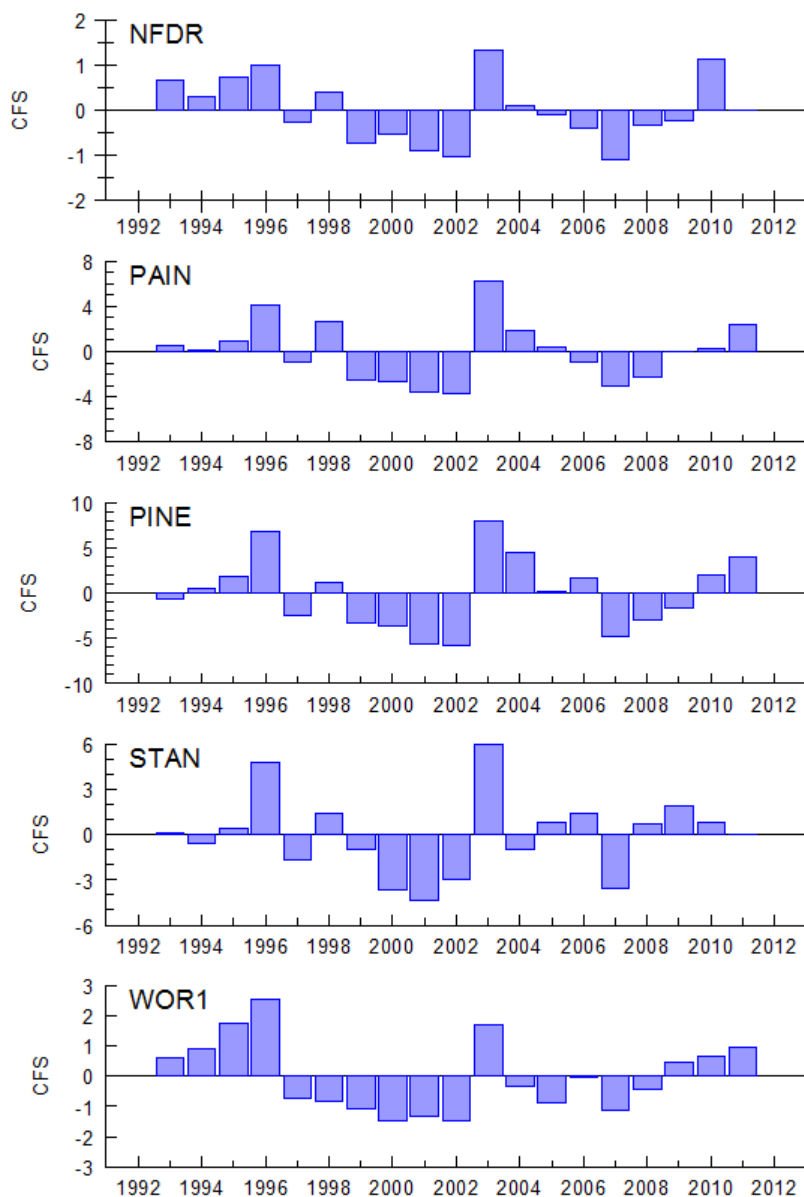


Figure 4 - Inter-annual variation in discharge around the long-term mean (1993-2010) discharge for gauged streams in SHEN.

APPENDIX 1

UVA Collab Site: SWAS-VTSSS AGENCY ACCESS

Contents Description

- Data associated with SWAS-VTSSS primary data collection sites, including sites in George Washington and Jefferson National Forests, Shenandoah National Park, and Virginia Wildlife Management Areas, and on other public and private lands.
- Data associated with TIME project data collection sites, including sites in Virginia, West Virginia, and Maryland.
- File names include the date of the most-recent update in YYYYMMDD format.

(1) CHEMISTRY DATA

Data are provided in Access and Excel formats.

A. ACCESS TABLES

SWAS_VTSSS_PRIMARY_YYYYMMDD.accdb - Access database with sample analyses and related data tables.

DATA_MODEL_YYYYMMDD.jpg - Diagram of table relationships for SWAS_VTSSS_PRIMARY_YYYYMMDD.accdb; shows table alignment but not table linkage (referential integrity is not enforced).

Tables included in SWAS_VTSSS_PRIMARY_YYYYMMDD.accdb:

SAMPLE_MEASUREMENTS_YYYYMMDD - Sample analysis results in row-major format, with separate row for each analysis result.

Data table creation, rules and notes

- includes records for samples with complete analysis, defined as including pH, ANC, SO₄, NO₃, Cl, Ca, Mg, K, Na
- includes additional analysis, if available, for samples with complete analysis
- values below method detection limits (MDLs) have not been censored (applies to some NO₃, NH₄, DOC, TMAL, and OMAL values)
- the Sample field is unique for each sample
- Synoptic, Quarterly, Weekly, and Episodic fields indicate association of sample records with specific data sets
- sample records may be associated with multiple data sets

SAMPLE_COLLECTOR_OBSERVATIONS_YYYYMMDD - Qualitative observations associated with sample collection, including weather, stream flow level, and stream turbidity.

SWAS_VTSSS_PRIMARY_SITE_DOCUMENTATION_YYYYMMDD - Site documentation data for primary SWAS-VTSSS sites, including current and historic synoptic survey, quarterly, weekly, and episodic sample sites, including date ranges for sample collection associated with specific data sets, stream and watershed disturbance notes, and site or map discrepancy notes.

LOCAL_CHARACTERISTICS_YYYYMMDD - Associates sample records with specific suites of sample collection, handling, preparation, and analysis methods.

METHODS_SAMPLE_COLLECTION_YYYYMMDD - Field method: grab sample or automated sample collection.

METHODS_SAMPLE_HANDLING_YYYYMMDD - Sample container, storage, and transport.

METHODS_SAMPLE_PREPARATION_YYYYMMDD - Sample treatment and preservation.

METHODS_SAMPLE_ANALYSIS_YYYYMMDD - Sample analysis technique, equipment, citations.

METHODS_MDL_YYYYMMDD - Methods for determination of method detection limits and citations.

B. EXCEL SPREADSHEETS

SWAS_VTSSS_PRIMARY_YYYYMMDD.xlsx - Spreadsheet with sample analyses in column-major format: analysis results are included in single rows for each sample. Explanatory text (derivation, rules for data set creation, notes) are provided at the top of the spreadsheet.

C. DATA QUALITY REPORTS

Prior to 2009, before SWAS-VTSSS data were posted on UVA Collab, data quality reports were combined with data reports. ZIP files are provided for reports that include multiple files.

(2) DISCHARGE DATA

SWAS_Discharge_YYYYMMDD.zip - Tables with daily and hourly discharge estimates (CFS) for streams in Shenandoah National Park, including White Oak Run, North Fork of Dry Run, Paine Run, Staunton River, and Piney River..

(3) SITE DOCUMENTATION

A. EXCEL SPREADSHEETS

SWAS_VTSSS_PRIMARY_SITE_DOCUMENTATION_YYYYMMDD.xlsx - Site documentation data for primary SWAS-VTSSS sites, including current and historic synoptic survey, quarterly, weekly and episodic sample sites, including date ranges for sample collection, stream and watershed disturbance notes, and site or map discrepancy notes. Explanatory text provided at the top of the spreadsheet. This an Excel version of the SWAS_VTSSS_PRIMARY_SITE_DOCUMENTATION_YYYYMMDD table included in the Access database, SWAS_VTSSS_PRIMARY_YYYYMMDD.accdb.

B. PDF FILES

Station reports in PDF formats, including site descriptions, coordinates, elevation, access descriptions, photographs, and maps.

(a) SWAS-VTSSS_PRIMARY_SITES

Station reports for SWAS-VTSSS primary sites in western Virginia provided as zip files for individual counties.

(b) TIME SITES

Station reports for TIME project sites in Virginia, West Virginia, and Maryland provided as a single zip file.