WATER CHEMISTRY OF NORTH BRANCH SIMPSON CREEK AND THE RICH HOLE WILDERNESS FIRE

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Abstract—In April 2012, the understory of the Rich Hole Wilderness Area in Virginia including the watershed of North Branch of Simpson Creek (NBSC) was burned in a major wildfire. This fire presented a unique opportunity for the study of effects of forest fires on streams in the Appalachian Mountains. In other locations wildfires have produced changes in soil composition, surface runoff, and water chemistry. As the most dramatic effects of wildfires on streams have been the result of episodic discharge, sampling was conducted May–September 2012 for precipitation runoff events. In addition, synoptic samples were taken in 2012 and 2013 throughout the stream reach. Chemical parameters including pH, acid neutralizing capacity, Na^+, K^+, Mg^{2+}, Ca^{2+}, Cl^-, NO_3^-, SO_4^{2-} , Al, turbidity, and conductivity were measured for comparison to previous data sets. A second stream, Bob Downy Branch, was not affected by the fire and served as a "control" with samples collected coincidentally with those from NBSC. The paper presents the unique combination of forest timber stands, historic and present day land use, acid deposition, geology, and the fire in the observed water chemistry of NBSC.

INTRODUCTION

North Branch Simpson Creek (NBSC) is located on the James River Ranger District of the George Washington National Forest about seven miles east of the Town of Clifton Forge, VA. The stream drains toward the south between the ridges of Mill and Brushy Mountains and enters Simpson Creek (SC). The 1837-acre watershed of NBSC is located within the boundary of the Rich Hole Wilderness Area (RHWA) and is forested primarily with a mixture of chestnut oak (*Quercus montana*), northern red oak (*Q.rubra*), white oak (*Q. alba*), red maple (*Acer rubrum*), and sugar maple (*A. saccharinum*). Rhododendron (*Rhododendron* sp.) and mountain laurel (*Kalmia latifolia*) shrubs are abundant, and there are some pine stands. Water chemistry has been obtained for this stream at a site near the Wilderness boundary (VT 16) from April 1987 to present as part of the quarterly monitoring program of the Virginia Trout Stream Sensitivity Study (VTSSS). On April 9, 2012, a human-caused wildfire occurred within the Rich Hole Wilderness. Since the fire was within a congressionally designed Wilderness, indirect suppression actions were taken including backfire operations, line construction, and limited aircraft support. Otherwise the fire was allowed to burn "naturally;" that is, as it would have done in the era before fire suppression became standard practice. By April 19, 2012, the fire was extinguished by rainfall and containment (fig. 1). It was estimated that 95 percent of the understory was burned to the forest floor with about 5 percent single and group torching.[2]

It is unusual for an entire watershed in the Ridge and Valley geophysical province of Virginia to be subjected to a "natural" fire, so the Rich Hole fire has provided an opportunity for research. It was suggested by Forest Service, U.S. Department of Agriculture staff that post-fire data for NBSC could provide useful information on the effect of forest fires on stream water. So in May 2012, the Forest Service requested the environmental group at James Madison University to participate in such a study. Limited funds were available so it was decided to limit the study to samples collected by a volunteer and/or Forest Service staff during episodic runoff events. It was thought that any short-term, post-fire changes in water chemistry might be observed in run off. A nearby stream that discharges from an unburned watershed, Downy Branch (DB), was sampled as a "control" in coincidence with NBSC sampling.

GENERAL COMMENTS ON THE EFFECTS OF FIRES ON STREAMS

Forested landscape may be roughly described with three main features: (in order of increasing solar irradiation) the soils and floor of the forest; low height vegetation including shrubs, juvenile trees and other plants called the understory; and an elevated crown of tree limbs

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and foliage termed canopy. All three of these features are affected by a forest fire with the extent dependent on seasonal timing, availability of fuel, type of fuel, air temperature, wind, and desiccation. Fire reduction of any of these features can change the physical and chemical nature of water discharging from a burned forest (Tiedemann and others 1978). Studies have demonstrated both short- and long-term changes in physical and chemical attributes of streams. Some changes such as increased sediment loading in discharge may be noted soon after the fire. Other changes such as base cation depletion and carbon balance may be long term. Considerable information on the impact of fires on streams may be found in the literature (Wade 1989). For the NBSC study, any changes in water chemistry that may have occurred from the Rich Hole fire should be evaluated in context of past/present land use and watershed geology.

Rich Hole Wilderness History and Geology

The name "Rich Hole" derives from the drainage holes (hollows) of Brushy Mountain. One of these depressions on the north slope contains a large stand of old growth northern red oak forest that is on the list of National Natural Landmarks (NPS 2009, p. 99). Described as a "cove" or protected virgin forest of large oak and hickory trees, this timber stand was the key to the naming and creation of the RHWA.

Pig iron production was the first major industry that developed in eastern Alleghany County. In 1827, a stone "cold blast" furnace, Lucy Selina (Cappon 1957; Lesley 1859, p. 71), opened on the south bank of Simpson Creek less than a mile downstream from NBSC. In 1854, a second furnace, the "hot blast" Australia Furnace, was built at the site. These furnaces required iron ore, limestone, and charcoal to produce iron metal. Iron was produced from mined deposits of limonite, which is a mixture of iron oxides and hydroxides known as Oriskany iron ore (Lesure 1987, p.11). This ore was 48.2 percent iron, and the two furnaces had the greatest production total of any in the State (Walker 1936, p. 28). Mining of iron ore from the mountain slopes of the then future RHWA caused significant changes and erosion of the landscape. In addition, the mountains were stripped of trees to make charcoal. Pig iron production by the process continued until after the end of the War Between the States. In fact, much of the iron used for Confederate cannon balls and other war material came from these furnaces. Rich Hole is in the headwaters of the James River, and transportation by canals and the river made transport to the forges in Richmond less challenging than other locations. Shortly after the war in 1869, the furnaces were acquired by Longdale Company (Morton, 1923, p. 71). In about 1873, charcoal was replaced by coke for iron production. Coke is made from coal, so it may be reasoned that the local mountain forests from that time forward were less stressed from harvest and regeneration occurred. Fancy Hill mine on the south slope of Mill Mountain in the RMWA was worked in the late 1800s and early 1900s (Watson 1907, p. 440). Production of iron in Virginia declined in the early twentieth century and by the end of World War I, the production of iron in the vicinity of RHWA became extinct due to competition with western and northern suppliers.

By 1935-36, many acres of the mountain lands of the iron manufacturing industry were purchased by the Federal Government for inclusion in the George Washington National Forest. The unique cove of trees mentioned above that had not been harvested was soon identified as worthy of special protection and the inclusive slopes of Brushy Mountain were designated as "roadless." In 1964, Congress passed the Wilderness Act (PL 88-577) that designated tracts of Federal land as Wilderness Areas. The Forest Service interpreted the act to include only those lands that were historically pristine and free of human disturbance. In 1974, Congress passed the Eastern Wilderness Act (PL 93-622) that extended the opportunity for inclusion of lands in Wilderness Areas previously used for the diverse activities of humanity which could return to a native condition by natural succession. In 1984, Congress passed the Virginia Wilderness Act (PL 98-586) that selected Rich Hole (and three other areas) for detailed study. In 1988, the Rich Hole Wilderness Area was established (PL 100-326).

Lesure (1957) mapped the geology of the ore deposits of the Clifton Forge iron district in Alleghany County, and repeated his interpretation in a mineral survey report done for Rich Hole Wilderness study area (Lesure 1987). In the later study, he mapped the hematite and limonite resources, both of which he termed "subeconomic" and referenced other studies of the geochemistry and geology of the RHWA. The National Geologic Database has provided on-line and downloadable maps of this work (Lesure and Nicholson 1985). Lesure (1987, p. 6) has also identified the sites of abandoned iron mines, charcoaling pits, cuts, and prospect pits. The largest mine site near NBSC, the Fancy Hill mine, was a 20-foot deep open cut 100-feet wide and 150-feet long on the south slope of Mill Mountain. Not indicated was the grade of a narrow gauge railroad that ran from the Fancy Hill mine to the Longdale Furnace site.

An understanding of the geology of NBSC is essential for interpreting its water chemistry (tables 1 and 2). Lesure's explanation (1987, p. 10) of the formation of limonite deposits in RHWA is that acidic groundwater in the Romney Shale dissolved iron sulfides which moved into underlying carbonate rock and precipitated as iron oxides. He describes the general geology as folded marine sedimentary rocks of the Paleozoic age with interbedded shale, siltstone, and limestone of Late Ordovician age, overlaying beds of sandstone, quartzite, and hematitic sandstone to Middle Silurian age and lower Devonium limestone (Lesure 1987, p. 1, 5). The immediate geology of the NBSC was mapped with the stream originating at 3000 feet elevation in Middle Silurian Keefer Sandstone (Sk), passing adjacent to landslide colluvium consisting of Keefer and Rose Hill Sandstone (Qlc) near 2600 feet, then resuming Keefer contact, encountering sandstone colluvium (Qa) near 2200 feet that follows the stream channel down to the confluence with SC near 1400 feet. Near 1800 feet and 1550 feet there are small groups of Lower Devonium and Upper Silurian rocks (DSu) on the west slope, the latter location having been explored for limonite. Near 1700 feet and 1600 feet there are insertions of Romney Sale (Dr) from the west slope. Kozak (1965) mapped the geology of 15 minute Millboro quadrangle that includes the RHWA. His interpretation shows NBSC originating from Clinton Formation (Scl) near 2800 feet elevation and passing Cayuga Group (Scy), Keyser Formation (Sk), Helderberg Group (Dhl), Oriskany Sandstone (Do), Millboro Shale (Dm), and Brallier Formation (Db) at the stream confluence with SC. Alluvium and colluvium are not shown as separate mapped areas. Regardless of which geologic interpretation is used for assessing water chemistry, the upper reach of NBSC drains from acidic sandstone, then encounters shale and basic limestone before entering SC.

Downy Branch Geology and History

The sampling location for Downy Branch (DB) lies 2.6 miles southwest of VT16 on NBSC. This stream is not within the RHWM area and was not included in some of the referenced geological surveys but was included in the Kozak (1965) study. Although DB drains toward the northwest from North Mountain, the geological associations are quite similar to that of NBSC. The same sandstone and limestone formations described above contribute to the watershed geology of DB.

The human use history of DB watershed has not been reported to the same extent as NBSC. The stream enters Blue Suck Branch within the boundaries of an old Civilian Conservation Corps constructed recreation area 0.6 miles upstream of the confluence with SC. There are small dams on DB that may have been built as reservoirs for the recreation area. Any mining or charcoal sites that may have been in the watershed are not identified on the U.S. Geological Survey (USGS) maps.

Coldwater Streams and Water Chemistry

The chemical and physical makeup of a stream is dependent on the watershed from which it discharges. Streams that discharge from high elevation (elevation > 1400 feet) sandstone and shale ridges in the Virginia Valley and Ridge geophysical province tend to be cold (maximum temperature < 22 °C), free of sediment, and low in dissolved minerals. In Alleghany County, such clean and clear streams support native brook trout (*Salvelinus fontinalis*) and have been included in the VTSSS project. A major goal of VTSSS is establishing the effect of atmospheric acid deposition (acid rain) on the water chemistry of these streams. The primary water quality criterion that is monitored is acid neutralizing capacity (ANC), which is defined as the summation of all titratable bases in the water. The only base of significance in low conductivity headwater streams is bicarbonate ion, which originates from the dissolution of carbonate-bearing minerals in the watershed geology of a stream. In geology where there is little carbonate mineral, the streams are low in ANC, and aquatic life is threatened from acid injections due to rain, snow, etc. Along with ANC, the most common water chemistry parameter is pH, which is the hydronium ion concentration expressed logarithmically. The experimentally found relationship between pH and ANC is illustrated in figure 2. Thus, the observed pH in stream water is the combination of acid from the atmosphere coupled with the ability of geology for a stream to provide neutralizing base (Sharpe and others 1987, Zhi-Jun and others 2000). Although there is no established value for mortality of brook trout and ANC/pH values, it has been observed that streams with negative ANC values and low pH are either devoid of trout or have low population numbers and biomass. Additional water chemistry parameters that are useful for evaluating cold water streams are base cations, acid anions, aluminum, conductivity, and turbidity.

Water Chemistry and NBSC Survey

On September 20, 2012, two Forest Service staff scientists, Dawn Kirk and Fred Huber, hiked the Rich Hole Trail to examine the Wilderness five months after the fire. Water samples were collected from the stream and two tributaries en route from the top of the mountain to the lower boundary. These sites were recorded with a GPS unit (table 3). The single day collection of samples took place two days following a seasonal storm that delivered an estimated 3 inches of rainfall to the NBSC watershed. It is estimated that the discharge peaked on September 18 and was in regression to base flow when the samples were collected. The pH and ANC values found for these samples revealed much about the way water chemistry is influenced by geology. Very low pH and ANC values were obtained for all samples taken more than a mile from the lower Wilderness boundary (table 4, fig. 3) and upstream of 1750 feet elevation. These low values reflect the acidic sandstone geology (Keefer) which constitutes the upper watershed. Near 1 mile upstream, the pH and ANC increase dramatically due to the injection of water from the limestone geology (Helderberg) that provides bicarbonate. On site examination of the 1-mile sampling location suggested that ash from the fire may have been a contributing factor. The pH and ANC decreased downstream from the 1-mile sample location, probably due to the injection of additional acidic water from the east side of the watershed. Aluminum is a metal toxic to fish that can be mobilized under acidic conditions. In this study, all observed aluminum values were low and not threatening for aquatic life.

Fish Populations

Simpson Creek (SC) drains the east side of Brushy Mountain and winds its way nearly 10 stream miles down to the confluence with the Cowpasture River 4 miles east of Clifton Forge. Self-sustaining brook and rainbow trout dominate SC fish populations for about 5 miles from its origin spring near elevation 3000 feet to the historic Longdale Furnace site at 1300 feet. Downstream of Longdale Furnace, the stream temperature increases and warm water fish populations dominate. North Branch Simpson Creek (NBSC) enters SC upstream of Longdale Furnace within the coldwater reach. Blue Suck Branch (BSB) with its tributary Downy Branch (DB) enters SC about 2 miles downstream of Longdale Furnace within the warm water reach. These confluences are important because coldwater fish could migrate from NBSC into SC and vice versa, whereas migration is less likely into/from BSB and DB.

Electrofishing surveys of the above streams have been performed by VDGIF (Fink 2012) with 27 different species of fish found (table 5). Most of these species are native and frequently found in headwater streams in western Virginia. Some species are introduced, e.g., rock bass, smallmouth bass and rainbow trout, either directly into the streams or from migration from the Cowpasture River. The diversity of the fish population is impressive given that for nearly two centuries, the human impact in the watershed has been dramatic. For about 100 years after Colonel John Jordan operated his first iron furnace Lucy Selina [Longdale], "heavy drafts" on the forests to make charcoal (Morton 1923, p. 71) and extensive mining took place along the SC drainage. This was done in an era when no effort was made to avoid sediment movement and damage to the riparian area of streams. Roads and railways were built along the stream, beginning as trails for mining and travel that connected the furnaces along Bratton's Run, the mineral spring resorts along Alum Creek and Jordan's furnaces. By 1832, the Lexington and Covington Turnpike was built over North Mountain, following the trace of the old trails (Morton 1920, p.164). In the late 1920s, the Turnpike became part of US 60, later designated SR 850 North Mountain Road when the interstate and Federal highway conjoined. In 1977, construction of I-64 sandwiched much of the stream between the two roads. An attempt was made to mitigate streambank erosion after the highway construction was completed (Standage 1986) with semipermeable matting, but recent erosion has continued to introduce sediment into SC.[3] Fish populations for both BSB and DB have been affected by the 1930s construction of dams that are part of a recreation area (Downey and others 2012). These dams are large enough to inhibit fish migration. It is noteworthy that BSB, DB, and NBSC have been listed as Exceptional State Waters-Tier III (VDEQ 2004).

Simpson Creek was included in the VDGIF trout stocking program until the time of construction of I-64. Hatchery raised rainbow trout (RBT) were stocked each year for decades, and it is likely that some of these fish parented the fish collected by VDGIF surveys in recent years. Of the eight different times SC has been surveyed (table 5), four found RBT, one found brook trout (BKT), and three found no trout at all. Unfortunately the location of surveys has varied and was not recorded in the database except those since 2001. For those locations that were identified, l=lower, m=middle and u=upper. The upper location is within the coldwater reach at Longdale Furnace and showed the greatest number of RBT. The other two identified locations are within the warmwater section of SC and did not have any trout. It is likely that the other surveys that didn't show trout in SC and BSB were done in warmwater sections. The survey (1995) for SC that showed BKT but no RBT was from far up in the watershed near 1600 feet elevation.[4] It was thought that the abundance of brook trout may have been due to fingerling stocking in a previous year. In streams in Virginia that have been colonized by RBT, water chemistry generally shows higher pH, ANC, and lower elevation, than in reaches of the same stream that contain BKT. The 1979 and 1995 electrofishing site for NBSC was also unspecified in the database, but VT16 was likely the surveyed site. The NBSC fish data showed BKT and nongame fish populations that matched the SC site surveyed on the same day.

A dramatic difference in water chemistry (table 6) was observed for sites collected near elevation 1444 feet a short distance upstream from NBSC and SC confluence in May 2012. Unlike NBSC, which discharges through sandstone rock for most of its distance, SC discharges mostly from Brallier Formation (Db) for several miles before reaching the confluence of the two streams (Kozak 1965). Thus SC has higher pH, ANC, calcium, and

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magnesium concentration than NBSC due to the greater contact with limestone and shale geology. This difference in stream chemistry has benefited the RBT that are not only thriving in SC but have replaced the native BKT. As no barrier to fish migration was found, the lower pH, etc. may also be a reason that RBT have not colonized NBSC.

Description of April 2012 Fire

The winter of 2011-2012 was an unusually dry period in western Virginia. At about 5:30 pm on April 9, 2012 (Dooley 2012), a small brush fire was reported along Rich Hole Road (North Mountain Road) near the Rockbridge/ Alleghany County line. With dry forest and high winds, the fire soon spread throughout the Simpson Creek valley, resulting in closure of I-64 for nearly 20 hours (Adams 2012). Rich Hole fire was one of six different major wildfires that became known as the Easter Complex due to their occurrence just after Easter Sunday. By April 19, all fires were contained. The Rich Hole fire covered more than 15,454 acres, including 100 percent of the 6450 acre RHWA burned (Inciweb 2012), ending when a sizeable storm front passed through the region delivering about 1 inch rainfall on April 18, 2012.

The Rich Hole fire occurred in the early spring before leaf out for deciduous trees and before most grasses and other plants had emerged from the forest floor. Most of the litter and dead wood that covered the forest floor was partially or totally consumed leaving a layer of gray colored ash. Small trees and bushes were also consumed, but larger trees mostly were not damaged except for minor burn scars in most cases. The fire did not char the soil; in fact, we could find no effect more than 0.8 inch below the surface in the locations we examined. By May, much of the forest canopy had grown out, especially in the riparian area, and throughout the summer the burned area gradually replenished with renewed plant life.

METHODS

Rainfall, Discharge and Sample Collection

Streams often show dramatic changes in water chemistry with changes in discharge that are due to contact time with soils, bedrock geology, and surface materials. During low flow periods, ground water makes up streams, while surface run off is a greater factor during high flows. It would have been worthwhile to measure discharge of the streams as part of this study and collect samples frequently at all stages. However, there was no funding available so sample collection relied entirely on volunteer labor and additional work was not possible. It was thought that the most likely immediate effects of the fire would occur during episodic runoff events, so sample collection was made before and after storms passed through the area during spring and summer 2012. It was necessary for sample collectors to note storm patterns and predict when to take samples. This was challenging particularly since the summer was relatively dry and some storms turned out to deliver small levels of precipitation that did not substantially change discharge. As things turned out, 15 and 14 water samples were collected from VT16 on NBSC and DB, respectively (table 7). As no stream gauges were in place in the study streams, general discharge was calculated. Eastern Alleghany County receives an average 3 inches rain annually (Citizen Steering Committee 2007). In other studies we have estimated annual yield at about 65 percent for similar rain and forest cover. With these values—stream gradients of 7.6 percent and 9.1 percent and watersheds of 1837 and 990 acres—the average annual discharge is 5.1 and 2.7 cubic feet for NBSC and DB, respectively. The deviation in these averages is near 0.5 cubic feet, ranging from near zero during droughts to more than ten fold the average with high precipitation.

Rainfall and stream discharge for the time when these samples were collected can be estimated from gauges maintained by several governmental agencies. Although no gauge is located right at the study site, the following may serve as surrogates. The IFLOWS network is a system of digital rain gauges located throughout the mountains for warning of potential flooding. The gauges operate with tipple buckets that record rainfall in 0.04-inch increments; data is sent by telemetry to county receivers and made available on the internet. Although the primary purpose of the gauges is public safety, archived rainfall data may be readily downloaded (table 8). Flows or discharge in streams may also be conveniently obtained from internet data for a wide network of stream gauging stations operated by USGS and other agencies. The nearest gauges to RHWA are two IFLOW rain gauges, one on Warm Springs Mountain 10 miles west, and another on North Mountain 3 miles southeast, with a stream gauge located on the Cowpasture River 6 miles southwest near Clifton Forge downstream of the confluence with Simpson Creek (fig. 4).

Efforts were made to begin this project soon after the fire occurred with the first samples collected May 8, 2012 when a rain front was moving through the region. Multiple samples were collected over several days for a storm which gave about 0.75 inches rain total. A large storm passed through about a week later with 1.5 inches rain total. Neither of these storms produced the large flushing event that was desired to determine whether sediment movement and other changes would occur as a result of the fire. Several late May storms and one in July were small and did not result in significant rainfall.

In September, about 3 inches of rain were delivered in a single storm to the NBSC watershed.[5]

Sample Processing

Observations of water temperature, conductivity, turbidity, and pH were made at the time of sample collection in the field. Determination of major ions contributing to charge balance and dissolved trace elements were done in our laboratories. Samples were measured for air-equilibrated pH and acid neutralizing capacity at 68 º F. After filtration with a 0.2-micron filter (Gelman 4406 LC PVDF), portions of the water samples were measured for acid anions (chloride, nitrate, and sulfate) directly by ion chromatography (Dionex ICS-3000), while a second portion was acidified with high purity nitric acid (Fisher Scientific Co.) and analyzed for calcium, magnesium, sodium, and potassium by flame atomic absorption (Varian SpectrAA 220FS). Other elements (aluminum, copper, iron, zinc, etc.) were analyzed in filtered, acidified samples by inductively coupled plasma–mass spectrometry (ICP-MS) (Agilent 7500). Analytical methods have been described elsewhere (APHA 1998, Downey and others 1994).

RESULTS AND DISCUSSION

Surface soil samples collected for the present study gave values of pH 4.23 and 7.76, respectively for unburned and burned sites. Corresponding alkalinity (bicarbonate) concentrations were 0 and 446 µeq/g. These results indicated a large amount of alkalinity was produced in the ash from carbon combustion by the forest fire. To evaluate whether the bicarbonate or other ash derived chemicals were contributing to post-fire stream water chemistry, data were compared for the results of our analyses to the VTSSS database for NBSC. Average and sample standard deviation values were calculated for all parameters. Fall and winter samples were excluded from the VTSSS set to provide better comparison to the spring and summer samples collected for the present study. At 95 percent confidence, the conductivity (mineral content), calcium, and magnesium increased (table 9). Other values increased but were not statistically significant. It is interesting that both ANC and pH decreased, which is the opposite of what would have been anticipated from the burned soil results, but there was no difference at 95 percent confidence.

Soil erosion was expected to be an important part of the post-fire effects of storms washing sediment into the stream. Turbidity was measured for all post-fire samples and did not increase above baseline values for both NBSC and DB, ranging from 1.0 to 2.5 NTU, except for the September 18 storm which produced values of 32 and 44 NTU, respectively. Both streams clarified by the second day after this storm. All data indicate that the fire did not create an erosion problem and that NBSC sediment is typical of a Virginia headwater trout stream.

The selection of Downy Branch as the "control" stream was made based on its proximity to NBSC, similarity in watershed size, land use, forest timber stands, etc. However, there are some differences in water chemistry that preclude a direct comparison of the paired samples taken for this study. For example, average values for pH / ANC were 6.18±0.47 / 19.5±6.0 and 6.52±0.15 / 56.7±13.1 for NBSC and DB, respectively. Yet information may be gleaned by comparing *changes* in water chemistry for the paired samples. For each parameter and for each sample collection, a difference (delta) value was calculated for the two streams and several trends were noted. In general, when storms elevate stream discharge dilution causes solute concentrations to decrease and delta values between comparison streams are smaller. However, when storm runoff occurred post fire in the present study, the delta value for ANC either increased (fig. 4) or did not decrease proportionally. This observation supports the observation that ANC for NBSC was reduced after the fire and indicates the decrease was greater with increased discharge. Conversely, both calcium and magnesium delta values increased as a result of concentrations increasing with storm flow. This increase may be due to the two cations flushing from ash. The most dramatic differences were observed during the largest episodic event of the study in September, when the concentrations of discharge calcium and magnesium were greater in NBSC than in DB. These observations may not be conclusive for this study due to the limited size of the data set.

CONCLUSION

The geology of the upper reach for both NBSC and DB consists mostly of sandstone with limited or no natural carbonate. The streams are acidic until they encounter limestone geology low in the watersheds. Mining, charcoaling, logging, and road construction were widespread in the watersheds before acquisition by the Forest Service in the 1930s, with forest timber recovery since that time. Pre- and post-fire data for NBSC indicate that the stream was discharging increased calcium and magnesium during the study period at 95 percent confidence level. These results agree with previous studies (Tiedemann and others 1979, p. 14). Both pH and ANC were lower but not statistically verified at 95 percent confidence. Other parameters also were not statistically different. Paired samples of DB and NBSC supported the observations that calcium and magnesium were increased, with ANC decreased. Soil tests indicated increased pH and bicarbonate due to ash in the burned forest over

[5]Personal Communication. 2012. William McNown. 405 Sammys Road Apt 7, Covington, VA 24426.

the unburned samples. It is not known why bicarbonate (ANC) was not released along with the base cations, but charge balance requires some other anions must be discharged as well. A small increase in sulfate was observed but not enough to match the amount of calcium and magnesium. Phosphorus was not measured for this study, and it is possible that phosphate is the "missing' anion.

Limitations of this study included a reliance on discharge and rainfall data information not directly taken at the watershed, a relatively small data set due to a lack of flushing storms during the project period, VTSSS data for which discharge data are not available, dissimilarity between the two streams, and very little pre-fire data for DB. Fire effects to the canopy were variable. There was 75-100 percent mortality in some areas, mostly on rocky dry ridges. While in other areas, there was little to no damage to the canopy. The soil layer was unaffected and in most places the organic duff layer was affected only low to moderate. Stream transport of sediment levels did not change as a result of the fire. It is possible but doubtful that future storms could erode the NBSC, introduce sediment, and change water chemistry. Most likely the landscape will soon recover and the casual visitor will be hard pressed to see that a forest fire occurred in this location.

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Table 1—General description of geologic map units of North Branch Simpson Creek and Downy Branch

ID	Name	Description
Qa	Alluvium (Holocene)	Sandstone sand and gravel
Qlc	Landslide and Colluvium	Quartzite and hematitic sandstone from Keefer and Rose Hill formation
Dr	Romney Shale	Black, pyritic, fissile shale
DSu	Undivided Devonium and Silurian	Contains Ridgeley Sandstone, Licking Creek Limestone, Oriskany iron deposits, Healing Springs sandstone, New Creek limestone, Kesyer limestone, several other sandstones and limestones all undivided
Sk	Keefer Sandstone	White and light gray sandstone quartz

Source: Lesure and Nicholson (1985).

Table 2—Comparison of sampling sites and heads of North Branch Simpson Creek and Downy Branch

Site	Latitude	Longitude	Elevation	Reach	Lesure	Kozak
			feet	*miles*		
NBSC VT16	N 37° 49.210	W 79° 40.296	1444	0.04	Qa	Db
NBSC head	N 37° 52.080	W 79° 39.054	2961	3.8	Sk	Scl
DB sample	N 37° 47.296	W 79° 41.865	1362	0.4	–	Db
DB head	N 37º 46.490	W 79º 40.400	2700	2.8	–	Scl

–These are data that were not collected by the study cited here.

Table 3—September 20, 2012 waypoints of sample sites on North Branch Simpson Creek in order of increasing elevation

Site	Latitude	Longitude	Elevation	Reach	Lesure	Kozak
			feet	*miles*		
NBSC009	N 37° 49.210	W 79° 40.296	1444	0.04	Qa	Db
NBSC008	N 37° 49.554	W 79° 40.241	1541	0.4	Qa	Dm
NBSC007	N 37° 50.076	W 79° 40.108	1749	1.0	Qa	Dhl
NBSC006	N 37° 50.431	W 79° 39.984	1877	1.6	Qa	Sk
NBSC005	N 37° 51.195	W 79° 39.654	2269	2.6	Sk	Scl
NBSC004	N 37° 51.513	W 79° 39.400	2579	3.1	Sk	Scl
NBSC003	N 37° 51.664	W 79° 39.220	2748	3.5	Sk	Scl
NBSC002	N 37° 52.080	W 79° 39.054	2961	3.8	Sk	Scl
Start 001	N 37° 52.198	W 79° 37.502	2279	trailhead	–	–
DB	N 37° 47.296	W 79° 41.865	1362	0.4	–	Db

Note: Downy Branch and the trailhead are included. The geology of the collection sites was identified by Lesure (1985) and Kozak (1965).

–These are data that were not collected by the study cited here.

Table 4—September 20, 2012 North Branch Simpson Creek water chemistry results

Elevation	pH	ANC	Cl	NO3	SO4	Na	K	Ca	Mg	Al	Con
feet											
1444	6.48	24.8	20.9	0.3	72.7	17.3	13.0	96.1	48.3	0	19.5
1541	6.36	25.6	20.8	0.5	73.0	17.4	12.1	97.9	48.1	0	20.2
1749	7.37	287.9	28.5	0.1	208.0	19.5	18.8	513.7	75.8	1	72.0
1877	5.03	-6.5	18.1	0.3	64.8	15.6	9.3	29.9	43.8	16	17.2
2269	4.90	-11.0	17.9	0.3	64.2	16.1	8.5	24.0	34.1	26	17.7
2579	4.79	-17.9	18.6	0.0	89.5	17.5	13.5	19.3	48.9	37	24.3
2748	4.86	-11.0	29.0	0.3	54.6	27.4	7.6	19.8	25.8	25	18.6
2961	4.90	-13.4	286.5	0.2	51.2	245.8	7.4	16.3	19.4	35	65.6

Table 5—Electrofishing information for streams near Longdale Furnace, VA

Stream	Date	SpDiv	BKT	RBT	BKD	FAD	MTS	TOS
Blue Suck	19860724	6	0	0	14	6	2	2
Blue Suck	19950731	5	0	0	10	10	0	4
Downy	19790131	3	1	0	9	0	2	0
Downy	19860724	4	3	0	25	0	2	2
Downy	19950731	4	3	0	40	1	0	4
NBSC	19760915	4	4	0	26	0	3	4
NBSC	19950731	3	13	0	12	0	0	2
Simpson	19790208	3	0	0	29	0	9	2
Simpson	19790808	9	0	7	10	4	0	4
Simpson	19850827	10	4	26	281	19	?	243
Simpson	19850828	19	0	39	128	?	?	?
Simpson	19950731	3	24	0	19	0	0	4
Simpson-l	20010710	12	0	0	0	0	16	3
Simpson-m	20010711	9	0	0	0	0	12	3
Simpson-u	20060811	9	2	48	13	1	3	7

Dates are provided as yearmonthday, SpDiv indicates the total number of different fish species found for a location and numbers of fish of selected species (all ages) found: BKT=brook trout, RBT=rainbow trout, BKD=blacknose dace, FAD=fantail darter, MTS=mottled sculpin,TOS=torrent sucker (Fink 2012).

Note: question marks indicate that species identification and numbers are uncertain.

Table 6—Comparison of North Branch Simpson Creek and Simpson Creek water chemistry

Site	pH	ANC	Ca	Mg	Cond	SO4	Na	Cl
NBSC	6.48	24.8	82.3	48.4	20	72.7	15.8	18.9
SC	7.17	351.1	759.1	130.8	106	180.3	215.5	190.5

Note: samples were collected May 11, 2012 about 200 feet upstream of confluence. Calcium, magnesium, and ANC are produced from carbonate dissolution; conductivity is due to total ionic composition; and sulfate is from pyrite and acid rain. NaCl is most likely from road salt used on SR 850 and I-64. Units are same as table 4.

Table 7—Dates and times of sample collection from North Branch Simpson Creek (NBSC) and Downy Branch (DB) taken for the present study

Stream	Date	Time
NBSC	5/8/2012	930
NBSC	5/9/2012	815
NBSC	5/9/2012	1600
NBSC	5/10/2012	940
NBSC	5/11/2012	1000
NBSC	5/15/2012	915
NBSC	5/15/2012	1515
NBSC	5/16/2012	1100
NBSC	5/22/2012	930
NBSC	5/25/2012	850
NBSC	5/30/2012	1000
NBSC	7/9/2012	1115
NBSC	9/18/2012	1440
NBSC	9/19/2012	830
NBSC	9/20/2012	1500

Stream	Date	Time
DB	5/8/2012	1015
DB	5/9/2012	930
DB	5/9/2012	1510
DB	5/10/2012	910
DB	5/11/2012	1130
DB	5/15/2012	940
DB	5/15/2012	1435
DB	5/16/2012	1020
DB	5/22/2012	910
DB	5/25/2012	820
DB	5/30/2012	920
DB	7/9/2012	1145
DB	9/18/2012	1400
DB	9/19/2012	900

Note: date is mon/day/yr; time is military.

Table 8—Rainfall recorded at North Mountain and Warm Spring Mountain IFLOW gauges

Date	Time	North Mountain	Warm Springs
	military	*inches*	*inches*
5/8/2012	930	0.04	0.00
5/9/2012	815	0.36	0.68
5/9/2012	1600	0.60	0.76
5/10/2012	940	0.16	0.12
5/11/2012	1000	0.00	0.00
5/15/2012	915	1.32	0.40
5/15/2012	1515	0.80	0.08
5/16/2012	1100	0.00	0.00
5/22/2012	930	0.20	0.00
5/25/2012	850	0.04	0.00
5/30/2012	1000	0.68	0.40
7/9/2012	1115	0.44	0.16
9/18/2012	1440	0.04	1.68
9/19/2012	830	0.08	1.28
9/20/2012	1500	0.08	0.00

Source: http://72.66.190.197/Virginia_IFLOWS/. [Date accessed 1/22/2013].

Table 9—Virginia Trout Stream Sensitivity Study (VTSSS) values for the period 1987-2010 and post-fire values for NBSC: comparison of average and sample standard deviation for water chemistry parameters

Parameter	April/July	Post-Fire	$P < 0.05$
pH	6.21 ± 0.15	6.18 ± 0.47	No
ANC (bicarbonate)	24.5 ± 7.5	19.5 ± 6.0	No
Conductivity	15.7 ± 1.0	23.3 ± 5.0	Yes
Sulfate	74.7 ± 9.3	76.3 ± 6.9	No
Chloride	17.5 ± 1.7	18.3 ± 2.0	No
Calcium	60.9 ± 4.6	89.0 ± 12.5	Yes
Magnesium	35.9 ± 2.1	48.8 ± 2.5	Yes
Potassium	13.6 ± 1.6	13.8 ± 2.7	No
Sodium	14.5 ± 0.9	16.6 ± 2.8	No

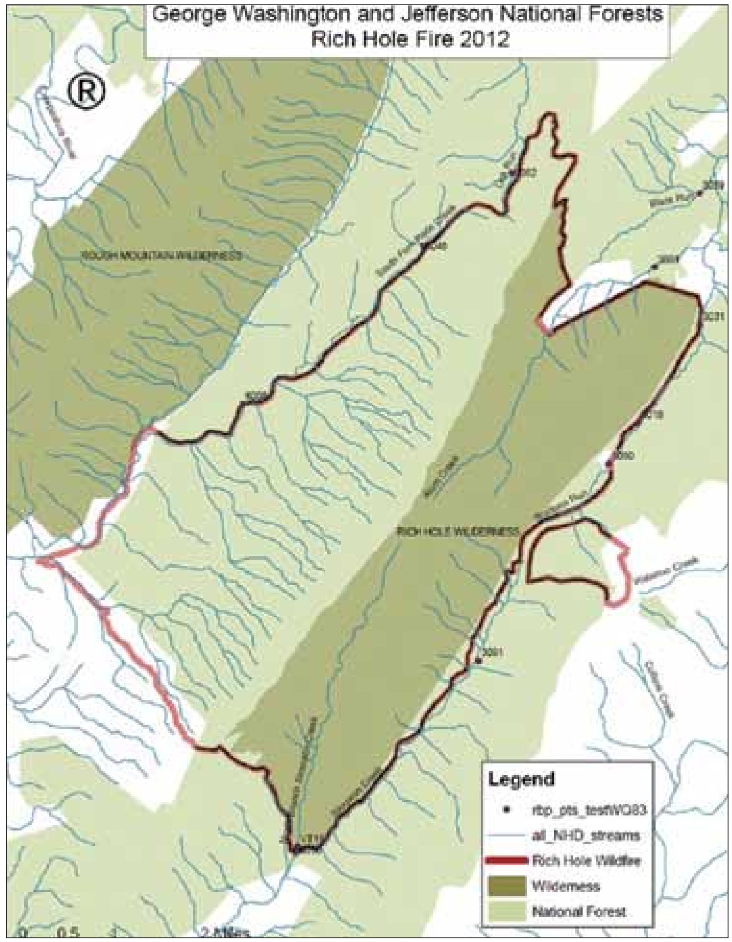

Figure 1—Map of 2012 Rich Hole fire. The 6000-acre fire burned within the areas bounded by bold lines. North Branch Simpson Creek VTSSS sampling location VT16 is located at the southern boundary of the fire. Downy Branch is located south of the mapped area. Map was provided by staff of the Forest Service, George Washington and Jefferson National Forests.

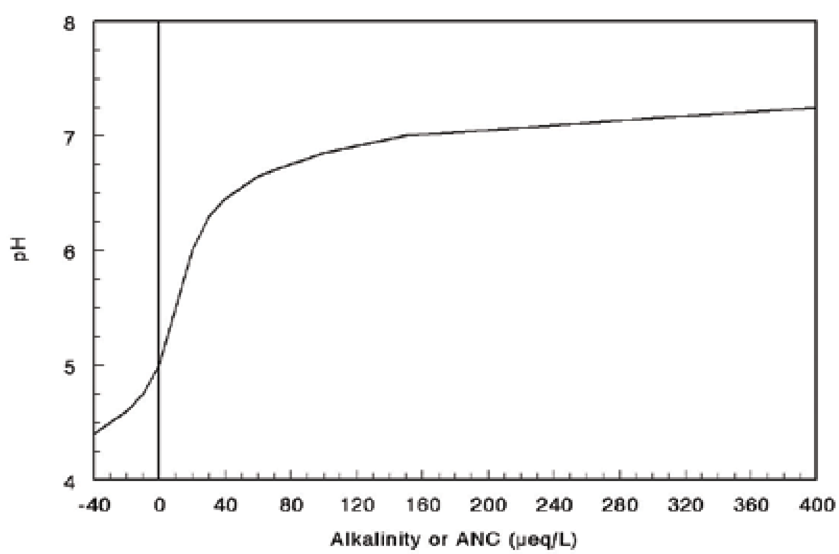

Figure 2—Plot of observed pH values for streams of varying ANC. Since ANC is mathematically determined from a two-endpoint titration method, it is possible for low pH streams (pH < 5.5) to have a negative value.

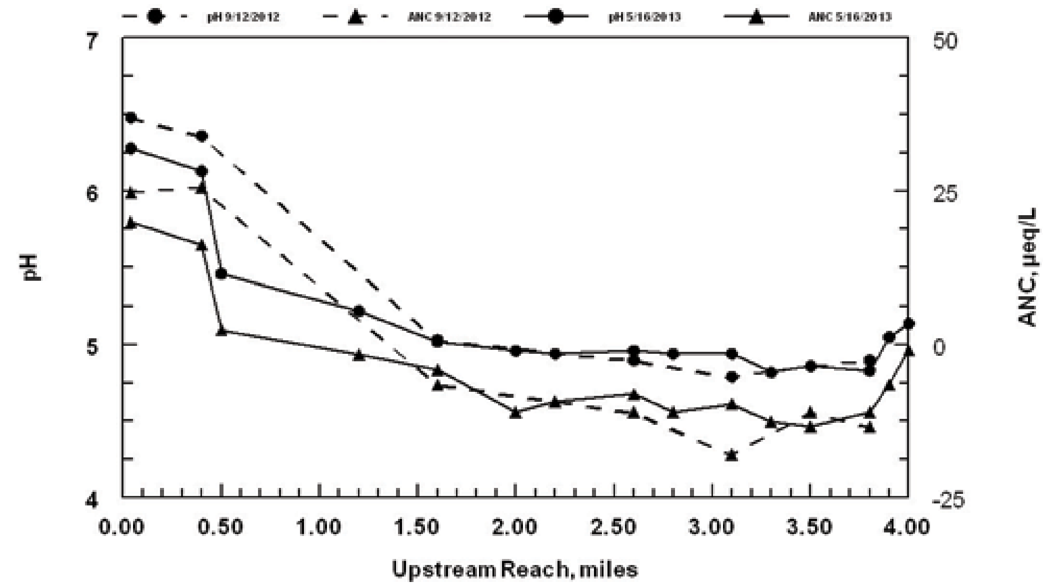

Figure 3—Observed pH and ANC values versus upstream stream distance for two synoptic sample collections for NBSC. The data points are connected for clarity of display and interpretation. Circle and triangle markings represent pH and ANC values, respectively. Broken and solid lines represent September 2012 and May 2013 values, respective

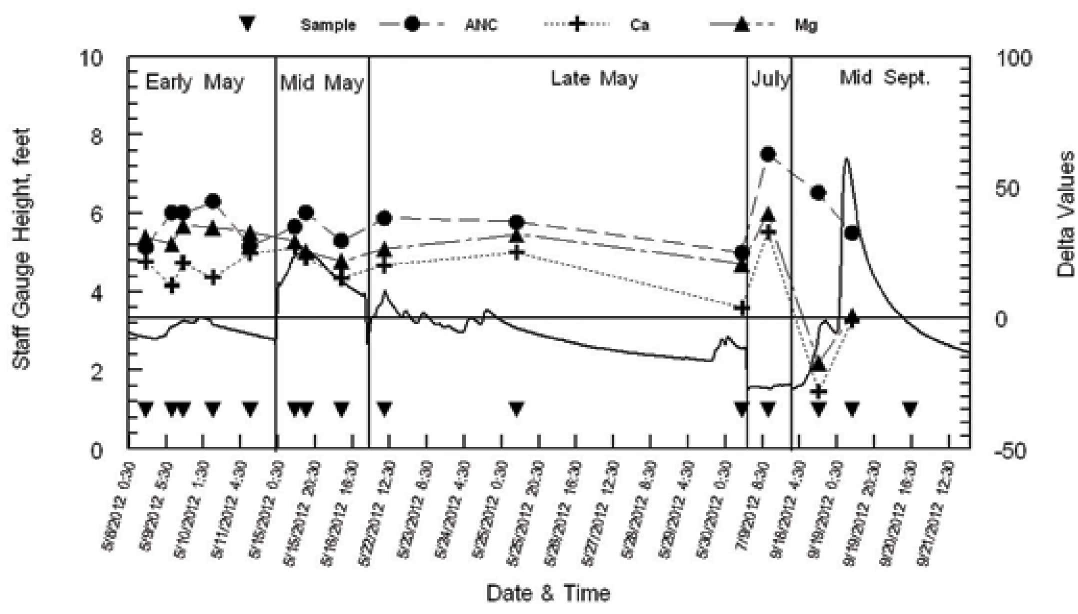

Figure 4—USGS staff gauge height for Cowpasture River and delta values for ANC, calcium, and magnesium for Downy Branch–North Branch Simpson Creek versus time for the project period. The downward triangles mark the dates of sample collection from North Branch Simpson Creek. Delta points are connected for clarity. Timeline is discontinuous. Discharge data obtained for USGS 02016000: http://waterdata.usgs.gov/va/nwis/uv/?site_no=02016000&PARAmeter_cd=00065,00060,62620,00062. [Date accessed: 2/1/2013].