National Park Service
U.S. Department of the Interior

Southeast Region
Atlanta, Georgia

Cumberland Piedmont Network Water Quality Report

Cumberland Gap National Historical Park

Natural Resource Report NPS/SER/CUPN/NRTR—2009/005



ON THE COVER
Shillalah Creek October 10, 2008
Photograph by: Joe Meiman

Cumberland Piedmont Network Water Quality Report

Cumberland Gap National Historical Park

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January 2009

U.S. Department of the Interior
National Park Service
Southeast Regional Office
Atlanta, Georgia

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Please cite this publication as:

Meiman, Joe 2009. Cumberland Piedmont Network Water Quality Report: Cumberland Gap National Historical Park NPS/SER/CUPN/NRTR—2009/005. National Park Service, Atlanta, Georgia.

NPS D-005, January 2009

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Introduction

In early Fiscal-Year 2003, a water quality monitoring effort began in the Cumberland Piedmont Network (CUPN). For all intents and purposes, park managers and program directors can think of this initial sampling effort as a water quality inventory, as for many parks in the CUPN, little was known regarding water quality. Each park, sampled in rotation, underwent a water quality inventory sampling period which also served as a proving-ground for water quality monitoring protocols and logistics. The report that follows is a park-specific document that describes the monitoring sites, parameters tested, results in graphic form, a brief interpretation of the results, and recommendations of parameters to be measured for the long-term.

Sampling sites were chosen following site visits by then Mammoth Cave National Park hydrogeologist Joe Meiman, and with consultation with park staff. Some sites were chosen to coincide with past inventories and monitoring efforts. In most cases sites were chosen at the downstream end of a watershed to serve as an integrator of the basin, and should yield characteristics and contributions from the entire watershed.

Initial CUPN water quality sampling includes a two-year period of intense activity. In the case of Cumberland Gap National Historical Park (CUGA), sampling occurred on fixed monthly dates (second Tuesdays) for 24 consecutive months – October 2006 through September 2008. The NPS Water Resources Division (WRD) requires each Network water quality program to monitor four core field parameters – water temperature, pH, specific conductance, and dissolved oxygen. Additional parameters of park interest, *Escherichia coli*, Acid Neutralizing Capacity, and turbidity were included at CUGA.

Brief Hydrologic Introduction

Cumberland Gap National Historical Park possesses the widest variety of hydrogeologic conditions within the CUPN. The entire park is underlain by a sequence of sedimentary strata – ranging from Devonian shales, through Mississippian limestones, to Pennsylvanian coals and silisiclastics. Geologic structure is abundant in the park as the mountains themselves are the result of an overthurst fault, and crossed by normal and reverse faulting – resulting in the Gap itself. Many surface streams originate upon the steep slopes of Cumberland Mountain flowing both westward into Kentucky and eastward into Virginia and Tennessee. Some streams, where they cross the steeply dipping limestones, are captured to the subsurface recharging karst aquifers and discharging at springs.

The streams of the park have undergone the most intensive water quality monitoring of the CUPN, in support of the Cumberland Gap Tunnel Project and restoration of the Wilderness Road (mid-1980's through the present). This effort has focused on the many streams, ranging from the larger Little Yellow Creek (Kentucky) and Gap Creek (Tennessee) to smaller tributaries like Tunnel Creek and Railroad Creek (Kentucky), all which drain the tunnel and restoration areas. Water quality sampling continues presently in support of the Gap restoration project.

With the exception of a small area of Middlesboro, Kentucky supplying urban runoff into Little Yellow Creek (this runoff enters the far downstream reach of the stream nearly at the park boundary) and the town of Cumberland Gap, Tennessee (complete with a waste-water treatment facility), the streams of the park originate from park lands. One further exception is the aforementioned streams, which are, in part, recharged by the tunnel and its roadways. As a testament to streams dominated by undeveloped forest lands (most of which are within a proposed Wilderness Area), water quality of these streams can be considered pristine – a rare occurrence in the Appalachians.

Although aquatic inventories have not been completed, much monitoring has been done with respect to the federally threatened Blackside Dace (*Phoxinus cumberlandensis*). This fish currently occurs only within a short reach of Davis Branch just above Middlesboro. The US Fish and Wildlife Service currently conducts annual monitoring of the Blackside Dace along this reach of Davis Branch. At this time there have been no aquatic inventories of Cudjo Cave.

As a final note to this preamble, I would like to thank the staff of CUGA for their tremendous support in this monitoring effort. Starting at the top, Superintendent Mark Woods never wavered in his full support of our program. There is no practical way that such a rigorous sampling program would have succeeded without the dedication and attention to detail of primary sampler, Biologist Rodney Martinez, and help from Natural Resource Management Specialist Jenny Beeler and Student Conservation Association Interns Amanda Deeds and Lindsay Nystrom. The results displayed in this document are fruits of their efforts.

Sampling Sites

Below is a map of water quality sampling sites at CUGA. During each monthly sampling round each site was visited and an additional Quality Assurance-Quality Control sample was extracted. Monthly sampling commenced in October 2006 and continued until September 2008, for a total of 24 sampling events. As all of these sites had been previously sampled by CUGA, we simply adapted their existing naming convention – two characters denoting the stream followed by a number designating its relative position within the watershed, with 1 as the headwaters and 10 at the base of the watershed or where the stream leaves the park.

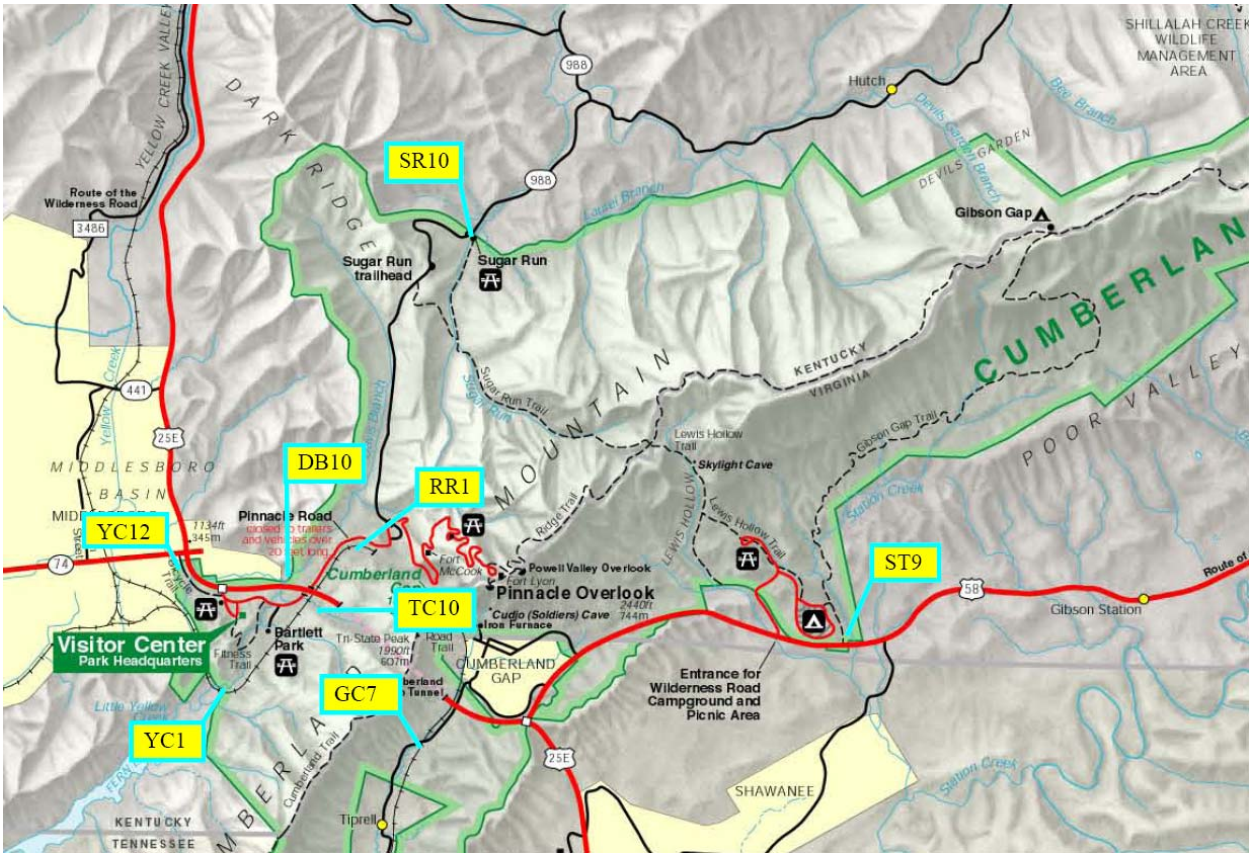


Figure 1. Map of water quality sampling sites in the eastern portion of CUGA.

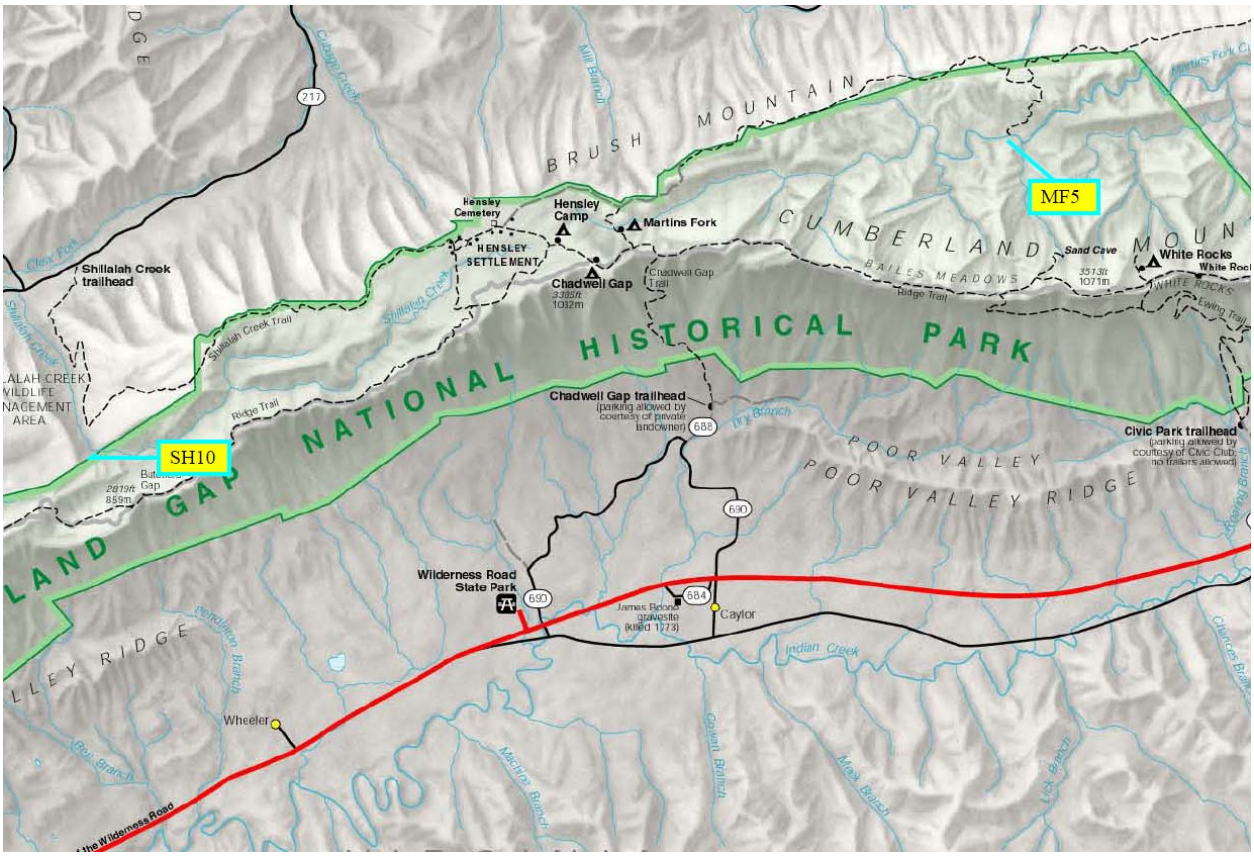


Figure 2. Map of water quality sampling sites in the western portion of CUGA.

Description of Sampling Sites

Davis Branch (DB10)

Located where Davis Branch leaves the park, immediately upstream of the city of Middlesboro Kentucky.



Figure 3. Davis Branch, looking upstream, as photographed November 20th, 2001 by Joe Meiman

Gap Creek (GC7)

Located at the railroad bridge and downstream from the town of Cumberland Gap, Tennessee and the town's waste-water treatment plant. This site is recharged by a combination of drainage from the tunnel, Giles Spring (fed by the tunnel cave), Gap (formerly Cudjo) Cave, and runoff from the town.



Figure 4. Gap Creek, looking downstream as photographed October 10th, 2006 by Joe Meiman

Martin's Fork (MF5)

Located in the remote northeastern portion of the park, this stream was added to the list of monitoring stations, but on as "when possible" basis rather than the set monthly schedule. Its remoteness (perhaps manifested in its relatively pristine condition) makes this a very difficult site to access. This site, located in Kentucky, was sampled whenever park staff had an opportunity (a total of nine visits during this study).



Figure 5. Martin's Fork as photographed December 19th, 2008 by Joe Meiman.

Rail Road Creek *(RR1)*
Located just off Pinnacle Road, this small perennial stream receives flow from the railroad tunnel as well as runoff from the restoration project area along the Wilderness Road. This stream discharges into Davis Branch.



Figure 6. Rodney Martinez monitors Rail Road Creek as photographed October 10th, 2006 by Joe Meiman

Shillalah Creek (SH10)

Primary sampling site where located as the stream exits the park and enters Kentucky Wildlife Management Area. This stream is very high gradient as it falls over large boulders as it flows down the western slope of Cumberland Mountain. It is headed at the Hensley Settlement.



Figure 7. Shillalah Creek as photographed November 20th, 2001 by Joe Meiman

Sugar Run (SRSR)

Draining park lands, this perennial stream flows along Sugar Run Trail and is adjacent to a picnic area. The main stem of Sugar Run is a dense corridor of Eastern Hemlocks and its watershed is entirely within the Commonwealth of Kentucky.



Figure 8. Rodney Martinez monitors the water quality of Sugar Run as photographed October 10th, 2006 by Joe Meiman

Station Creek (ST9)

Located as Station Creek leaves the park and passes under SR58, this stream is recharged by rural private lands and park lands, including the park campground (septic system). This is the only site located in Virginia.



Figure 9. Station Creek, looking upstream, as photographed October 10th, 2006 by Joe Meiman

Tunnel Creek (TC10)

Located along Pinnacle Road, this perennial stream, which prior to the construction of the tunnel was a seasonal stream, receives recharge from US25E leading to the tunnel as well as drainage from the Kentucky side of the tunnel.



Figure 10. Rodney Martinez monitors Tunnel Creek as photographed October 10th, 2006 by Joe Meiman

Upper Little Yellow Creek (YC1)

This site is located where Little Yellow Creek enters the present park boundary. It is just downstream from Fern Lake Dam (public drinking water supply for Middlesboro Kentucky). The majority of the watershed is forested with several abandoned strip mines (coal). Through acquisitions by the Trust for Public Lands, the park now protects 1620 hectares of the Yellow Creek watershed above Fern Lake.



Figure 11. Upper Little Yellow Creek as photographed November 20th, 2001 by Joe Meiman

Little Yellow Creek (YC12)

Downstream from the confluence of Davis Branch, this site also receives runoff from a small portion of Middlesboro as well as the park's maintenance, headquarters and Visitor Center areas. This site is where Little Yellow Creek exits the park at the intersection of US25E.



Figure 12. Little Yellow Creek, looking downstream, as photographed October 10th, 2006 by Joe Meiman

Parameters for Water Quality Inventory

Field Measures

Temperature

Measurements of water and air temperatures at the field site are essential for water-data collection. Determinations of dissolved-oxygen concentrations, conductivity, pH, rate and equilibria of chemical reactions, biological activity, and fluid properties rely on accurate temperature measurements. Accurate water- and air-temperature data are essential to document thermal alterations to the environment caused by natural phenomena and by human activities. A thermistor thermometer is an electrical device made of a solid semiconductor with a large temperature coefficient of resistivity. An electrical signal processor (meter) converts changes in resistance to a readout calibrated in temperature units. Thermistors commonly are incorporated in instruments used for surface water and groundwater measurements.

Specific Conductance

Electrical conductance is a measure of the capacity of water (or other media) to conduct an electrical current. Basically, Specific Conductance (SpC) is a quick and reliable estimation of the dissolved solids in the water. Electrical conductance of water is a function of the types and quantities of dissolved substances in water, but there is no universal linear relation between total dissolved substances and conductivity. A dip-cell electrode sensor was used.

pH

The pH of an aqueous solution is controlled by interrelated chemical reactions that produce or consume hydrogen ions. Water pH is a useful index of the status of equilibrium reactions in which water participates. The pH of water directly affects physiological functions of plants and animals, and it is, therefore, an important indicator of the health of a water system. The electrometric measurement method uses a hydrogen ion electrode.

Dissolved Oxygen (DO)

Accurate data on concentrations of dissolved oxygen (DO) in water are essential for documenting changes to the environment caused by natural phenomena and human activities. Sources of DO in water include atmospheric reaeration and photosynthetic activities of aquatic plants. Many chemical and biological reactions in groundwater and surface water depend directly or indirectly on the amount of oxygen present. Dissolved oxygen is necessary in aquatic systems for the survival and growth of many aquatic organisms. The most commonly used field method for measuring DO in water is the amperometric method, in which DO concentration is determined with a temperature-compensating instrument or meter that works with a polarographic membrane-type sensor.

Discharge

Discharge, or flow, is the anchor of all water quality data. Discharge data are used to compute the mass flux, or loading, of a particular constituent. Mass flux yields valuable insight as to the mode of contaminant entrainment and transport through the watershed.

Laboratory Measures

Acid Neutralizing Capacity (ANC)

ANC is basically a measure of buffering capacity – the ability of water to buffer the effects of acid. Waters of low ANC are more susceptible to decreased pH by acid precipitation. During the January 2005 CUPN Science Technical Committee (STC) meeting, it was determined that the Hach ANC method was not producing reliable results. A new protocol was written and in June 2005 the CUPN began using a modified version of Standard Method 403 Alkalinity test. ANC analysis was performed at the CUGA lab at conclusion of sampling round.

Bacteria

Fecal indicator bacteria are used to assess the quality of water because they are not typically disease-causing, but are correlated to the presence of several waterborne disease-causing organisms (pathogens). The concentration of indicator bacteria (the term "indicator bacteria" is used synonymously with fecal indicator bacteria in this section) is a measure of water safety for body-contact recreation or for consumption. The most widely used indicator bacteria are of the total coliform, fecal coliform, enterococci, and fecal streptococci groups, and *E. coli.* Standard Method 9222D, membrane filtration for fecal coliform was used.

During the January 2005 CUPN STC meeting, it was determined that the 922D fecal coliform method was not producing reliable results. A new protocol was written and in June 2005 the CUPN began using the IDEXX (Standard Method 9223 – Enzyme Substrate Coliform) *Escherichia coli* and total coliform bacteria test. All three bacteria are members of the coliform group and are found in the gastrointestinal track of warm-blooded animals; *E. coli* is the most common member of fecal coliform, and fecal coliform a subset of total coliform. *E. coli* analysis was performed at the CUGA lab at conclusion of sampling round.

Turbidity

Turbidity measures the scattering effect that suspended solids have on light: the higher the intensity of scattered light, the higher the turbidity. Primary contributors to turbidity include clay, silt, finely divided organic and inorganic matter, soluble colored organic compounds, plankton, and microscopic organisms. The measurement is qualitative and cannot be correlated directly as micrograms per liter of suspended solids. Measurements were made in the laboratory with a nephelometer using Standard Method 214 A. Turbidity analysis was performed at the CUGA lab at conclusion of sampling round.

Stream Designated Uses

Each water body sampled within the CUPN has either been assigned a designated use by the state, or, by using the same ranking criteria, by this author (in red). Each stream in CUGA has been designated by the states (see table below). The USEPA, besides mandating these rankings, also directed the states to develop water quality standards for each designated use. We can use these water quality standards as a minimum to track water quality trends in CUPN parks. By adapting the state standards, we can also track park water quality trends within the states, regions, or watersheds. For more information on Kentucky, Tennessee and Virginia water quality standards, please see:

Kentucky: 401 KAR 5:026. Designation of Uses of Surface Waters.
Tennessee: Rules 1200-4-3-01, Tennessee Department of Environment and Conservation.
Virginia: 9 VAC 25-260-5 at seq. Water Quality Standards.

Table 1. The table below shows the designated uses for each site.

CUGA	YC1	Little Yellow Creek, upstream	KY	Warmwater Aquatic Habitat Primary Contact Recreation Secondary Contact Recreation
CUGA	DB10	Davis Branch	KY	Warmwater Aquatic Habitat Primary Contact Recreation Secondary Contact Recreation Outstanding State Resource Water
CUGA	YC12	Little Yellow Creek, downstream	KY	Warmwater Aquatic Habitat Primary Contact Recreation Secondary Contact Recreation
CUGA	TC10	Tunnel Creek	KY	Coldwater Aquatic Habitat
CUGA	RR1	Railroad Creek	KY	Warmwater Aquatic Habitat
CUGA	SR10	Sugar Run	KY	Warmwater Aquatic Habitat Primary Contact Recreation Secondary Contact Recreation
CUGA	SH10	Shillalah Creek	KY	Coldwater Aquatic Habitat Primary Contact Recreation Secondary Contact Recreation
CUGA	GC7	Gap Creek	TN	Fish & Aquatic Life Irrigation Livestock Watering & Wildlife Trout, Recreation
CUGA	ST9	Station Creek	VA	Class vi
CUGA	MF5	Martin Fork	KY	Coldwater Aquatic Habitat Primary Contact Recreation Secondary Contact Recreation Outstanding State Resource Water

Results and Interpretation

The following graphs are a composite of 24 consecutive monthly rounds of sampling at CUGA. Data are represented in the graphs below as box-plots. Here is a key to understanding the structure of a box-plot:

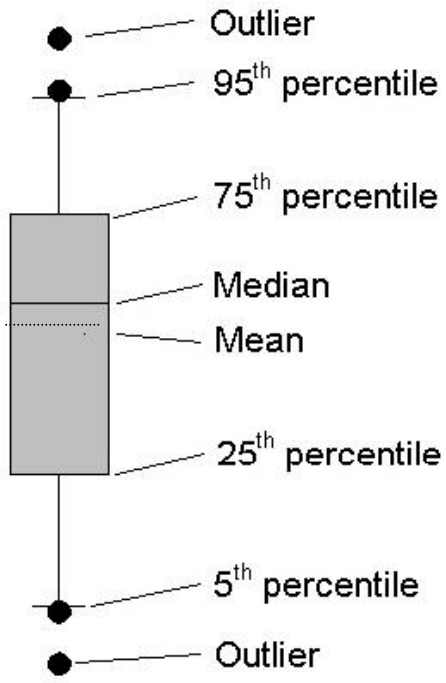


Figure 13. Structure of a box-plot

Note that there will be no outliers plotted for Martin's Fork as there are only nine data points for this site (a minimum of 10 points are required for outlier plotting).

Field Measures

Water Temperature

Water temperatures of CUGA are considered to be within range to support native aquatic life. The compressed temperature range at Tunnel Creek (TC10) is caused by the exclusive recharge of this site by groundwater drained from the tunnel. While Kentucky has designated both Martin's Fork and Shillalah Creek as "Coldwater Aquatic Habitats", there is not a specific temperature requirement, only that they will not "be increased through human activities above the natural seasonal temperatures".

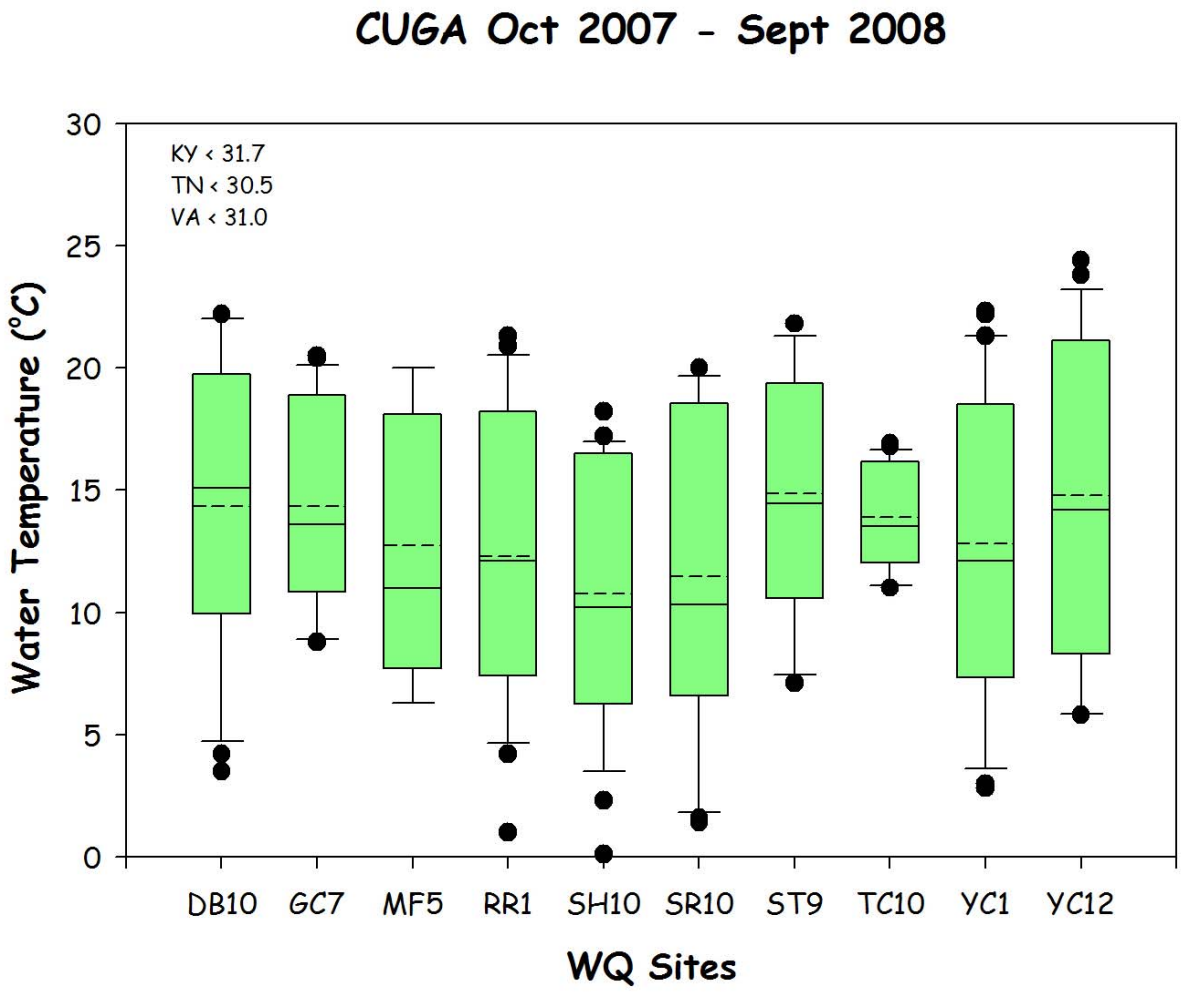


Figure 14. Water temperature at CUGA

Specific Conductance

The distribution of specific conductance (SpC) of CUGA is reflective of the amount of dissolved solids, which is primarily controlled by lithology and residence time. The tight pattern of low SpC values at Martin's Fork (MF5), Shillalah Creek (SH10), Sugar Run (DR10), and Upper Little Yellow Creek (YC1) are consistent to limited contact with carbonate strata. On the other end of the range, Gap Creek (GC7) and Station Creek (ST9) are recharged by watersheds containing ample carbonates (limestone); Lower Yellow Creek (YC12) is a mix of YC1 and Davis Branch (DB10). The range of values is due to flow condition. Following a rainfall event, waters are typically low in dissolved ions – quick flow having little interaction time with the rock. The inverse is true for low flow periods. There are no state standards for SpC.

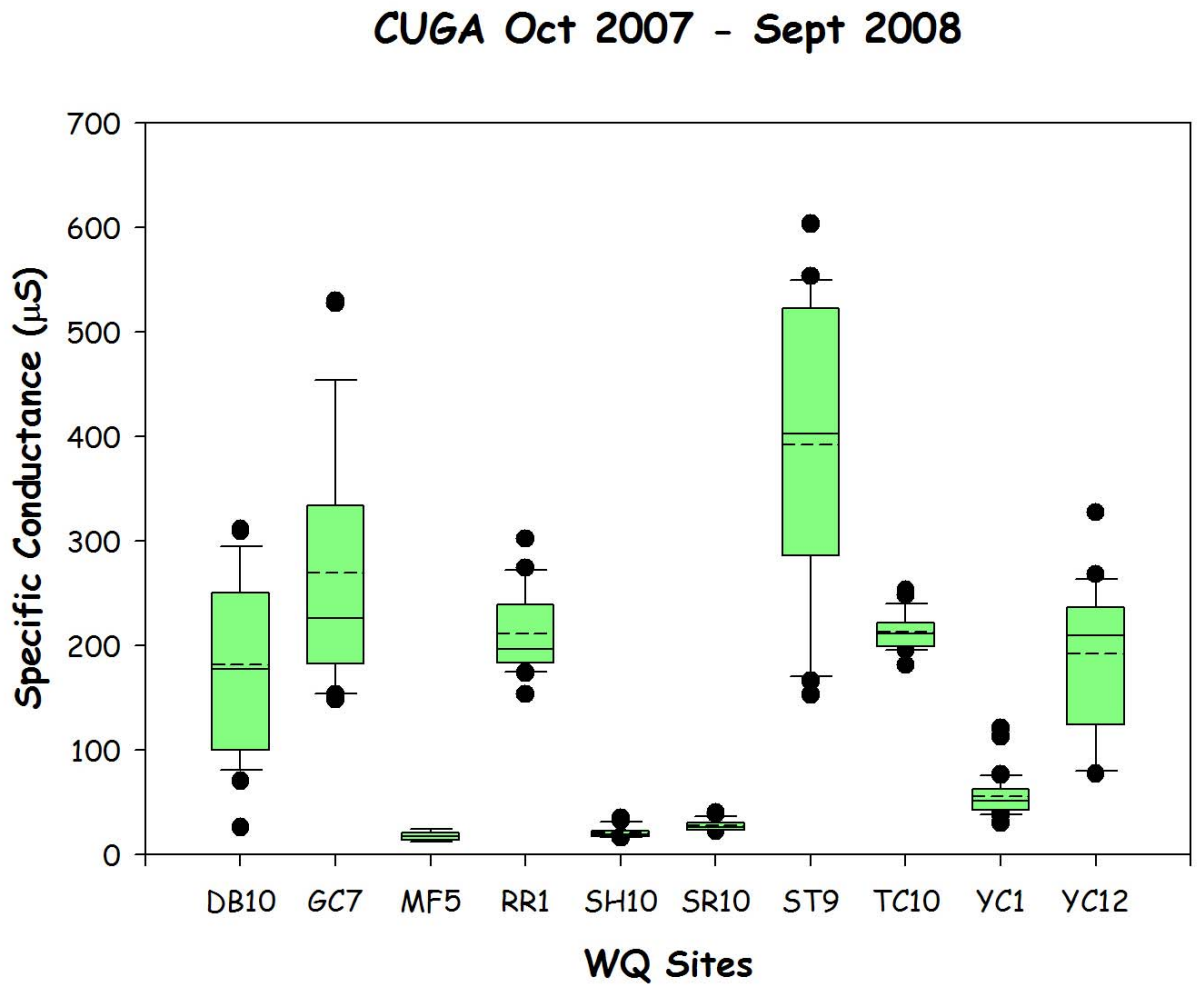


Figure 15. Specific Conductance at GUGA

pH

The pH of CUGA waters is summarized by the geology of specific watersheds: If carbonates are present, pH is buffered towards neutral to basic (7 and above); if not, pH is acidic (below 7). Rainfall is naturally acidic (about 5.6 to 5.8 SU), combined by natural humic acids (from soils and leaf decay), pH tends to remain low unless the water contacts carbonate strata. The dissolution of carbonate rock, such as limestone, liberates calcium (Ca^{+}) and bicarbonate (HCO_3^{-}) ions, the latter is an alkaline and comprises the bulk of a water's capacity to neutralize acid.

MF5 was always below, SH10 almost always below, and SR10 and YC1 sometimes below the Kentucky pH lower limit of 6.0 SU. This, however, may not constitute violations of state water quality standards. Section 10 (2) of 401 KAR 5:031 (Exceptions of Criteria for Specific Surface Waters) states: "The analysis shall show that the water quality criteria cannot be reasonably achieved either on a seasonal or year-round basis due to natural conditions…" Results of CUPN monitoring and published USGS geologic maps indicate that low pH values are to some degree natural. There are no carbonate rocks within the watersheds upstream of the Martin's Fork or Shillalah Creek sites, and very little upstream of Sugar Run and Upper Little Yellow Creek. Additional CUPN monitoring is presently making this determination.

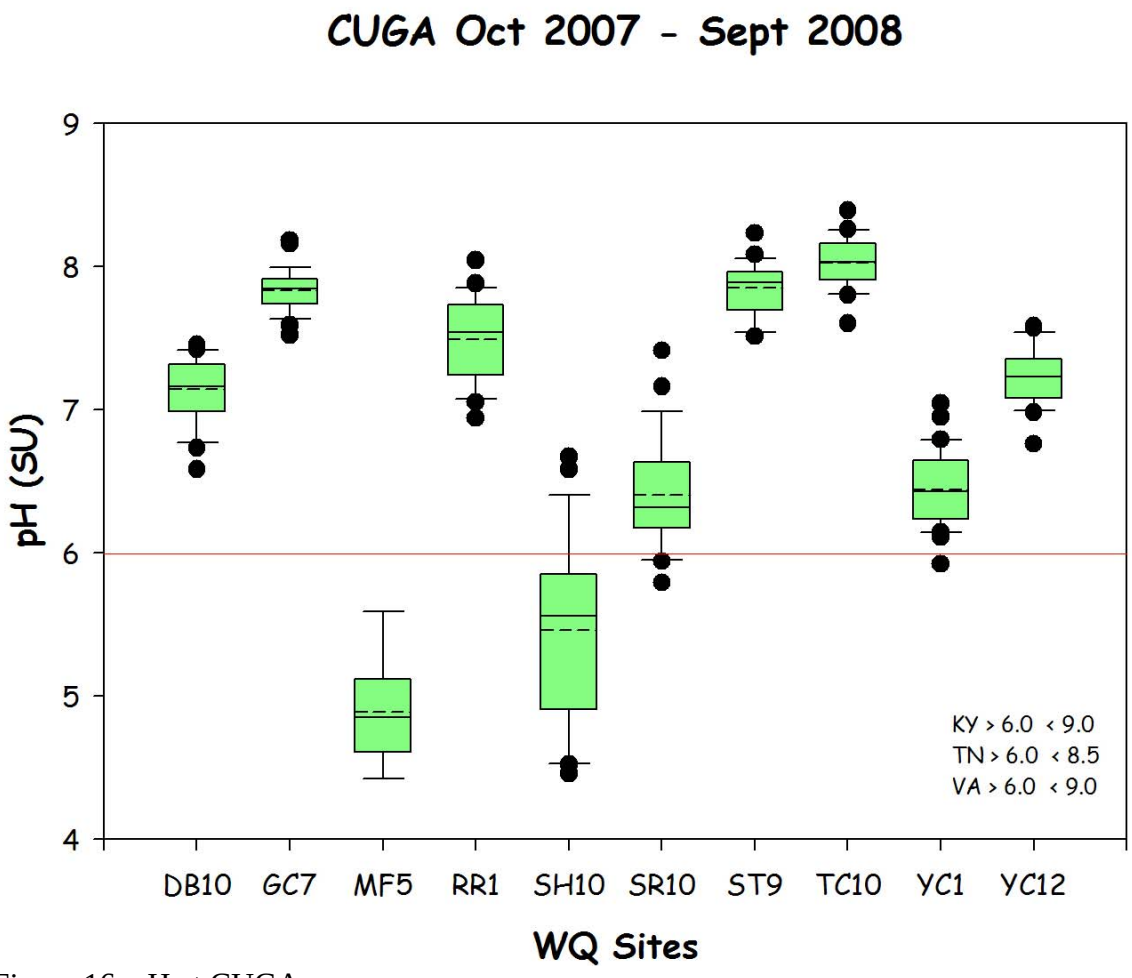


Figure 16. pH at CUGA

As mentioned above, data and geology support the claim that Martin's Fork, Shillalah Creek and Sugar Run have naturally depressed pH. This is due to a combination of facts that 1) rainwater is naturally acidic, and 2) there are no carbonate rocks within their watersheds to provide a pH buffer. Natural rain has a pH of about 5.6 SU, mainly because in the in-gassing of atmospheric carbon dioxide (CO_2) as the raindrop forms and falls, producing carbonic acid (H_2CO_3). The addition of sulfur and nitrogen oxides (mainly from emissions of coal combustion and vehicles) form sulfuric (H_2SO_4) and nitric (HNO_3) acids in the atmosphere and are brought to earth in rainfall. The nearest National Atmospheric Deposition (NADP) program site is located in Speedwell, Tennessee – some 35 km from the Hensley Settlement, the common watershed boundary between Shillalah Creek and Martin's Fork. Weekly pH readings at Speedwell (July 1999 – February 2008) show an average of 4.56 SU, maximum of 6.48 SU and a minimum of 3.74 SU. On only four occasions was the pH of rainfall collected at this NADP site above what is generally considered natural rainwater pH of 5.6 SU.

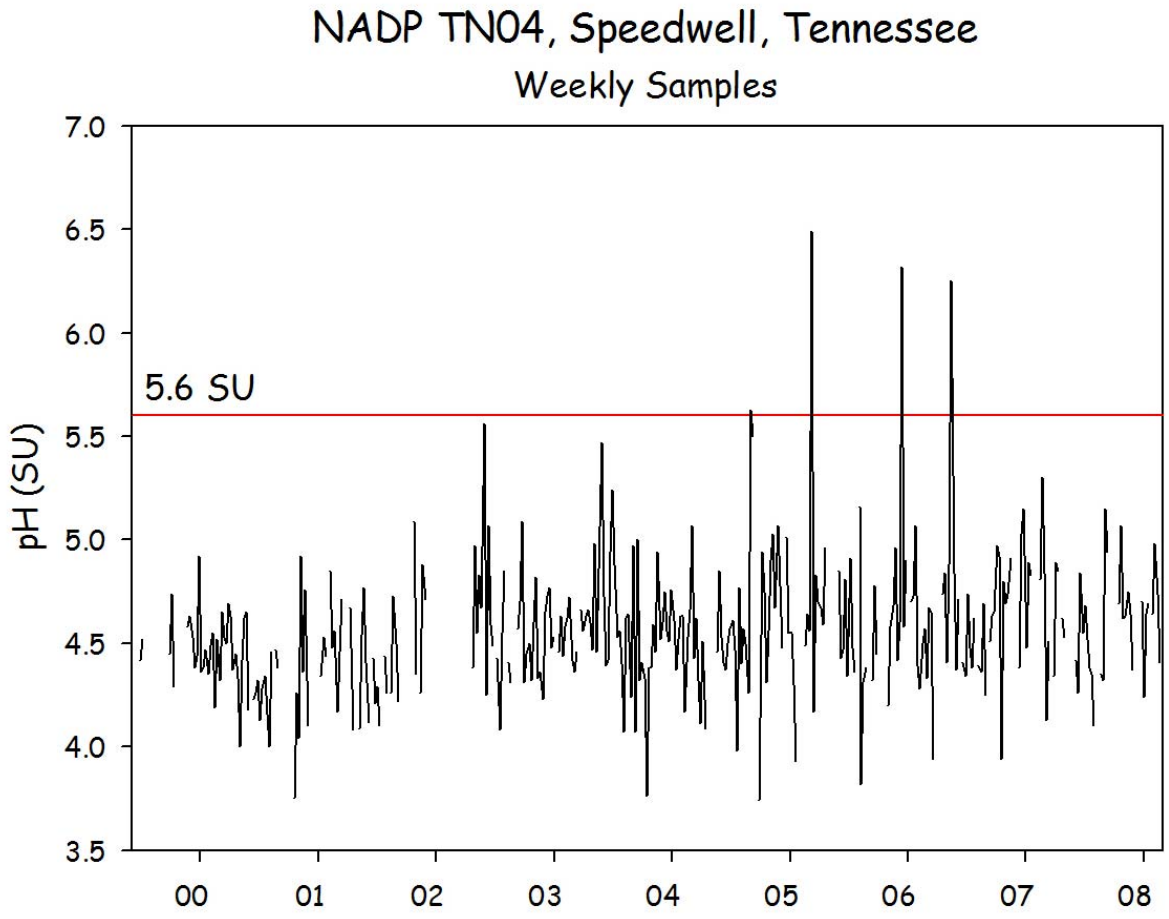


Figure 17. pH at NADP site in Speedwell Tennessee.

All flow in the mountain streams (Shillalah Creek, Martin's Fork and Sugar Run) originate from rainwater. Some rainwater, during and immediately following a precipitation event, runs off into the streams as "quick-flow". Quick-flow has almost no residence time – that is contact with the soils and strata. Some precipitation soaks into the soils and fluvial deposits adjacent to the streams as "bank-storage" and gradually seeps into the streams. Bank-stores may be retained in these near-surface environments for several weeks or months. A portion of the rainwater eventually enters the fractures and bedding planes of the bed rock and becomes groundwater. Groundwater may be months, years, or even decades old. The longer water is retained, the longer it is in contact with rock and soil, the more opportunity it has to dissolve these materials.

If one were to examine a general hydrograph beginning with a rainfall event and ending with a drought, the proportion of flow from each of these three provinces would vary in the extreme. During and immediately after the rains, quick-flow may comprise 90% of the flow, 9% from bank-stores and perhaps 1% (if that much) from groundwater. A week after the rain, there would be 0% quick-flow, 95% bank-stores, and maybe 5% groundwater. Months after the rain, even the bank-stores will dry as eventually 100% of the stream flow is from long-residing groundwater. It is groundwater, slowing dissolving components of the bedrock during its long storage, which sustains flow during droughts. One such component is bicarbonate, even it minute quantities in the bedrock, is dissolved and buffers the groundwater that is slowly released into the streams.

This relationship can be seen in Figure 18 as pH is plotted against flow at Shillalah Creek. During times of high flow (sampled during or immediately after a rainfall event), stream pH is at its lowest. As flow decreases, and recharge is generated from bank-stores and groundwater, pH increases. Finally, at very low flows, where 100% of the flow is from groundwater, pH is at its highest.

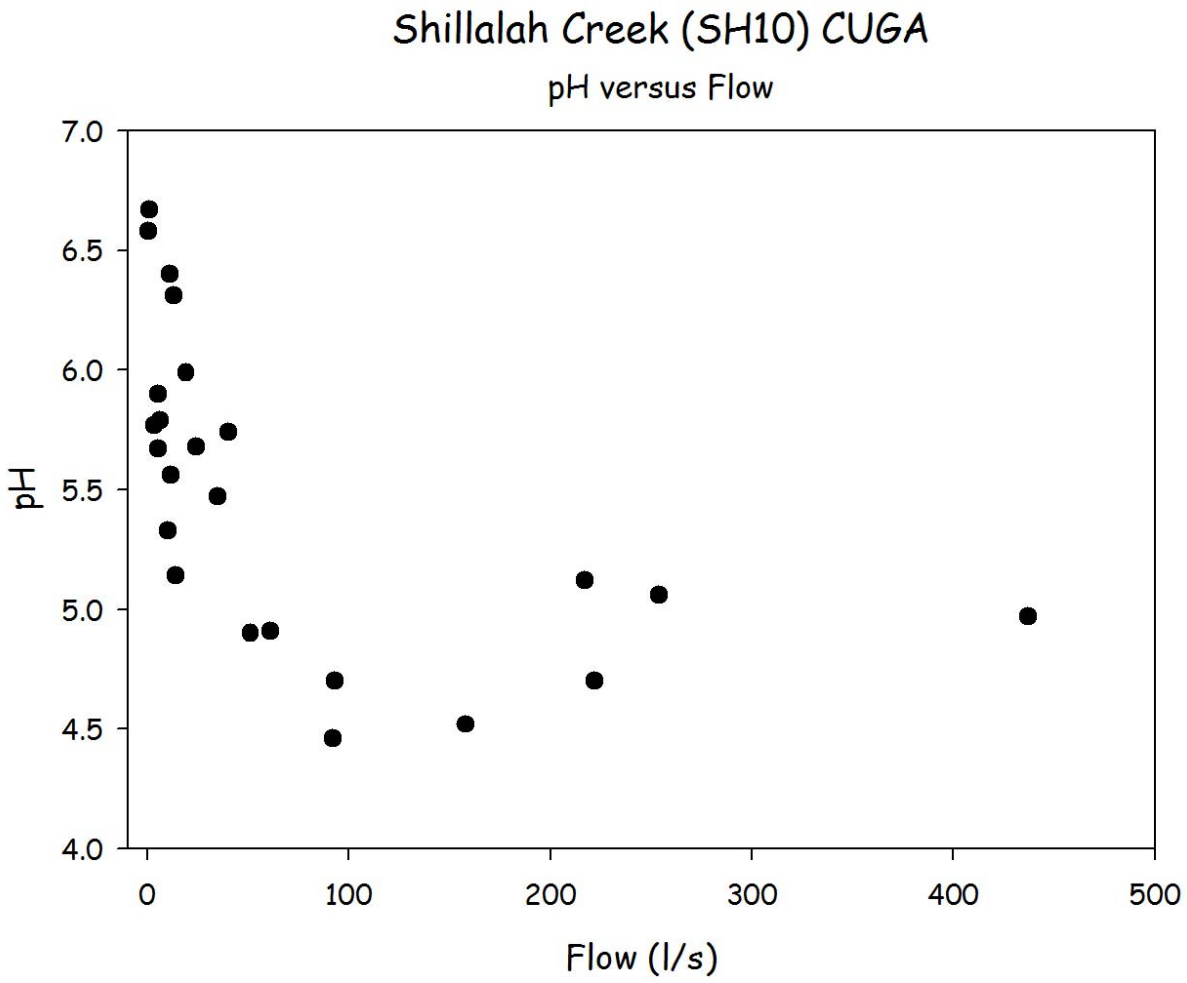


Figure 18. pH versus flow at Shillalah Creek.

While routine monthly grab samples lay the foundation for long-term water quality monitoring, much can be gained from continuous recording and the resulting time-series data set. During the drought of late summer through autumn for 2007 and late autumn of 2008 continuous-recording datasondes were placed in Shillalah Creek, Sugar Run and Martin's Fork. Although these data will be used as part of our long-term monitoring, they are important to understanding a stream's response to rainfall events.

pH and SpC data shown in Figure 19 were collected every 15 minutes at Martin's Fork (MF5) during November and December 2008. The large gap in early December was caused by the datasonde being washed up on the bank during a large rain event. Data collection resumed during a subsequent rainfall when the stream rose to meet the sensors. Rainfall data are hourly totals from the nearest meteorological station, at the CUGA Visitor Center, some 23 km from the MF5 site. While rainfall and stream response do not match for all events due to precipitation variances between the sites, what is obvious is a decrease of pH and an increase of SpC following every dose of rainfall. pH at the beginning of the record, while the stream was at base flow (it had not rained in over one month) was at 5.4 SU, it ended one month later at 4.4 SU. As

the pH scale is logarithmic, this is decrease of ten fold with respect to hydrogen ion concentration. Each rainfall event lowered the pH a bit more. The frequency of rainfall events keeps pH depressed – this is common throughout the winter and spring months as the asymptotic recovery of pH is interrupted by rainfall events. As the stream has no buffering capacity, stream pH eventually approximates the rain. Recall the average pH at the NADP site in Speedwell (July 1999-February 2008) was 4.56 SU.

SpC is plotted to further indicate the arrival of a precipitation event. Its response is opposite to pH, in that the quick-flow component has a higher dissolved load than bank-stores. The average SpC of rain at the Speedwell site was 21.8 μS. Examination of additional time-series data may explain this phenomenon.

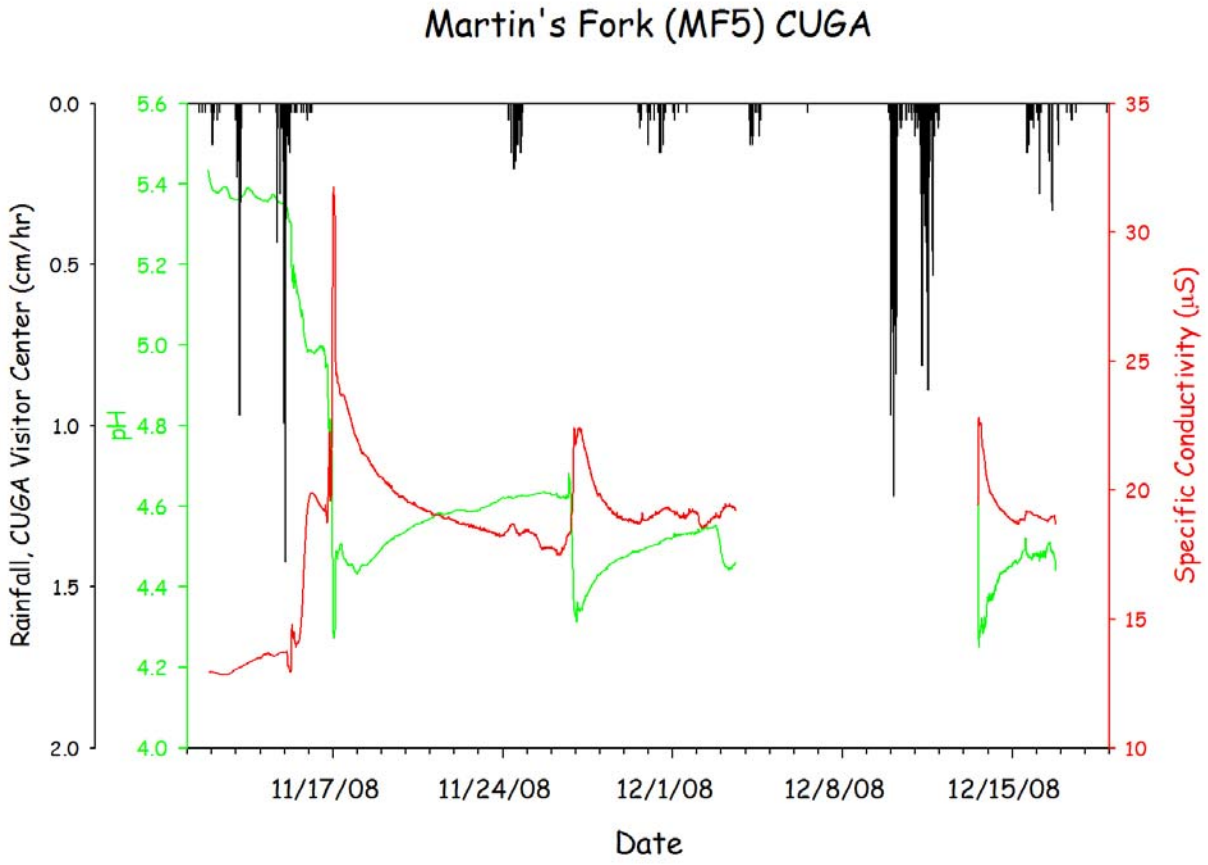


Figure 19. pH and SpC response to rainfall at Martin's Fork,

Dissolved Oxygen

All Tennessee and Virginia waters met state dissolved oxygen (DO) standards of 5.0 and 4.0 mg/l, respectively. There were two occasions (September 11, 2007 and June 10, 2008) where the DO levels at Upper Little Yellow Creek (YC1) dropped below the Kentucky warm water standard of 4.0 mg/l, and one occasion (September 26, 2007) where Martin's Fork dropped below the cold water standard of 5.0 mg/l. These sampling events were coincident with very low flows (little aeration) and at times of higher temperature – warm water holds less dissolved gases, including oxygen, than cold water. A combination of low flow and high temperature was the likely cause of depressed DO levels. At this time there is no reason to believe that CUGA has a DO problem, as these rare events coincide with exceptionally low flow conditions.

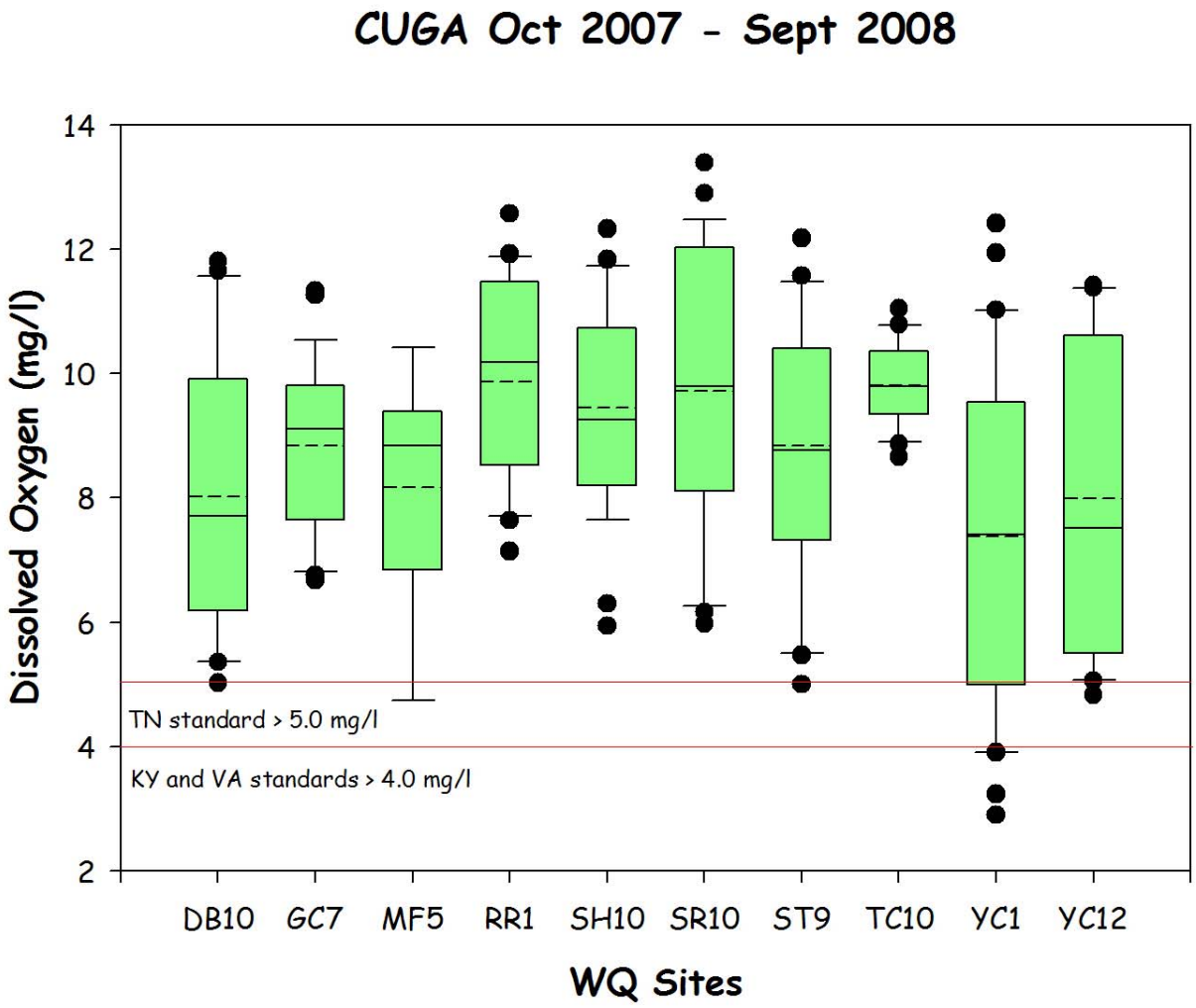


Figure 20. Dissolved Oxygen at CUGA

Discharge

Discharge, or flow, helps put all water quality into context. As will be presented later in the bacteria discussion, discharge relative to parametric concentration can greatly assist interpretation of results. All sites, with the exception of TC10, are centered low with high outliers, as most sampling rounds were during low flow, with the occasional high-flow event. Tunnel Creek's flow is nearly exclusively groundwater and is far less variable.

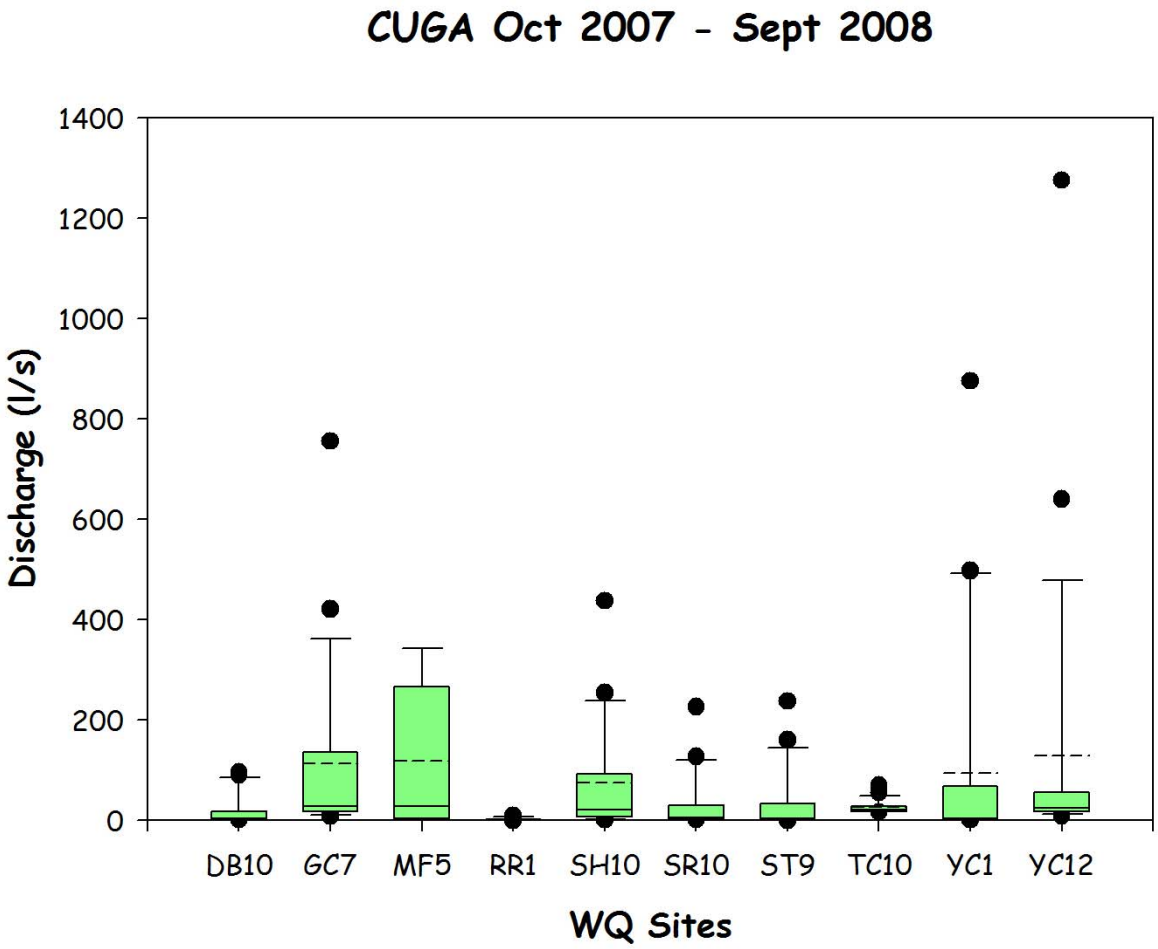


Figure 21. Discharge at CUGA

Laboratory Measures

Acid Neutralizing Capacity

The program focused Acid Neutralizing Capacity (ANC) only upon those streams that had low pH values (streams with high pH have high ANC and are of little monitoring interest). ANC is the measure of the stream's ability to cope with, or neutralize, acid. In the pH ranges of CUGA waters, the specie driving ANC is the bicarbonate anion. The more bicarbonate, the higher the ANC, thus the lower the pH. The ANC graph is reminiscent of the pH graph. There are no carbonate rocks upstream of MF5 and SH10. Current CUPN monitoring is suggesting that the only times that ANC ranges above 1-2 mg/l at SH10 are times of drought where 100% of the flow is bedrock-derived, where tiny amounts of bicarbonates are discharged with groundwater.

One of the main values of monitoring ANC is that it gives insight into related water quality issues. Kentucky has a provision that a water is not considered in violation if it comes by it naturally. ANC results show that there are little or no bicarbonates to buffer pH at MF5, SH10, and perhaps SR10. Secondly, as this well may be a natural condition, results help explain the presence or absence of aquatic species.

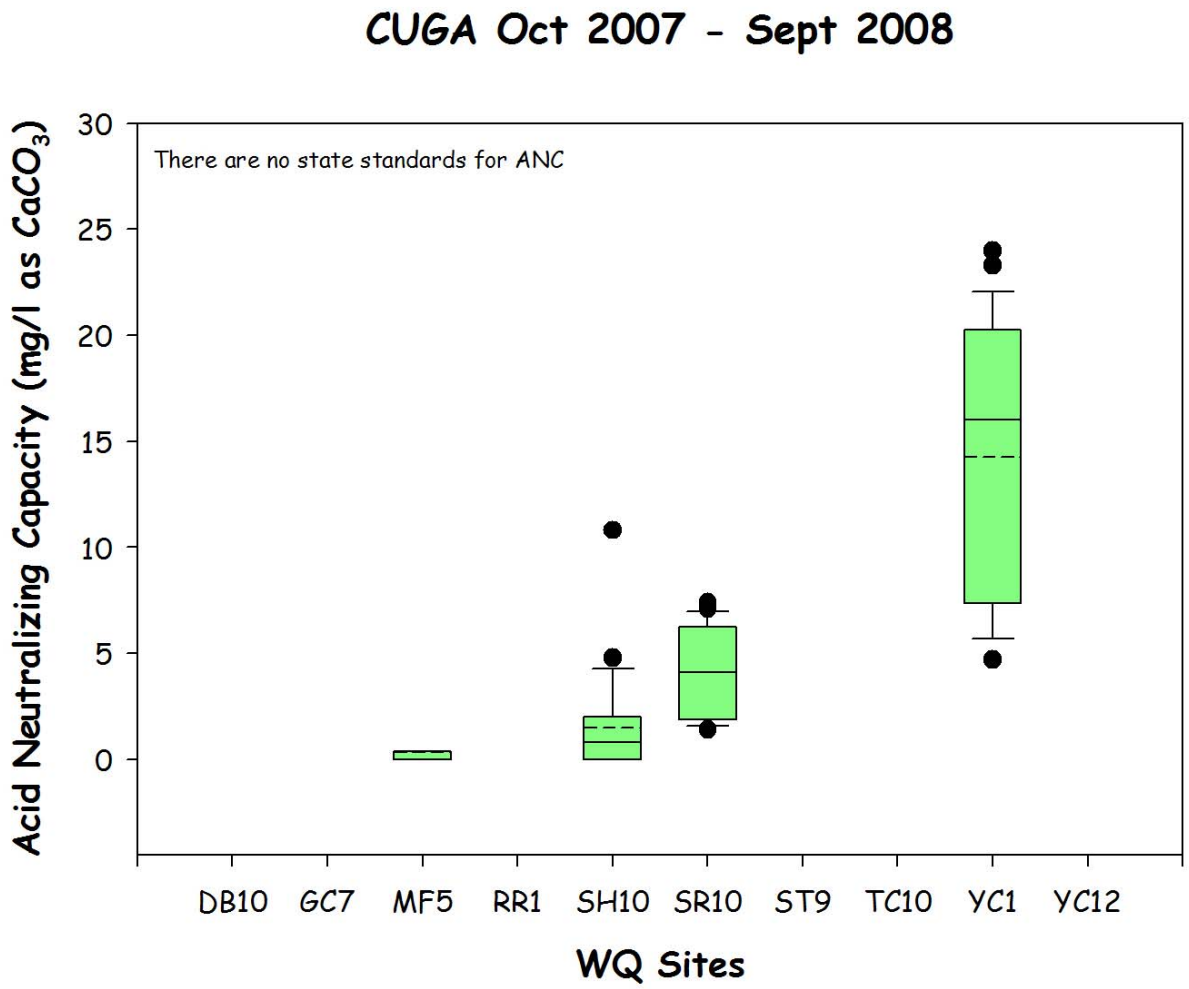


Figure 22. Acid Neutralizing Capacity at CUGA

Escherichia coli

Escherichia coli (*E. coli*) is a naturally-occurring bacteria found in intestines and feces of warm-blooded animals. While not generally a human pathogen (a substance that causes harm to people), some strains of *E. coli*, 0157:H7 for example, have been linked to illness in contaminated foods. As *E. coli* are associated with pathogens, they are considered an indicator species, and thus used for a measure of water quality.

E. coli bacteria enters a stream by point source (direct injection at specific points), and non-point source (run-off over a broad area). Point sources include failing septic systems and inadequate waste water treatment facilities. Non-point sources include surface run-off from livestock pastures and wildlife habitat.

While each method of entrainment produces the same result – bacterial contamination of a waterbody – both point and non-point sources have distinct relationships to rainfall events and resultant stream flow condition. Non-point sources are washed from a broad area into a stream during a rainfall event. Point sources enter a stream at a constant rate, regardless of rainfall.

A point source contaminant concentration diminishes at times of high flow as it is diluted. Conversely, at times of low flow it is concentrated. The exact opposite can be expected for a non-point source contaminant; at times of low stream flow, its concentration would be very low as a rainfall event is needed to wash it from the land. At times of high flow (the result of rainfall events) non-point source contamination is high as the land surface is washed of contaminants in the form of run-off.

With the exception of MF5 (which may be simply an artifact of a smaller sample size), every water monitored at CUGA exceeded state WQ standards for *Escherichia coli*. This should not necessarily alarm the resource manager as high levels are associated with rainfall events, thus a non-point source is the likely contributor. Consider the pristine watershed of Shillalah Creek or Sugar Run. While devoid of development, there are times, immediately after rainfall, where the USEPA single sample limit of 476 Colony Forming Units (CFU)/100ml is exceeded. This is a natural condition. A bear, like many animals, does indeed defecate in the woods. It is likely that the occasionally elevated levels in Davis Branch (DB10) are due to the high beaver activity immediately upstream of the sampling site. It also appears that there is no impact of the facilities at the Sugar Run picnic area to the adjacent stream.

What may be of use to park management are the bacteria levels found at Station Creek (ST9) and Gap Creek (GC7). These sites commonly exceeded state standards – mean values of Gap Creek topped the Tennessee limit for National Park waters of 487 CFU/100ml, while the Virginia single sample standard of 1173 CFU/100 ml was exceeded over 25% of the time in Station Creek. These two sites exhibit point and non-point source contamination signatures to be further explored in the following figures.

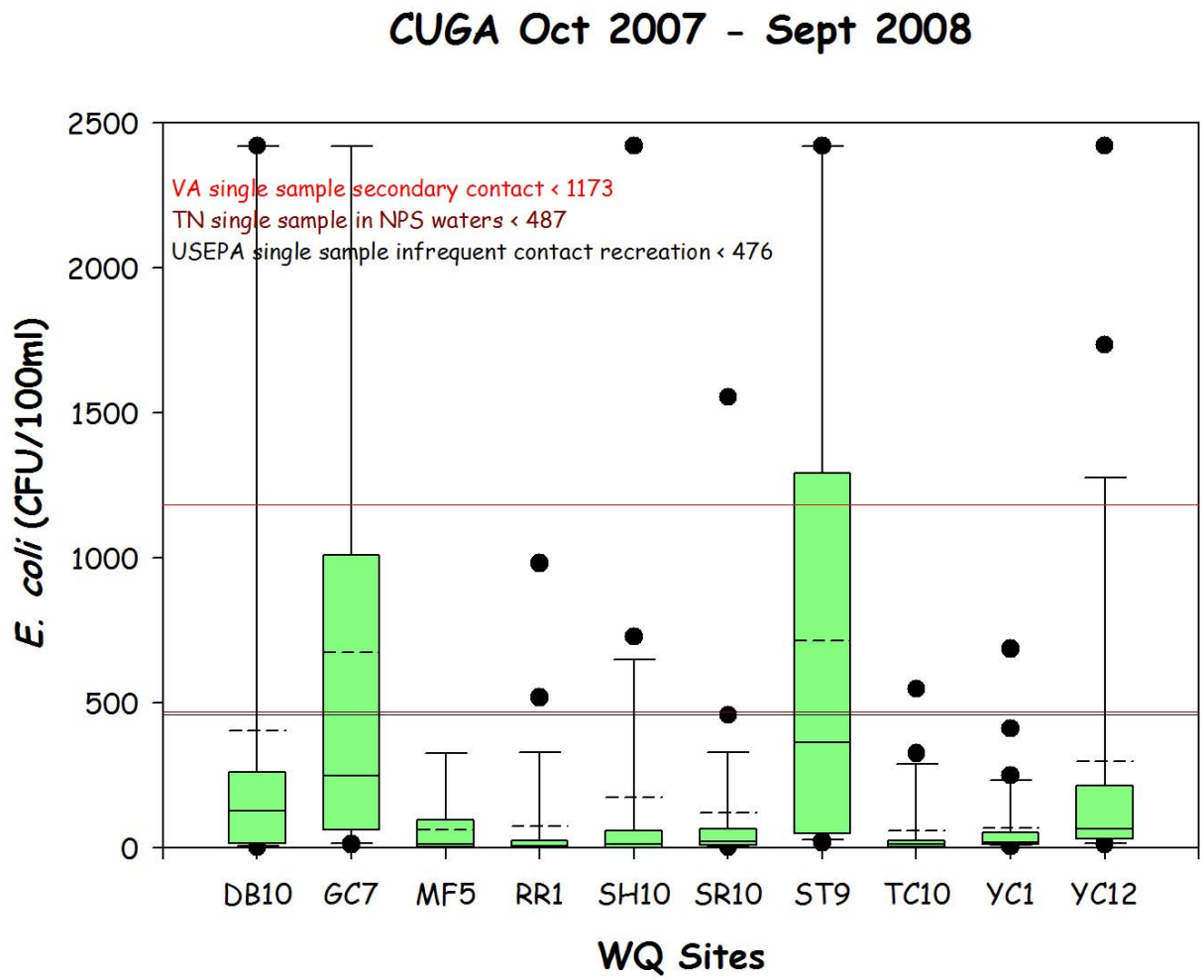


Figure 23. *E. coli* at CUGA

Station Creek displays a point-source contamination signature. There is no correlation between rainfall events and high bacterial loads, rather *E. coli* levels are the highest when flow is the lowest – rising in late spring, peaking through the summer and trailing off in the autumn. Higher flow periods in the winter months are coincident with low *E. coli*. There are two possible sources: either animals defecating directly into the stream (as seen where livestock is given access) or failing/overwhelmed septic fields. The park has begun to take additional samples to isolate the source.

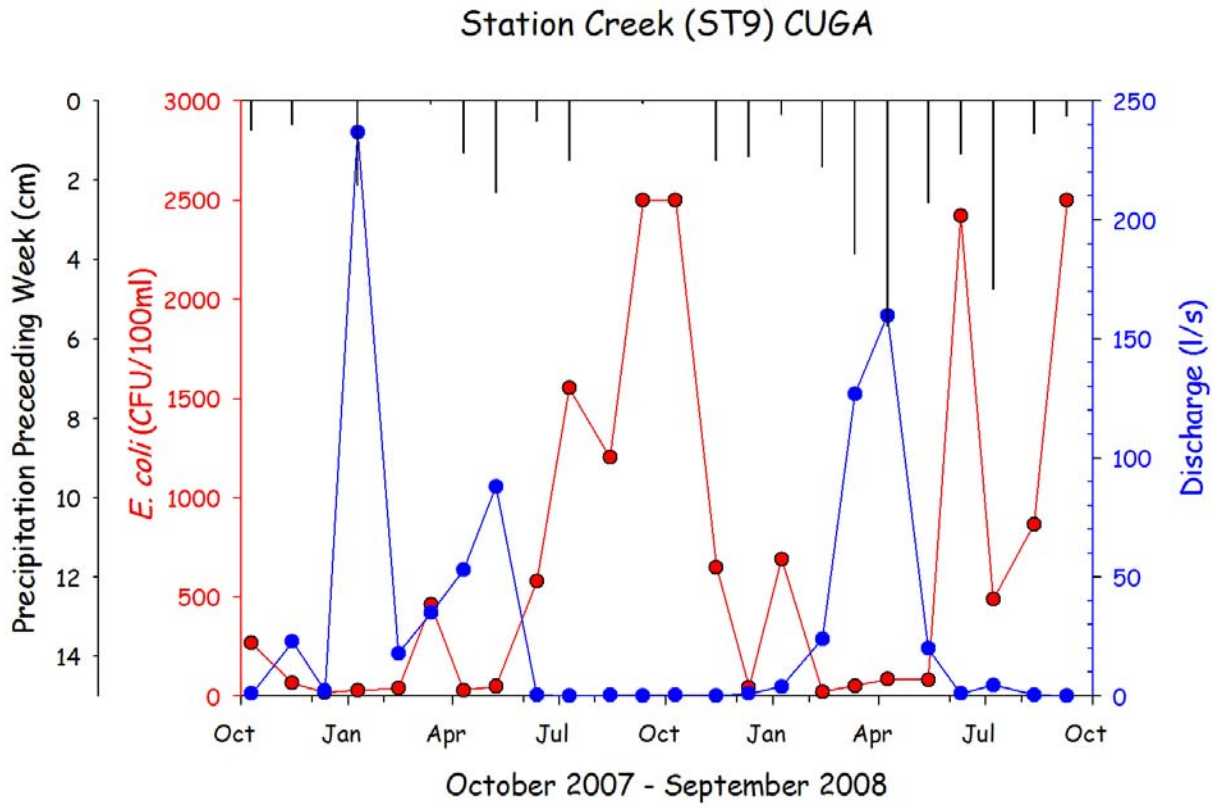


Figure 24. *E. coli* at Station Creek

E. coli data at Gap Creek (GC7) show both point and non-point source contamination. Several times, January 2007, May and July 2008, bacteria counts were above quantification limits of the test (>2419 CFU/100ml). The exceedences of the later two dates may have been compounded by construction at the Cumberland Gap wastewater treatment plant. This facility, which was found to be discharging untreated effluent into Gap Creek by Park Ranger Justin Cully, has had a history of poor operation. Rodney Martinez brought the situation to the attention of the Tennessee Water Commission and was told of planned improvements, which occurred during the late spring and summer of 2008.

While there was no rainfall the week prior to the September 9, October 9, and November 11, 2007 rounds, it is likely that non-point sources are the main contributors as these events took place during or immediately following rains the day of sampling. It should be noted that not every high flow is met with high bacteria, as this relationship is dependent also upon the distribution, intensity, and timing of rainfall events prior to sampling, which are not necessarily represented in the course scale of the graph.

It is also quite possible that during high flow times, which are coincidental with high infiltration rates of gravity-collection sewers, that the capacity of the Cumberland Gap waste-water treatment works is exceeded. A simple sampling effort taking samples above and below the facility would effectively partition the creek and determine the source. A series of samples should be taken above and below the facility, and during low and high flows.

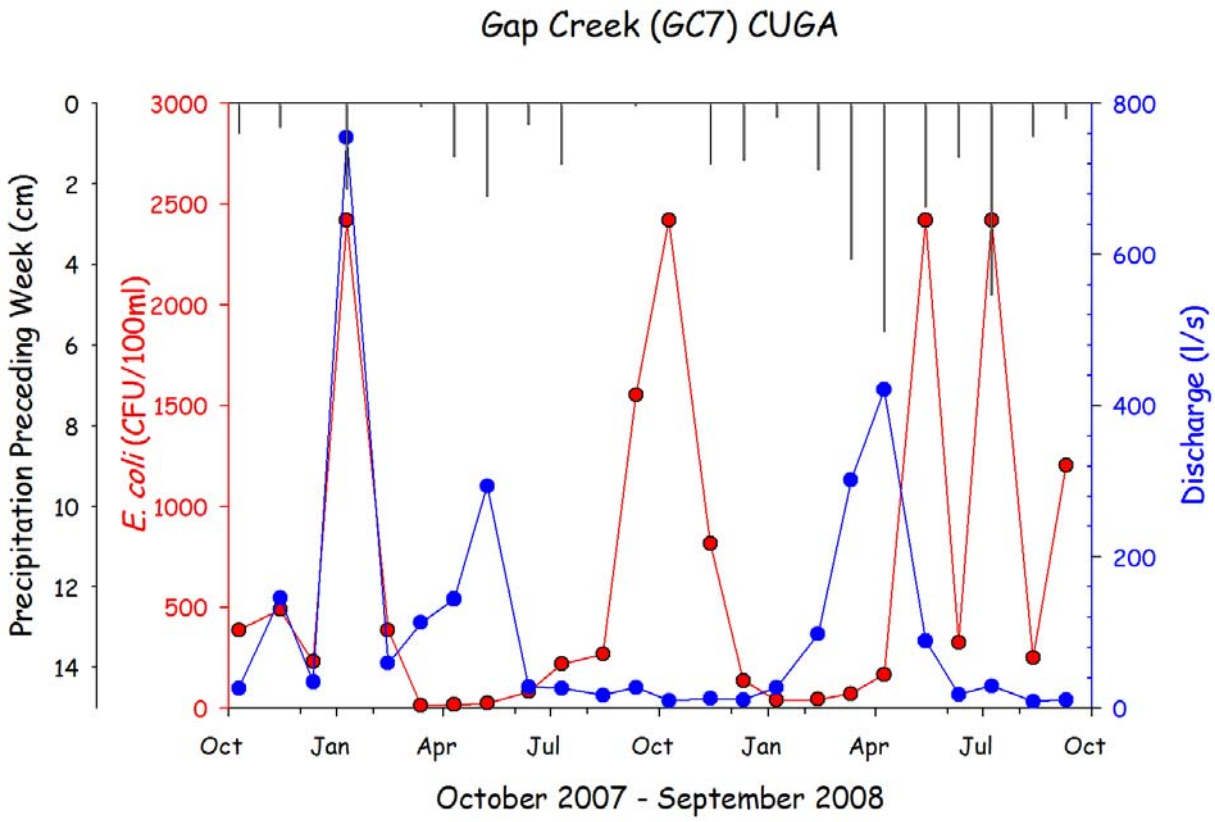


Figure 25. *E. coli* at Gap Creek

Turbidity

Turbidity is a general measure, or approximation of the amount of suspended material in the water. It is not directly correlative to suspended solids as particle size, shape and color all play a role in the transmission of light through the water column. In general, the higher turbidity values are associated with muddy or turbid waters. In general, waters of CUGA were clear to slightly turbid. This range is due to sample collection in respect to rainfall events –high turbidity associated with high flow. Turbidities 50 NTU (Nephelometric Turbidity Units) above background are considered violation of state standards. There are three outliers at RR1, YC1, and YC12. A possible cause for the former two is sediments being disturbed in sample collection, while the later was localized near the Middlesboro Kentucky Fried Chicken which is adjacent and just upstream of YC12.

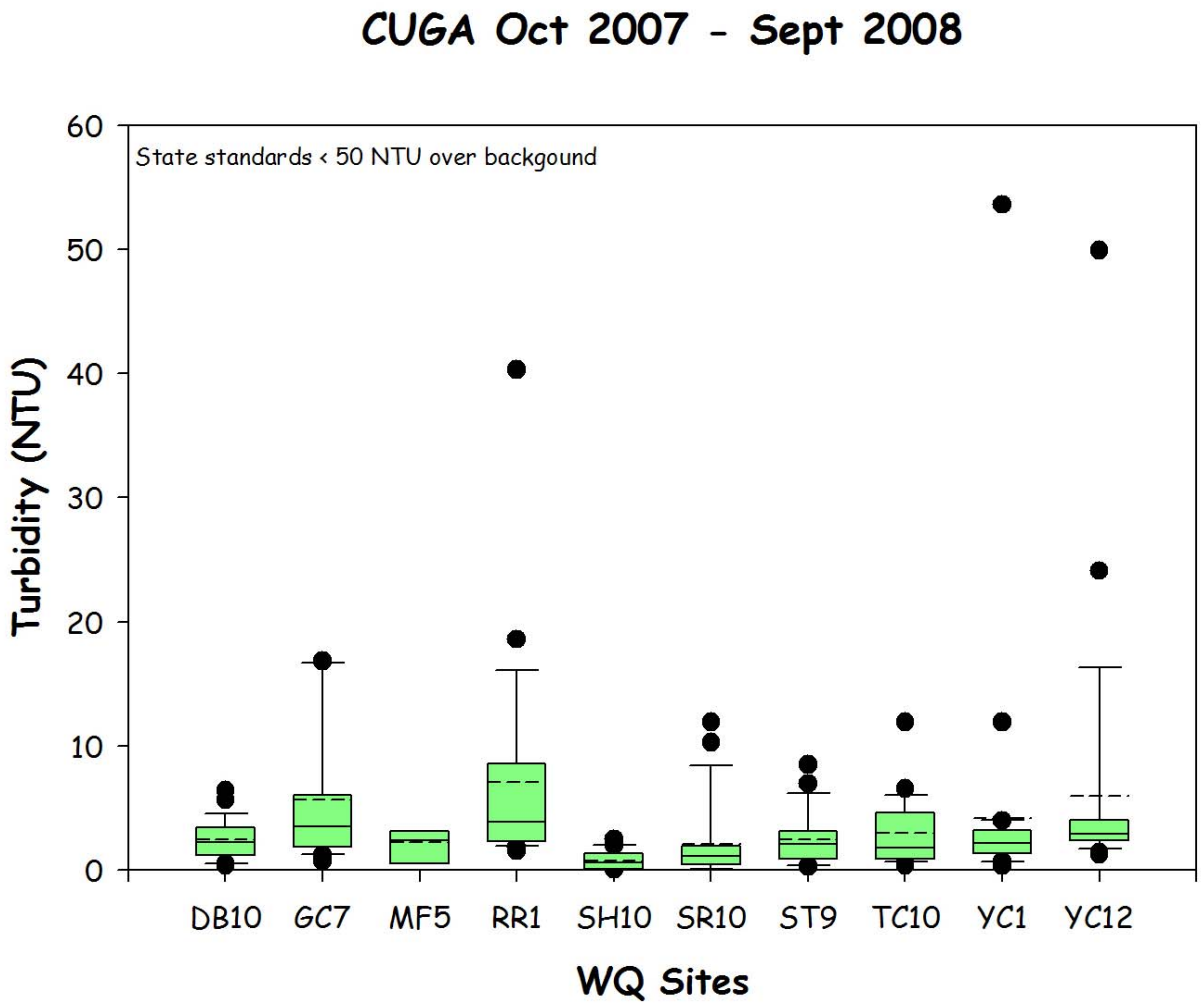


Figure 26. Turbidity at CUGA

General Water Quality Status

Water quality of the eight sites sampled at CUGA is good. The only exceptions would be the low pH of Martins Fork, Shillalah Creek, and Sugar run, and high *Escherichia coli* of Station Creek and Gap Creek.

The causative agent of low pH is currently being investigated by the CUPN. During the autumns and early winters of 2007 and 2008 continuous-recording datasondes were deployed to examine the response to drought conditions and subsequent recoveries. This information, combined with data discussed in this report will give insight to how the streams would react to the addition of acids – namely acid rain. Waters of the park, with exception of those draining areas containing carbonate strata, are naturally low in pH and ANC. While pH values exceed the state pH standard, they should not be considered non-attainment to their designated uses, as they are naturally acidic. This claim is supported by ANC concentrations.

The high bacteria found in Station and Gap Creeks both warrant additional, concise monitoring. It is possible that *E. coli* levels in Station Creek are due to a failing or overwhelmed septic system at the park's campground. Additional samples taken above and below the campground, during high and low flow should determine the source. Approximately 20 sample events would be needed. Gap Creek should also be similarly sampled and partitioned above and below the town of Cumberland Gap's wastewater treatment facility.

Future Water Quality Monitoring Recommendations

The CUPN is required in accord with the national water quality program to monitor water temperature, specific conductance, pH, and dissolved oxygen. In addition, there is sufficient reason to continue to monitor ANC, *Escherichia coli* and turbidity, as long-term data may serve to alert the park to impending water quality issues.

Water quality sampling will be conducted to produce the highest-quality long term record, a rotation of two years of intense monthly non-conditional synoptic sampling (as done with the data presented), followed by five off years. While CUPN water quality monitoring will begin again at CUGA in October 2013, the Park can continue to rely on the CUPN for logistic support for its extant program and general council on water resource issues.

Long-Term Monitoring will include:

Water Temperature
Specific Conductivity
pH
Dissolved Oxygen
Acid Neutralizing Capacity
Escherichia coli
Turbidity

List of Abbreviations

Table 2. Abbreviations used in this document

ANC	Acid Neutralizing Capacity
$CaCO_3$	Calcium carbonate
CUGA	Cumberland Gap National Historical Park
CUPN	Cumberland Piedmont Network
DO	Dissolved Oxygen
km	kilometer
l/s	liters per second
mg/l	milligrams per liter
µS	micro Siemens
NADP	National Atmospheric Deposition Program
NPS	National Park Service
NTU	Nephelometric Turbidity Unit
SpC	Specific Conductance
SU	Standard Unit (pH)
USEPA	United States Environmental Protection Agency
USGS	United States Geological Survey

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NPS D-005, January 2009



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