



Real-time Monitoring to Support Environmental Impact Management Strategies for Road Construction Activities on Foothills Parkway: Wears Valley

Natural Resource Data Series NPS/XXXX/NRDS—201X/XXXX





ON THIS PAGE

Dunn Hollow Watershed.

ON THE COVER

Aerial Photo of Foothills Parkway Construction, Wears Valley Tennessee

Photo Credit: Great Smoky Mountains National Park Service

Real-time Monitoring to Support Environmental Impact Management Strategies for Road Construction Activities on Foothills Parkway: Wears Valley

Natural Resource Data Series NPS/XXXX/NRDS—201X/XXXX

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Executive Summary

The need to monitor surface water quality has been increasingly recognized in recent years in environmental and natural resource management. The advent of real-time remote monitoring technologies has accelerated and enhanced this process. Field observations of water quality data are able to be conducted and analyzed in ways that were previously unavailable.

The objectives of this project were to deploy a real-time remote monitoring system for three small watersheds (Hembree, Dunn, and Rudd Hollows) in the Great Smoky Mountains. The watersheds ranged in size from 12 to 19 ha. The monitoring stations were established in forested watersheds downstream from construction of the Foothills Parkway in East Tennessee. Sondes measured and recorded water quality data during the course of a seven-year period for turbidity, pH, conductivity, and temperature. Water quality data were analyzed to assess impacts of highway construction on first-order streams within these watersheds.

For periods of no construction within the watersheds, mean turbidity ranged from 62.9 to 189 NTU. Mean pH ranged from 6.35 to 7.24, while mean conductivity ranged from 0.053 to 0.163 mS/cm. Mean temperature ranged from 13.2 to 13.9 °C. For periods of construction, mean turbidity ranged from 26.7 to 64.0 NTU. Mean pH ranged from 6.29 to 7.17, while mean conductivity ranged from 0.064 to 0.147 mS/cm. Mean temperature ranged from 13.0 to 15.3°C.

Based on review of the data collected within all three watersheds and the routine monthly inspections of the streams, National Park Service construction activities located at the top of each watershed, did not have any offsite impacts as determined by the monitoring stations located on the private landowners property. Any fluctuations were due impart to the characteristics of the watershed itself and the internal disturbances.

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Introduction

Water quality has increasingly become an area of concern over the past several decades. Mountain streams are no exception to this, especially in the Great Smoky Mountains of East Tennessee.

Unique species of trout thrive in Southern Appalachian streams, and certain sensitive plant species flourish in this region. The area is rich in wildlife diversity and rugged mountain terrain. Although the Smokies are home to pristine natural environments, the area has experienced excessive land development and urban growth. Because of sensitive ecosystems in the Smokies, increase in urban growth and development, and importance of maintaining healthy water quality, the National Park Service (NPS) initiated a program to monitor water quality in remote streams near construction on the Foothills Parkway.

The Foothills Parkway (FHP) is a scenic highway in east Tennessee, just north of Great Smoky Mountains National Park (GRSM). It is owned and maintained by the National Park Service (NPS) and has been under construction for several decades. Construction of the Parkway has been sporadic since its authorization by Congress in 1944, only certain sections of highway are complete. The area of interest for this study was the “missing link” section, a 1.65-mile gap between Townsend and Wears Valley, Tennessee. Due to bridge construction upstream from private property, NPS monitored water quality in sites downstream of construction from May 2010 through March 2017. NPS was concerned with stream water quality that could be affected by stormwater runoff coming from construction sites, especially since runoff has potential to adversely affect nearby streams located on private property.

Real-time water quality monitoring of FHP was conducted by Clemson University. Remote monitoring stations were set up in three watersheds downstream of highway construction. Stream water quality was monitored using sondes, which transferred raw data to dataloggers. Rainfall data were collected using rain gauges connected to the dataloggers. Dataloggers were connected to cellular modems, which sent data via Internet connections to Clemson University. Remote stations collected data on pH, conductivity, temperature, and turbidity in order to monitor water quality near Foothills Parkway construction.

Collected field data were used to compare conditions before construction to those during construction. Background streamflow data were needed to determine hydrologic interactions within watersheds without interference from external disturbances, namely, FHP construction. Two of the watersheds contained road cuts created by landowners prior to highway construction; therefore, it was necessary to distinguish between affects caused by these pre-existing conditions and those potentially brought on by FHP construction activities. The other watershed had no prior disturbances. The objectives of this monitoring program were to:

- Deploy and maintain a remote data acquisition system for stream flow monitoring.
- Obtain background data for watersheds with no NPS construction occurring.
- Compare watershed streamflow water quality for periods of no FHP construction versus the same watersheds during construction.

Real-time Water Quality Monitoring

Water quality monitoring and modeling of streams has significantly grown, developed, and improved over the past several years, and continues to be expanded and refined. With the advent of real-time remote monitoring capabilities, strides have been made to not only more thoroughly understand natural and human interactions in watersheds, but also to improve preventative measures to avoid disturbances. Computer technology improvements, such as the development of terminal-to-modem connections, have allowed significant enhancements to monitoring water quality through faster data transfer and device communication (Glasgow et al., 2004).

A common monitoring system is structured around a few key components: a monitoring station, an intermediate data transfer (communications) system, and a database receiving station. Monitoring stations are located in the field where parameters of interest are measured, such as in a stream or river. Data collected in the field is relayed to a communication device for transmission to a receiving station. Typically, transfer devices are land-lines or cellular phone modems. A receiving station is the terminal end of the data transfer chain and where data is processed, organized, analyzed, and archived (Rouen et al., 2005).

Monitoring stations are designed to be robust in order to withstand dynamic environments. Rapidly-changing weather, high humidity, extreme temperatures, and wildlife and human interferences are examples of influences that may sabotage remote monitoring systems. Thus, devices installed in the field are typically enclosed in weather-tight and sturdy boxes. Because a monitoring station contains communication devices as well as sampling instrumentation, added precaution is exercised to protect data transfer equipment.

Cell phone connections are often used to relay data from monitoring stations to databases. In places where cell phone coverage is limited or non-existent, either land-line phone networks or radio telemetry is incorporated. Receiving stations consist of computers that are linked to communication devices in the field via wireless or hard-wired connections. Natural resource managers are provided access to field monitoring devices through these connections and have the ability to configure field settings, such as sampling intervals. With 24-hour access to field observations, researchers can significantly reduce the number of site visits required to maintain monitoring stations. Maintenance of remote monitoring stations is minimal and usually consists of probe calibrations, checking device connections, and ensuring proper exposure of measurement devices to the environment of interest.

Conventional monitoring techniques consist of traveling to specific sites, taking grab samples, storing samples for travel, transporting samples to laboratories, and analyzing samples. Indeed, traditional water quality monitoring has proven to be costly and time-consuming, as samples frequently have to be shipped to distant regions of the country and, in some cases, overseas for analysis (Glasgow et al., 2004; Toran et al., 2001).

Using real-time remote monitoring, these steps can be bypassed, allowing nearly instantaneous observations and analysis. Remote monitoring systems with real-time capabilities can cut down on sampling and analytical costs, improve overall data collection and organization, and even allow alert

notification systems to be established. Although grab samples have the advantage of allowing replications of laboratory measurements, real-time systems provide instant access of remote data without laboratory processing.

In addition to saving time and money, real-time monitoring systems allow continuous access and observation of remote and potentially dangerous areas where human access may not be feasible or even possible. Because these distant areas are often difficult to reach and sample, episodic fluctuations in stream water quality, such as those associated with storm events, may be missed (Deyton et al., 2009). If monitoring equipment can be installed and maintained in remote regions, safety risks during sampling can be greatly reduced while maintaining access to observations in stream water quality.

Sampling frequency and duration should also be important considerations in designing a real-time remote monitoring system in order to make the most efficient use of the system. There is considerable variability in how often and how long samples should be taken, and this depends specifically on the water quality monitoring objectives. For instance, monitoring water quality in smaller watersheds may require higher sampling frequencies to account for variability, as streams in smaller catchments have less buffering capacity against stochastic processes than larger streams and rivers (Kirchner et al., 2004). Sampling data spanning longer than one year is often needed to understand annual fluctuations and trends in water quality (Tate et al., 1999; Kirchner et al., 2004). Studies pairing watersheds of similar characteristics or in similar regions are highly beneficial and are often necessary to draw thorough conclusions about water quality behavior (Tate et al., 1999). In many instances, reducing sampling frequency does not produce more accurate or precise results and does not shed significantly more insight into stream water behavior; for example, 15-minute data may not reveal any more specific trends than hourly data (Kirchner et al., 2004).

Sampling frequency studies have produced a variety of results indicating best sampling strategies to implement. It has been shown that for streamflow data, bias significantly differs from zero at sampling intervals greater than 15 minutes (King & Harmel, 2003). In this study, 15-minute samples resembled true loadings of water quality constituents to various watersheds. Another study found that confidence interval widths for means of water quality parameters increased with increasing sampling intervals (Loftis & Ward, 1980). In almost all of the analyses, a positive linear relationship existed between confidence interval width and sampling interval (days). These studies indicate that error in measurement can be eliminated by selecting higher sampling frequencies, but the range of watersheds selected for research in these studies varied greatly in size and geographic region. Sampling strategies are highly site-specific and thus must be chosen with careful consideration.

Water Quality Measurements

Turbidity

Turbidity is a measure of water clarity. When passed through a water sample, light will scatter depending on the amount of suspended matter (Sadar, 2002). Higher turbidity correlates to murky, cloudy water because more light is scattered. As more suspended sediment is introduced into a stream, it becomes more opaque, or turbid. Turbidity has been shown to be a reasonable and

valuable metric for water quality management (Lloyd, 1987). In particular, turbidity data are desired to assess impacts of disturbances, such as highway construction (Anderson & Potts, 1987).

Turbidity is commonly measured using the nephelometric technique (Henley et al., 2000; Sutherland et al., 2002; Lloyd, 1987). This method uses a probe containing two devices: an emitter and a detector. The emitter is a light source that sends light at a specified wavelength into the sample. The detector is a photodiode that detects scattered light from particles in a sample and converts scattered into nephelometric turbidity units (NTU). More light reaching the detector will correspond to higher turbidity output due to particles in suspension. These probes are designed so that light scattered at a 90-degree angle is detected by the photodiode (YSI, 2010).

Ease of measurement is one of the attributes of turbidity that makes it attractive as an indicator of water quality. It is a direct measure of light penetration and an indirect measure of suspended sediment concentration, and is comparable in validity to using fecal coliform bacteria counts as a parameter relating purity and safe use of drinking water (Lloyd, 1987). Both can be used as indicators of water quality.

Turbidity has been shown to be a relatively successful indirect measure of sediment impacts on stream water quality and associated biota, particularly with respect to cold-water fish species and other remote stream organisms (Lloyd, 1987; Bonner & Wilde, 2002; Miner & Stein, 1996; Sigler et al., 1984). Turbidity thresholds can be determined to protect aquatic organisms particularly sensitive to suspended sediment concentrations, such as salmonid species, which are found in the Smokies. Although relationships between turbidity and suspended sediment are highly site-specific and may contain discrepancies, turbidity has been found to be a reasonable metric for water quality management (Lloyd et al., 1987).

pH

Because of its effects on biological functionality, pH can also be used as a health indicator for stream ecosystems. pH is a measure of hydrogen ion $[H^+]$ concentration. Hydrogen ions present in water cause acidity, which can adversely affect water quality and aquatic life. Water is defined as acidic if pH ranges from 0 to 7. Probes measuring pH use a bulb filled with a solution that is nearly neutral on the pH scale (~7). When the bulb is immersed in a solution having a different pH than the bulb solution, a differential is created that generates an electric potential. This electric potential is what is actually measured by pH devices. Voltage readings are then converted into pH units (YSI, 2010).

Similar to turbidity, pH is a relatively simple measurement to perform. Data collection and analysis is straightforward and can be used to make predictions about water quality. Organisms have ranges of pH that they can tolerate; therefore, pH readings observed outside these ranges can prove detrimental to aquatic life and indicate disturbances.

Several environmental factors cause changes in pH. Rainfall can cause pH to fluctuate. An example of this phenomenon is the flushing effect observed in watersheds when nitrogen and sulfur deposited from the atmosphere accumulate between rain events. Storm events wash accumulated acid from catchments and deposit them in streams, lowering pH. In addition, vegetation removal causes stored

organic acids to be released and carried with stormwater runoff, also terminating in streams and lowering pH. Bedrock geology can also influence groundwater and surface water chemistry. Certain rock formations release acids into water, lowering pH. These influences, however, are general descriptions of factors affecting pH. As discussed subsequently, pH is highly dependent on watershed characteristics, and research has indicated that generalizing trends in stream pH may not be, and is mostly likely not, possible (Deyton et al., 2009; Bolstad & Swank, 1997; Martin et al., 2000; Zampella et al., 2007; Dow & Zampella, 2000).

Conductivity

Conductivity is measured by applying an AC voltage to conducting metal electrodes, such as nickel. When a conductivity probe is placed in solution, current flows out of the probe and into solution. Depending on characteristics of solution, particles in solution will have some conductive properties that enable current flow. Current flowing through the electrodes and solution is directly related to the conductivity of solution (YSI, 2010).

Conductivity is dependent on temperature of solution. Specific conductance is conductivity normalized to 25 degrees Celsius. Oftentimes, conductivity probes are manufactured to incorporate temperature probes on them. Many monitoring devices measure both specific conductance and conductivity, depending on what parameter is desired for analysis. Conductivity and specific conductance measurements are commonly reported in milli- or micro Siemens per centimeter (mS/cm or μ S/cm).

Conductivity can be used as a potential indicator of disturbance events by measuring changes in stream water chemistry. Pollutants associated with stormwater runoff, such as toxic metals and major ions, have inherent conductivity that can be detected by probes. Conductivity can be used along with rainfall data to draw conclusions about observed phenomena, indicating whether events are natural or human-induced (Zampella et al., 2007; Dow & Zampella, 2000).

Temperature

Temperature is a measure of heat energy and molecular activity. Materials that conduct electricity also have internal resistance and therefore, to certain extents, resist current flow. Metals' resistance changes with temperature; therefore, resistance can be converted to temperature (YSI, 2010). Temperature measurements are perhaps some of the simplest of all field parameters to collect. Measurement involves immersing a probe into solution. Temperature probes are often manufactured to be attached to conductivity probes.

Temperature spikes can be associated with stormwater runoff from heated pavement (Van Buren et al., 2000; Roa-Espinosa et al., 2003). Monitoring stream water temperature, along with air temperature, can detect disturbances associated with construction and urbanization.

Forested Watershed Responses to Natural Phenomena and Disturbances

Streams in forested watersheds experience natural fluctuations in physical and chemical parameters. There are several factors that dictate physical and chemical conditions in streams: weather patterns, bedrock geology and soil type, and land cover attributes of watersheds all influence the health and

function of streams within watersheds (Flum & Nodvin, 1995; Cook et al., 1994; Sutherland et al., 2002; Price & Leigh, 2006). Spatial and temporal influences can sometimes have unexpected and unquantifiable effects on stream water quality. Seasonal variations and gaps in monitoring data are examples of temporal effects; non-point source pollution, such as stormwater runoff, is an example of a spatial variable.

Rainfall impacts on stream water quality vary depending on the season, as rainfall patterns differ seasonally in the Southern Appalachians. During summer months, storms are more localized and convective. Storm events of this type tend to be shorter in duration and come in “bursts”. In contrast, winter storm events tend to last longer as they are frontal systems that are more regional in scale (Price & Leigh, 2006).

Rainfall generates stormwater runoff that transports sediment and other materials to streams and causes turbidity. Decaying organic matter from leaf litter and roots and naturally-occurring fine sediments are internal sources of turbidity generated by watersheds themselves. Soil type and bedrock geology also contribute natural turbidity to streams. Depending on the percentages of sand, silt, and clay, soils will contribute varying degrees of turbidity. If heavy rain events occur, soil-generated turbidity can increase significantly. Even in third- and fourth-order streams, differences between baseflow and stormflow turbidity can be greater than 100 NTU for undisturbed watersheds (Sutherland et al., 2002).

Turbidity has been shown to be seasonally-dependent. One study (Anderson & Potts, 1987) observing changes in streams after road construction and logging found that turbidity followed streamflow: during low-flow periods, such as peak summer and early fall months, turbidity was observed to be lower, on the order of 10 NTU or less. During peak flow months, such as those following snowmelt and early spring, turbidity reached nearly 40 NTU. Low-flow periods have less turbidity because only fine sediments contribute to suspended load during this time; larger, heavier particles settle out of the water column and do not contribute. When spring rain occurs and flows increase, streams carry more energy and are able to resuspend bedload sediments, which contribute more turbidity (Anderson & Potts, 1987). This again shows that bedrock geology and soil type influence turbidity by dictating the percentages of suspended load and bedload sediments within streams.

Vegetation and forest type act as natural buffers against erosion and can mitigate how much sediment can be transported in watersheds. Leaves act to intercept rainfall and reduce terminal velocity of rain drops hitting the forest floor, which reduces the amount of energy that rainfall delivers to the soil and prevents dislodging of soil. Sediment can be removed from upper reaches of watersheds where canopy may be sparser. This can be curtailed by foliage in lower reaches of watersheds that impedes stormwater runoff and traps soil, preventing transport to streams and elevated turbidity (Haan et al., 1994).

When land is cleared and vegetation is removed from watersheds, natural stream buffers are often eliminated from the ecosystem. This results in higher turbidity as more sediment reaches streams through overland flow. In watersheds containing as little as 20% disturbance, turbidity can be two to

three times as high during stormflow compared to watersheds with 5% disturbance or less, with turbidity reaching 500 NTU and higher during stormflow in disturbed watersheds (Sutherland et al., 2002). Other studies have produced similar results. Stormflow turbidity for a watershed with 30% disturbance can be well over 100 NTU higher than a watershed with less than 5% disturbance (Price & Leigh, 2006). For watersheds with 10% disturbance or less, turbidity may be as high as 40 NTU above baseflow during storm events (Bolstad & Swank, 1997). In all studies, highways were present in watersheds containing disturbances.

Highway construction activities scrape soil and vegetation from sites, resulting in soil that can remain bare for extended periods of time. Rainfall acts to dislodge soil left exposed by construction activities. Once rainfall dislodges soil and other particles, stormwater runoff washes materials from construction sites and deposits them in surface waters, resulting in increased turbidity. Vegetation clearing for highway construction can eliminate natural buffers on the landscape that act to impede and trap materials that may be transported during storm events (Wheeler et al., 2005).

Stream ecosystems tend to be more severely affected by highway construction than other ecosystems due to limited space within streams (Wheeler et al., 2005). Water quality in streams can be affected not only temporarily during highway construction, but indefinitely as highways become part of the surrounding environment. Transport of fine sediments is initialized by highway construction and can remain an issue as long as highways are present unless controls are implemented to reduce erosion.

Stream structure and morphology can be affected by increased sediment from highway construction. Channelization can occur as a result of increased runoff velocity and scouring of sediment in streams located near highways. Channelization can result in permanent, detrimental alterations to stream flow and bed morphology, particularly in headwater streams. Headwater (first-order) streams in upper reaches of catchments tend to receive more immediate influence from disturbances in watersheds (Sutherland et al., 2002).

Not only are streams themselves directly affected by highway-associated disturbances, fish and other biota within streams are affected as well. Increases in fine sediments can hinder respiration in fishes and other aquatic organisms and can result in habitat loss for organisms by reducing stream bed surface area available for use. Benthic organisms can be starved if sediment accumulates and significantly covers stream beds, limiting access to food sources. Breeding habits of fishes and aquatic organisms can be adversely affected by as little as 10% watershed disturbance or less (Wheeler et al., 2005; Price & Leigh, 2006).

Sediments can carry metals and organic compounds that can alter stream chemistry and adversely affect wildlife due to their toxicity. Metals deposited on roadways are washed away during rain events and become contaminants in stream water and sediment (Wheeler et al., 2005). As discussed subsequently, the presence of certain metals associated with stormwater runoff can affect fish health and lead to asphyxia.

The impacts of turbidity from highway construction depend on intensity of sediment loads and duration of sedimentation events (Henley et al., 2000). Longer and heavier sediment loads

correspond with increasing damage to ecosystems. Increases in turbidity of only 25 NTU can inhibit enough sunlight penetration in water columns to restrict plant production by as much as 13-50% in shallow streams (Lloyd et al., 1987). This inhibition of plant growth may also retard growth of organisms depending on stream plants for food and habitat. Fish and other predatory animals have been found to suffer from increases in turbidity as small as 23 NTU, as visibility is reduced and food sources are blocked by opaque water (Shaw & Richardson, 2001). Similar results have been discovered in other aquatic predator-turbidity studies (Tippets & Moyle, 1978).

When suspended sediment settles out of the water column, spaces formerly used as habitat by organisms can become clogged (Henley et al., 2000). Habitat loss associated with stream bed restructuring can lead to shifts in species diversity and reductions in populations of certain organisms where sedimentation occurs (Henley et al., 2000). Sediment deposits can eliminate breeding space for fish and can also restrict oxygen transport to eggs if spawning does occur (Henley et al., 2000). In many cases, recovery from increased turbidity and sedimentation events may require excessive periods of time, and this recovery may not be complete for certain organisms.

Chemical influences from watersheds play a role in dictating stream chemistry. Watershed studies in the southern Appalachians almost always document bedrock geology and soil type due to their associations with stream chemical trends. Observations in the Great Smoky Mountains link pyritic rock formations, such as Anakeesta, with acidic conditions in streams (Cook et al., 1994; Flum & Nodvin, 1995; Deyton et al., 2009). Although pyritic rock formations are not predominant throughout the entire Great Smoky Mountains region, these findings still indicate how geology and soils affect stream chemistry.

Comparisons of baseflow and stormflow stream chemistry in the southern Appalachians vary considerably. High-elevation studies in the Smokies have found pH to decrease by as much as 1.0 pH unit or higher during storms in undisturbed watersheds (Deyton et al., 2009; Neff et al., 2008). These studies have linked atmospheric deposition of sulfuric and nitrogenous compounds with episodic stream acidification. Rain events cause flushing of deposited nitrates and sulfates, leading to episodic reductions in stream pH. Streams in the Smokies have small amounts of alkalinity, affording greater opportunity for variations in pH (Deyton et al., 2009; Cook et al., 1994). Besides storm events and associated increases in stream discharge, time between storm events, or days since last rainfall (DSL_R), was a variable that also had significant effects on stream chemistry. Stream pH can decrease with increasing discharge and larger DSL_R values (Deyton et al., 2009). In order for stream pH trends to be thoroughly observed, stream discharge data should be incorporated into the body of research.

Stream pH is a parameter of concern, especially in the Smokies, where pH drops have been found to adversely affect fisheries. Studies have shown that fluctuations in pH have caused native southern brook trout (*Salvelinus fontinalis*) populations to be reduced. At pH values of 5.5-6.4, asphyxia in fishes has been observed (Neff et al., 2008). Ion regulation is affected by pH reductions when H⁺ concentrations interfere with gill transport of ions and sodium ions are lost. Lower pH values induce certain aluminum species to become mobile in water, which also affects fish gill function. These effects can be observed after pH drops of 1.0 unit or less (Neff et al., 2008).

Other research in the Appalachians has documented pH fluctuations as a function of land use and disturbance with mixed results. Research in the southern Appalachians have general trends of pH decreasing during storm events and with increasing disturbance; pH dropped an average of 0.3 units during SF for less than 10% watershed disturbance (Bolstad & Swank, 1997). Even with this overall trend, one site of this study observed an increase in pH. Still, the overall trend was a negative correlation between storms and pH.

Organic acids from trees and other vegetation can become released following disturbances in watersheds. Many of the areas within the Smokies have thin topsoil layers, offering little buffering capacity of soil to protect against acidification events. Other research in the southeastern US has shown a positive relationship between pH and percent catchment disturbance for baseflow conditions; pH was nearly 1.0 unit higher for approximately 14% disturbance compared with zero disturbance (Houser et al., 2006).

Research in the northern Appalachians reported increased H^+ concentration (decreased pH) after clear-cutting of trees but then a return to pre-cut conditions of lower H^+ concentrations (Martin et al., 2000). Other studies in the northern Appalachians have found pH to increase with percentage of land altered or disturbed. Average stream pH differed by almost 3.0 units between zero disturbance and 50% disturbance (Zampella et al., 2007; Dow & Zampella, 2000). This illustrates the spatial and temporal variability in pH data associated with factors such as rainfall and land cover/disturbance, and demonstrates why it is difficult to establish universal trends in stream pH.

Conductivity can be used to measure salt and other ion concentrations in stream water. Salt and other major ions can interfere with osmotic pressure regulation in freshwater organisms (Koryak et al., 2001). Streams contain natural levels of salt and other major ions during dry periods; however, storm events can drastically increase ion concentrations to ecologically unhealthy levels. Salt contamination in streams occurs during storm events after salt is used as a deicing agent along roads and highways. In absence of deicing salts, streams tend to experience drops in conductivity during storm events compared with dry spells. When deicing salts are used, however, salts that become deposited in watersheds during winter months get flushed with spring and summer rains events, causing spikes in conductivity (Koryak et al., 2001).

Results from water quality studies on conductivity as a parameter have also varied greatly in magnitude and behavior. One study in the southern Appalachians found conductivity to increase during SF at three of five sites but decrease at two sites. The magnitudes of change seem insignificant in scale; conductivity increased roughly $2.0 \mu S/cm$ and decreased one $\mu S/cm$ or less during SF for watersheds with less than 10% disturbance (Bolstad & Swank, 1997). Research in the northern Appalachians observed that conductivity increased with increasing percent disturbance; conductivity was nearly $70 \mu S/cm$ higher for 50% disturbance versus zero disturbance (Zampella et al., 2007; Dow & Zampella, 2000).

It follows that conductivity increases with increasing disturbance, especially during SF: land clearing releases ions that may not otherwise be present in stream water, at least not in magnitudes as those associated with disturbances. Since conductivity is a surrogate for stream ion concentration,

electrical conductivity should increase as more ions are present in solution, allowing greater potential for electrical current than with no ions present. As with pH, it would be beneficial to include stream discharge data in the analysis of rainfall effects on conductivity.

Temperature is perhaps one of the most difficult stream water quality parameters for which to establish trends, especially during storm events; however, generalizations can be observed. Stream water temperature is highly-dependent on air temperature. Theoretically, stream temperature should be higher than air temperature during colder months and lower than air temperature during summer months (Shanley & Peters, 1988). This is because of groundwater influences on stream water, especially in headwater streams of watersheds. Groundwater is the most buffered of the three measurements, with air temperature being the least buffered and stream temperature falling in the middle. Experimental observation has confirmed this theory (Smith & Lavis, 1975).

Generally, stream temperature will follow air temperature in behavior throughout the year. Discrepancies exist, however, when short, intense storm events occur. Rainfall temperature can be approximated to air temperature (Roa-Espinosa et al., 2003). If stream discharge rises at such a rate that it cannot be heated by air temperature, stream temperature will decrease even on the rising limb of a daily temperature cycle (Smith & Lavis, 1975). In other words, if a large enough storm event occurs, stream temperature can experience a decrease, even during the warmest part of the day.

Flow length has an effect on stream temperature. A positive correlation should be seen between flow length and stream temperature: as flow length increases, stream water has greater exposure to air temperature and solar radiation, allowing greater increases in stream temperature as the stream progresses through the watershed. Research has verified the above statement: for five monitoring stations along a watershed, from headwater to outlet, BF stream temperature increased from 11.9 °C to 12.8 °C (Bolstad & Swank, 1997). These results were also compounded by the fact that percent watershed disturbance increased along the watershed, indicating that disturbance affects stream temperature as well.

Stream water temperature is significantly impacted by watershed disturbances. Stormwater runoff associated with highway presence and urbanization can have higher temperatures compared with stormwater runoff from undisturbed watersheds. Heated stormwater from pavement is generated by afternoon thunderstorms that occur during warmer seasons (Kieser et al., 2003).

Aquatic ecosystems can be particularly sensitive to stream temperature fluctuations. Fish species can suffer physiologically from such increases in water temperature, and mortality rates have been known to increase from temperature spikes (Van Buren et al., 2000; Jones et al., 2006; Wang et al., 2003). Certain salmonid species, such as brown trout (*Salmo trutta*) have a limited range of tolerable temperatures (7-17 °C), above which become stressed (Roa-Espinosa et al., 2003). This is especially a concern for the Smokies, considering that they serve as a habitat for sensitive trout species (Neff et al., 2008).

Previous studies have focused on heated stormwater runoff from pavement, such as parking lots (Van Buren et al., 2000; Jones et al., 2006; Roa-Espinosa et al., 2003; Thompson & Vandermuss, 2004).

Although these analyses were beyond the scope of this thesis, effects of heated stormwater runoff can still be inferred from previous studies. To emphasize a recurring theme, air temperature and stream discharge, when possible to acquire, are important in observing trends between rainfall and water quality parameters. This is essential perhaps more so for stream temperature, especially in forested watersheds.

Methods

Study Site Locations

The Foothills Parkway (FHP) is a scenic highway owned and maintained by NPS. Its construction was initiated in 1944 and has been sporadic at best since then, with only two sections open for vehicular use to the public (NPS, 2009). The FHP runs 72 miles along the northern boundary of Great Smoky Mountains National Park (GRSM) in east Tennessee. Figure 1 displays a map of FHP with completed and uncompleted segments of highway. Figures 2-4 show images taken by

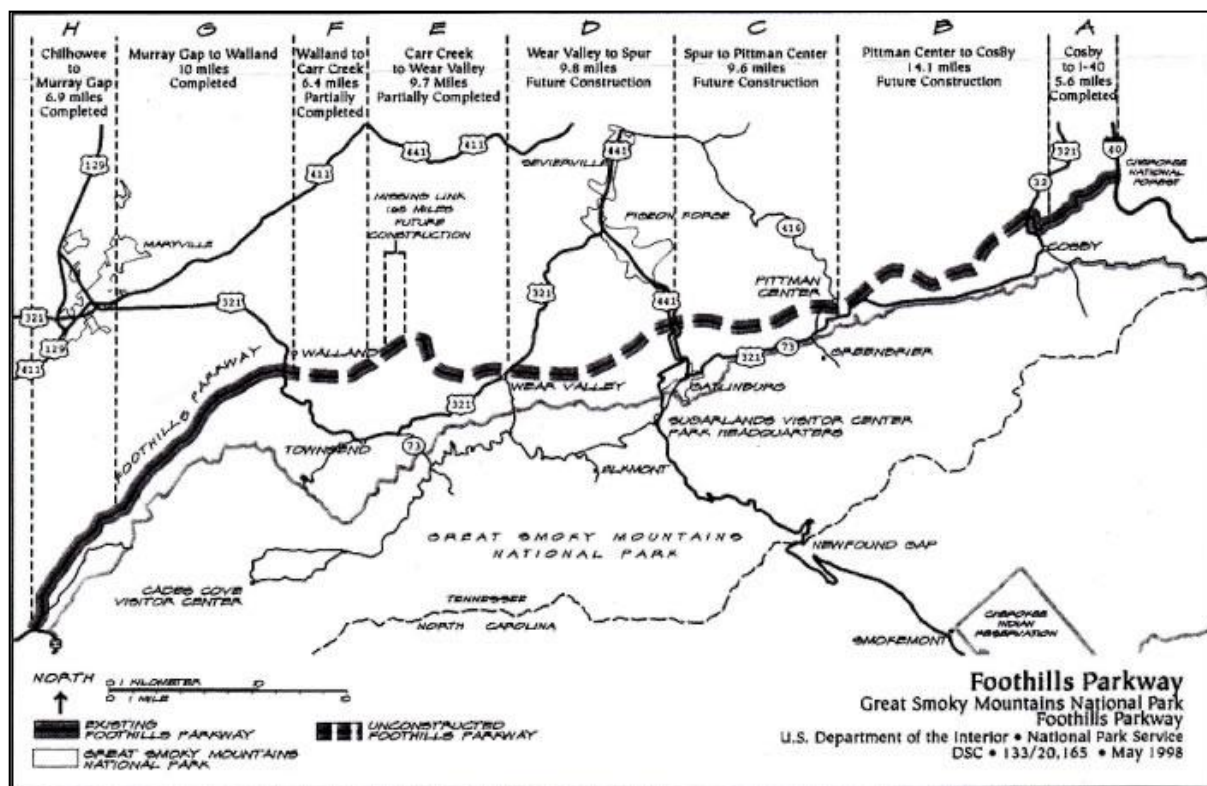


Figure 1. Foothills Parkway map showing individual segments of completed road and planned construction.



Figure 2. Aerial image of Foothills Parkway construction. (Photo Credit: Great Smoky Mountains National Park Service).



Figure 3. Aerial Photo of Foothills Parkway construction of Bridge 3. (Photo Credit: Great Smoky Mountains National Park Service).



Figure 4. Aerial photo of Foothills Parkway construction highlighting land disturbance activities. (Photo Credit: Great Smoky Mountains National Park Service)

Within this construction zone, three sub watersheds were selected as monitoring locations due to accessibility. These three subwatersheds as shown in Figure 5 are Hembree Hollow (HH), Dunn Hollow (DH), and Rudd Hollow (RH). Portions of all three watersheds were located on private property. HH site was accessible by vehicle. DH site was accessible by foot, and RH was accessible by four-wheel drive vehicle and on foot. HH was 730 m (2,400 ft) from construction, DH was 770 m (2,500 ft) from construction, and RH was 670 m (2,200 ft) from construction. Road construction commenced toward DH, starting on either side at HH and RH and closing the gap between the two above DH. Construction began in late October of 2010 in HH, while construction in RH began in late December 2010.

Figure 6 provides a more detailed view of these three watersheds and sonde locations projected onto a topographic map. Figure 7 details the changing watershed elevations from highway construction to sonde location. Watershed elevations ranged from just over 500 m (1,540 ft) to almost 820 m (2,680 ft), approximately.

Numerous small streams fill the southern slope of the ridge. Figure 8 shows stream networks in and near study sites. Heavier black lines indicate ridges, or places of no flow. Brighter white lines indicate longer stream flow lengths. Streams displayed in grayish color represent groundwater flow, as each of the streams draining to monitoring stations are first-order streams.

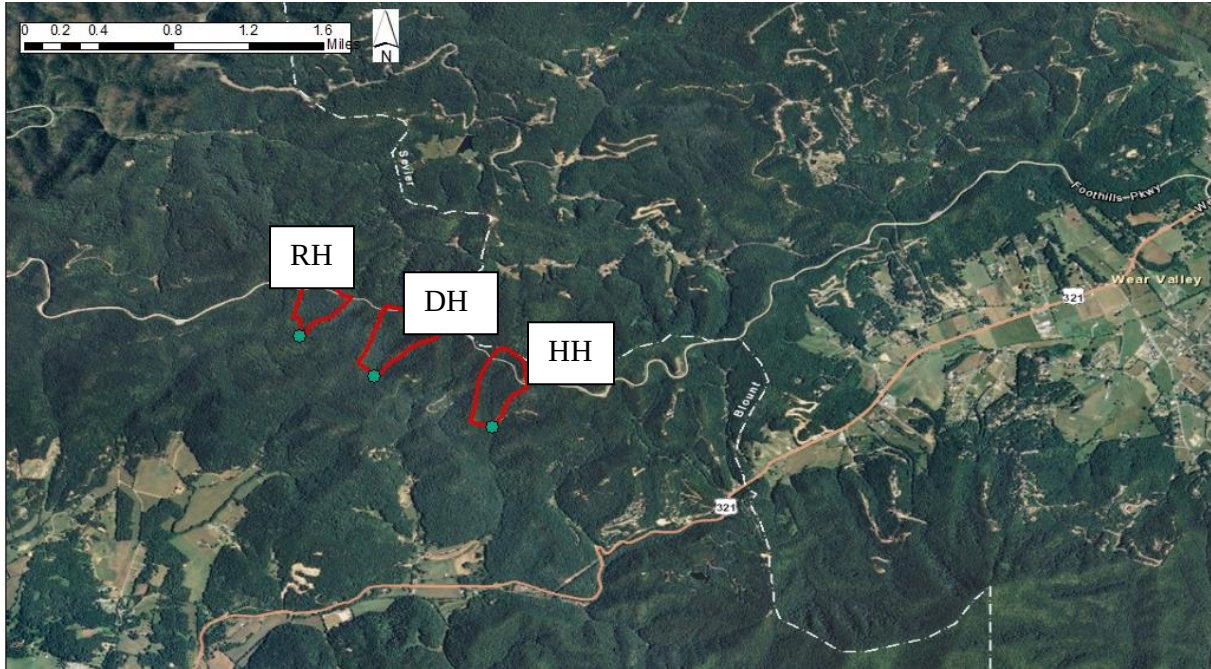


Figure 5. Location of Foothills Parkway stream monitoring sites and represented watersheds.

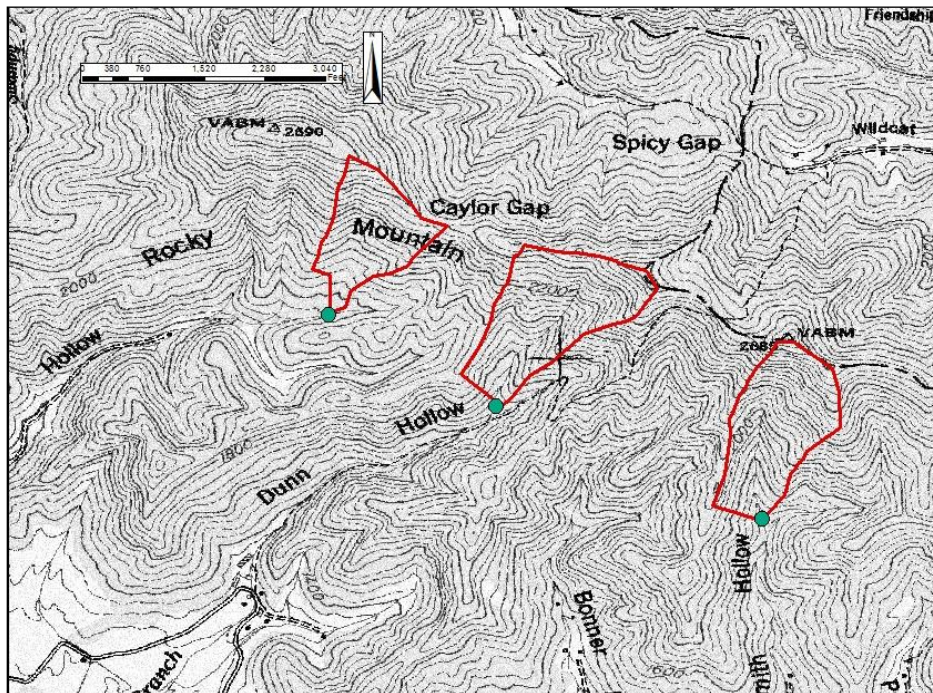


Figure 6. Topographic map showing Foothills Parkway watershed boundaries and sonde locations.

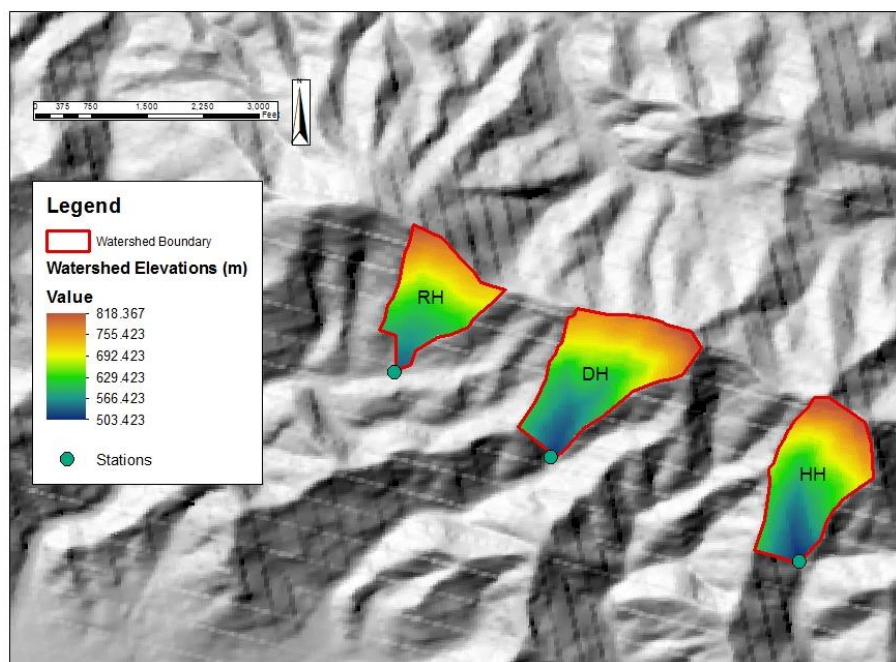


Figure 7. Foothills Parkway watershed elevations calculated using GIS.

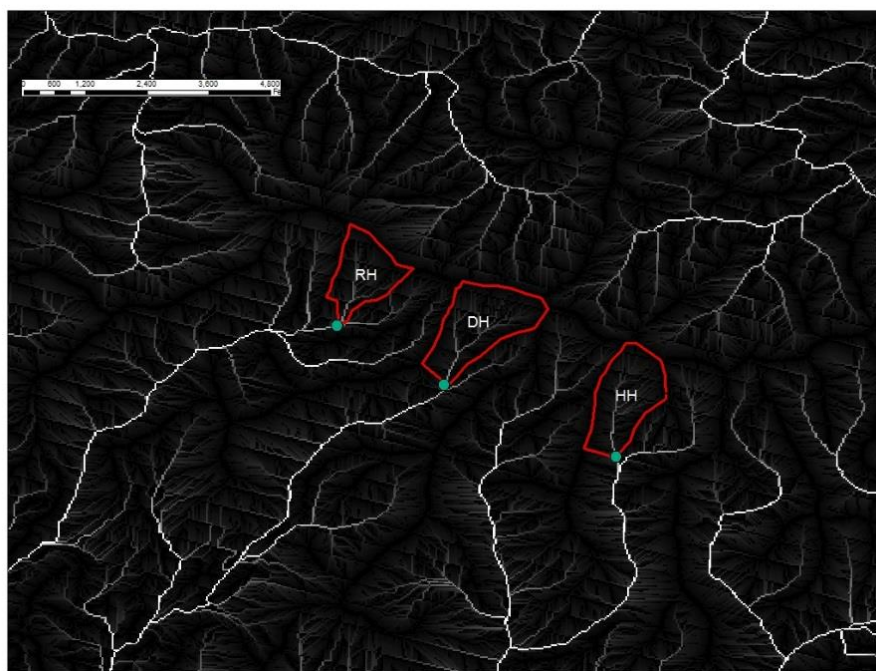


Figure 8. Foothills Parkway stream networks in monitored watersheds.

Steep slopes were characteristic of many places within these watersheds. Since upper areas of watersheds bordered the ridge where FHP was located, steep gradients were observed in upper

reaches, and stream slopes were steep in certain places. Figure 9 shows slope variations in study watersheds.

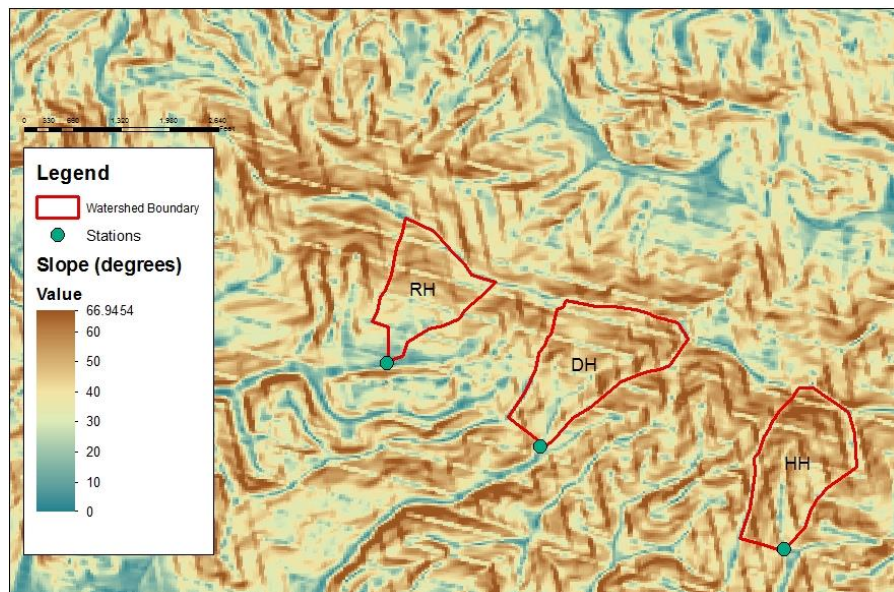


Figure 9. Slope variations in monitored watersheds of the Foothills Parkway.

Hembree Hollow (HH)

HH is a 15.9-ha (39.2-acre) watershed bordering FHP right-of-way. The station at HH is at elevation 504 m (1,655 ft). HH contained approximately 4% disturbance from FHP construction and an additional 1% from internal disturbances.

HH contains mostly hardwoods, such as poplars and maples; few evergreens were observed. Road cuts expose bare soil above and below the monitoring station. Understory is sparse, especially along road cuts; what brush does exist is mostly mountain laurel and other shrubs. There were approximately 640 m (2,100 linear ft) of road cuts in HH above monitoring station. Canopy coverage at the monitoring station is open; rain gauge receives direct rainfall with negligible interception from canopy.

Slopes were as steep as 65° in upper regions of HH; however, terrain near the monitoring station was more level, with less than 10° slope. Landowners built a cabin near the monitoring station, and human activity is apparent by vehicle, tractor, and ATV tracks. Approximately 100 yards upstream from monitoring location, road cuts cross the stream with no bank stabilization, buffers, or culvert.

Soil surveys of Blount County, TN indicated that a Ramsey slaty silt loam (Rb) was predominant in HH (USDA, 2011). Bedrock geology consisted of a Cambrian period shale siltstone. This was evident by brittle, stratified rocks characteristic of slate found along road cuts and in sediment deposits in and alongside stream banks. Thin topsoil is apparent in this watershed, with shallow organic layers observed along edges of road cuts. Sediments deposited in streams were clean and

rocky, which indicated that fine organic material was minimal in soil, again echoed by a shallow organic horizon. Laboratory analysis indicated the following results: soil pH at HH was found to be 5.4, cation exchange capacity (CEC) was 6.6 meq/100 g, and soil acidity was 4.4 meq/100 g.

The stream where monitoring was conducted was classified as a first-order stream. A first-order stream is one that has not been joined or had confluence with another stream (Strahler, 1952). Streams such as these have intimate contact with the groundwater table, with flow occurring during wet weather and little to no flow otherwise. Stream width was less than one m (three ft) in most places. In many places streamflow went underground and resurfaced several meters downstream. Laboratory testing revealed that stream chemistry consisted of the following constituents: K (0.7 ppm), Ca (11.0 ppm), Mg (6.1 ppm), SO₄ (8 ppm), and Na (2 ppm). No PO₄ or NO₃ were detected. TDS at HH was 77 ppm, and EC was 0.12 mmhos/cm. Using Rosgen stream classification system, HH stream was defined as a type A5a+ stream.

HH stream bed material consisted primarily of sandy material transported by runoff from various places within the watershed; occasional bedrock was exposed in stream. Woody debris frequently blocked flow and in some cases acted to trap sediment. Several fallen trees lay across the stream above sonde location. Trapezoidal channel geometry and negligible sinuosity was predominantly observed in the stream. An average slope of 10-20% characterized this stream.



Figure 10. Hembree Hollow stream within the Foothills Parkway stream monitoring area.



Figure 11. Hembree Hollow sonde before storm event.



Figure 12. Hembree Hollow sonde after storm event.

Dunn Hollow (DH)

DH watershed drains 19.9 ha (49.1 acres) above the sonde location. DH watershed boundary bordered FHP right-of-way. Station elevation is 520 m (1,700 ft), and flow path at the station was 770 m (2,530 ft).

DH is the least disturbed watershed. A single foot path limited access to sampling location. Understory was thicker than at Hembree, with mountain laurel and other shrubs consistent along stream banks. Poplars were most common trees, with occasional beeches and oaks. Slopes as high as 65° closed DH and prevented sunlight penetration in many places; closed canopy was more frequently observed. No human activity was apparent beyond landowner yards and fields that border dense woods leading to sonde location. The watershed was free of road cuts and other disturbances.

Ramsey slaty silt loam underlay DH, just as with HH. The same bedrock geology was found in DH as in HH. Slaty rocks were apparent less than one foot below ground surface, as well as in stream and along banks. Topsoil appeared to be thin, being less than two feet in certain places. Stream sediments appeared more silty and fine and less sandy than in HH. Soil pH was 5.5, CEC was 9.5 meq/100 g, and soil acidity was 5.2 meq/100 g.

The stream at DH was classified as a type A1a+, first-order stream. Trapezoidal channel geometry was dominant with minimal sinuosity. Slope averaged 10-20% in stream. Streamflow was more consistent in this watershed and less dependent on rainfall, which made for ideal monitoring conditions. In only very few places did streamflow disappear underground. Pools were frequent in this stream, and the sonde was located in a larger pool where flow appeared most consistent. In contrast to HH, this stream was relatively free of fallen trees blocking flow. Bed material consisted mostly of bedrock with some silty sediments observed after rain events. Leaves and fine organic matter were frequently observed in bottom of the pool. Testing at Clemson Agricultural Laboratory indicated that stream chemistry consisted of the following species: K (0.4 ppm), Ca (3.8 ppm), Mg (2.2), SO₄ (3 ppm), and Na (1 ppm). No PO₄ or NO₃ were present. TDS was 38 ppm, and EC was 0.06 mmhos/cm.



Figure 13. Dunn Hollow watershed near the Foothills Parkway stream monitoring site.



Figure 14. Dunn Hollow monitoring station at the Foothills Parkway stream monitoring site.

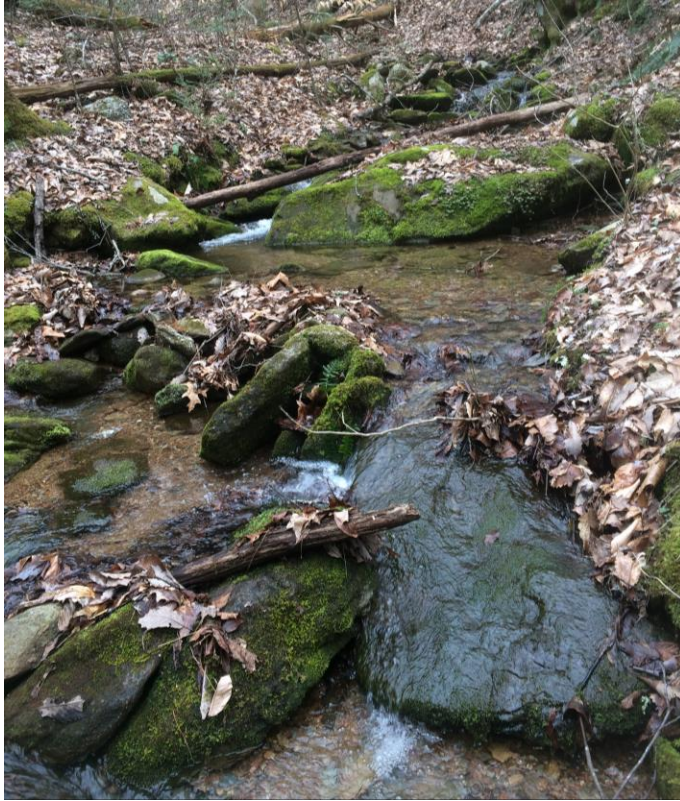


Figure 15. Dunn Hollow stream at the Foothills Parkway stream monitoring site.

Rudd Hollow (RH)

RH is 11.6 ha (28.6 acres) in size, making it the smallest watershed. Elevation at monitoring station was 540 m (1,760 ft), making it the highest station elevation. RH has approximately 12% disturbance in the upper reaches of the watershed.

Rudd is heavily covered with hardwoods, such as poplars, maples, oaks, and beeches. Understory was thick with mountain laurel and other shrubs. Slopes were as steep as 60° and enclosed portions of the watershed. The area in which monitoring was conducted could be described as a “bowl”, with ridges and steep banks surrounding the monitoring station on every side. Landowners partially built a shed approximately 100 yards upstream from monitoring site. Human activity in Rudd is apparent as shotgun shells and casings were observed during late winter and spring months, and surveying flags are seen around the area.

Rudd contained Ramsey slaty silt loam as with the other two watersheds. Again, as with HH and DH, Cambrian shale siltstone comprised bedrock geology. Soil pH was 4.8, CEC was 5.9 meq/100 g, and soil acidity was 4.4 meq/100 g. Stream bed material consisted primarily of sand and small pebbles; very little fine sediments were observed. Similar to Hembree, Rudd experienced periods of no flow during summer months, which posed problems for monitoring. Sandy/gravelly material transported during heavy rain events tended to constrict flow. Rudd was classified as a type A5a+ due to the amount of sand/gravel mix present with little bedrock observed. Stream channel geometry was trapezoidal, and sinuosity was minimal. Stream chemistry consisted of the following

constituents: K (0.4 ppm), Ca (2.7 ppm), Mg (1.3 ppm), SO₄ (2 ppm), and Na (1 ppm). No PO₄ or NO₃ were detected. TDS was 26 ppm, and EC was 0.04 mmhos/cm.



Figure 16. Rudd Hollow watershed and stream within the Foothills Parkway monitoring area.

Monitoring Station Design

Each remote monitoring station consisted of five primary components: water quality sonde, rain gauge, datalogger, cellular modem, and power source. YSI® 6600 EDS V2 sondes were used to continuously measure and record water quality data on pH, temperature, conductivity, depth, and turbidity. Global Water® RG200 rain buckets were deployed to collect precipitation data.

Sondes had internal data storage capacity, which was used as a data back-up in case of modem or datalogger failure. Campbell Scientific® CR200X dataloggers were used to receive data from

sondes and rain gauges. Sierra Wireless® AirLink Raven XT cellular modems were used to transmit data. Sondes were connected to dataloggers using SDI-12 and dataloggers were connected to modems using RS-232.

Twelve volt deep-cycle batteries were used to power dataloggers and modems. BP® SX375J solar panels were used to capture sunlight and recharge 12-V batteries. Morningstar® ProStar-15 solar charger controllers were employed to regulate battery voltage and to monitor battery and load voltages and solar amps. An additional solar panel was deployed at DH to capture more sunlight, as the station was located under thick canopy.

Equipment was contained within NEMA 3R metal boxes that were weather-resistant and sturdy. Each site had two boxes attached to an eight-foot, six-inch wooden post. Solar panels were positioned on top of posts. All external wires were protected inside PVC conduit. The bottom box contained 12-V batteries and solar charge controller, while the top box contained datalogger and modem. Figure 7 provides an example of station setup, specifically at HH. This setup was used for each study site.



Figure 17. Station setup at HH showing solar panel, equipment boxes, and rain gauge.

All three stations were installed on May 24-25, 2010. All components were deployed at this time except for rain gauges. HH began recording sonde data during installation, while DH and RH recording was started on July 6, 2010.

Monitoring Station Maintenance

Monitoring stations had to be maintained throughout the duration. Most common maintenance issues involved sonde probe calibration/repair, modem resets, and battery power supply. Sonde probes

were calibrated approximately every two months. This was done to ensure accuracy and precision of water quality measurements. Importance was placed on sonde calibration, as sondes were the most direct source of instantaneous observations of changes in water quality data. Because study sites were located nearly three hours from Clemson campus, sensor calibrations were conducted in the field, except for times when probes were damaged and had to be brought back to campus. On these occasions, sondes were calibrated in the lab at Clemson. Calibration cups, solutions, distilled water, spare bottles, laptop computer, and connector cables were transported to individual sites for calibration during site visits.

Calibration of sonde water quality probes was relatively straightforward. Calibration cups were used to contain calibration solutions of turbidity, pH, and conductivity. In the calibration process, conductivity was calibrated first, followed by pH and turbidity. This was done in accordance with manufacturer recommendations to prevent pH solution, which is high in salt concentrations, from causing errors in conductivity calibrations and measurements due to residual pH solution on the probes (YSI, 2010). To prevent residual solution interference, probes were rinsed thoroughly with distilled (DI) water between each use of calibration solutions.

Conductivity probes were calibrated using a 10,000- μ S/cm standard. Temperature sensors were incorporated as composite components with conductivity sensors; temperature was automatically calibrated. pH sensor calibration was performed using three standards: 4.0, 7.0, and 10.0 pH units. DI water was used to rinse probes thoroughly between solution contact with probes. Turbidity was calibrated using two standards: a zero NTU standard (distilled water) and a 126-NTU standard. Zero NTU standard was entered first, followed by 126-NTU standard. DI water was used liberally to rinse probes and cups after contact with each solution.

On more than one occasion, sonde probes were found to be broken or damaged by unknown events. Upon damaged sensors, new sensors were installed. Sondes themselves were periodically removed and returned to YSI for manufacturer testing, repairs, and software upgrades.

Statistical Analysis

All statistical analysis was performed using JUMP statistical analysis software package. Key analyses performed on water quality data included ANOVA and contingency analysis. No construction and construction conditions for water quality were compared for each of the three sites. For Hembree Hollow, construction activities occurred during the time period of April 2010 to December 2012. Dunn Hollow did not have construction begin until January 2012 and was ongoing till the end of the monitoring period. For Rudd Hollow, construction activities have been ongoing since January 2011. Background turbidity, pH, conductivity, and temperature data were compared for each site. Data collected before construction (NC) were then compared to during construction (DC) for each site. Contingency analysis was performed on the data from all three watersheds whereby the number of turbidity occurrences (levels) above and below the individual watershed site means were determined and then compared for both construction and no construction periods to determine if the percent occurrences were similar or different.

Water quality data were collected in three Great Smoky Mountain watersheds for seven years. Data included turbidity, pH, conductivity, and temperature. Data were analyzed to determine behavioral trends using various statistical analysis methods. In the following Figures (8-19), the blue portion of graphs represent duration of monitoring where no construction was taking place while red represents period when Foothills construction was occurring. The black line represents mean values.

Results

Turbidity

As seen in Figures 18-20, turbidity reached over 1,400 NTU at each site numerous times over the period of monitoring. It can be seen that high turbidity events occurred most frequently at Hembree while Dunn appears to have less frequent turbidity spikes. From frequent site visits throughout the duration of the monitoring, it was noted that Hembree often times experience sonde burial events due to the large sediment load within that small stream. Heavy siltation was observed after storm events in Hembree. These events happened throughout the monitoring independent of any Parkway construction and were isolated to internal disturbances from landowner activity such as road cuts and other land clearing activities. During rain events, runoff washed soil from these disturbances into the stream. Analysis of variance indicated that the mean turbidity of each of the three watersheds were significantly different for the seven-year time period. Hembree Hollow had the highest overall mean turbidity of 133 NTUs while Dunn had the lowest at 36.3 NTUs.

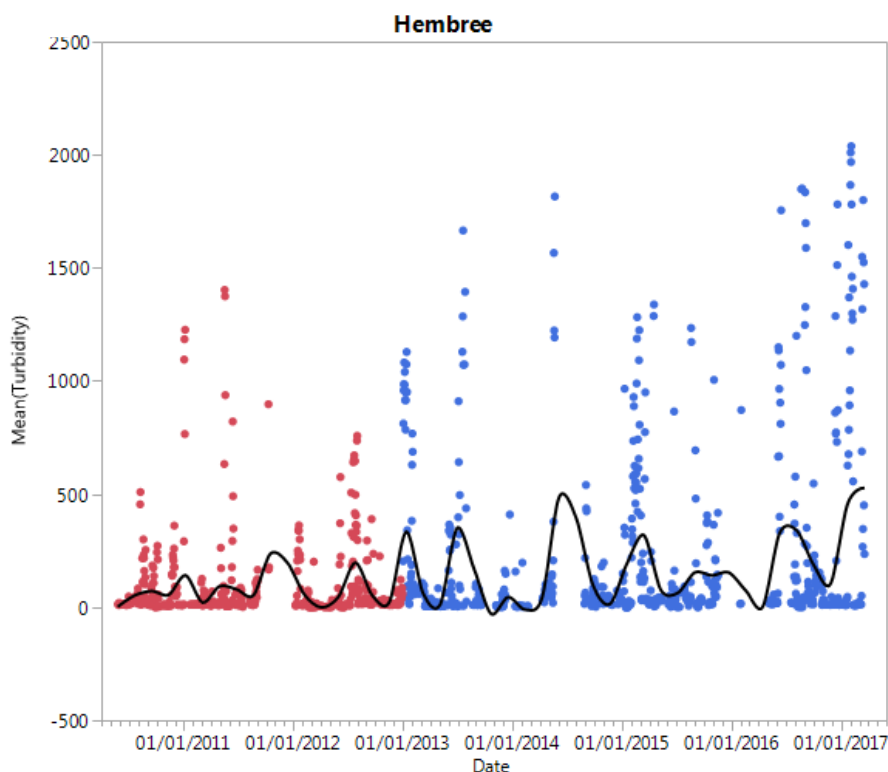


Figure 18. Turbidity (NTUs) for Hembree Hollow.

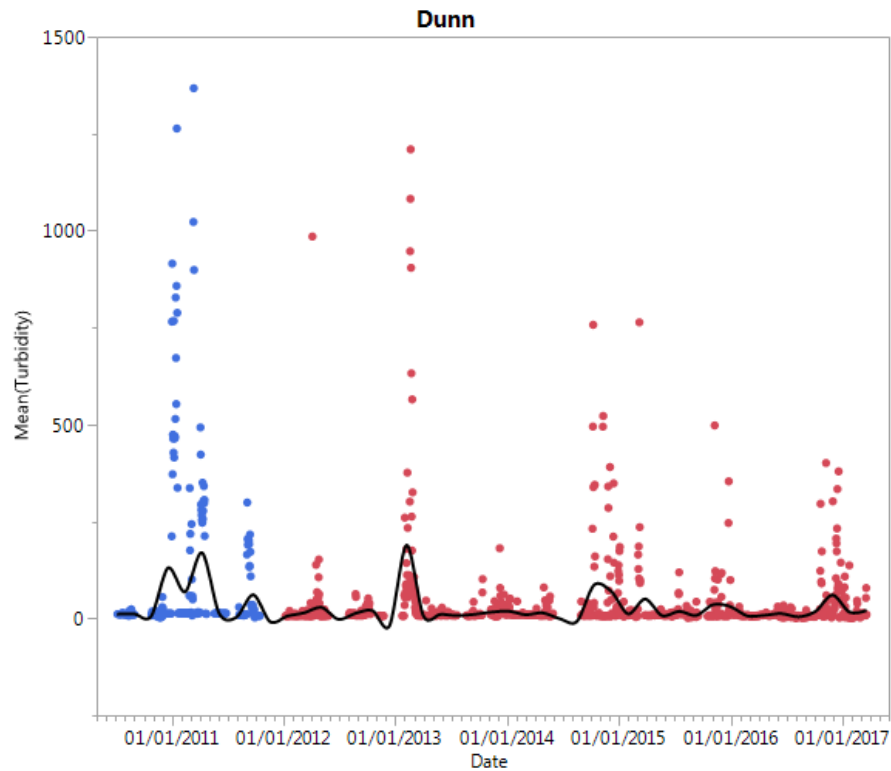


Figure 19. Turbidity (NTUs) for Dunn Hollow.

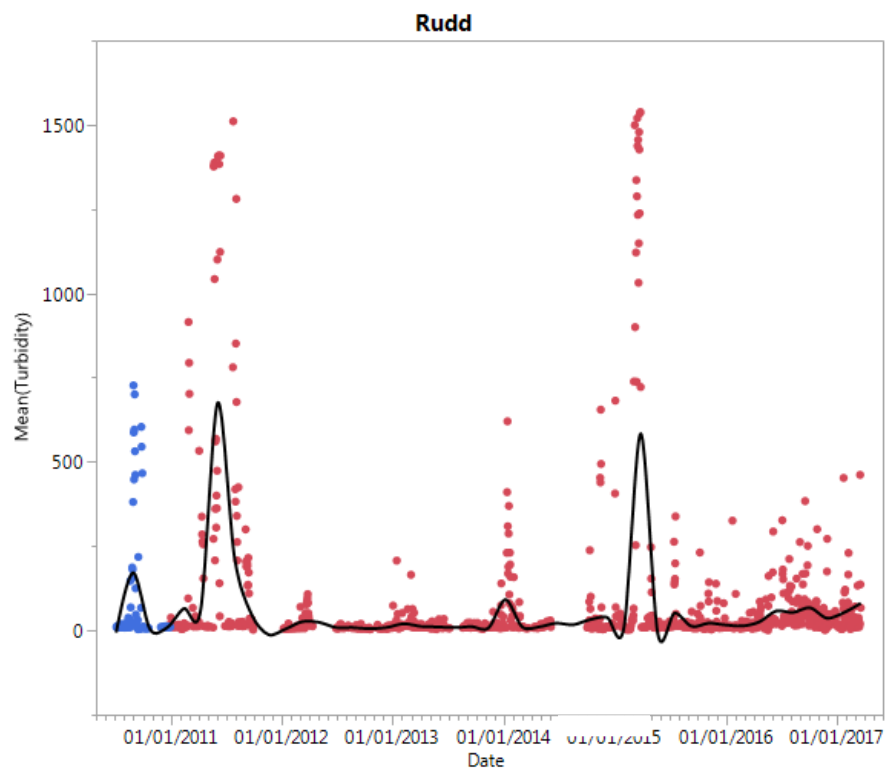


Figure 20. Turbidity (NTUs) for Rudd Hollow.

Statistical analysis of the mean daily turbidity values showed that the average means during construction activities versus no construction within all three watersheds were actually lower. The mean turbidity in Hembree, Dunn, and Rudd (64.0, 26.7, and 59.3 NTUs) in times of disturbance are significantly lower than mean turbidity in times of no disturbance (189, 80.3, and 62.9 NTUs). Table 1 summarizes site comparisons for turbidity for no construction activities (NC) and construction activities (C).

Table 1. Mean turbidity at each site with no construction (NC), during construction (C), and for entire monitoring period.

Site	NC (NTU)	C (NTU)	Mean (NTU)
HH	189	64.0	133
DH	80.3	26.7	36.3
RH	62.9	59.3	59.5

An additional contingency analysis was performed on the data from all three watersheds whereby the number of turbidity occurrences (levels) above and below the site mean were determined and then compared for both during construction and with no construction to determine if the percent occurrences were similar or different. For Hembree, the probability of being above the turbidity threshold in times of disturbance (0.1258) is significantly lower than the probability of being above the turbidity threshold in times of no disturbance (0.2508). For Dunn, the probability of being above the turbidity threshold in times of disturbance (0.1113) is significantly lower than the probability of being above the turbidity threshold in times of no disturbance (0.1810). The same then is also true for Rudd. The probability of being above the turbidity threshold in times of disturbance (0.1214) is significantly lower than the probability of being above the turbidity threshold in times of no disturbance (0.1397). These results can be found in Table 2 below.

Table 2. Contingency analysis of Foothills Parkway turbidity events occurring above and below the mean threshold with no construction (NC) and construction (C) activities.

Site	NC (% > Mean)	NC (% <= Mean)	C (% > Mean)	C (% <= Mean)
HH	25.1	74.9	12.6	87.4
DH	18.1	81.9	11.1	88.9
RH	14.0	86.0	12.1	87.9

pH

Of all the water quality parameters measured, pH was the most difficult. Due to malfunction or breakage, pH probes were periodically replaced. In some instances, if streams went dry, pH probes would dry out and have to be replaced. Upon calibration, often times it could be determined that due

to issues with calibration, probes needed to be replaced. Spikes seen in Figures 21-23 below are most likely due to probe issues rather than actual changes in chemistry of the stream itself. Analysis of variance indicated that the mean pH of each of the three watersheds were significantly different for the seven-year time period with Hembree being the highest at 7.21, Dunn at 6.61 and Rudd at 6.31. In all three instances, the standard error for mean pH was 0.01.

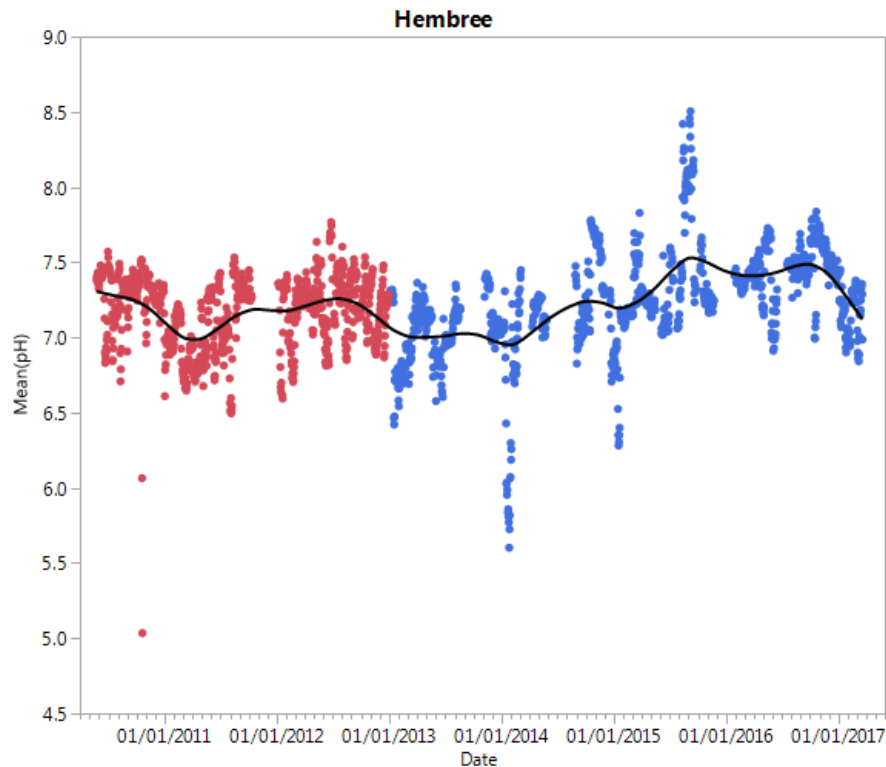


Figure 21. Stream pH for Hembree Hollow within the Foothills Parkway stream monitoring area.

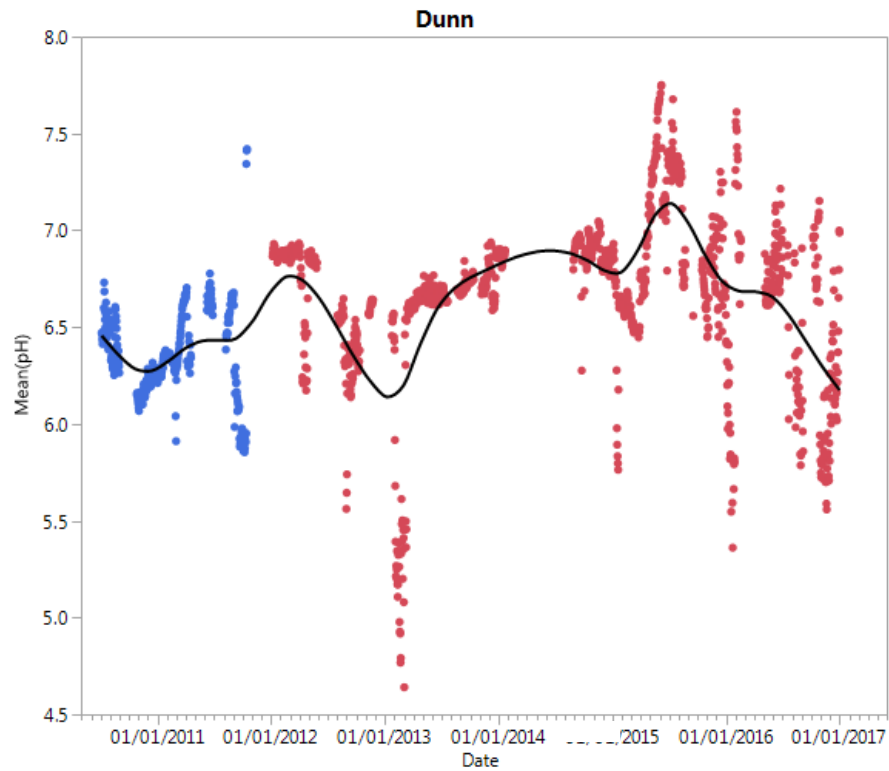


Figure 22. Stream pH for Dunn Hollow within the Foothills Parkway stream monitoring area.

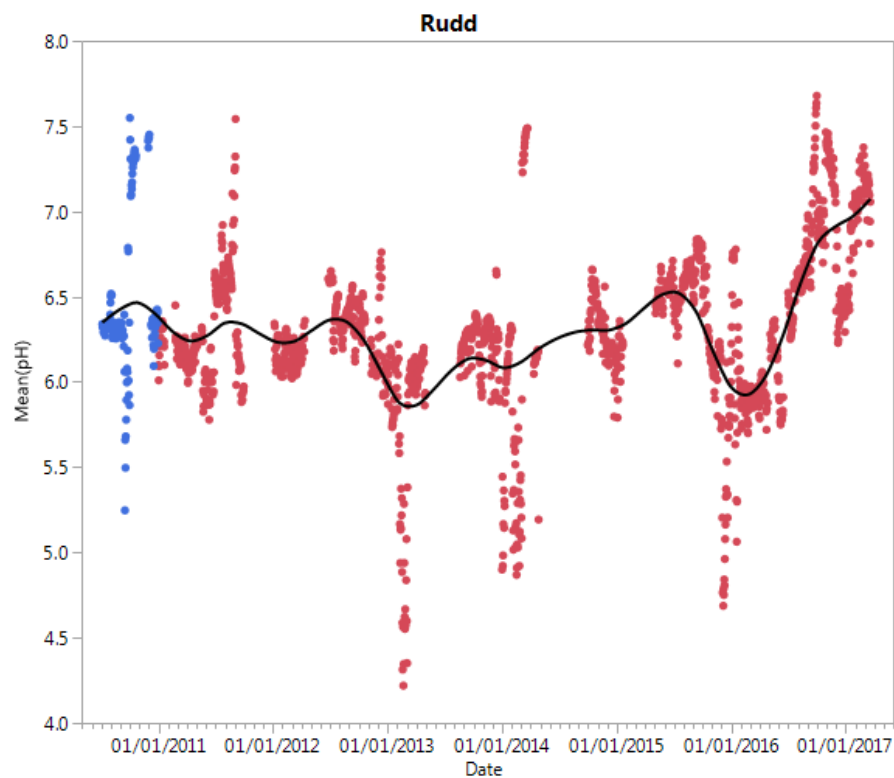


Figure 23. Stream pH for Rudd Hollow within the Foothills Parkway stream monitoring area.

Statistical analysis of the mean daily pH values showed that the average means during construction activities versus no construction within all three watersheds varied. The mean pH in Hembree (7.17) and Rudd (6.29) in times of disturbance is significantly lower than mean pH in times of no disturbance (7.24 and 6.46 respectively). However, mean pH in Dunn in times of disturbance (6.68) is significantly greater than mean pH in times of no disturbance (6.35). Table 3 summarizes site comparisons for pH for no construction activities (NC) and construction activities (C).

Table 3. Mean pH at each site with no construction (NC), during construction (C), and for entire monitoring period.

Site	NC (pH)	C (pH)	Mean (pH)
HH	7.24	7.17	7.21
DH	6.35	6.68	6.61
RH	6.46	6.29	6.31

An additional contingency analysis was performed on the data from all three watersheds whereby the number of pH occurrences (levels) above and below the site mean were determined and then compared for both during construction and with no construction to determine if the percent occurrences were similar or different. For Hembree, the probability of being above the pH threshold in times of disturbance (0.5432) is not significantly different from the probability of being above the pH threshold in times of no disturbance (0.5469). For Dunn, the probability of being above the pH threshold in times of disturbance (0.7352) is significantly greater than the probability of being above the pH threshold in times of no disturbance (0.1615). However, the opposite is the case for Rudd. The probability of being above the pH threshold in times of disturbance (0.4523) is significantly lower than the probability of being above the pH threshold in times of no disturbance (0.6765). These results can be found in Table 4 below.

Table 4. Contingency analysis of pH events occurring above and below the mean threshold with no construction (NC) and construction (C) activities.

Site	NC (% > Mean)	NC (% <= Mean)	C (% > Mean)	C (% <= Mean)
HH	54.7	45.3	54.3	45.7
DH	16.1	83.9	73.5	26.5
RH	67.7	32.3	45.2	54.8

Specific Conductivity

General conductivity fluctuations, during the monitoring period for each watershed, can be seen in Figures 24-26. Analysis of variance indicated that the mean specific conductivity of each of the three watersheds were significantly different for the seven-year time period. Hembree had the highest mean specific conductivity of 0.156 mS/cm. The specific conductivity at Hembree was twice that of the other two watersheds. Dunn and Rudd mean specific conductivities were 0.077 and 0.067 respectively. The main difference within the three watersheds being the amount of internal disturbances found within Hembree.

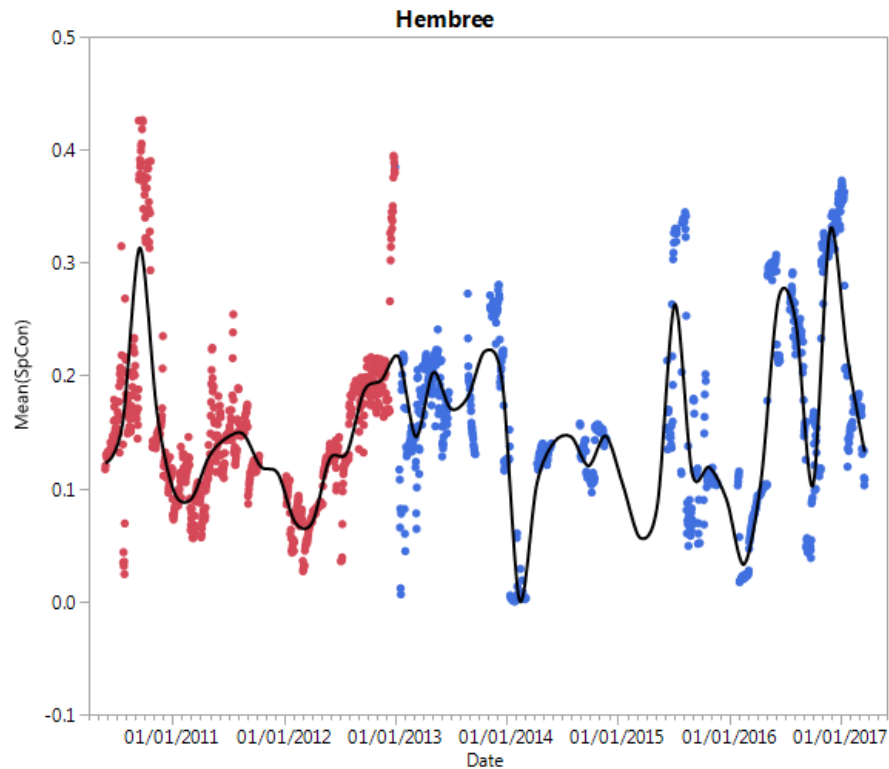


Figure 24. Conductivity (mS/cm) for Hembree Hollow within the Foothills Parkway monitoring area.

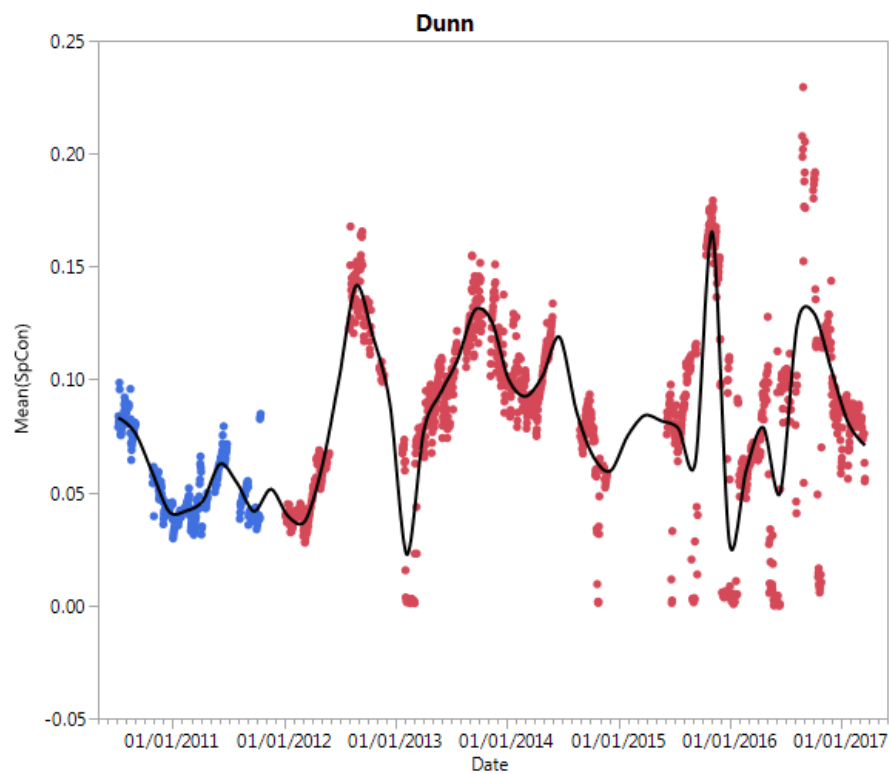


Figure 25. Conductivity (mS/cm) for Dunn Hollow within the Foothills Parkway stream monitoring area.

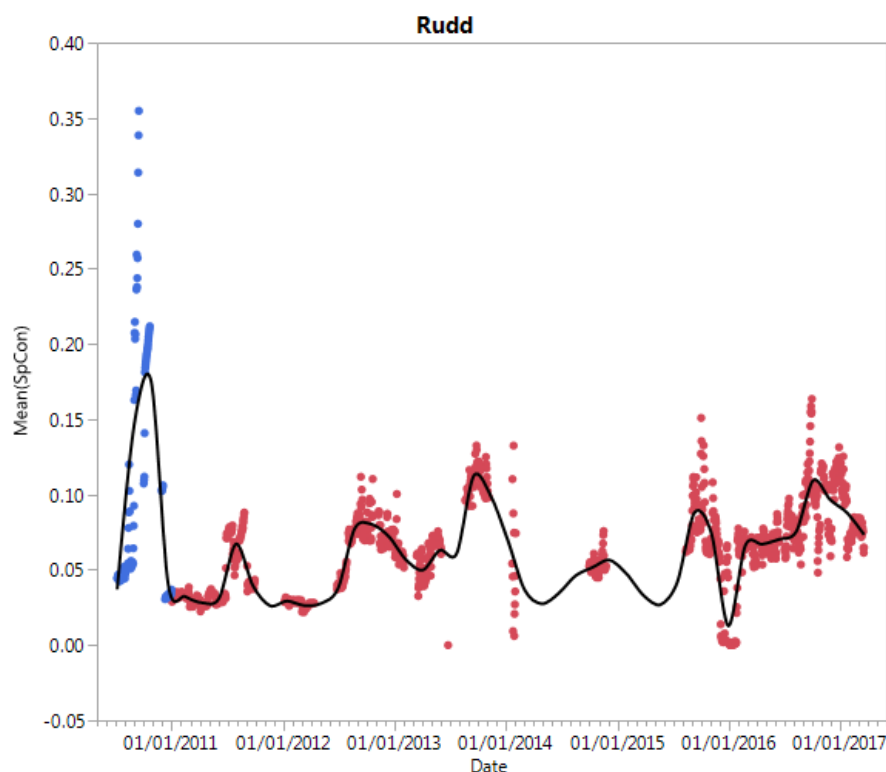


Figure 26. Conductivity (mS/cm) for Rudd Hollow within the Foothills Parkway stream monitoring area.

Statistical analysis of the mean daily specific conductivity values showed that the average means during construction activities versus no construction within all three watersheds varied. The mean specific conductivity in Hembree (0.147) and Rudd (0.083) in times of disturbance is significantly lower than mean specific conductivity in times of no disturbance (0.163 and 0.099 respectively). However, mean specific conductivity in Dunn in times of disturbance (0.084) is significantly greater than mean specific conductivity in times of no disturbance (0.053). Analysis of variance also indicated that the mean specific conductivity of each of the three watersheds were significantly different for the seven-year time period. Table 5 summarizes site comparisons for specific conductivity for no construction activities (NC) and construction activities (C).

Table 5. Mean specific conductivity at each site with no construction (NC), during construction (C), and for entire monitoring period.

Site	NC (mS/cm)	C (mS/cm)	Mean (mS/cm)
HH	0.163	0.147	0.156
DH	0.053	0.084	0.077
RH	0.099	0.064	0.067

An additional contingency analysis was performed on the data from all three watersheds whereby the number of specific conductivity occurrences (levels) above and below the site mean were determined and then compared for both during construction and with no construction to determine if the percent occurrences were similar or different. For Hembree, the probability of being above the specific conductivity threshold in times of disturbance (0.34589) was significantly lower than the probability of being above the specific conductivity threshold in times of no disturbance (0.4471). For Dunn, the probability of being above the specific conductivity threshold in times of disturbance (0.6149) is significantly greater than the probability of being above the specific conductivity threshold in times of no disturbance (0.1399). However, the opposite is the case for Rudd. The probability of being above the specific conductivity threshold in times of disturbance (0.4914) is not significantly different than the probability of being above the specific conductivity threshold in times of no disturbance (0.4050). These results can be found in Table 6 below.

Table 6. Contingency analysis of specific conductivity events occurring above and below the mean threshold with no construction (NC) and construction (C) activities.

Site	NC (% > Mean)	NC (% <= Mean)	C (% > Mean)	C (% <= Mean)
HH	44.7	55.3	34.6	65.4
DH	14.0	86.0	61.5	38.5
RH	40.5	59.5	49.1	50.9

Temperature

General stream temperature fluctuations during a yearly cycle for each watershed can be seen in the following figures (Figures 27 -29). Analysis of variance indicated that the mean temperature of each of the three watersheds were significantly different for the seven-year time period. Hembree had the overall highest mean temperature at 14.1°C, followed by Rudd at 13.4°C and then Dunn at 13.1°C. Both Hembree and Rudd had the shortest flow paths above the location of the sonde and Hembree had the most open canopy due to internal disturbances. As one note with respect to Rudd, there was only a limited number of data points, mainly occurring in the summer months, for the no construction data set which skewed the temperature for this group.

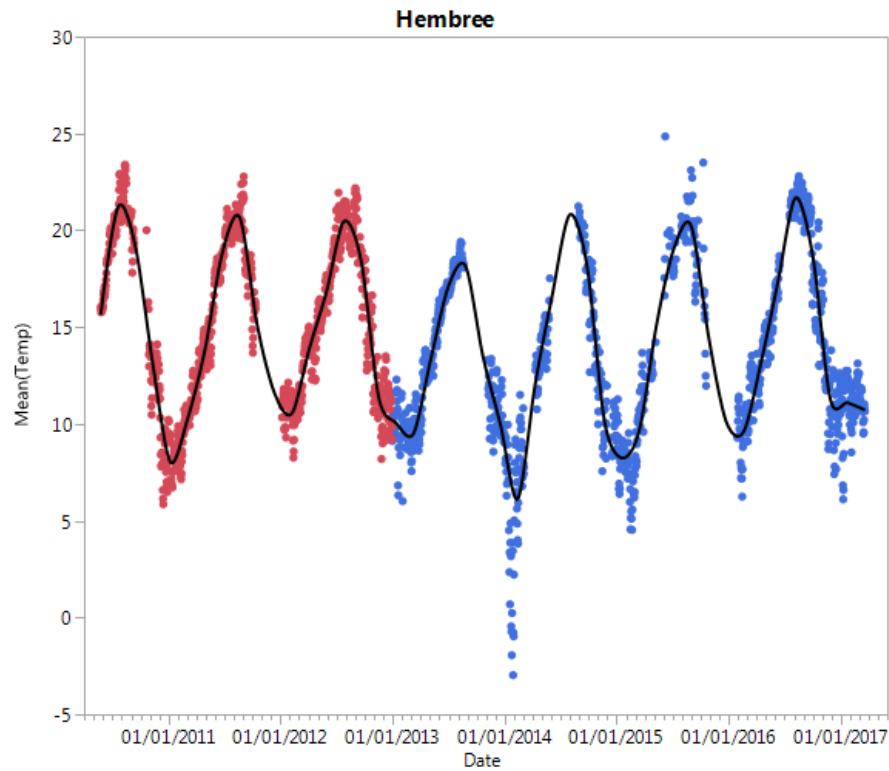


Figure 27. Stream temperature (°C) for Hembree Hollow within the Foothills Parkway monitoring area.

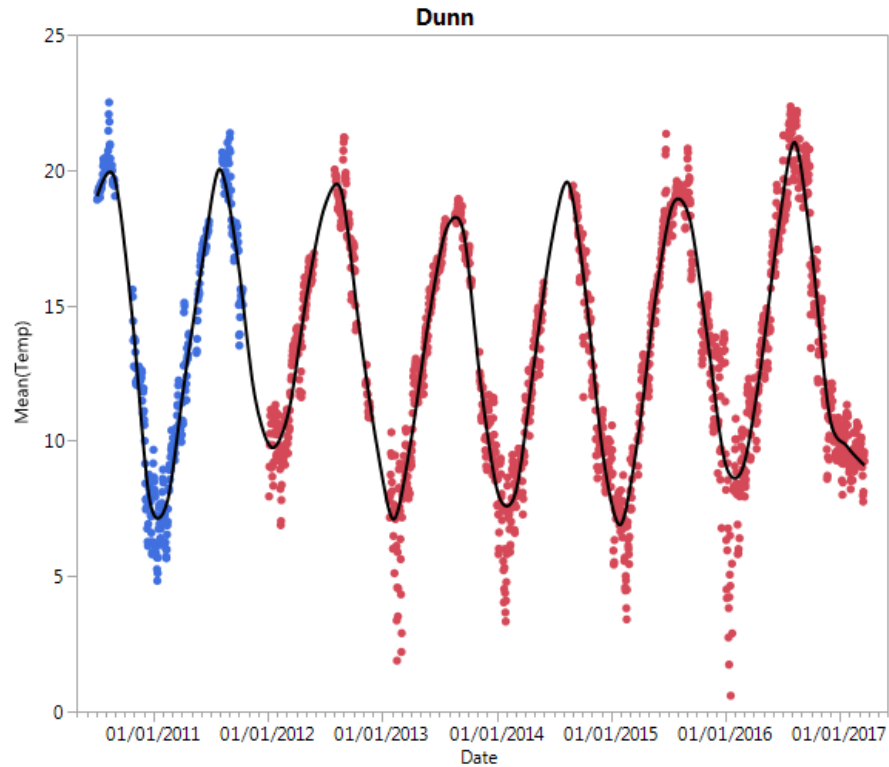


Figure 28. Stream temperature (°C) for Dunn Hollow within the Foothills Parkway monitoring area.

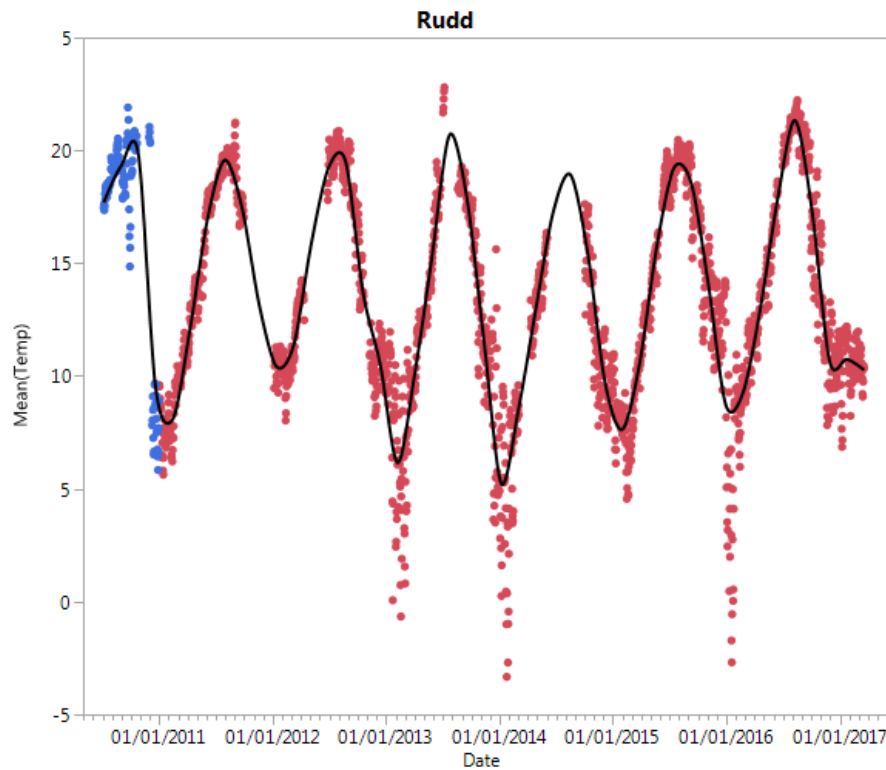


Figure 29. Stream temperature (°C) for Rudd Hollow within the Foothills Parkway monitoring area.

Statistical analysis of the mean daily temperature values showed that the average means during construction activities versus no construction within all three watersheds varied. The mean temperature in Dunn (13.0 °C) and Rudd (13.2 °C) in times of disturbance is significantly lower than mean temperature in times of no disturbance (13.9 and 17.3 °C respectively). However, mean temperature in Hembree in times of disturbance (15.3 °C) is significantly greater than mean temperature in times of no disturbance (13.2 °C). Table 7 summarizes site comparisons for temperature for no construction activities (NC) and construction activities (C).

Table 7. Mean temperature at each site with no construction (NC), during construction (C), and for entire monitoring period.

Site	NC (°C)	C (°C)	Mean (°C)
HH	13.2	15.3	14.1
DH	13.9	13.0	13.1
RH	17.3A	13.2	13.4

^A Data mainly limited to summer/fall months of partial year.

An additional contingency analysis was performed on the data from all three watersheds whereby the number of temperature occurrences (levels) above and below the site mean were determined and then compared for both during construction and with no construction to determine if the percent occurrences were similar or different. For Hembree, the probability of being above the temperature

threshold in times of disturbance (0.5692) is significantly higher than the probability of being above the temperature threshold in times of no disturbance (0.3757). For Dunn, the probability of being above the temperature threshold in times of disturbance (0.4583) is significantly greater than the probability of being above the temperature threshold in times of no disturbance (0.5274). The probability of being above the temperature threshold for Rudd in times of disturbance (0.4348) is significantly lower than the probability of being above the temperature threshold in times of no disturbance (0.8309). Once again, there is limited data for Rudd temperature before construction began. These results can be found in Table 8 below.

Table 8: Contingency analysis of temperature events occurring above and below the mean threshold with no construction (NC) and construction (C) activities within the Foothills Parkway monitoring area.

Site	NC (% > Mean)	NC (% <= Mean)	C (% > Mean)	C (% <= Mean)
HH	37.6	62.4	56.9	43.1
DH	52.7	47.3	45.8	54.2
RH	83.1	16.9	43.5	56.5

Internal Disturbances

As mentioned earlier in this section, a couple of the monitored watersheds did contain internal disturbances. Hembree Hollow had existing road cuts already in place before monitoring began (Figure 30). As the monitoring period progressed, additional road cuts and land disturbing activities took place (Figure 31).



Figure 30. Road cut alongside Hembree Hollow stream within the Foothills Parkway monitoring area.



Figure 31. Internal disturbances within Hembree Hollow Watershed.

The second watershed which had minimal internal disturbances before monitoring began was Rudd Hollow. However in winter of 2016, new road cuts were graded primarily for ATV use within this watershed. The location of one of the road cuts was just upstream of where the NPS monitoring station was located. Figure 32 shows the road cuts that was graded just upstream from the monitoring location within Rudd Hollow. Figure 33 shows the fine material that has been deposited on the monitoring sonde after this road cut was graded.



Figure 32. New road cut across Rudd Hollow stream within the Foothills Parkway monitoring area.



Figure 33. Sonde showing signs of sediment deposition after new road cuts within Rudd Hollow.

Discussion and Conclusions

The objectives of this research were to deploy and maintain real-time remote monitoring systems for three small watersheds below the Foothills Parkway in the Great Smoky Mountains. Water quality data (with a specific focus on turbidity) was monitored over the course of seven years to determine trends for construction versus no construction activities for undisturbed/disturbed watersheds. Water quality data were analyzed to assess impacts of highway construction on first-order streams within these watersheds. The objectives were satisfied and conclusions drawn from this monitoring project were as follows:

The mean turbidity during construction was actually less than times of no construction within all three watersheds.

- HH turbidity averaged 189 versus 64.0 (no construction vs construction)
- DH turbidity averaged 80.3 versus 26.7 (no construction vs construction)
- RH turbidity averaged 62.9 versus 59.3 (no construction vs construction)

The mean specific conductivity and pH during construction was actually less than times of no construction within Hembree and Rudd. Dunn was actually higher.

- HH specific conductivity and pH averaged 0.163 mS/cm and 7.24 versus 0.147 mS/cm and 7.17 (no construction vs construction)
- RH specific conductivity and pH averaged 0.099 mS/cm and 6.46 versus 0.064 mS/cm and 6.29 (no construction vs construction)
- DH specific conductivity and pH averaged 0.053 mS/cm and 6.35 versus 0.084 mS/cm and 6.68 (no construction vs construction)

Overall, the most internally disturbed watershed, Hembree Hollow, had the highest mean turbidity, specific conductivity, temperature and pH of all three watersheds. Dunn, the only undisturbed watershed, had the lowest mean turbidity.

Based on review of data collected within all three watersheds and routine monthly inspections of streams, National Park Service construction activities located at the top of each watershed, did not have any offsite impacts as determined by the monitoring stations located on the private landowners property. Any fluctuations were due impart to the characteristics of the watershed itself and the internal disturbances.

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Appendix A

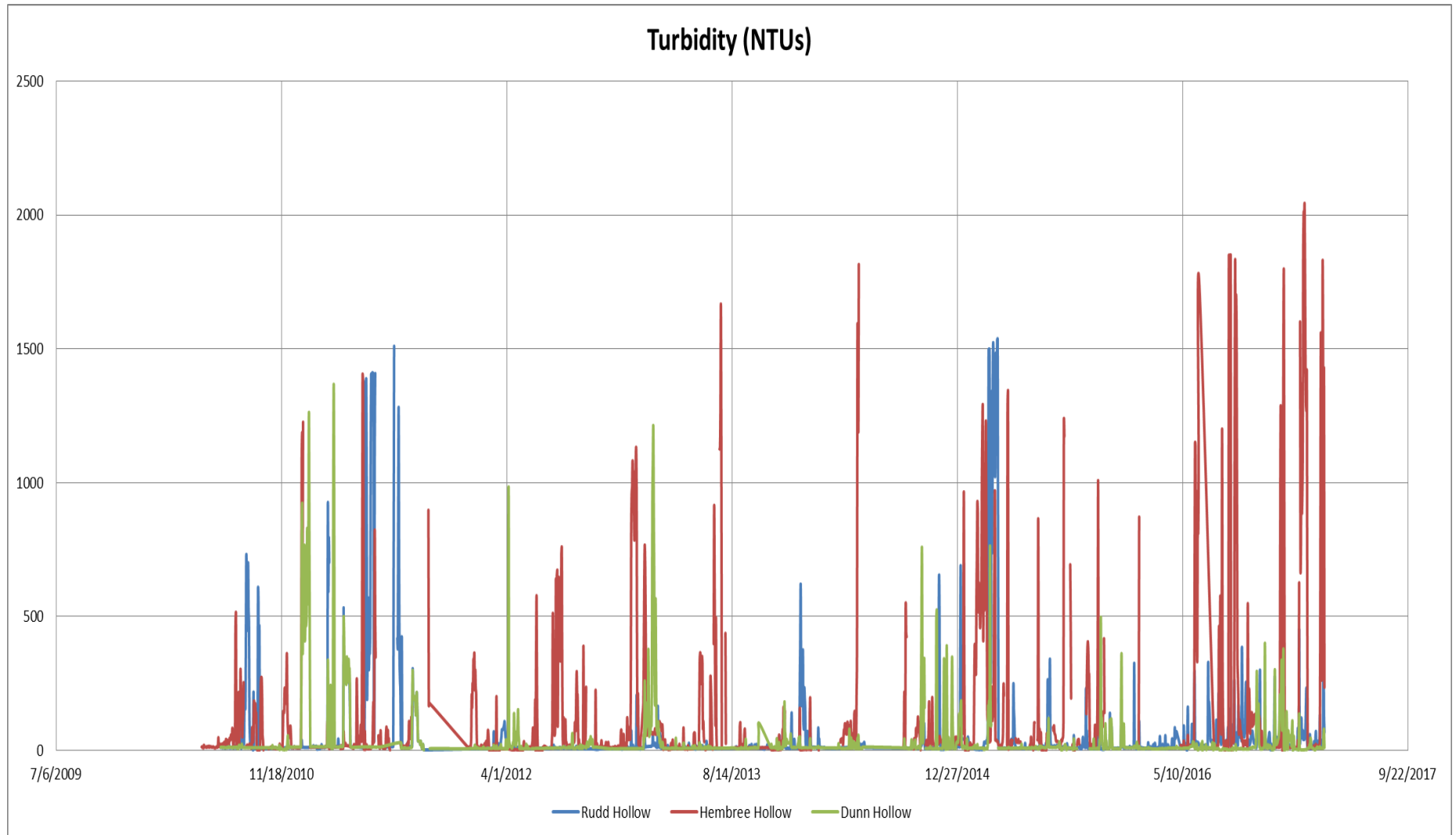


Figure A-1. Turbidity comparison of all three watershed streams.

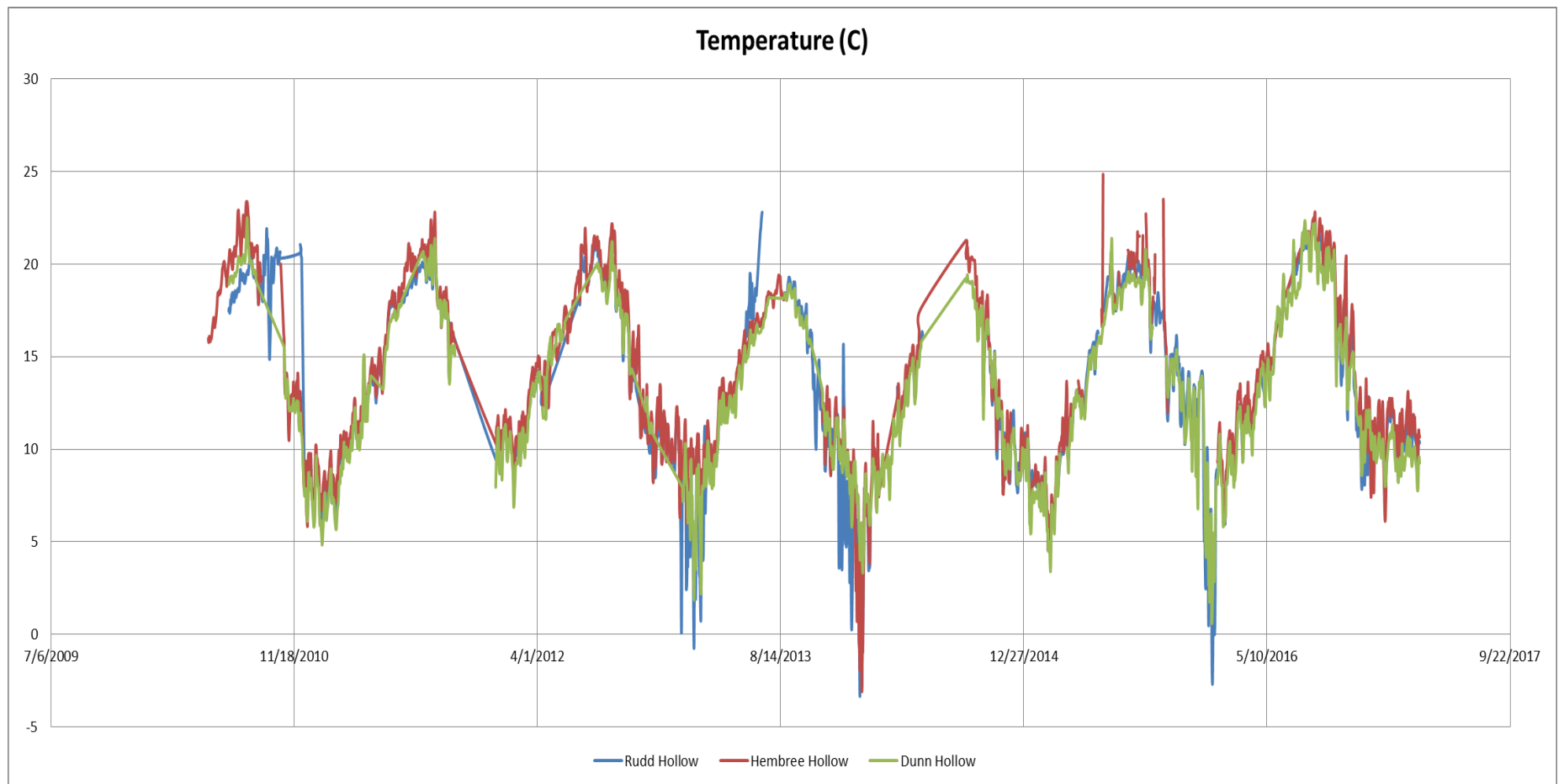


Figure A-2. Temperature comparison of all three watershed streams.

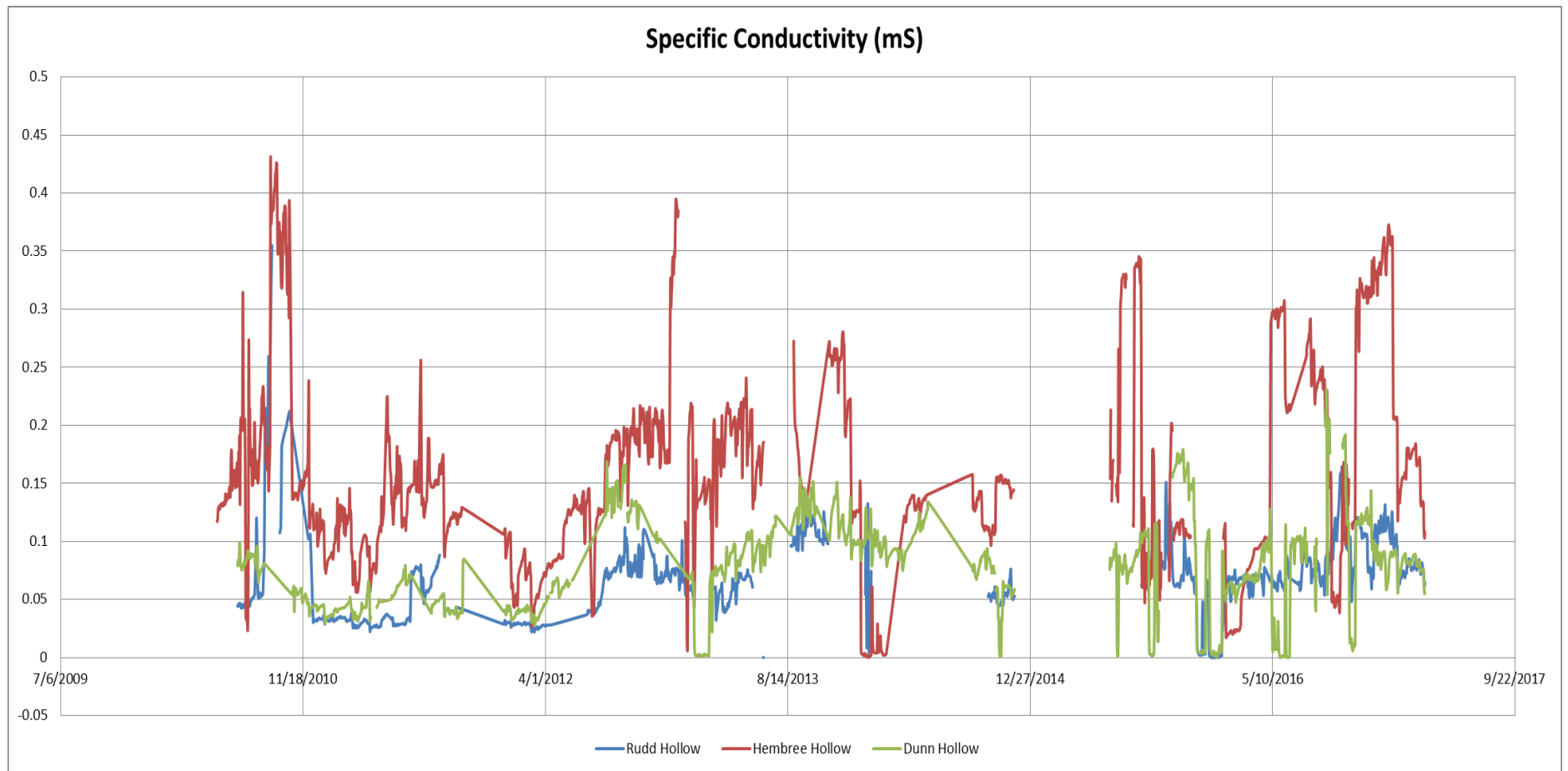


Figure A-3. Specific conductivity comparison of all three watershed streams.

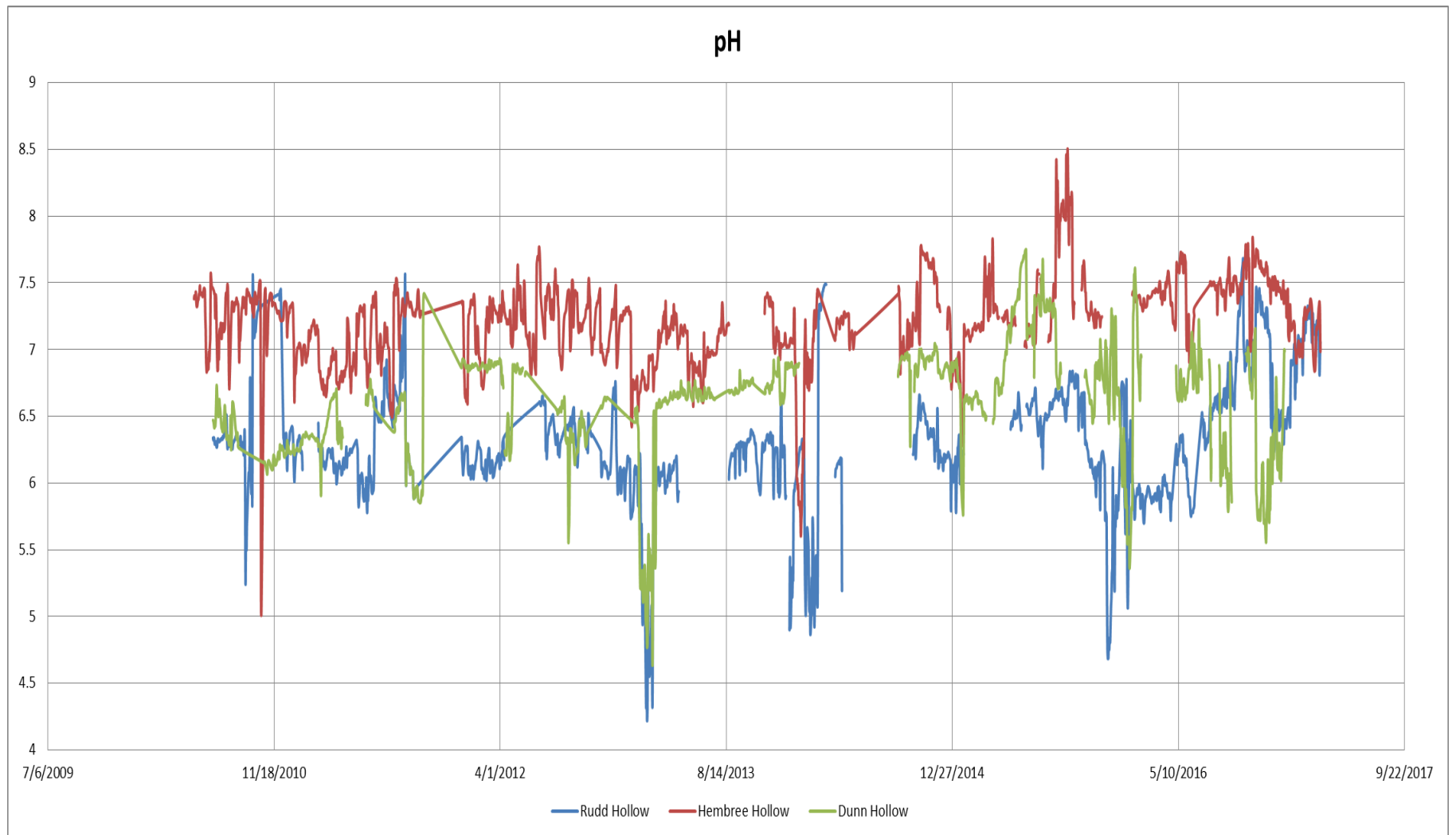


Figure A-4. pH comparison of all three watershed streams.

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