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Modeling Impacts of Foothills Parkway Construction on Stream Water Quality Using Real-time Remote Monitoring

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MODELING IMPACTS OF FOOTHILLS PARKWAY CONSTRUCTION ON STREAM WATER QUALITY USING REAL-TIME REMOTE MONITORING

A Thesis
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the Graduate School of
Clemson University

In Partial Fulfillment
of the Requirements for the Degree
Master of Science
Biosystems Engineering

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by
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Accepted by:
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ABSTRACT

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 research were to deploy and test 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. Real-time remote monitoring stations were established in three small, forested watersheds downstream from construction of the Foothills Parkway in East Tennessee. Water quality sondes measured and recorded streamflow data during the course of a year for turbidity, pH, conductivity, temperature, and stream depth. Rain gauges were used to collect precipitation data. Baseflow and stormflow data were compared to determine effects of storm events on both undisturbed and disturbed forested watersheds. Equations were generated for the purpose of predicting water quality based on storm characteristics. Water quality data were analyzed to assess impacts of highway construction on first-order streams within these watersheds.

For baseflow conditions within the watersheds, mean turbidity ranged from 11.5 to 56.8 NTU. Mean pH ranged from 6.25 to 7.22, while mean conductivity ranged from 0.032 to 0.151 mS/cm. Mean temperature ranged from 8.53 to 18.34 °C. For stormflow conditions, mean turbidity ranged from 77.1 to 285.5 NTU. Stormflow pH, conductivity, and temperature did not significantly differ from baseflow conditions.

Collectively, study of baseflow condition data indicated that Dunn and Rudd were similar in water quality, while Hembree was noticeable different. It was concluded that these differences in water quality between watersheds was due to internal disturbances in Hembree prior to monitoring and, more importantly, before highway construction.

Prediction equations were established describing change in turbidity in terms of precipitation, days since last rainfall, and storm duration. R^2 values were highest at Rudd during leaf-on ($R^2 = 0.80$) and Dunn during leaf-off ($R^2 = 0.81$), while lowest values were found at Hembree during leaf-off ($R^2 = 0.48$). Leaf-on had higher R^2 values than leaf-off at each site except for Dunn.

Before construction and during construction comparisons for each site revealed that Hembree and Rudd mean turbidity for stormflow both decreased from before construction conditions. Analysis of Dunn water quality data also indicated changes during the timeframe of Hembree and Rudd construction. However, because no construction occurred in Dunn during project duration, it was determined that construction activities did not negatively impact water quality in Hembree and Rudd, and that variations in water quality were due to seasonal effects within these watersheds.

DEDICATION

I would like to dedicate this thesis to my parents, Tommy and Kim Chewning, for teaching me the meaning of selflessness by showing me selflessness. To my sister and brother, Sarah and Daniel, for showing me how to laugh and be a kid, and reminding me to stay true to my roots. This is a poor attempt to thank the four of them for an entire life's worth of love, support, and encouragement. To Anna, my best friend, for believing in me and seeing me through this whole journey. To my whole family, my very dear friends, and my church, for their faithful encouragement, support, prayers, and love; they have been my joy and my motivation, and I cannot thank them enough. To my future family: I did all of this for you. Lastly, and most importantly, I would like to dedicate this thesis to my Lord and my Savior, Jesus Christ, without whom I am nothing and would be nothing, but in whom I live and move and have my being.

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CHAPTER 1 – 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 as well. 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, and only certain sections of highway are complete. The area of interest for this particular 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 is monitoring water quality in sites downstream of construction. NPS is concerned with stream water quality that may 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 through the Intelligent River™ initiative. The Intelligent River™ is an on-line data acquisition and management system created to facilitate sharing of environmental data between researchers, natural resource managers, and the general public. Like other online database networks, such as those provided by the United States Geological Survey (USGS) and the US Environmental Protection Agency (EPA), Intelligent River™ is made available to the public via the Web. Rapid data downloads and graphical user interfaces allow better data management and organization. The Intelligent River™ system was used for this research to acquire, organize, and analyze data.

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 the Intelligent River™ database maintained by Clemson University.

Remote stations collected data on pH, conductivity, temperature, turbidity, and depth in order to monitor water quality near Foothills Parkway construction. 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 thresholds were used to establish recommendations for alert notification systems based on construction site effluent limits. EPA ruled in December 2009 that a 280-NTU average daily turbidity limit was determined for construction sites of 10 acres or more (EPA, 2009). Although the final rule was being challenged during the course of this project, 280 NTU was used as a monitoring limit for establishing alert notification systems for contractors at construction sites. Because 280 NTU was based on a 24-hour average, alert system recommendations were designed to notify Clemson researchers and NPS-affiliated individuals of turbidity readings outside the specified range for a time period less than 24 hours. In doing this, site managers could be given sufficient time to visit construction sites to assess situations to verify alerts and determine an appropriate course of action to avoid excessive disturbances and potential permit violations.

Collected field data were used to compare baseflow conditions with storm events for undisturbed forested sub-watersheds. Background streamflow data were needed to determine hydrologic interactions within watersheds without interference from external disturbances, namely, FHP construction. Data were also used to establish correlations between streamflow parameters and rainfall for the purpose of making predictions about water quality based on storm events for undisturbed forested conditions. These correlations were developed as a means of establishing standards for water quality in remote streams within undisturbed watersheds in the Smokies.

Data were also used to compare disturbances in watersheds during construction with undisturbed forested conditions to determine impacts of Parkway construction on remote streams. One 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 two watersheds had minimal to no prior disturbances. The watershed with completely undisturbed conditions was used for comparison with the watershed containing more significantly disturbed conditions.

The objectives for this project were as follows:

- Deploy and maintain a remote data acquisition system for stream flow monitoring.
- Obtain background baseflow data for comparison with storm events for an undisturbed forested watershed.
- Establish predictive methods and standards for stream water quality based on background information obtained for an undisturbed flow condition within a forested watershed.
- Compare streamflow between forested watersheds that were undisturbed versus the same watersheds during construction of a highway.

CHAPTER 2 – LITERATURE REVIEW

Real-time Water Quality Monitoring and Modeling

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 that is 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 is where data is processed, organized, analyzed, and archived (Rouen et al., 2005). Many universities, research, and state organizations employ databases for analysis and archival purposes.

Monitoring stations are designed to be robust 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; site visits can be limited to one or two visits a month. 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. Alert systems can be used to notify natural resource managers of readings outside of specified limits or of impending threshold violations using prediction models, which also provides the added benefit of saving time and money with remediation efforts.

In addition to saving time and money, real-time monitoring systems allow continuous access to 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 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.

In addition to measuring data on common water quality parameters, such as temperature, conductivity, pH, and turbidity, research also strongly recommends obtaining streamflow data (Harmel et al., 2006). This is to better understand runoff contributions from watersheds during rain events as opposed to simply measuring rain depths. In many watersheds, especially in remote regions on headwater streams, traditional stream discharge control devices are often difficult or impossible to install and maintain. Headwater streams often contain such small flows as to be impractical to measure. Storm seasons are commonly the only times during which headwater streams contain flow, also confounding consistent measurement of stream discharge (Tate et al., 1999). At a minimum, study sites should be examined as thoroughly as possible prior to implementing water quality monitoring programs in order to make the best use of the available technologies and equipment. Researchers should gain an understanding of watershed characteristics and general seasonal trends in weather to anticipate more accurately when, how often, and how long sampling should occur.

The Intelligent River™ project at Clemson University is an example of a monitoring system that uses real-time technology with graphical user interfaces to observe, analyze, and archive instantaneous responses in environmental data. The Intelligent River™ is defined as “an environmental and hydrological observation system engineered to support research and management of water resources at watershed scales”. The Intelligent River™ also provides visualization tools for organizing, analyzing, and storing data. Visualization tools allow observation of trends in data and geographic locations in a real-time setting (pers. comm., White, 2010). A data management system such as this could be used to receive real-time data from remote locations, process and organize data to desired formatting, and establish alert notification systems to inform natural resource managers of a disturbance event or limit exceedances (White et al., 2010). Through the Intelligent River™ project, an online database network has already been established in South Carolina and other parts of the Southeast (Eidson et al., 2010), and other remote monitoring systems similar to this have been implemented elsewhere across the globe (Le Dinh et al., 2007).

On-line monitoring networks such as Intelligent River™ can be modified to include or exclude any variety of parameters and measurement combinations. Sampling intervals and reading reports can be adjusted to fit researchers' or environmental managers' needs. Determining appropriate sampling intervals and alert systems is highly site-specific and depends on the objectives of the monitoring program.

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 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 microSiemens per centimeter (mS/cm or μS/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.

Rainfall

Although rainfall is not a direct indicator of water quality, it can be used to determine effects on water quality. Rainfall is typically measured with rain gauges, or rain "buckets". Buckets consist of a conical-shaped cylinder that directs incoming rain from top to bottom of a funnel. Rain drips through a small opening at the bottom and collects in containers enclosed by the funnel. Containers are positioned on a pivot that tips and spills rain when the containers are full. The bottom of the pivot is a magnetic bar that passes over a magnetic strip, which sends a signal indicating a reading. The opening at the bottom of the funnel and the containers are calibrated to measure a certain volume or depth of rainfall. When rain drips into the container, fills it, and tips it over, a reading is taken when the magnetic bar passes over the reed switch, a magnetic strip attached to the base of the bucket.

Rainfall can move sediment and other materials from construction sites to streams. Turbidity has been shown to increase with increasing rainfall, with days since last rainfall (DSLR) being an important determinant (Deletic, 1998). Depending on baseflow conditions, pH can rise or fall with increasing rainfall. Similar to pH, conductivity can be affected by storm events, rising or falling depending on baseflow. Rainfall data can therefore be used to indicate fluctuations in stream water quality characteristics which may impact stream health and wildlife diversity and habitat (Price & Leigh, 2006).

Stream Depth

Although stream depth may not be a direct, obvious indicator of disturbance, it can be used to observe human influences on watersheds. Stormwater runoff generated from impervious surfaces has higher peak flow volume than runoff from undisturbed areas of equal size. Depth readings can be collected in an undisturbed watershed to establish trends during baseflow and storm events. After construction is initiated, depth can be monitored to observe readings above typical ranges for the same watershed in an undisturbed state. For instance, even during large rain events, an undisturbed watershed may not experience depth readings nearly as high as those associated with a disturbance, such as construction. Depth measurements can be used in conjunction with rainfall data to determine if significant disturbances are occurring within a watershed.

Depth is measured by converting pressure readings. Strain gauges are attached to the surface on which pressure is applied. Applied pressure causes displacement of the surface which is detected by strain gauges. Strain gauges give a voltage output which can then be converted proportionally to hydrostatic pressure. Hydrostatic pressure is the pressure applied to an object submerged in a column of water. Pressure can be calculated using the hydrostatic pressure equation:

$$P = \rho * g * h \tag{2-1}$$

P is hydrostatic pressure, force per unit area [N/m^2 (Pa)], ρ is the fluid density, mass per unit volume [kg/m^3], g is the gravitational constant [m/s^2], and h is the height of water of centroid of object [m].

Fluid density, which is a function of temperature, and the gravitational constant are known. Once pressure readings are obtained, the equation above can be solved to obtain depth of stream flow. Depth sensors must be calibrated to exclude atmospheric pressure and include only hydrostatic pressure.

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 affects 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 more sparse. 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 at 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 (DSLR), was a variable that also had significant effects on stream chemistry. Stream pH can decrease with increasing discharge and larger DSLR 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 units 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 μS/cm and decreased one μS/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 μS/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.

Water Quality Standards for Construction Site Stormwater Effluent

Standards are established so that natural resources and all who benefit from them can be protected. The U.S. EPA is the governing body exercising control over water quality conservation and regulations. In December 2009, EPA released the first national discharge limits for turbidity from construction sites (EPA, 2009). The proposed effluent guidelines state the following regarding turbidity: “The numeric limitation is 280 NTU, expressed as a maximum daily discharge limitation”. This means that an average turbidity of 280 NTU is the maximum turbidity that can be discharged from a construction site in a given 24-hr period. Limitations on turbidity under this rule may ultimately apply to any activities involving construction that disturb 10 acres of land or more simultaneously (EPA, 2009). Before this rule, states had the option of independently requiring monitoring specifications for construction sites. If enacted, the new regulation would require all states to monitor stormwater discharge from construction sites and meet the 280-NTU effluent limit. The final rule proposed in December 2009 has received opposition from contractors and builders associations across the nation. In many instances, challenge of the final rule has resulted in court appeals, as contractors claimed that the limit would be impossible to follow and incredibly costly (NAHB, 2010). EPA admitted that there were errors in data and calculations used to determine the limit. Until a new effluent limit was established, EPA opted to retain the limit of 280 NTU. EPA intends to reach a revised final rule by May 30, 2011 in order to enact the revision effective June 29, 2011 (EPA, 2010).

The State of Tennessee currently does not have a numeric limitation on turbidity associated with construction stormwater. The General NPDES Permit for Discharges of Storm Water Associated with Construction Activities, Permit No. TNR100000 states the following concerning sediment: “Sediment should be removed from sediment traps, silt fences, sedimentation ponds, and other sediment controls as necessary, and must be removed when design capacity has been reduced by 50%.” (TDEC, 2005). With regard to turbidity, the permit addresses as follows: “The construction activity shall be carried out in such a manner that will prevent violations of water quality criteria as stated in the TDEC Rules, Chapter 1200-4-3-.03. This includes but is not limited to the prevention of any discharge that causes a condition in which visible solids, bottom deposits, or turbidity impairs the usefulness of waters of the state for any of the uses designated for that water body by TDEC Rules, Chapter 1200-4-4.” (TDEC, 2005). General Water Quality

Criteria published by TDEC declares, with respect to fish and aquatic life in waters of the state, "There shall be no turbidity, total suspended solids, or color in such amounts or of such character that will materially affect fish and aquatic life. In wadeable streams, suspended solid levels over time should not be substantially different than conditions found in reference streams." (TDEC, 2008). Because TN did not have numeric effluent limitations on turbidity associated with construction activities, the 280-NTU limit imposed by EPA was used as turbidity guidelines for this research.

CHAPTER 3 – METHODS

Geographic Information System (GIS) Analysis

Sonde locations and random watershed points were collected using a Trimble® GeoXT GPS (Global Positioning System) unit running TerraSync software. Points were post-processed and differentially corrected using Microsoft® GPS Pathfinder Office software.

Geographic and watershed analysis was performed exclusively using ESRI® ArcGIS Desktop 10.0 with ArcCatalog and ArcMap. Digital elevation models (DEMs) from USGS were used to conduct spatial analysis of elevation and stream data. 10-m DEMs were acquired from USGS Seamless Data Warehouse. Contours and hydrologic maps were created from these DEMs. Geologic maps were also acquired from USGS. Soil maps were acquired from NRCS (National Resource Conservation Service) Soil Data Mart.

Watershed Characteristics and Site Descriptions

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 3.1 displays a map of FHP with completed and uncompleted segments of highway.

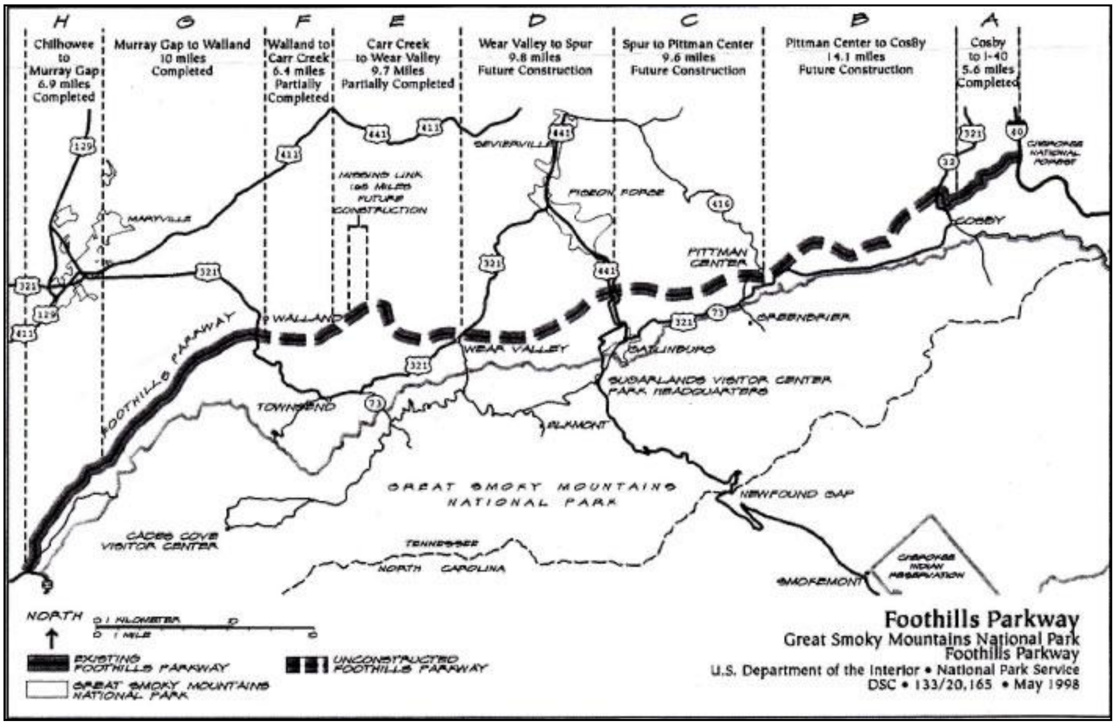

Figure 3.1: Foothills Parkway map showing individual segments of completed road and planned construction.

The area of interest in this research lies outside of GRSM, to the northwest of the park boundary between Townsend and Wears Valley, TN. In Figure 3.1, this area is designated the “Missing Link”. There were three sites in this research, located along Tennessee State Highway 73/U.S. Highway 321. The sites are Hembree Hollow (HH), Dunn Hollow (DH), and Rudd Hollow (RH). Figure 3.2 shows a Google® map of the surrounding area, including Townsend and Wears Valley. Pigeon Forge, TN and Gatlinburg, TN are a few miles east. The mean annual precipitation in Gatlinburg is 141 cm, and the mean annual temperature is 13.2 °C (SERCC, 2007).

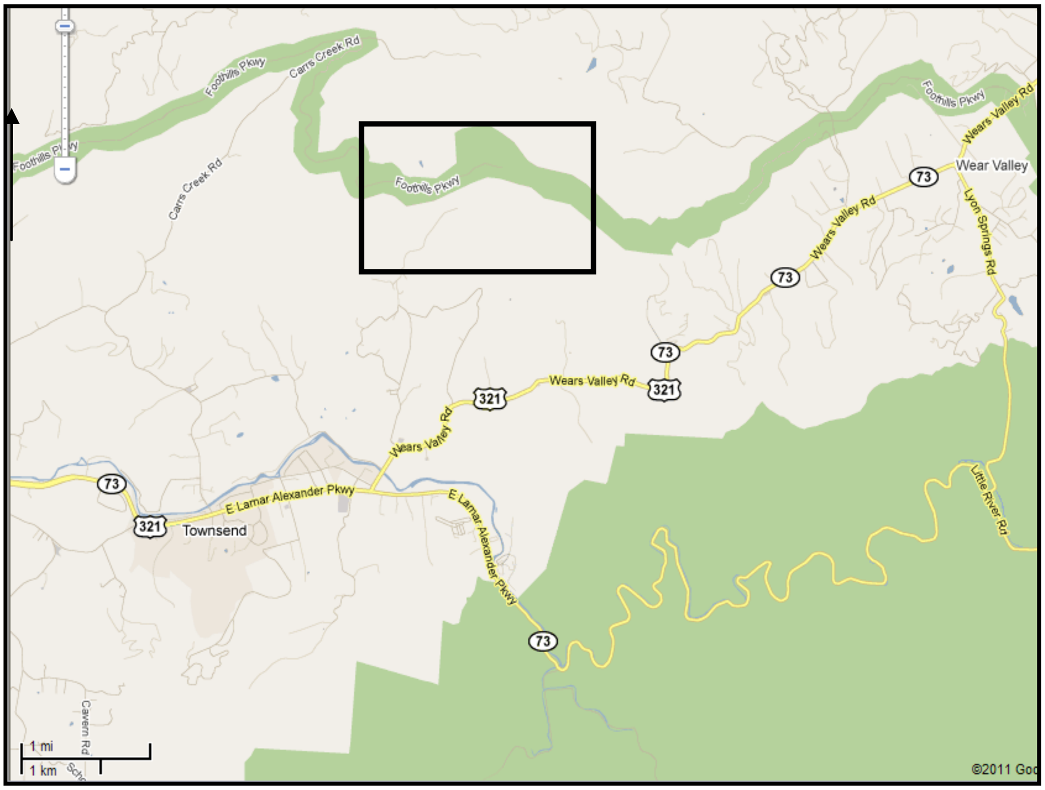

Figure 3.2: Google® Map showing vicinity of research area.

Study sites were located in Blount County, Tennessee along stretch of highway between FHP right-of-way and the larger area dominating lower portions of the map, signifying GRSM boundary. The box indicates approximate research site areas. Figure 3.3 shows location of sites in relation to each other and to Parkway. Red lines indicate watershed boundaries, and green dots represent monitoring station locations.

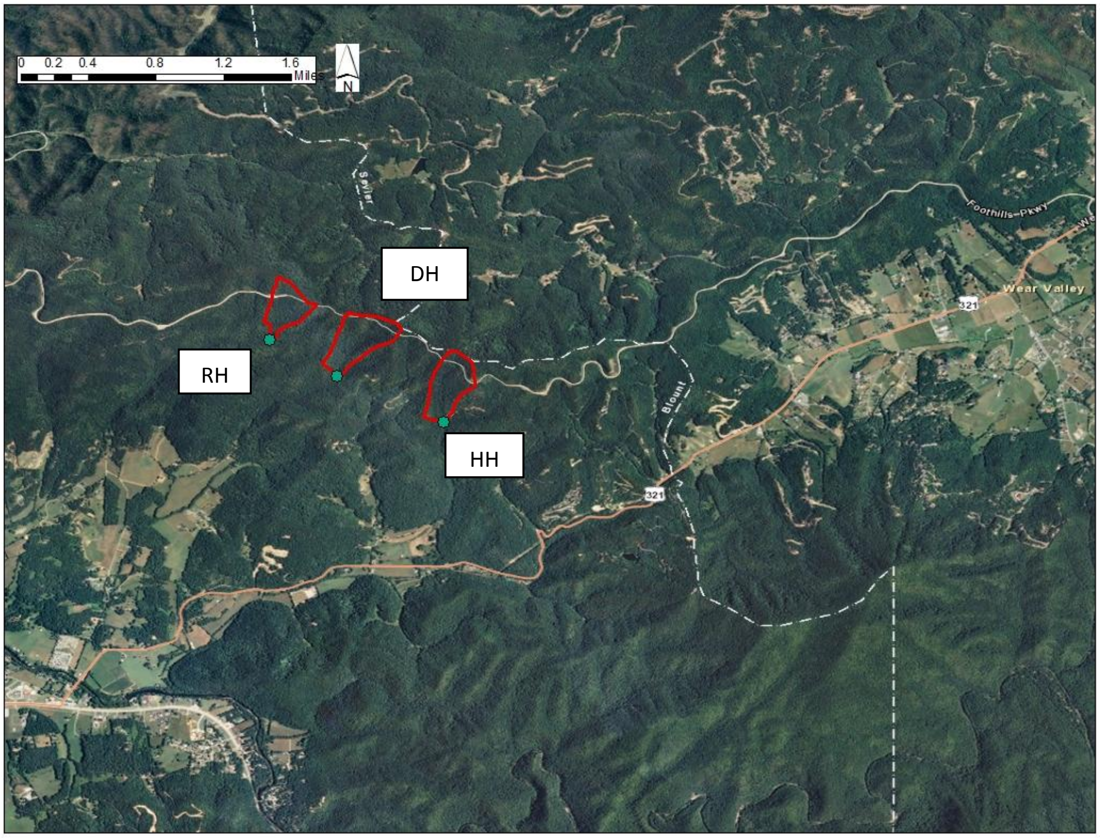

Figure 3.3: Location of sites using GIS imagery.

The white line running through watersheds is FHP right-of-way. Although Figure 3.3 shows a filled white line, construction between watersheds had not been completed. As seen in Figure 3.3, FHP was planned to run along the southern slope of ridge in northern regions of research watersheds. 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 3.4 provides a more detailed view of watersheds and sonde locations projected onto a historical topographic map.

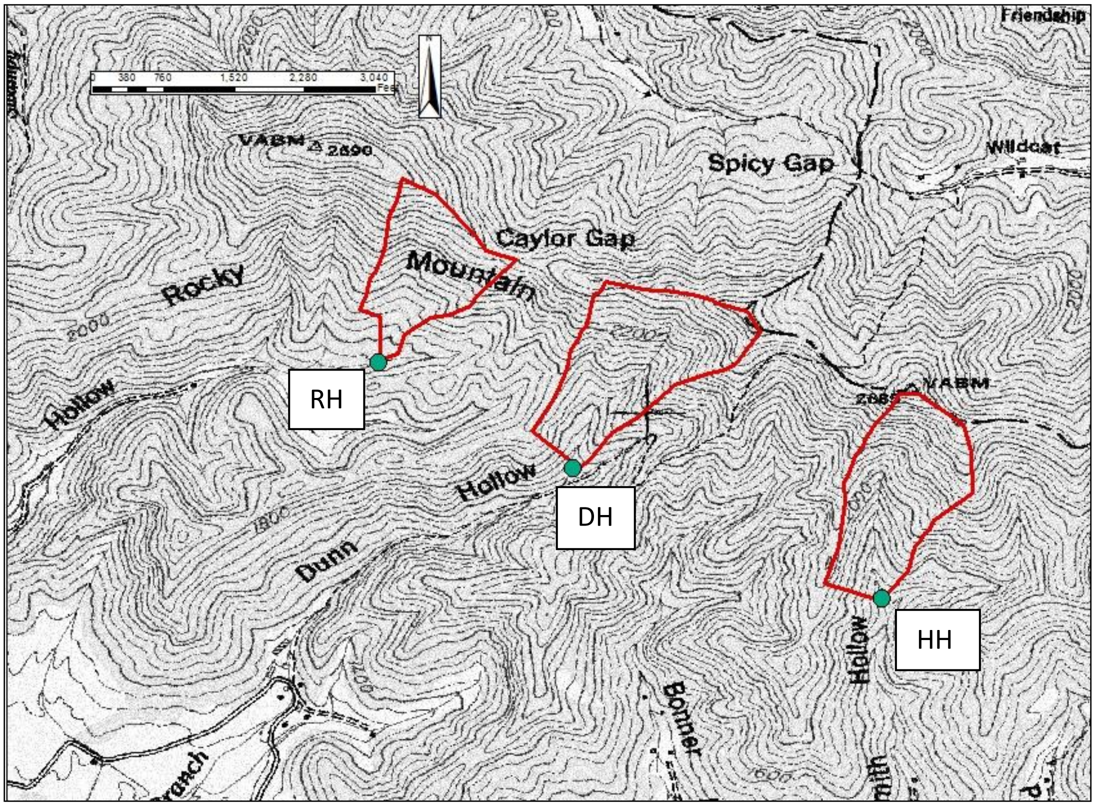

Figure 3.4: Historical topographic map showing watershed boundaries and sonde locations.

As seen on Fig. 3.4, Rudd Hollow and Dunn Hollow are approximately 610 m (2,000 ft) apart, and Dunn Hollow and Hembree Hollow are approximately 910 m (3,000 ft) apart. The research watersheds were all within one km (one mile) of each other. Figure 3.5 displays watershed elevations.

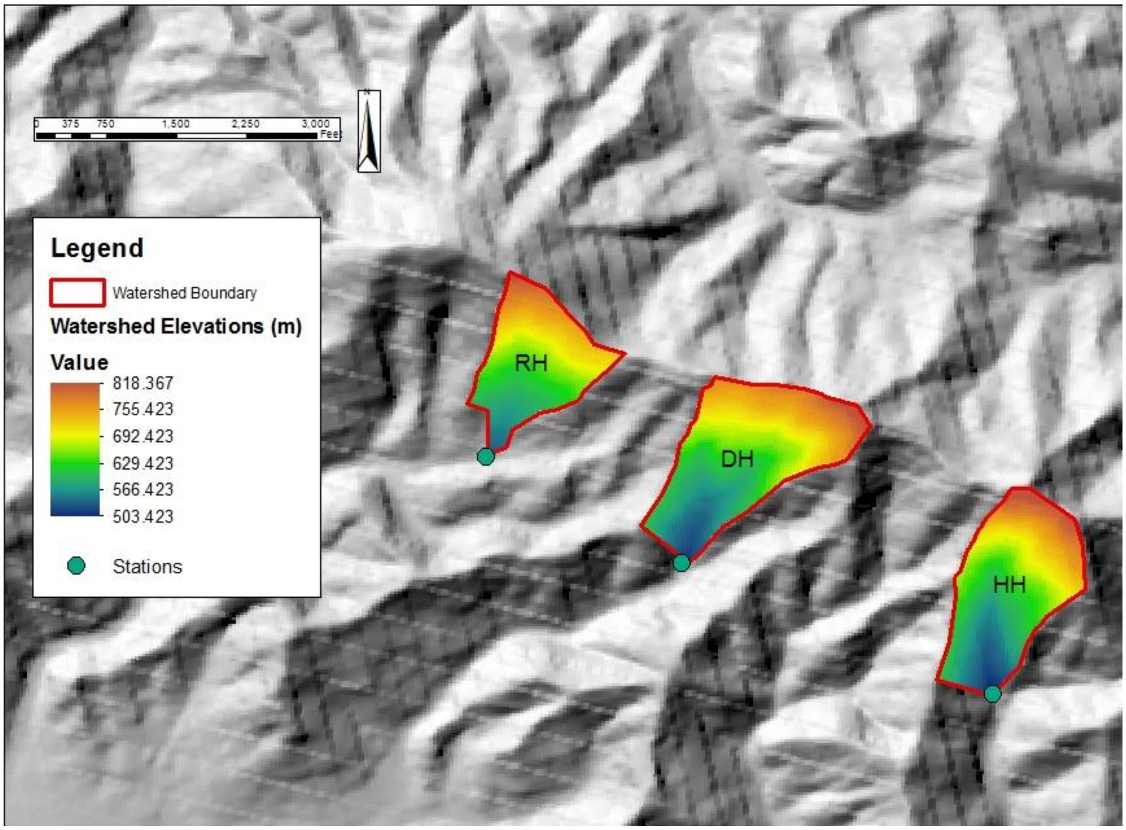

Figure 3.5: Watershed elevations calculated using GIS.

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 3.6 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. Specific watershed characteristics are discussed subsequently.

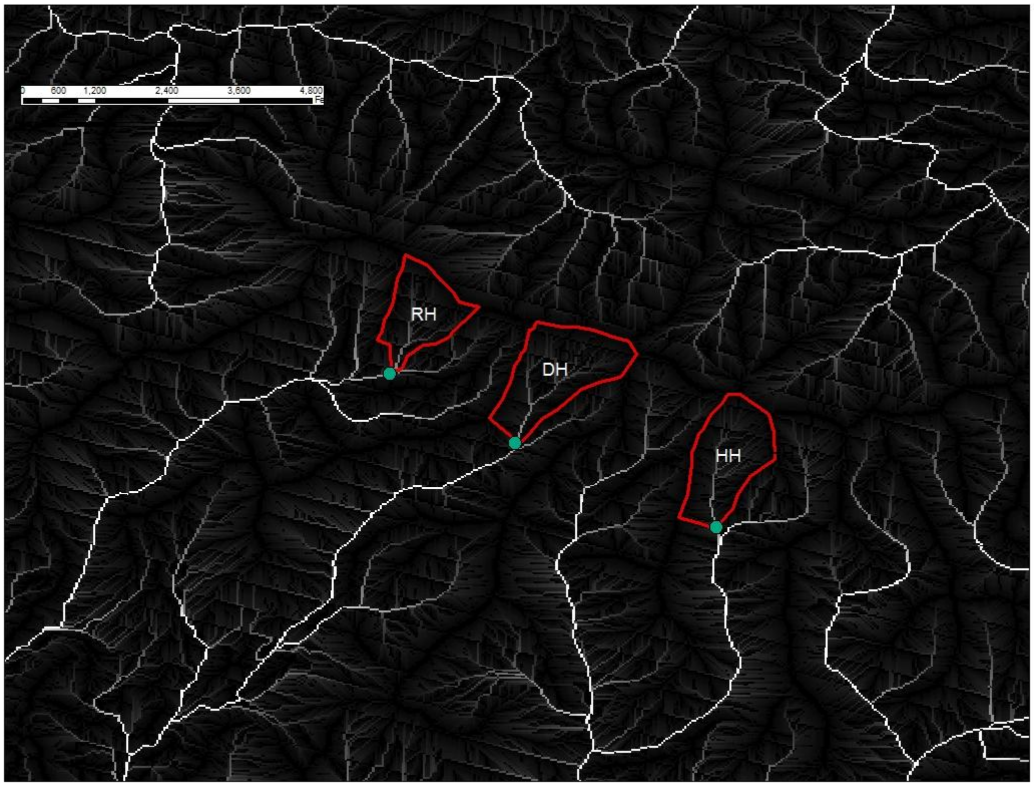

Figure 3.6: Stream networks in research watersheds.

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 3.7 shows slope variations in study watersheds.

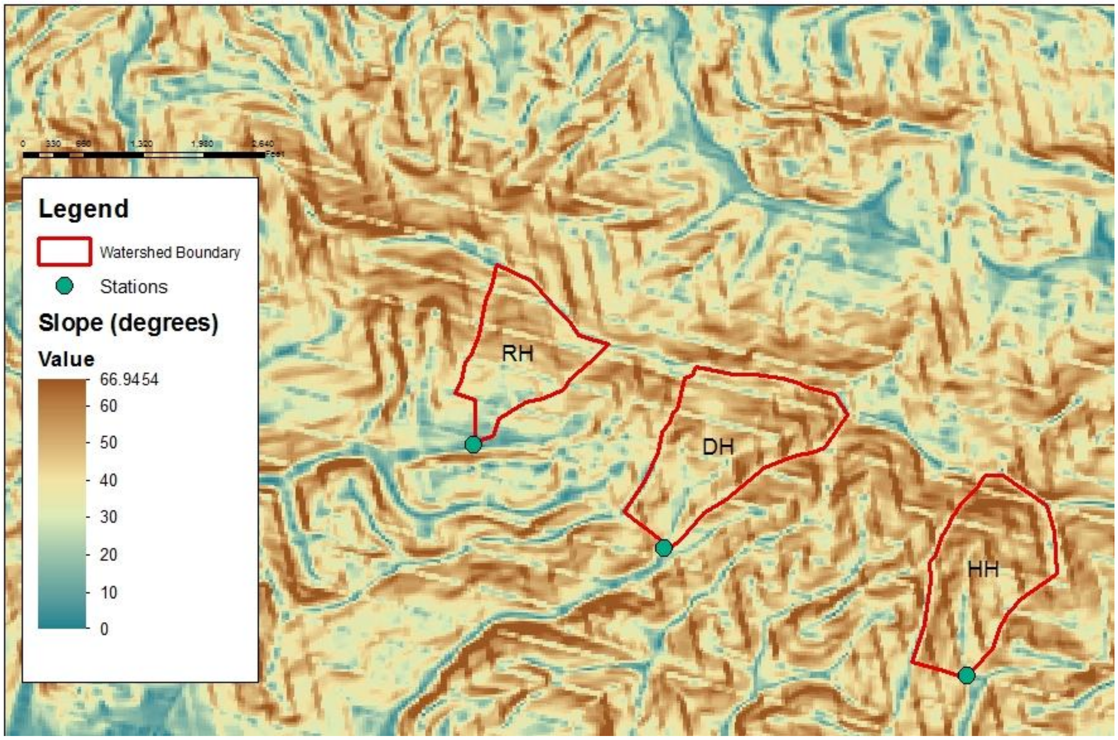

Figure 3.7: Slope variations in research watersheds.

<u>Hembree Hollow</u>

HH was a 15.9-ha (39.2-acre) watershed bordering FHP right-of-way. The station at HH was at elevation 504 m (1,655 ft). HH flow path was 730 m (2,400 ft), which is the distance from site to furthest point away in the watershed. 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. Rain gauges were placed strategically within each watershed to examine effects of various canopy cover on rainfall.

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 was apparent by ATV tracks. Approximately 100 yards upstream from monitoring location, road cuts crossed 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. HH experienced periods of no flow during peak summer months, which caused problems for monitoring as probes could not maintain contact with water. There were several incidents where turbidity readings were above 1,000 NTU simply because the sonde become buried under sediment, or "silted over". In many places streamflow went underground and resurfaced several meters downstream. Because of these inconsistent flow conditions, stream discharge was not measured at HH. Several salamanders were observed in the pool where monitoring occurred. Salamander activity was observed to cause fine sediment resuspension which complicated the issue of eliminating false turbidity spikes during periods of low flow in summer months.

Laboratory testing revealed that stream chemistry consisted of the following constituents: K (0.7 ppm), Ca (11.0 ppm), Mg (6.1 ppm), SO_4 (8 ppm), and Na (2 ppm). No PO_4 or NO_3 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. A chart summarizing Rosgen classification types is shown in Figure 3.8.

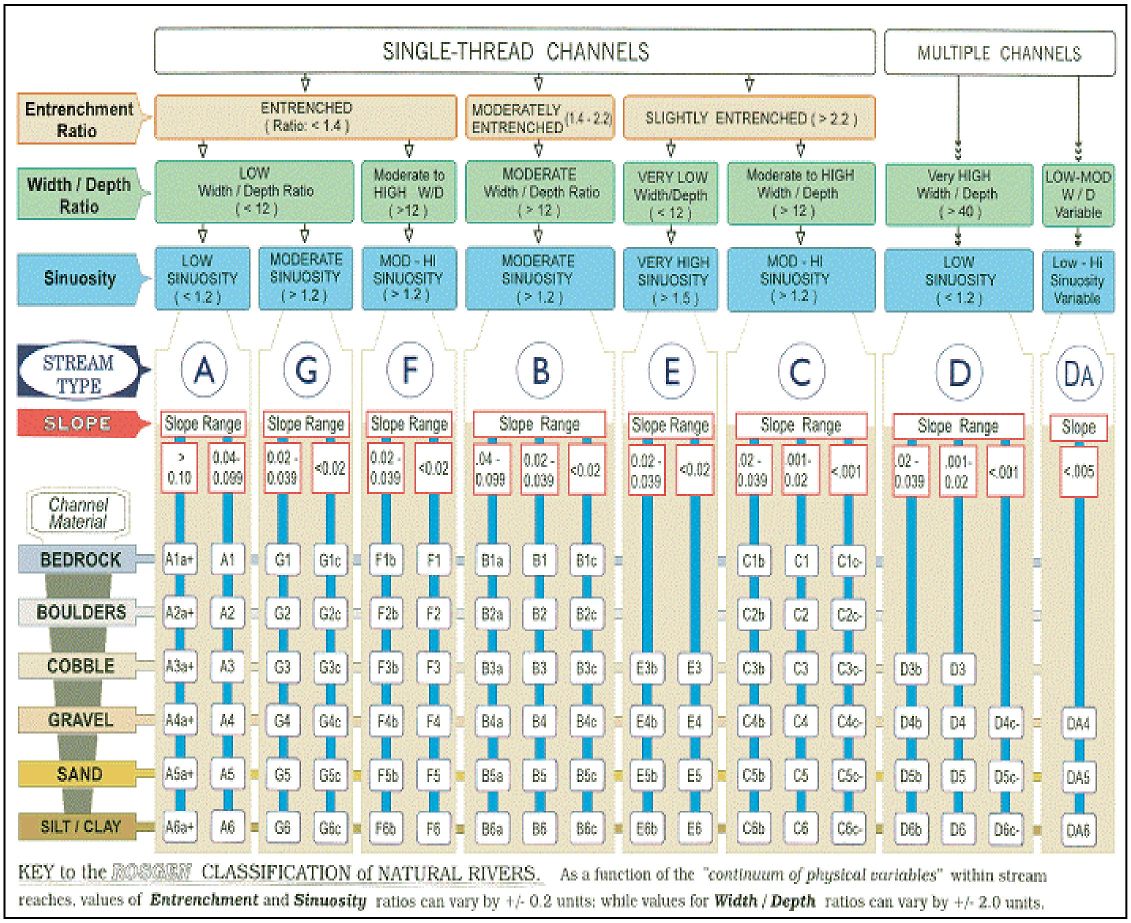

Figure 3.8: Rosgen stream classification system (Rosgen, 1996).

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% and an approximate Manning's n of 0.035 characterized this stream (Haan et al., 1994).

Dunn Hollow

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

DH was 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. More so than at HH, fine materials frequently settle on sonde and surrounding bedrock in stream. This was attributed to altered flow regimes within the pool where monitoring occurred. Pools act to reduce flow velocity in streams and, therefore, reduce the potential for sediment transport within streams. This phenomenon was observed at both HH and DH. Leaves and fine organic matter were frequently observed in bottom of the pool. Frogs were observed near boulders along stream bank beside pool where monitoring occurred. Observation revealed that frog activity stirred up sediments, similar to HH.

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), SO_4 (3 ppm), and Na (1 ppm). No PO_4 or NO_3 were present. TDS was 38 ppm, and EC was 0.06 mmhos/cm.

Rudd Hollow

RH was 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. The sonde was 670 m (2,200 ft) from furthest point in the watershed, making it closest in proximity to FHP right-of-way. RH had approximately 12% disturbance in the upper reaches of the watershed.

Rudd was 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 was apparent as shotgun shells and casings were observed during late winter and spring months, and surveying flags were 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), SO_4 (2 ppm), and Na (1 ppm). No PO_4 or NO_3 were detected. TDS was 26 ppm, and EC was 0.04 mmhos/cm. Tables 3.1 and 3.2 summarize watershed characteristics for each study site.

Table 3.1: Topographic characteristics of research watersheds.

Site	Area (ha)	Station Elevation (m)	Soil Type	Bedrock Geology	Percent Disturbance (%)
HH	15.86	504	Rb	Cambrian shale siltstone	5
DH	18.27	519	Rb	Cambrian shale siltstone	0
RH	11.59	536	Rb	Cambrian shale siltstone	12

Time of concentration, which is defined as the time required for flow to reach watershed outlet from hydrologically most remote point in the watershed (Haan et al., 1994), was calculated based on flow velocity along the flow paths within the watershed. Flow velocity was calculated using the following equation (Haan et al., 1994):

$$v = a * S^{1/2} \tag{3-1}$$

In Eq. (3-1), v is flow velocity in ft/s, a is a coefficient based on surface cover type in ft/s, and S is slope is ft/ft, or percent. Travel time was then calculated by dividing flow length for that segment by flow velocity. Time of concentration was then calculated by summing the individual travel times. Times of concentration calculated for each watershed are given subsequently, along with other hydrologic characteristics.

Table 3.2: Hydrologic characteristics of research watersheds.

Site	Stream Type	Flow Path (m)	Time of Concentration (min)	Slope (%)	Manning's n	HSG
HH	A5a+	731	21.79	10-20	0.035	D
DH	A1a+	770	23.43	10-20	0.035	D
RH	A5a+	672	18.86	10-20	0.035	D

Table 3.3: Soil attributes of research watersheds.

Site	pH	CEC (meq/100g)	Acidity (meq/100g)
HH	5.4	6.6	4.4
DH	5.5	9.5	5.2
RH	4.8	5.9	4.4

Monitoring Station Design and Sampling Interval Selection

Each remote monitoring station consisted of five primary components: a water quality sonde placed in stream, a rain gauge, a datalogger, a cellular modem, and a power source. YSI® 6600 EDS V2 sondes were used at each of the three sites 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. Ecowatch® software was used to communicate with sondes for configuration, performing calibrations, adjusting sampling settings, and downloading recorded data.

Grab samples were collected weekly during summer 2010. After this time, grab samples were collected during site visits, which were approximately every four weeks. Approximately 100 grab samples were taken in all. Beginning in January 2011, hand-held pH probes were taken to field and measurements taken in-stream.

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 and transmit to Sierra Wireless® AirLink Raven XT cellular modems. Sondes were connected to dataloggers using SDI-12 terminals, and dataloggers were connected to modems using RS-232 terminals. Clemson web servers downloaded data from modems. Dataloggers and modems transmitted data in 15-minute intervals, which was consistent throughout the entire project.

Two 12-volt deep-cycle gel batteries were used to power dataloggers and modems. Batteries were connected in parallel to both limit voltage going into the circuit and to conserve longer battery life. BP® SX375J solar panels were used to capture sunlight and recharge 12-V batteries. Morningstar® ProStar-15 solar charger controllers were employed to regulate voltage into 12-V batteries as well as 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 3.9 provides an example of station setup, specifically at HH. This setup was used for each study site. Figure 3.10 shows equipment housed in boxes, Figure 3.11 shows the sonde in stream at HH.

Figure 3.9: Station setup at HH showing solar panel, equipment boxes, and rain gauge.

Figure 3.10: Wireless communication, datalogging, and power equipment at HH.

Figure 3.11: Sonde in stream at HH.

Rain gauges were placed strategically at study sites to determine canopy cover effects on rainfall. HH rain gauge was placed away from trees in direct view of the sky. The gauge was positioned on a platform approximately two m (six ft) high. Bubble levelers were used to level rain gauges at each site. DH rain gauge was attached to the base of a large oak tree approximately two m from the ground. RH rain gauge was placed in the same manner as at HH. Positioning rain gauges in different ways at each site facilitated comparison of rain data for various canopy covers.

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. The reason for the difference was that sonde logging activity was not verified with computer software. Rain gauges were not installed initially due to software compatibility issues. DH rain gauge was installed on October 27, 2010, HH on November 17, 2010, and RH on December 9, 2010.

In order to include missing rainfall data in statistical analysis, data from Cades Cove in GRSM was used as a substitute for study site rainfall data (NPS, 2011). Cades Cove is a valley located in northwestern GRSM. It is approximately nine miles from study sites and is similar to monitoring stations in elevation. This was the closest station to the monitoring watersheds from which precipitation data could be obtained.

Monitoring sites were chosen based on consistency of stream flow. As mentioned previously, streamflow frequently went from surface to subsurface and back again. Since the primary objective was to acquire water quality monitoring data, study sites had to be established in places with most consistent flow as possible. In order to eliminate as many internal effects as possible at HH, only a small 100-yd length of streamflow was available for study. Although streamflow at RH was slightly longer and less internally disturbed than at HH, sufficient streamflow for observation at RH was also limited. Only in DH was stream flow consistently sufficient as to provide observable readings for water quality.

Initially, readings were taken every 10 minutes with the sondes. After turbidity “spikes” were observed during periods of no rain or flow in summer months, particularly at HH, sampling intervals for the sondes were reduced to five minutes to determine potential sources of spikes. Sampling intervals were statistically compared to determine which was most appropriate. Because HH turbidity data appeared more “flashy”, HH turbidity data was chosen for analysis of most appropriate sampling interval.

Monitoring Station Maintenance

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

Sonde probes were calibrated approximately every two to four weeks. 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. Appendix A provides information concerning sonde calibration schedule.

Sondes were calibrated as frequently as possible to avoid drift in instrumentation measurements. Drift was not noticed in any sonde probes at any site except for periods when probes were damaged or sondes were buried in sediment. It was later discovered that such frequent calibrations were not necessary (YSI, 2010). However, calibrating sonde probes approximately every month ensured that water quality readings were accurate and precise.

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-μS/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. This happened at least once at each site. In September 2010, HH temperature/conductivity probe was found broken in half, with sonde lying in stream with sticks and sediment clogging the sensor cage. It was suspected that a storm event caused heavy sedimentation to sweep across the sonde sensor cage, causing sticks to become lodged, potentially breaking the sensor. Also in September 2010, RH sonde was found lying on the stream bank with a severed connector cable. The sonde was brought back to Clemson campus for repairs and calibration. It was uncertain as to the cause of such an incident; vandalism was suspected.

In April 2011, DH sonde experienced the same issue, as it was found lying on the stream bank downstream from its original placement in stream. Visual observation revealed that no probes had been damaged. The sonde was returned to its location and monitored from Clemson campus. A couple of weeks later, the sonde had to be pulled from the stream and taken to Clemson campus to troubleshoot hardware/communication issues with the laptop. The sonde was not responding to computer commands, so it was brought back and monitored. Insufficient internal battery voltage was determined to be the cause of communication issues, and damage from being out of stream was ruled out as a cause for this behavior.

Modems occasionally experienced communication failures. In these instances, modems could often be reset through wireless connections from Clemson computers. On other occasions, however, hard resets were required to enable modem connections with Clemson servers, which required site visits.

Because of solar panel placement in DH, 12-volt batteries experienced difficulty in charging to maximum potential. This was most dramatically noted during leaf-on months when canopy significantly blocked sunlight from reaching the solar panel. Modems required majority of the power supplied by 12-volt batteries, and proper and constant modem function was essential to maintaining observations at remote sites. When battery voltage dropped below a certain level, usually around 11.7 V, modems experienced failure due to lack of power. To resolve this issue, batteries were taken out of HH, where sunlight was plentiful because of open canopy, and placed in DH, where they could keep station running temporarily. Depleted DH batteries were placed in HH to charge.

Statistical Analysis

All statistical analysis was performed using SAS® 9.2 statistical analysis software package. Key analyses performed on water quality and precipitation data included ANOVA, multiple regression, correlation analysis, and slope-intercept regression.

ANOVAs (ANalysis Of VAriance) were performed on multiple data sets using a PROC GLM procedure in SAS® to compare descriptive statistics between sets. Baseflow and stormflow conditions for turbidity were compared for each of the three sites for both “leaf-on” and “leaf-off” seasons. Leaf-on and leaf-off periods indicated months when leaves were on and off trees, respectively. Leaf-off was between Nov. 1, 2010 and Mar. 31, 2011. Leaf-on data spanned May 25, 2010 to Oct. 31, 2010 and Apr. 1, 2011 to May 22, 2011. This incorporated seasonal variability in water quality and precipitation data and is consistent with literature documenting water quality studies in the Great Smoky Mountains region (Deyton et al., 2009). Baseflow pH, conductivity, and temperature data were compared for each site. Rain data were compared for each site between leaf-on and leaf-off seasons. Turbidity data collected before construction (BC) were compared to during construction (DC) turbidity data for each site between leaf-on and leaf-off. Baseflow was defined as an average of measurements taken between storm events for each parameter. Stormflow was defined as the average from the time of storm commencement to three hours after storm subsidence. This was determined after visual observation of graphs including rainfall and water quality measurements superimposed. These graphs indicated that a three-hr lag occurred between peak rainfall and fluctuations in water quality parameters, as seen in Figure 3.12. LSD and Tukey tests were used to pair data sets based on statistical similarity.

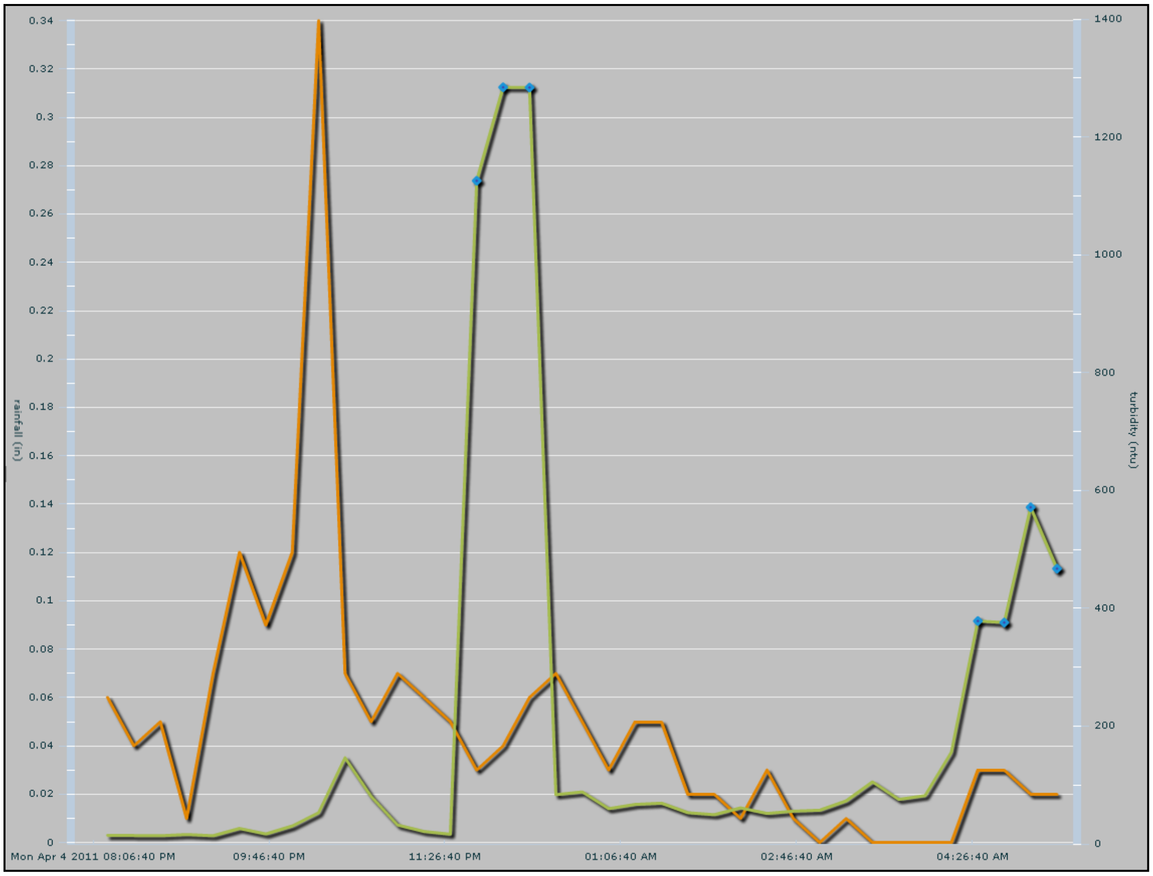

Figure 3.12: Example of time lag between rainfall (in) and turbidity (NTU) for RH.

Multiple regression (MR) was used to determine trends in data sets. MR analysis included all water quality parameters for leaf-on and leaf-off at each site. Data were examined graphically first for any observable trends in data. Correlation analysis was then used to statistically determine best correlations between water quality variables and rain data. The objective was to establish trends (if any) between storm events and fluctuations in water quality parameters, particularly turbidity. Correlation analysis aided in determining which variables were most closely correlated with each other and with rain.

Best correlations were determined using a PROC CORR procedure in SAS®, and regression analysis was performed using a PROC REG statement to determine relationships between correlated variables. Parameter transformations converted variables into squared, square root, and natural logarithmic scales during leaf-on and leaf-off. Days since last rainfall (DSLR) was added as a variable in attempt to better explain behavior and increase R^2 values for regression analysis. As a final addition, storm duration was used as a variable. A PROC UNIVARIATE procedure then revealed which data points were outliers. These outliers were removed and regression analysis was performed again with edited data.

Slope-intercept regression was used as a more thorough comparison of behavioral patterns between parameters as opposed to simply comparing means. This was used to determine the validity of using Cades Cove data as a substitute for missing precipitation data from study sites before rain gauges were installed. Cades Cove precipitation data was plotted against rain data collected at each site during times when both Cades Cove and study sites acquired rain data. Plots determined if slopes were 1:1 and intercepts were zero. If slopes differed significantly from 1, or if intercepts differed significantly from zero, behavioral patterns between Cades Cove and study sites were determined to be different enough as to present difficulty in finding true rainfall influences on water quality variables.

Slope-intercept regression was also used to determine an appropriate turbidity alert system and sampling interval for sonde data. 2-hr, 4-hr, 8-hr, 12-hr, 16-hr, 20-hr, and 24-hr running turbidity averages were calculated and plotted against each other. The objective was to determine if running averages differed significantly in behavior from each other using analysis previously mentioned. This was done in order to notify FHP site managers of potential violations of EPA-specified turbidity effluent limitations. It was desired to determine a running turbidity average as close to 24 hr as possible while still allowing adequate time for site inspections in the event of a potential effluent violation. 5-min, 10-min, 15-min, 30-min, and 60-min sampling intervals for water quality parameters were plotted against each other as well. The objective was to determine a sampling interval that would produce best-resolution data in water quality measurements so as to better understand influences in both natural and disturbed forested watersheds.

CHAPTER 4 – RESULTS & DISCUSSION

Water quality data were collected in three Great Smoky Mountain watersheds for one year. Data included turbidity, pH, conductivity, temperature, and precipitation. Data were analyzed to determine behavioral trends using statistical analysis. The results presented subsequently are outlined according to the thesis objectives to which they pertain.

Objective 1

The first objective was to deploy and maintain a remote data acquisition system in three small mountain watersheds. This included determining an appropriate sampling interval and turbidity alert system.

Water quality data were collected over the course of a year. Raw data acquired by sondes included observations that were taken during all conditions, including instances when sondes may have been reading incorrectly or when sondes were displaced from streams. Figure 4.1 shows a graph of conductivity data at RH during an event which captured incorrect data.

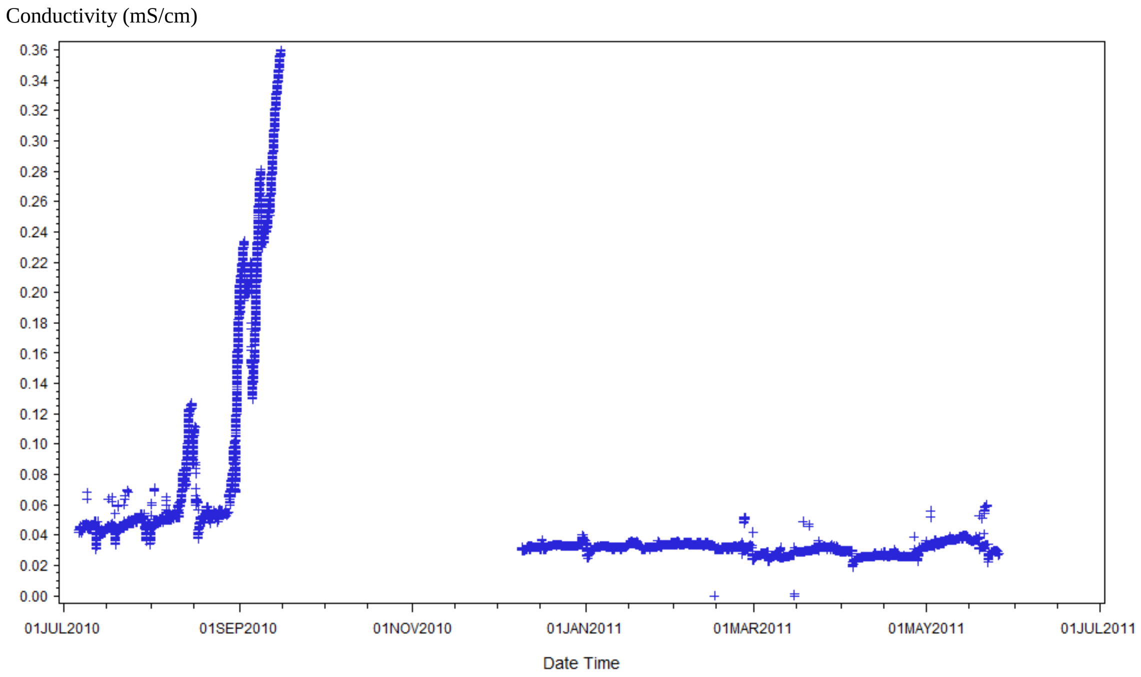

Figure 4.1: RH conductivity plot showing incorrect data readings.

As seen in the figure, there appear to be readings that are outside the normal range for RH conductivity data. Around the beginning of September 2010, conductivity increased significantly during a short period of time. This was attributed to incorrect sonde readings due to the sonde being found outside of the stream during a site visit. This illustrates the importance of analyzing data to ensure that accurate data are reflected in comparisons and statistical analysis.

Turbidity data for stormflow conditions at HH were used to determine most efficient sampling interval to capture most accurate behavioral trends in turbidity data. Readings were categorized into 5-, 10-, 15-, 30-, and 60-min intervals. Turbidity readings were also grouped into 2-, 4-, 8, 12-, 16-, 20-, and 24-hr running averages to determine most appropriate turbidity alert system for construction site managers.

Comparison of mean turbidity for each sampling interval revealed that sampling interval did not have an effect on turbidity. Means between 5-min, 10-min, 15-min, 30-min, and 60-min turbidity samples were not significantly different (α = 0.05). Table 4.1 summarizes comparison of mean turbidity for each sampling interval at HH.

Table 4.1: Comparison of mean turbidity for each sampling interval at HH.

Statistic	5-min	10-min	15-min	30-min	60-min
Mean (NTU)	30.7	30.1	31.0	30.3	31.2
Std. Dev.	93.4	89.3	97.5	91.6	96.6
Max	1434.3	1432.3	1434.3	1387.4	1387.4
Min	1.2	1.2	2.4	2.4	2.4

The table shows that mean turbidity values do not differ significantly between sampling intervals. This is likely due to large standard deviations associated with these readings, indicating large variations in data. For each site, variance was determined to be equal for mean turbidity readings at each sampling interval (α = 0.05). These results show that there is no significant difference between mean turbidity for sampling intervals of 5 min, 10-min, 15-min, 30-min, and 60-min. Therefore, one could use a 60-min sampling interval to measure turbidity and expect to retain as much variation in behavior as for a 5-min turbidity sampling interval. However, the data used for this analysis consisted of stormflow turbidity taken during late winter and early spring months, when storms tend to be longer in duration than during summer months. If a storm event occurred that was less than one hr while a 60-min sampling interval was used and caused severe turbidity increases, these elevated turbidity levels would be missed. Similar suggestions have been put forth by previous research (Tate et al., 1999; Kirchner et al., 2004; King & Harmel, 2003; Harmel et al., 2006). To summarize, the following outline lists advantages and disadvantages of 5-min and 60-min sampling intervals:

5-min:

- Provides higher-resolution data during storm events
- Eliminates false positives for turbidity readings
- Creates unnecessarily large databases with redundancy during baseflow; resolution is not increased
- More expensive because more sampling is required

60-min:

- Reduces database size, allows for easier data management; no resolution lost during baseflow
- Cheaper because less samples are being taken
- Potential for missing data during storm events, especially during summer months with shorter storm durations

Correlation analysis of turbidity alert system revealed that for each site, lowest Pearson correlation coefficients were for 2-hr and 24-hr running average comparisons. This was to be expected, as a two-hr running turbidity average would differ most from a 24-hr running turbidity average given the range of averages selected. The lowest correlation coefficient was for RH (r = 0.89969). Conversely, when compared to a 24-hr running turbidity average, a 20-hr running turbidity average had highest Pearson correlation coefficient for each site. This also was to be expected.

Although 20 hrs would be most ideal to select as a turbidity alert system, as it is most closely correlated to 24 hrs, it would be impractical to schedule a 20-hr alert because site managers would not be given ample time to visit sites in event of a sediment release, let alone make attempts to remediate issues in order to avoid permit violation. It was decided, therefore, that a 16-hr turbidity alert system would best resemble turbidity for a 24-hr period while still providing site managers sufficient time to visit sites in event of an emergency and decide appropriate course of action for remediation.

After a 16-hr alert was selected, slope-intercept regression analysis determined how closely a 16-hr interval resembled a 24-hr alert. Table 4.2 summarizes slope, intercept, and R^2 for regression analysis on each site.

Table 4.2: Slope-intercept regression analysis using 16-hr interval for each site.

Site	Slope	Intercept	R^2
HH	1.00182	-0.47936	0.9915
DH	1.00453	-0.29842	0.9783
RH	1.00463	-0.21794	0.9738

If a 16-hr average perfectly resembled a 24-hr average, slope would equal 1.0, intercept would equal zero, and R^2 would equal 1.0. The table above reveals how closely each parameter is to true resemblance. Therefore, it was determined that a 16-hr running turbidity alert system would work best given real-world field conditions. These results, however, are recommendations; site managers may chose to implement shorter or longer turbidity alert systems depending on variables such as travel time to sites, remediation time, and other factors. Using a shorter or longer running turbidity average to model turbidity for a 24-hr average system would have statistical validity.

Objective 2

The second objective was to obtain background baseflow data for comparison with storm events for undisturbed forested watersheds. Water quality data used to compare between watersheds for BF and SF conditions during leaf-on and leaf-off included turbidity, pH, conductivity, and temperature.

Rainfall

Cades Cove (CC) precipitation data was needed to substitute for missing data at each research site. Slope-intercept regression analysis was used to compare rain data for each site to CC and to between research sites. Table 4.3 summarizes slope-intercept regression results for rainfall data substitution using CC data.

Table 4.3: Slope-intercept regression comparing rain data for each site to Cades Cove.

Site	Slope	Intercept	R^2
HH-CC	1.18756	-0.00605	0.8003
DH-CC	1.44708	0.00135	0.7288
RH-CC	1.29111	-0.00754	0.8287

As seen in the table above, CC data did not perfectly match study site data. However, in order to determine regression models for water quality variables and storm events, rain data was essential. Discussion with a meteorologist revealed that rainfall can vary considerably between sites separated by a few miles or less (pers. comm., Linvill, 2011). Therefore, CC rain data was chosen based on proximity to sites and similarities in elevation and canopy.

Comparison of rain data between individual sites was also performed. Results are summarized in Table 4.4.

Table 4.4: Slope-intercept regression comparing rain data between individual research sites.

Site	Slope	Intercept	R^2
HH-DH	1.21072	0.00708	0.8989
HH-RH	0.91410	0.00123	0.9536
DH-RH	1.14507	0.00334	0.9176

As seen in the table above, HH and DH rain data were least similar of all three comparisons. This result is to be expected. HH rain gauge is positioned in open canopy, free from interception of leaves and branches overhead. DH rain gauge is fastened against a large oak tree and is thus placed in closed canopy. This difference in forest cover above rain gauges explains variability between HH and DH rain data. The results in Table 4.4 indicate that use of CC data for substituting missing rainfall data was valid; R^2 values observed for HH-DH comparison were similar to RH-CC rain data comparison. Since variations in rainfall were observed between sites less than one km away from each other, it was concluded again that CC rainfall data could be used as a substitute for missing rain data at the research sites.

Rain data for each site were compared. Table 4.5 summarizes these comparisons. For all tables, means are upper values and standard deviations are lower values in parentheses. The data is based on 67 individual storm events (n = 67).

Table 4.5: Precipitation for each site.

Site (n = 67)	Precipitation (cm)	Depth per Storm (cm)
HH	53.75	0.81 (1.19)
DH	42.22	0.61 (0.97)
RH	50.11	0.69 (1.09)

Collectively, HH rainfall was highest of three sites, while DH was lowest. This can be explained using same logic above for slope-intercept regression between sites: HH rain gauge was open canopy, while DH rain gauge was positioned under tight canopy.

Turbidity

General turbidity fluctuations during a yearly cycle for each watershed can been seen in the following figures (Figures 4.2 through 4.4). All turbidity readings are in NTU.

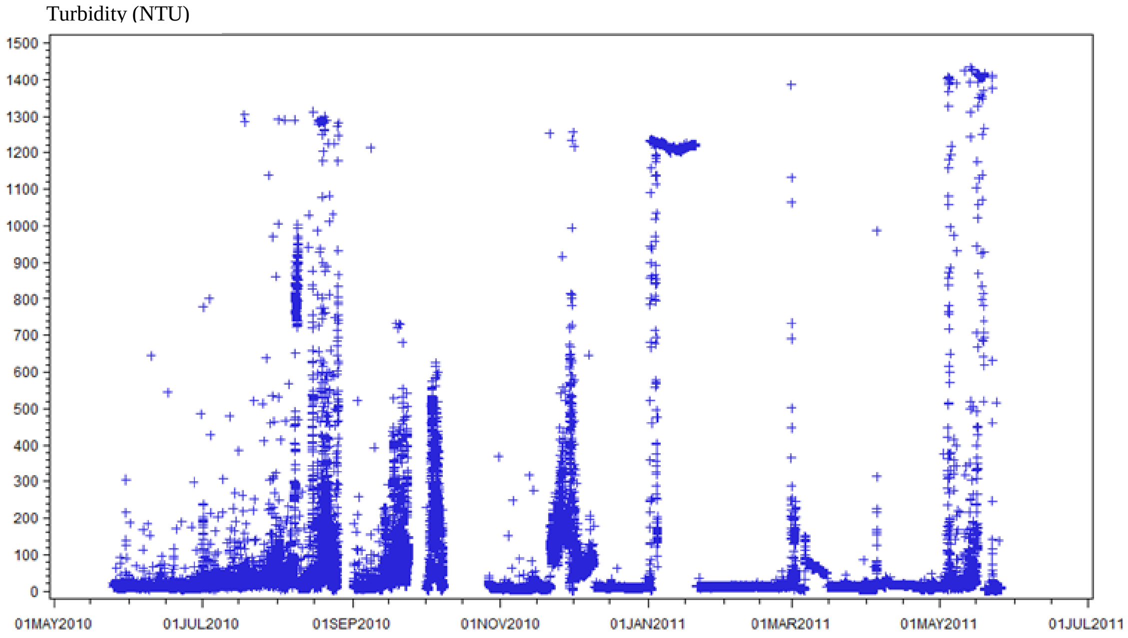

Figure 4.2: Annual turbidity fluctuations for HH.

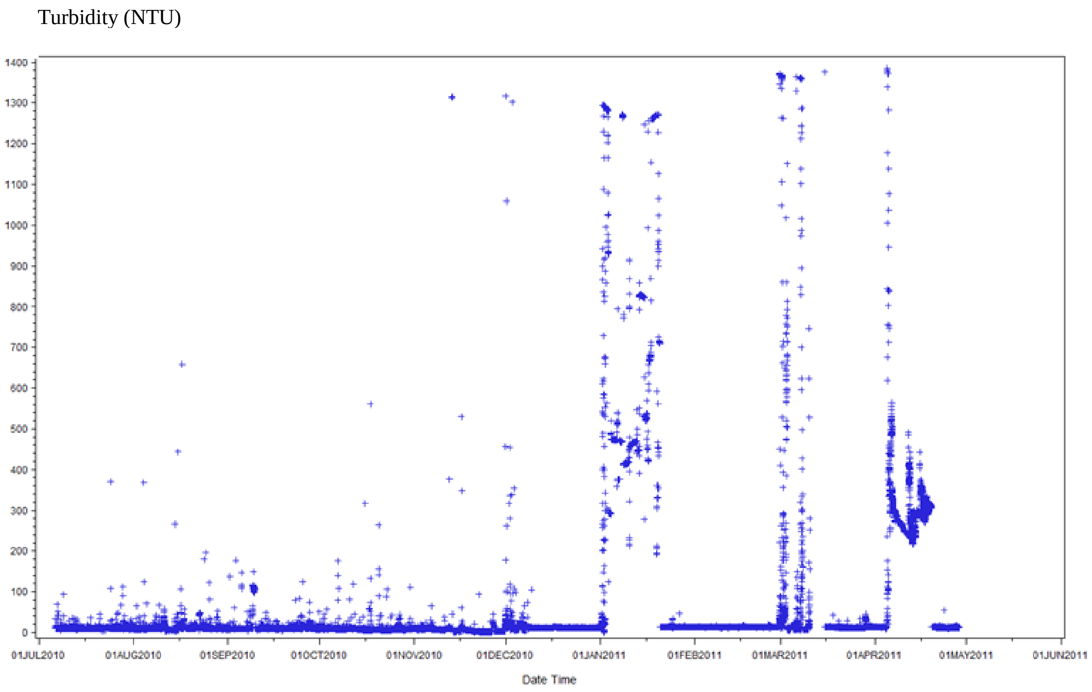

Figure 4.3: Annual turbidity fluctuations for DH.

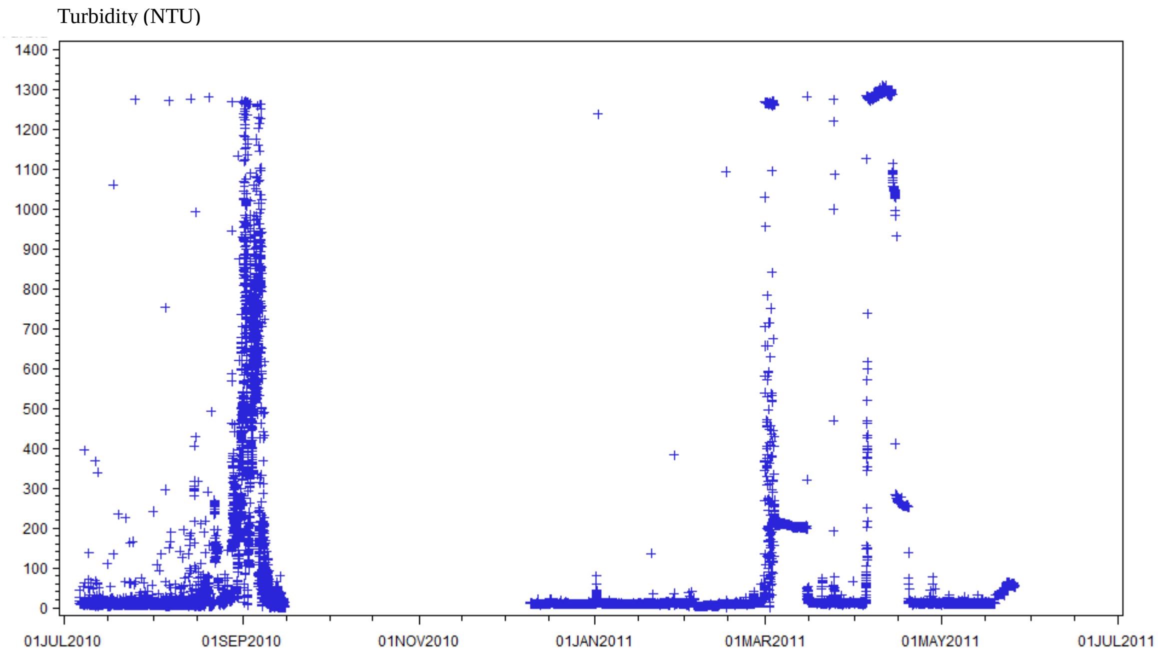

Figure 4.4: Annual turbidity fluctuations for RH.

As seen in the preceding figures, there are gaps in turbidity data for both HH and RH. This is because of maintenance issues that were discussed previously. These were periods of time when sondes were not in streams at monitoring locations, but were at Clemson campus being assessed for damage and functionality.

The “flashy” behavior of turbidity is evident from the figures. Spikes in turbidity caused uncertainty in determining behavior trends, again echoing what was discussed earlier. Turbidity reached over 1,400 NTU at each site; this was near the upper range of sonde turbidity probe measurement capability. It can be seen that high turbidity events occurred most frequently and lasted longest at HH. This was possibly due to prior internal disturbances from landowner activity and road cuts. During rain events, runoff washed soil from road cuts and into the stream at intersection of road cut and stream. Heavy siltation was observed after storm events in HH. Given these conditions, HH was deemed most extensively disturbed of the three watersheds. It was suspected that road cuts and preexisting disturbances caused sedimentation and stream chemistry fluctuations.

DH turbidity spikes were limited mostly to late winter, early spring months. This is likely due to less leaf interception and larger drainage area at DH than at HH and RH, allowing more sediment to be dislodged and deposited in stream.

During leaf-on, baseflow turbidity at HH was higher than at DH and RH. DH and RH turbidity during baseflow conditions averaged 11.5 NTU and 22.7 NTU during leaf-on, respectively, while RH turbidity averaged 56.8 NTU. Leaf-off turbidity data did not exist for undisturbed conditions for HH because construction began in this watershed in October 2010. Limited leaf-off data was available for RH as well, as construction began in late December 2010 in this watershed. Therefore, only DH had complete leaf-off data for undisturbed watershed conditions. When turbidity was compared between watersheds for stormflow conditions during leaf-on, HH turbidity was highest with a mean of 285.5 NTU. LSD and Tukey tests indicated that for stormflow conditions, RH and DH were not statistically different ($\alpha = 0.05$) during leaf-on. The same tests also determined that for stormflow conditions during leaf-on, mean turbidity at HH differed significantly compare to DH and RH. Table 4.6 summarizes site comparisons for turbidity for baseflow (BF) and stormflow (SF) conditions during leaf-on and leaf-off.

Table 4.6: Mean turbidity at each siteduring leaf-on and leaf-off.

Site	BF leaf-on (NTU)	BF leaf-off (NTU)	SF leaf-on (NTU)	SF leaf-off (NTU)
HH	56.8 (157.3)	N/A	285.5 (391.7)	N/A
DH	11.5 (17.0)	23.0 (99.0)	70.1 (228.2)	149.8 (374.0)
RH	22.7 (54.3)	10.6 (0.8)	98.2 (254.9)	5.2 (4.6)

The table above reveals that there are indeed significant seasonal variations in turbidity, particularly for stormflow conditions. A general trend of turbidity increasing during stormflow was observed for each watershed. Seasonal and baseflow-stormflow trends observed for this research were consistent with other findings (Bolstad & Swank, 1997; Sutherland et al., 2002).

As stated previously, a numeric limit of 280 NTU was used as a turbidity threshold for monitoring construction impacts from FHP, as specified by EPA. 24-hr average turbidity data were plotted with rainfall to determine the number of rain events causing turbidity to exceed 280 NTU. The 24-hr average was defined to be from the first rain measurement to 24 hr from that measurement. Graphs were generated for each site. Figures 4.5-4.7 show the results.

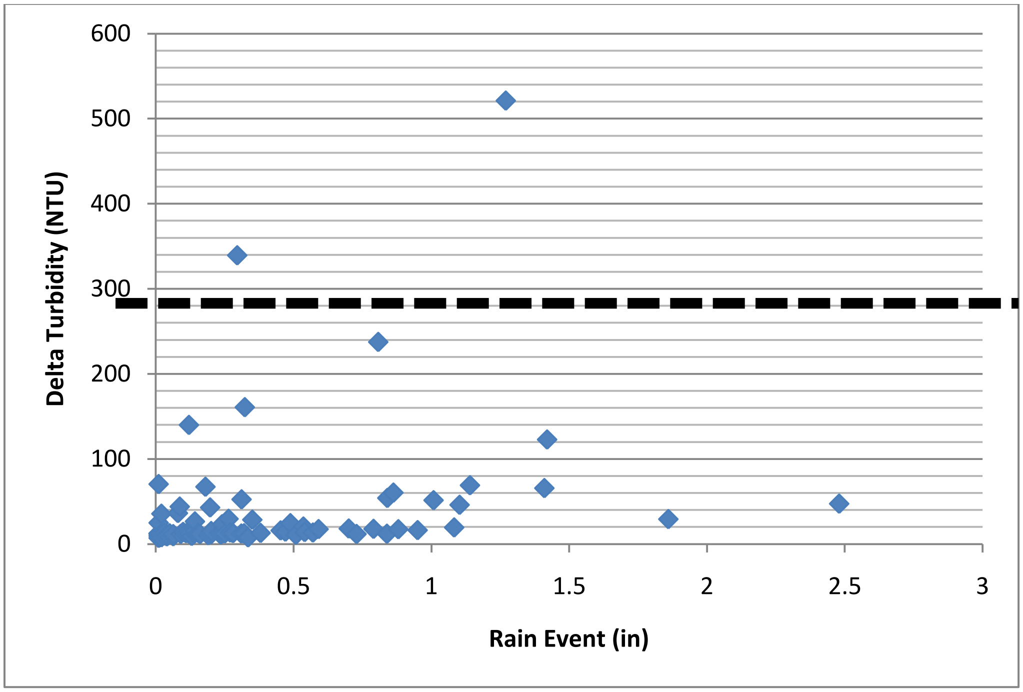

Figure 4.5: 24-hr average turbidity with 280-NTU limit for HH.

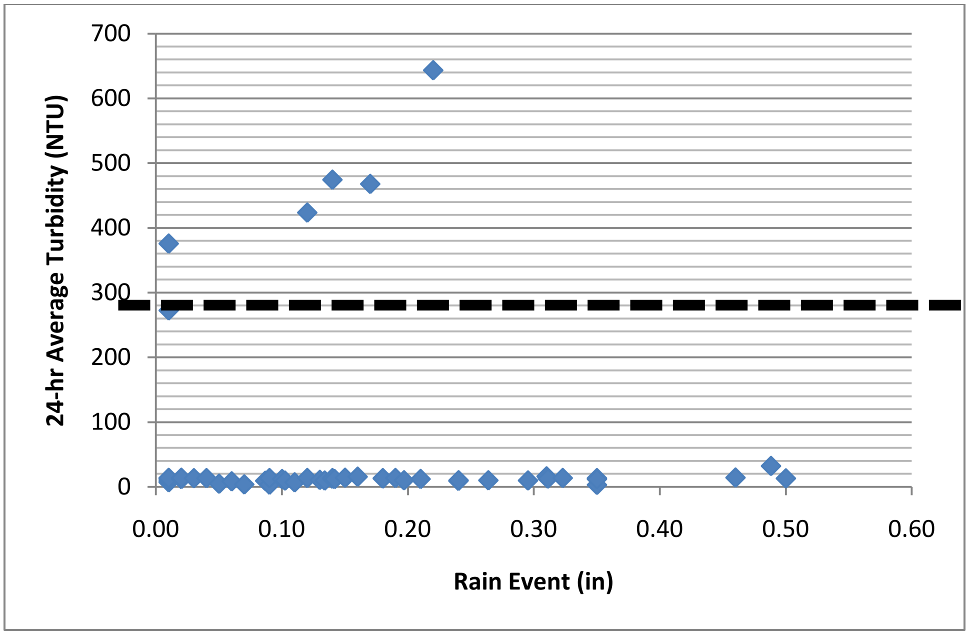

Figure 4.6: 24-hr average turbidity with 280-NTU limit for DH.

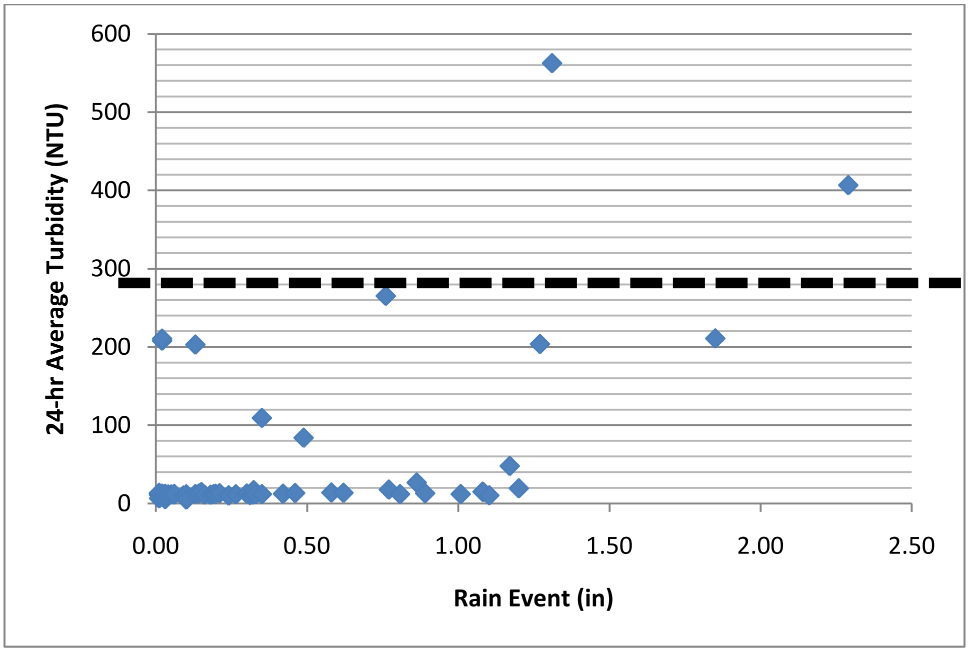

Figure 4.7: 24-hr average turbidity with 280-NTU limit for RH.

The figures show that even for undisturbed watersheds, especially, DH, turbidity values exceed 280 NTU for a 24-hr average. HH and DH have more turbidity averages exceeding 280 NTU than RH; however, it can be seen that all three sites exceeded 280 NTU for a 24-hr average.

pH

General pH fluctuations during a yearly cycle for each watershed can been seen in the following figures (Figures 4.8 through 4.10). All pH readings are in standard pH units (dimensionless).

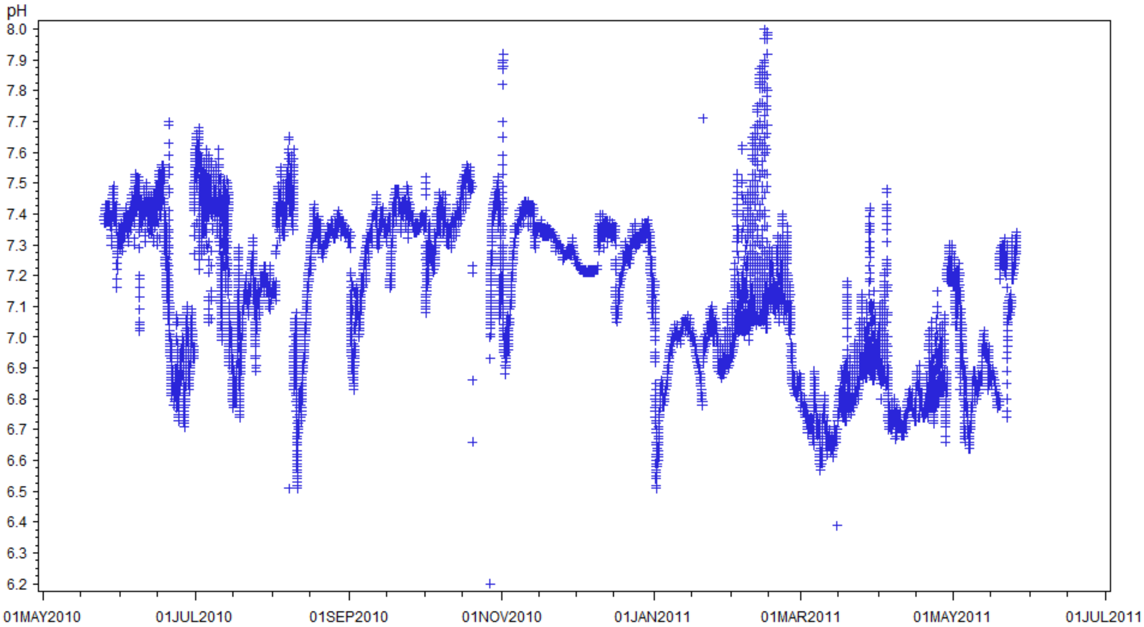

Figure 4.8: Annual pH fluctuations for HH.

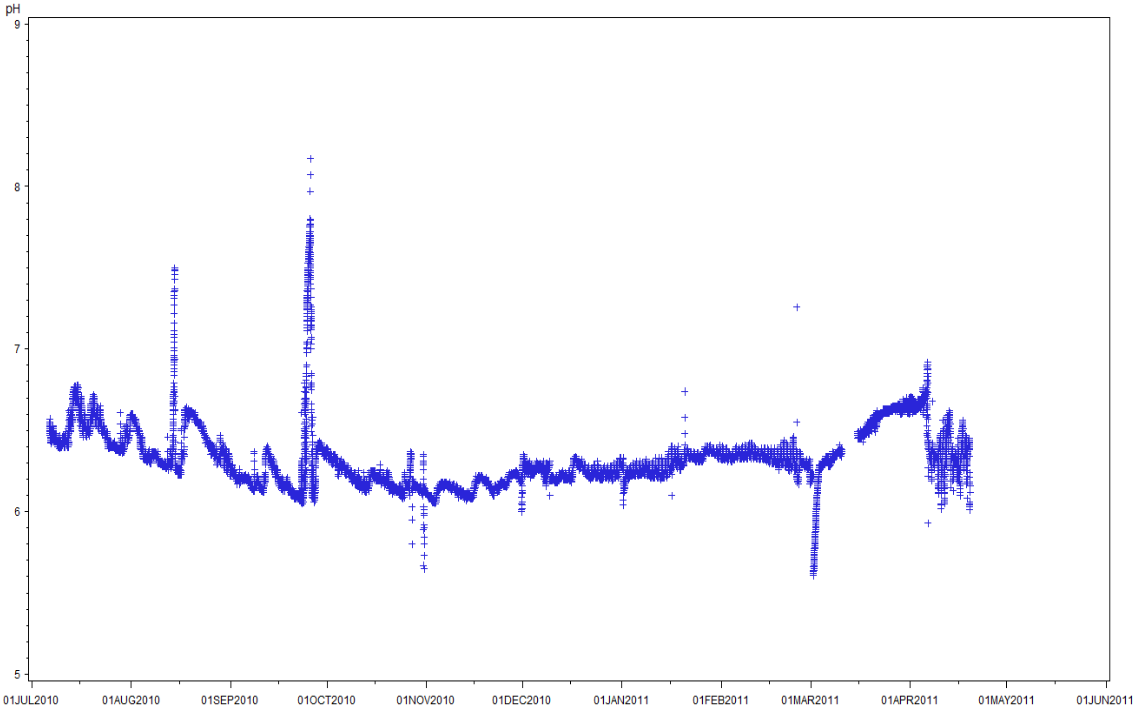

Figure 4.9: Annual pH fluctuations for DH.

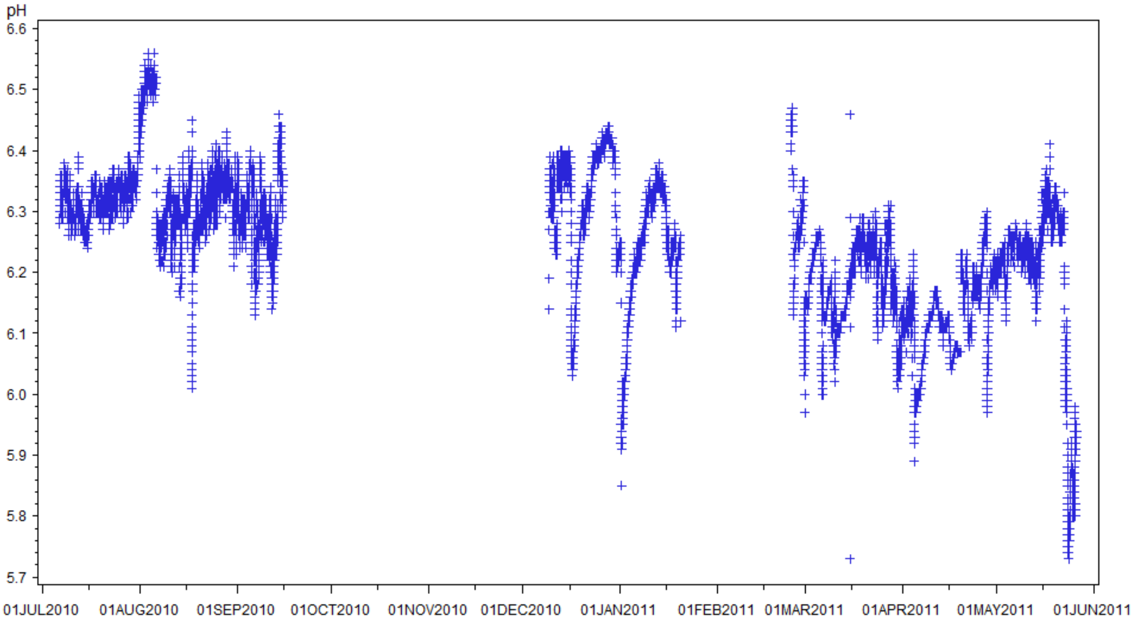

Figure 4.10: Annual pH fluctuations for RH.

The figures show that there are gaps in pH data for each site. This is because sonde probes were under repair during these times and were not in streams at monitoring sites. HH had greatest variation in pH readings, while RH pH measurements ranged less than 1.0 pH units. It should be noted that Figures 4.5-4.7 are on different scales; Figure 4.6 ranges 5-9 pH units, while Figure 4.7 spans less than one pH unit.

During baseflow conditions, mean pH was highest at HH. Mean pH for baseflow conditions during leaf-on for HH was 7.22, while mean pH at DH and RH was 6.35 and 6.27, respectively. Although LSD and Tukey tests indicated that mean pH differed significantly ($p < 0.0001$, $\alpha = 0.05$) between sites during baseflow conditions, RH and DH are on same order of magnitude, while HH was nearly 1.0 pH unit higher than DH and RH. Possible reasons for this could be that HH had prior internal disturbances, causing differences in pH. It could also be that because actual open channel flow length above HH monitoring station was less than 100 yds, the stream had more contact with groundwater, allowing more basic conditions to exist in stream flow. Regardless, it can be shown that HH pH data differed in magnitude from DH and RH. Table 4.7 summarizes mean pH data during baseflow conditions.

Table 4.7: Mean pH at each site during leaf-on and leaf-off.

Site	BF leaf-on	BF leaf-off	SF leaf-on	SF leaf-off
HH	7.22 (0.24)	N/A	7.18 (0.25)	N/A
DH	6.35 (0.20)	6.29 (0.14)	6.40 (0.20)	6.32 (0.14)
RH	6.27 (0.12)	6.33 (0.09)	6.27 (0.09)	6.34 (0.07)

It can be seen from the table above that pH was lower at DH during leaf-off compared to leaf-on. There are several possible reasons for this. One could be that there was greater opportunity for atmospheric nitrogen and sulfur to actually reach stream water during leaf-off because there would have been no interception from leaves, thus making pH lower while leaves were off trees. Another explanation could be that there was less uptake by trees and plants during the dormant season, allowing more N and S to reach stream water. It is also possible that greater deposition occurred during this time period, creating an all-around over-abundance of acidity in the watershed, thereby decreasing pH (Deyton et al., 2009; Cook et al., 1994). Seasonal variations in pH, whatever the cause, were also observed in other research (Deyton et al., 2009).

Trends in pH during stormflow conditions were difficult to make. Baeflow pH was compared to an average pH from storm event commencement to three hours after storm subsidence (ΔpH). No conclusive trends were determined. These ΔpH values range from positive to negative in equal magnitudes. DH mean pH hardly changed at all between baseflow and stormflow during both leaf-on and leaf-off. During leaf-on, HH and RH mean pH was 7.22 and 6.27, respectively, for baseflow. It would be possible to make inferences in ΔpH values if the trend was more positive than negative, or vice versa, but this was not the case. It has been documented that higher-elevation streams experience greater fluctuations in pH during storm events due to increased deposition than lower-elevation streams (Deyton et al., 2009). The reason these streams did not experience greater changes in pH during storms could be attributable to elevation. It was determined that pH behavior during storm events did not change significantly when compared to baseflow conditions.

Conductivity

General conductivity fluctuations during a yearly cycle for each watershed can been seen in the following figures (Figures 4.11 through 4.13). All conductivity readings are in mS/cm.

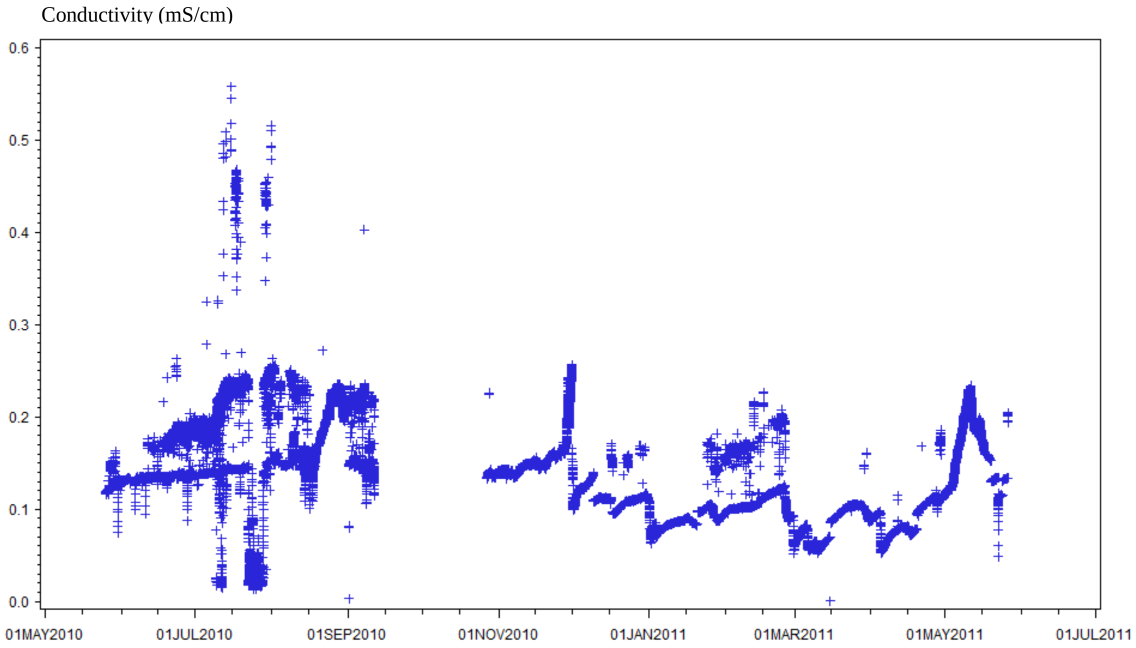

Figure 4.11: Annual conductivity fluctuations for HH.

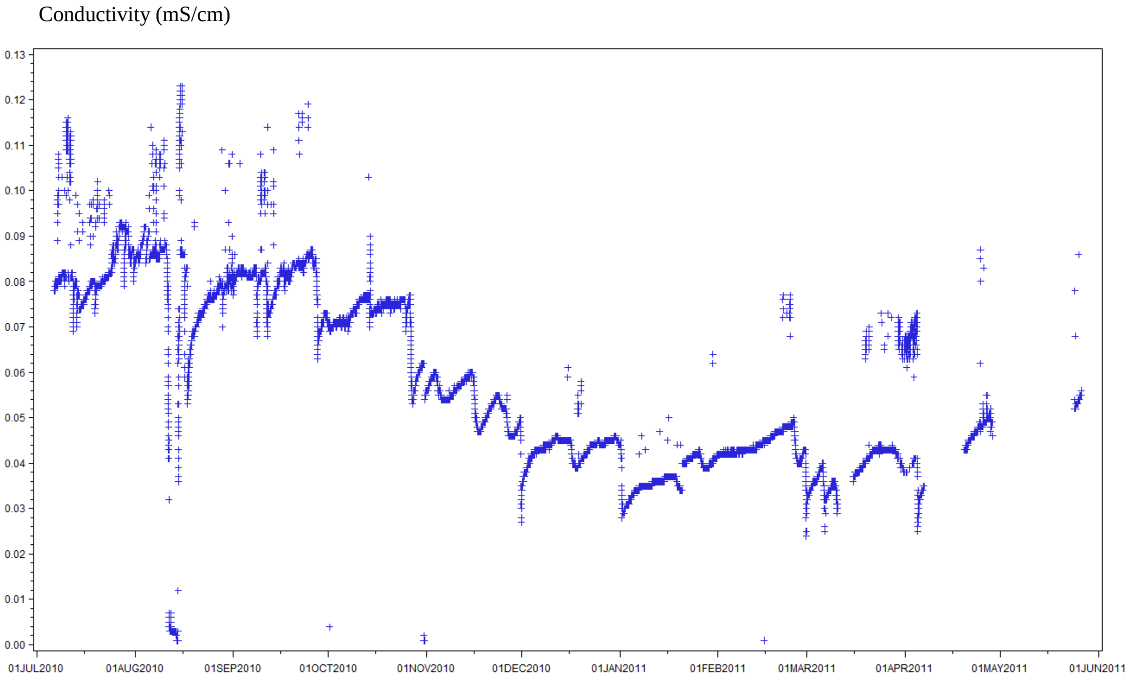

Figure 4.12: Annual conductivity fluctuations for DH.

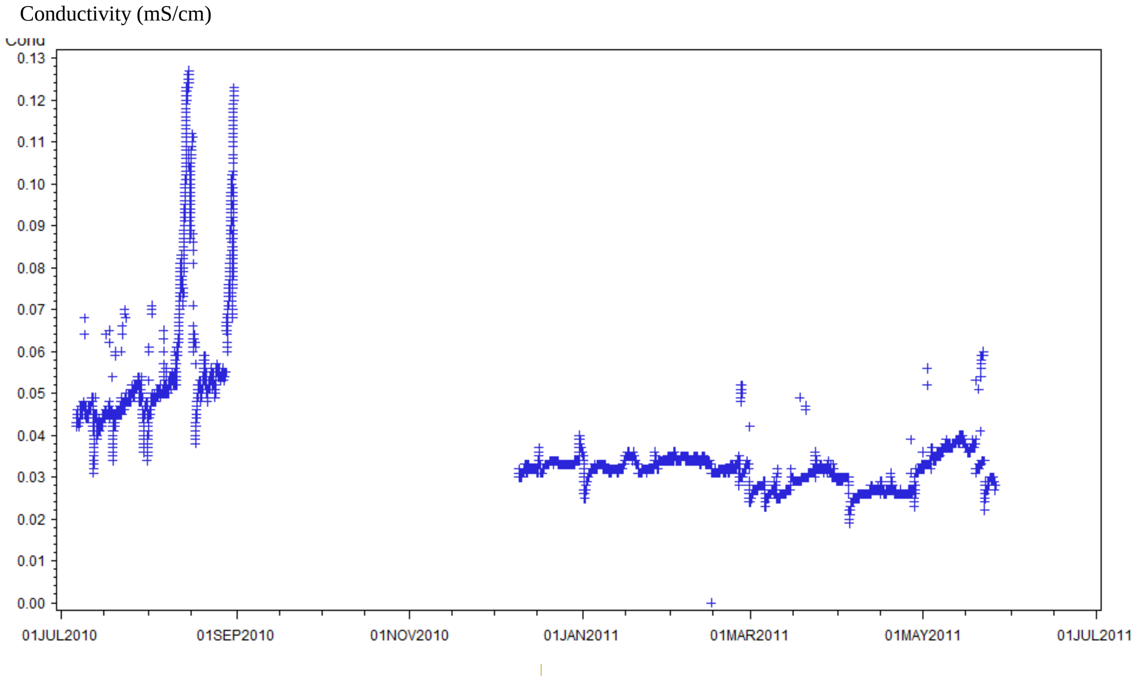

Figure 4.13: Annual conductivity fluctuations for RH.

Scales are different for Figures 4.11-4.13, as for pH figures. Similar to turbidity and pH data, there were gaps in conductivity for the same reasons as for turbidity and pH. It is noted that RH conductivity experienced a severe increase after 9/1/2010. This is most likely due to the sonde being found out of stream during this time. It was after this event that the sonde was brought back to Clemson campus for assessment, which is indicated in figure by the gap following conductivity increase. The incorrect data recorded by the sonde was not included in analysis for comparisons.

Conductivity during baseflow conditions was highest at HH, with a mean of 0.151 mS/cm. DH and RH mean conductivity was 0.075 mS/cm and 0.075 mS/cm, respectively. LSD and Tukey tests indicated that mean conductivity differed significantly

($p < 0.0001$, $\alpha = 0.05$) between HH and DH, and between HH and RH during baseflow conditions. However, LSD test indicated a significant difference in mean conductivity between DH and RH, while Tukey test did not.

Although LSD and Tukey tests returned different results, it can be observed that mean conductivity at RH and DH is on same order of magnitude, while HH was nearly 0.060 mS/cm unit higher than DH and RH. Possible reasons for this could be that HH contains road cuts above sonde location, contributing more ions to stream water than DH and RH. Prior to monitoring, storm events may have deposited sufficient ions from road cuts in stream to significantly alter stream chemistry compared to DH and RH, neither of which contain road cuts above monitoring. Regardless, it can be shown that HH conductivity data differed in magnitude from DH and RH for baseflow conditions. Table 4.8 summarizes mean conductivity data during baseflow conditions.

Table 4.8: Mean conductivity at each site during leaf-on and leaf-off.

Site	BF leaf-on (mS/cm)	BF leaf-off (mS/cm)	SF leaf-on (mS/cm)	SF leaf-off (mS/cm)
HH	0.151 (0.054)	N/A	0.145 (0.044)	N/A
DH	0.075 (0.016)	0.044 (0.007)	0.073 (0.014)	0.044 (0.007)
RH	0.075 (0.074)	0.033 (0.002)	0.061 (0.062)	0.034 (0.001)

The table above reveals that mean conductivity was lower during leaf-off at DH compared to leaf-on. Reasons for this occurrence were not explicitly known. It could be that there was less ionic contribution to stream chemistry during leaf-off, which could be indicated by lower turbidity, but this was not observed. Mean turbidity, as shown previously, was higher during leaf-off than for leaf-on. Therefore, causes of seasonal variations in conductivity remained largely unknown.

Similar to pH data, trends in conductivity during stormflow conditions were difficult to make. Baseflow conductivity was compared to an average conductivity from storm event commencement to three hours after storm subsidence (Δcond). No conclusive trends were determined. These Δcond values range from positive to negative in equal magnitudes. HH mean conductivity during leaf-on was 0.151 mS/cm for both baseflow and stormflow. DH mean conductivity during leaf-on was 0.075 and 0.073 mS/cm for baseflow and stormflow, respectively. Lastly, RH conductivity during leaf-on averaged 0.075 mS/cm for both baseflow and stormflow. None of the means were significantly different at each site ($\alpha = 0.05$). It would be possible to make inferences in Δcond values if the trend was more positive than negative, or vice versa, but again, this was not the case. Therefore, no conclusions were made about conductivity behavior during storm events other than conductivity did not appear to change during or after rainfall.

Temperature

General stream temperature fluctuations during a yearly cycle for each watershed can been seen in the following figures (Figures 4.14 through 4.16). All temperature readings are in °C.

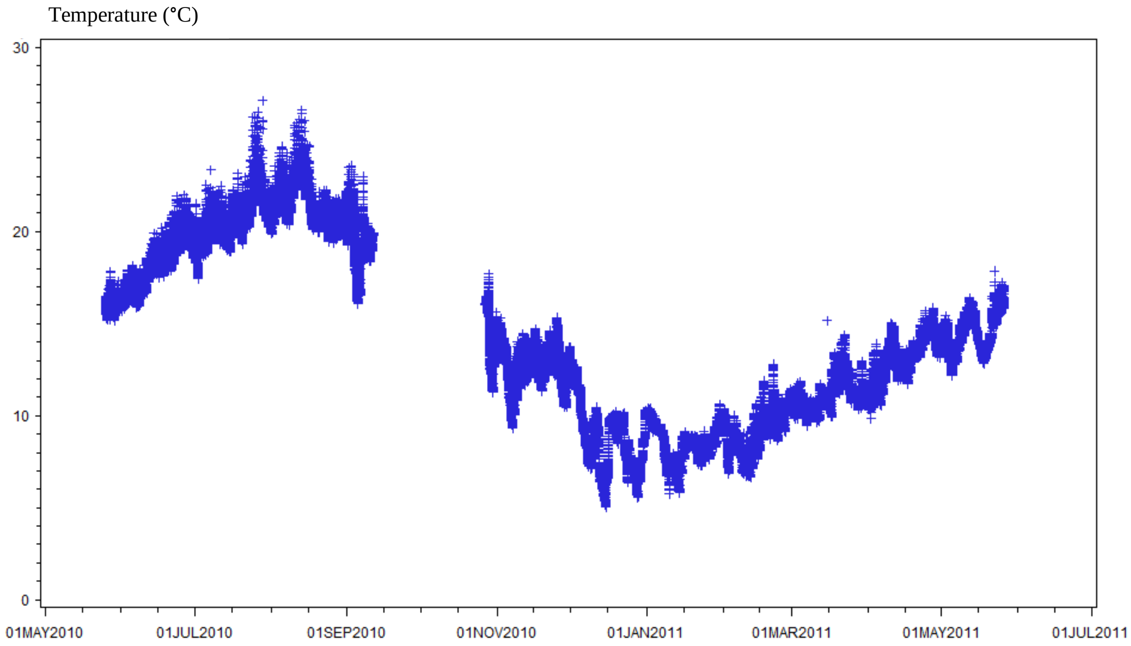

Figure 4.14: Annual stream temperature fluctuations for HH.

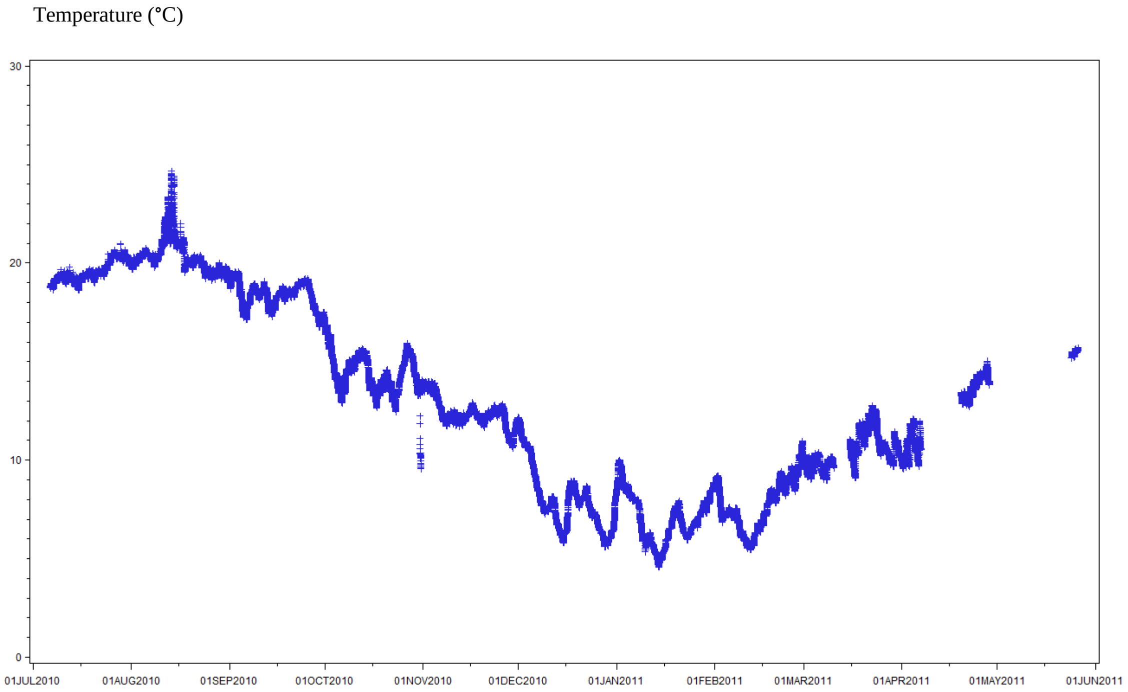

Figure 4.15: Annual stream temperature fluctuations for DH.

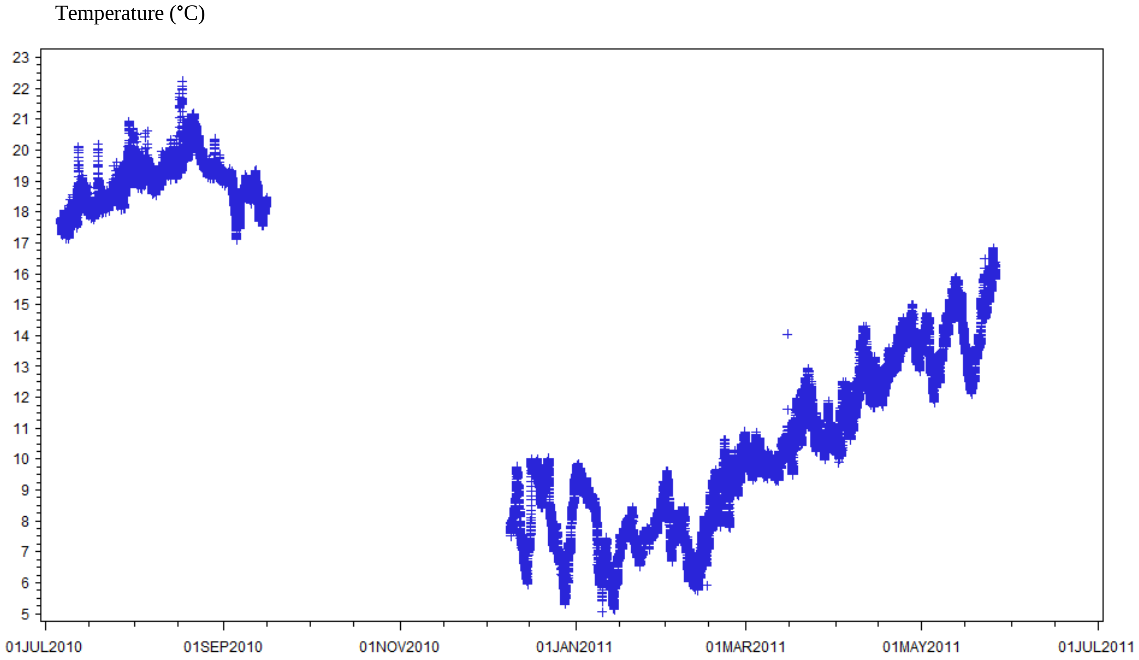

Figure 4.16: Annual stream temperature fluctuations for RH.

Temperature followed expected trends during seasons at each site. Again, gaps signify sonde removal from streams following suspected damage or malfunction. It can be seen from the figures that temperature was most consistent water quality parameter measured, as there are few outliers or stray points in data.

During leaf-on, baseflow temperature at HH was highest, with a mean of 18.34 °C. DH and RH temperature averaged 17.68 °C and 16.10 °C, respectively. Table 4.9 summarizes mean temperature at each site for BF conditions during leaf-on and leaf-off.

Table 4.9: Mean temperature at each site for BF conditions during leaf-on and leaf-off.

Site	BF leaf-on (°C)	BF leaf-off (°C)
HH	18.34 (3.26)	N/A
DH	17.68 (2.81)	9.00 (2.38)
RH	17.10 (2.79)	7.89 (1.22)

HH had the highest temperature during leaf-on, while RH had the lowest temperature. HH sonde was placed in a location in the stream where it was exposed to direct sunlight for the majority of the day, thereby causing higher temperature readings than the other sites. RH sonde was placed less than 100 m downstream from the spring source for the stream, causing significant influence from groundwater temperature upstream.

During leaf-on, LSD test indicated significant difference between mean baseflow temperature at DH and RH, while Tukey test did not indicate significant differences between the three sites. During leaf-off, both LSD and Tukey tests indicated significant differences between mean temperatures at RH and HH. This difference could be attributed to RH having the lowest mean temperature for both leaf-on and leaf-off.

Similar to pH and conductivity, no discernable trends were noted during stormflow conditions for temperature. Fluctuations in temperature during storm events ranged from positive to negative. More definitive inferences could possibly have been drawn if air temperature and stream discharge data were recorded. Lack of these data, however, leave pH, conductivity, and temperature behavior during stormflow indeterminate. There were, however, distinguishable trends observed during stormflow conditions for turbidity, which was crucial in determining effects of FHP construction uphill from study sites, as will be discussed subsequently.

Objective 3

The third objective was to establish predictive methods for stream water quality based on background information obtained for undisturbed flow conditions with forested watersheds. Water quality data were used to establish correlations and predictive models for changes in turbidity, pH, conductivity, and temperature for stormflow conditions. Best correlations were determined, and regression analysis was performed to determine relationships between correlated variables. Parameter transformations converted variables into squared, square root, and natural logarithmic scales during leaf-on and leaf-off to determine best fit trends in data. Days since last rainfall (DSLR) was added as a variable in attempt to better explain behavior and increase R^2 values for regression analysis. As a final addition, storm duration (dur) was used as a variable.

After initial transformations, HH change in turbidity (Δturb) during leaf-on showed highest correlation to rain depth squared (rain^2) and square root of DSLR (sr-DSLR). Initial regression analysis resulted in an R^2 value of 0.16 for this relationship. After outliers were removed, R^2 value for this relationship increased to 0.35. A better relationship was found after outlier removal, which included square root of turbidity

($\sqrt{\text{turb}}$), rain depth (rain), and DSLR^2. For this relationship, $R^2 = 0.43$. After duration was added as a variable, the final analysis resulted in an R^2 value of 0.57. During leaf-off, R^2 increased from 0.37 to 0.45 after outlier removal, but no additional increase in R^2 occurred after addition of duration as a variable. Table 4.10 summarizes R^2 values for HH during leaf-on. Equation (4-1) shows the relationship between turbidity and rain data for HH during leaf-on.

Before showing prediction equations generating using regression analysis, it may be beneficial to universally define variables appearing in appropriate equations.

- rain = rain depth (in)
- DSLR = days since last rainfall (day)
- dur = storm duration (hr)
- Δturb = change in turbidity (NTU)
- ln = natural logarithm operator
- $\sqrt{}$ = square root operator

Table 4.10: Regression analysis (R^2 values) for turbidity at HH during leaf-on and leaf-off.

	Leaf-on
All Data	0.16
All Data minus Outliers	0.43
After adding duration	0.56

Plots of change in turbidity versus rainfall were generated for each site showing both all data and data after outliers were removed. Figures 4.17 and 4.18 show change in turbidity versus rainfall for HH.

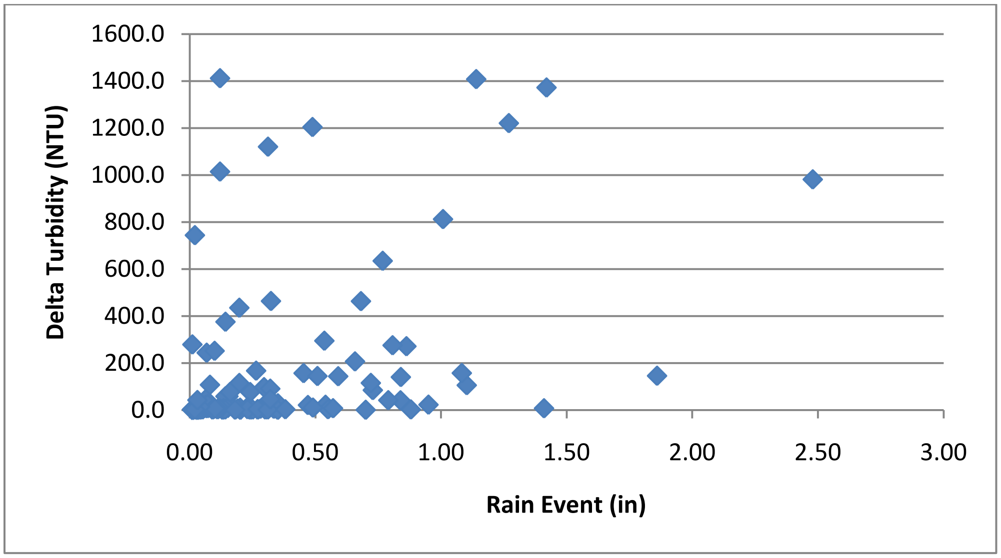

Figure 4.17: Change in turbidity vs rain for HH before removing outliers.

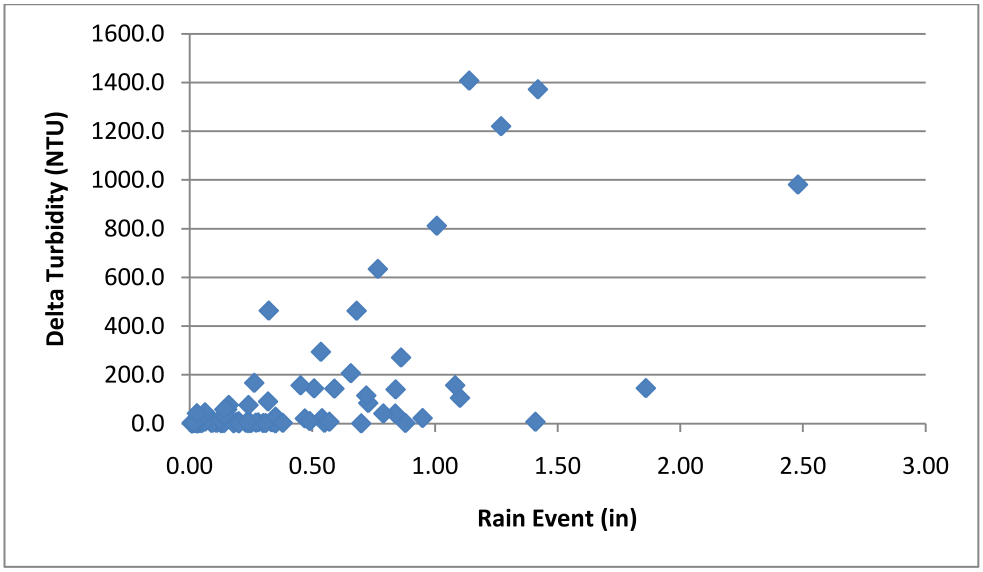

Figure 4.18: Change in turbidity vs rain for HH after removing outliers.

HH leaf-on:

$$\sqrt{\Delta turb} = 8.0444 + 16.728*rain - 0.0072*DSLR^2 - 3.6369*\sqrt{dur} \qquad (R^2 = 0.56) \qquad (4\text{-}1)$$

This regression process returned similar results for DH and RH. Variable transformations differed slightly between sites, which are documented subsequently.

Table 4.11: Regression analysis (R^2 values) for turbidity at DH during leaf-on and leaf-off.

	Leaf-on	Leaf-off
All Data	0.67	0.48
All Data minus Outliers	0.67	0.68
After adding duration	0.71	0.81

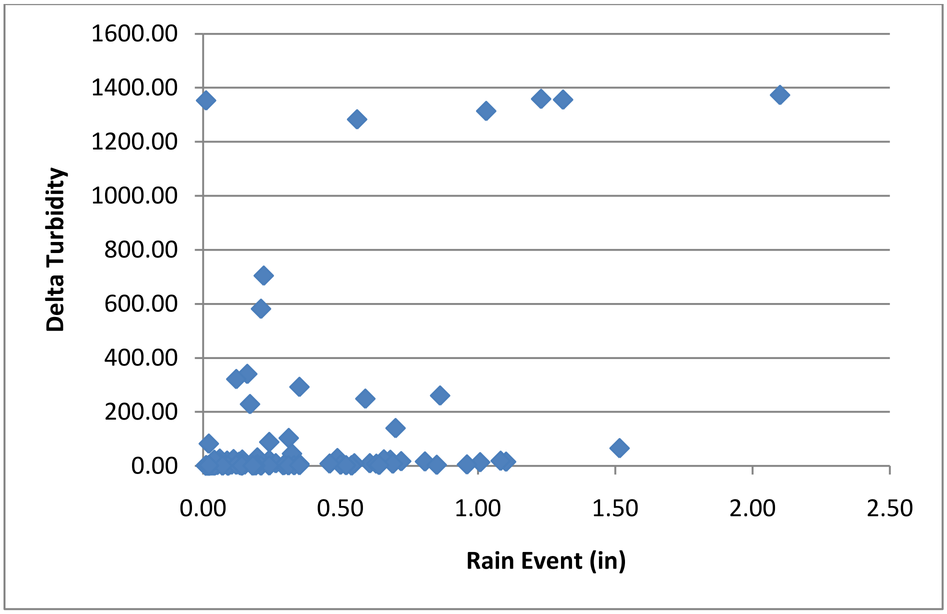

Figure 4.19: Change in turbidity vs rain for DH before removing outliers.

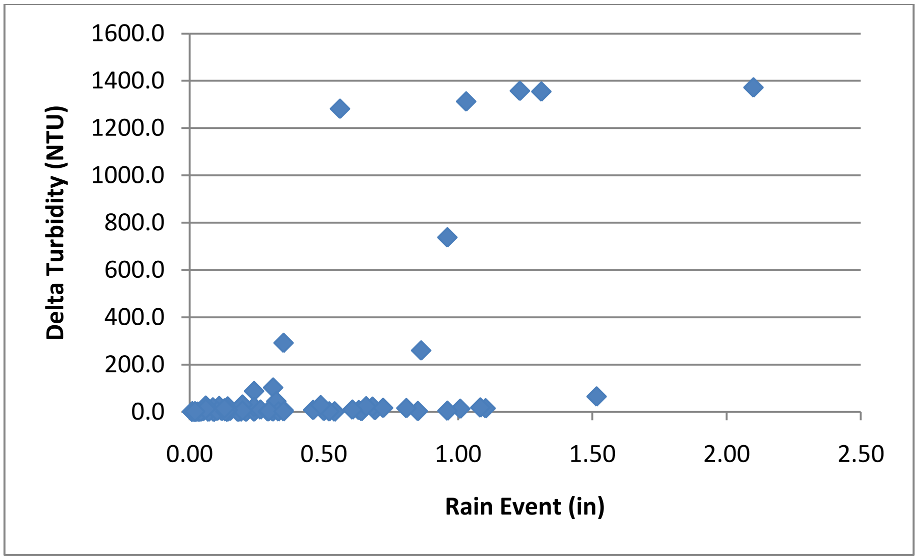

Figure 4.20: Change in turbidity vs rain for DH after removing outliers.

DH leaf-on:

$$\Delta\text{turb} = -45.196 + 153.15*\text{rain}^2 - 0.2509*\text{DSLR}^2 + 1.5656*\text{dur}^2 \qquad (R^2 = 0.71) \qquad (4\text{-}2)$$

DH leaf-off:

$$\Delta\text{turb} = -47.947 + 734.79*\text{rain}^2 - 3.0156*\text{DSLR}^2 + 0.5817*\text{dur}^2 \qquad (R^2 = 0.81) \qquad (4\text{-}3)$$

Table 4.12: Regression analysis (R^2 values) for turbidity at RH during leaf-on and leaf-off.

	Leaf-on	Leaf-off
All Data	0.79	0.38
All Data minus Outliers	0.80	0.60
After adding duration	0.80	0.79

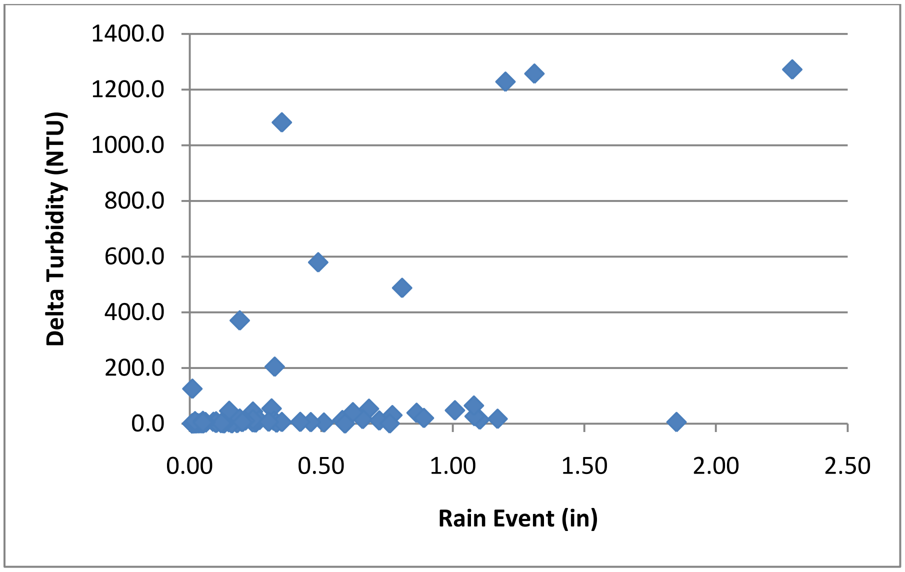

Figure 4.21: Change in turbidity vs rain for RH before removing outliers.

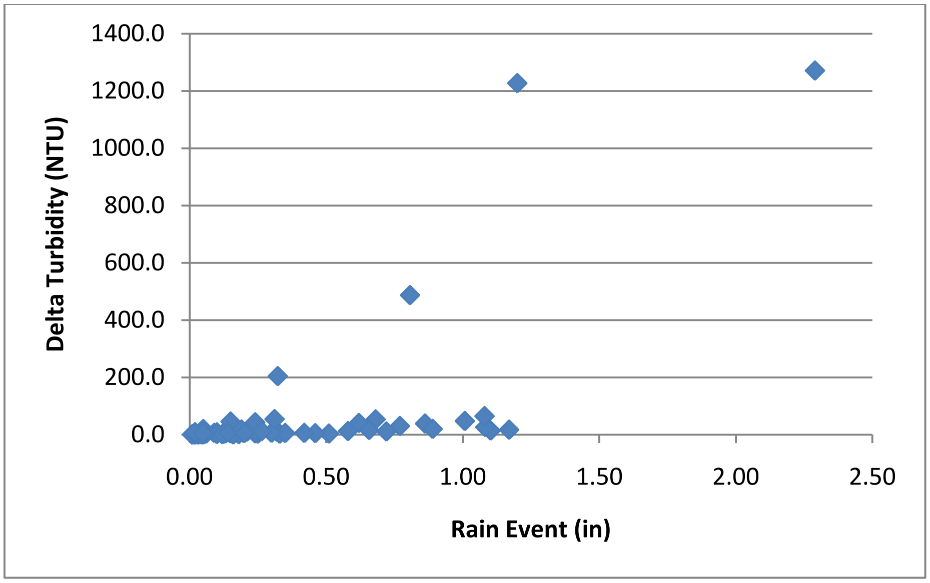

Figure 4.22: Change in turbidity vs rain for RH after removing outliers.

RH leaf-on:

$$\Delta turb^2 = -89221 + 262737*rain^2 + 336.19*DSLR^2 + 2194.9*dur \qquad (R^2 = 0.80) \qquad (4\text{-}4)$$

RH leaf-off:

$$\ln(\Delta turb) = 0.831 + 1.326*\ln(rain) + 1.845*\sqrt{DSLR} - 0.00378*dur^2 \qquad (R^2 = 0.79) \qquad (4\text{-}5)$$

RH equations for Δturb were similar to HH in variables used and R^2 value differences between leaf-on and leaf-off. This could be due to the fact that stream substrate types were highly similar between HH and RH, resulting in similar prediction models for change in turbidity during stormflow conditions. Substrates at HH and RH were predominantly sand/gravel mixes with fewer fines than at DH. Equations for predicting change in turbidity during leaf-on were better than those during leaf-off for RH. The R^2 values for equations predicting change in turbidity between different seasons followed trends seen in objective 2 and, as will be discussed, for objective 4. It has been determined that rainfall and turbidity behavior both vary with seasons; therefore, it follows that prediction models incorporating forms of rainfall and turbidity would change between seasons as well.

R^2 values indicate the amount of variability described by selected parameters to predict the dependent variable of interest. For example, the R^2 value of 0.80 seen in Equation (4-4) means that 80% of the variability in turbidity can be explained by the variables given in that equation. In other words, one could predict with 80% certainty the change in turbidity if parameters are given.

All equations generated for determining change in turbidity in the watersheds were relatively similar in terms of the variables used to describe the data. For simplicity, one general equation was generated for all three watersheds, which included less complex mathematical operators for calculation:

$$\Delta turb = -46.191 + 286.64*rain + 0.7179*DSLR + 1.4751*dur \qquad (R^2 = 0.62) \qquad (4\text{-}6)$$

In summary, these empirical equations could be used to predict change in turbidity (NTU) for this area if rain depth (in), days since last rainfall, and storm duration (hr) are known. Resource managers and construction site operators have potential to anticipate turbidity levels downstream given these variable conditions.

Objective 4

Water quality data for each site were analyzed for baseflow and stormflow conditions both before and during construction (BC and DC, respectively) to assess potential impacts of FHP construction on natural and disturbed forested watersheds.

Turbidity

HH and RH both had higher mean turbidity BC compared to DC. DC turbidity at HH and RH was 126.1 NTU and 81.0 NTU, respectively, while BC turbidity averaged 248.8 NTU at HH and 100.7 NTU at RH. Comparison revealed that for both HH and RH, BC and DC mean turbidity was not significantly different ($\alpha = 0.05$), although turbidity during BC at HH was twice as high as during DC.

For comparison, DH turbidity data BC and DC timeframe for HH and RH were analyzed. Although no construction or disturbance conditions existed in DH at any time during monitoring, this was done to test temporal changes only, and HH and RH construction timeframes were used for this comparison. DC conditions began in October 2010 at HH, while DC conditions at RH began in December 2010. DH turbidity during BC and DC conditions were compared using DC timeframes for both HH and RH. DH turbidity for HH timeframe was 31.8 NTU and 148.3 NTU for BC and DC, respectively, while for RH timeframe turbidity was 56.4 NTU and 170.5 NTU for BC and DC, respectively. Table 4.13 summarizes BC and DC turbidity comparisons for each site for stormflow conditions. Again, since no construction occurred in DH during this project, only BC conditions existed, which is reflected in the following tables.

Table 4.13: Mean SF turbidity comparisons for BC and DC conditions for each site.

Site	BC (NTU)	DC (NTU)	BC - HH (NTU)	DC - HH (NTU)	BC - RH (NTU)	DC – RH (NTU)
HH	248.8 (310.0)	126.1 (333.6)	N/A	N/A	N/A	N/A
DH	120.3 (328.7)	N/A	31.8 (53.5)	148.3 (372.1)	56.4 (202.4)	170.5 (395.7)
RH	100.7 (176.1)	81.0 (282.0)	N/A	N/A	N/A	N/A

Baseflow mean turbidity was also compared between BC and DC conditions for each watershed. Table 4.14 summarizes the results.

Table 4.14: Mean BF turbidity comparisons for BC and DC conditions for each site.

Site	BC (NTU)	DC (NTU)	BC - HH (NTU)	DC - HH (NTU)	BC - RH (NTU)	DC – RH (NTU)
HH	50.5 (125.4)	49.0 (144.1)	N/A	N/A	N/A	N/A
DH	15.8 (62.0)	N/A	10.6 (1.8)	77.8 (199.0)	10.1 (7.9)	102.2 (227.3)
RH	24.4 (63.0)	14.6 (36.8)	N/A	N/A	N/A	N/A

As seen in the tables above, HH and RH turbidity decreased between BC and DC for stormflow but increased between BC and DC for BF. DH turbidity increased between BC and DC for both baseflow and stormflow. Again, no construction occurred in DH during project monitoring. If construction had occurred in DH and turbidity increased in all three sites, it may be concluded that construction impacted water quality. However, as noted earlier, DH experienced seasonal differences in turbidity; leaf-off had higher turbidity than leaf-on. Given turbidity behavior in DH during both seasons and baseflow and stormflow conditions, it was determined that FHP construction did not have an impact on turbidity in these watersheds, but that differences were due to seasonal variations.

Since FHP effects on turbidity were dismissed, leaf-on and leaf-off comparisons were conducted for HH and RH. Table 4.15 summarizes these comparisons for all three sites.

Table 4.15: Mean turbidity comparisons for each site during leaf-on and leaf-off for BF and SF conditions.

Site	BF leaf-on (NTU)	BF leaf-off (NTU)	SF leaf-on (NTU)	SF leaf-off (NTU)
HH	56.8 (157.3)	36.2 (77.9)	285.5 (391.7)	62.0 (231.1)
DH	11.5 (17.0)	23.0 (99.0)	70.1 (228.2)	149.8 (374.0)
RH	22.7 (54.3)	10.6 (0.8)	98.2 (254.9)	5.2 (4.6)

pH

pH at both HH and RH decreased between BC and DC conditions. DH pH decreased using HH timeframe but increased using RH timeframe. Tables 4.16 and 4.17 summarize these results.

Table 4.16: Mean BF pH comparisons for BC and DC conditions for each site.

Site	BC	DC	BC - HH	DC - HH	BC – RH	DC – RH
HH	7.27 (0.21)	7.11 (0.25)	N/A	N/A	N/A	N/A
DH	6.33 (0.18)	N/A	6.46 (0.30)	6.31 (0.15)	6.32 (0.26)	6.36 (0.13)
RH	6.33 (0.07)	6.21 (0.11)	N/A	N/A	N/A	N/A

Table 4.17: Mean SF pH comparisons for BC and DC conditions for each site.

Site	BC	DC	BC - HH	DC - HH	BC – RH	DC – RH
HH	7.32 (0.14)	7.02 (0.20)	N/A	N/A	N/A	N/A
DH	6.34 (0.17)	N/A	6.45 (0.20)	6.31 (0.15)	6.32 (0.20)	6.36 (0.14)
RH	6.33 (0.04)	6.30 (0.69)	N/A	N/A	N/A	N/A

The reason for the pH increase at DH between BC and DC using RH timeframe was unknown. The general trend, however, appeared to be a decrease in pH between BC and DC, as well as between leaf-on and leaf-off for DH. These results are not definitive enough to conclude that FHP construction had impacts on stream pH in the watersheds. Table 4.18 summarizes comparison of pH during both leaf-on and leaf-off for baseflow and stormflow at each site.

Table 4.18: Mean pH at each site for BF and SF conditions during leaf-on and leaf-off.

Site	BF leaf-on	BF leaf-off	SF leaf-on	SF leaf-off
HH	7.22 (0.24)	7.10 (0.23)	7.18 (0.25)	7.05 (0.20)
DH	6.35 (0.20)	6.29 (0.14)	6.40 (0.20)	6.32 (0.14)
RH	6.27 (0.12)	6.25 (0.10)	6.27 (0.09)	6.34 (0.07)

Again, it can be seen that pH decreased between leaf-on and leaf-off. Given these trends, it was determined that fluctuations between BC and DC conditions for pH were due to seasonal variations and not FHP construction.

Conductivity

Mean baseflow and stormflow conductivity was compared for each site between BC and DC conditions. Conductivity was lower for DC conditions than for BC. All three sites had lower mean conductivity DC than BC. Tables 4.19 and 4.20 summarize the comparisons.

Table 4.19: Mean BF conductivity comparisons for BC and DC conditions for each site.

Site	BC (mS/cm)	DC (mS/cm)	BC – HH (mS/cm)	DC – HH (mS/cm)	BC – RH (mS/cm)	DC – RH (mS/cm)
HH	0.161 (0.055)	0.118 (0.035)	N/A	N/A	N/A	N/A
DH	0.063 (0.020)	N/A	0.081 (0.007)	0.046 (0.009)	0.069 (0.015)	0.043 (0.007)
RH	0.057 (0.022)	0.031 (0.004)	N/A	N/A	N/A	N/A

Table 4.20: Mean SF conductivity comparisons for BC and DC conditions for each site.

Site	BC (mS/cm)	DC (mS/cm)	BC – HH (mS/cm)	DC – HH (mS/cm)	BC – RH (mS/cm)	DC – RH (mS/cm)
HH	0.156 (0.041)	0.110 (0.030)	N/A	N/A	N/A	N/A
DH	0.053 (0.017)	N/A	0.080 (0.006)	0.045 (0.009)	0.068 (0.015)	0.042 (0.006)
RH	0.088 (0.083)	0.032 (0.003)	N/A	N/A	N/A	N/A

No construction occurred in DH during monitoring. Because the same trends were observed in a watershed where no construction occurred as in watershed where construction was occurring, it was concluded that FHP construction did not have an effect on conductivity. Table 4.21 summarizes leaf-on and leaf-off comparisons for conductivity at each site for baseflow and stormflow conditions.

Table 4.21: Mean conductivity at each site during leaf-on and leaf-off for BF and SF conditions.

Site	BF leaf-on (mS/cm)	BF leaf-off (mS/cm)	SF leaf-on (mS/cm)	SF leaf-off (mS/cm)
HH	0.151 (0.054)	0.116 (0.032)	0.145 (0.044)	0.106 (0.025)
DH	0.075 (0.016)	0.044 (0.007)	0.073 (0.014)	0.044 (0.007)
RH	0.075 (0.074)	0.033 (0.002)	0.061 (0.066)	0.034 (0.001)

The table above reveals seasonal differences in conductivity for baseflow and stormflow conditions. Conductivity at each site was lower during leaf-off than for leaf-on. These results indicate that behavioral trends in conductivity were caused by seasonal variations, not FHP construction.

Temperature

Mean baseflow temperature was compared between BC and DC for each site. It was observed that temperature decreased at each site between BC and DC conditions. Table 4.22 summarizes these results.

Table 4.22: Mean BF temperature comparisons for BC and DC conditions for each site.

Site	BC (°C)	DC (°C)	BC – HH (°C)	DC – HH (°C)	BC – RH (°C)	DC – RH (°C)
HH	19.92 (2.02)	11.21 (2.60)	N/A	N/A	N/A	N/A
DH	14.26 (5.00)	N/A	19.43 (1.35)	10.02 (2.68)	16.25 (3.66)	8.93 (2.20)
RH	19.00 (0.81)	10.21 (2.76)	N/A	N/A	N/A	N/A

At each site, mean temperature was lower for DC than for BC. This was suspected to be the result of seasonal differences, as leaf-on corresponded with warmer months while leaf-off corresponded with colder months. Table 4.23 shows mean temperature for baseflow conditions during leaf-on and leaf-off for each site.

Table 4.23: Mean BF temperature comparisons during leaf-on and leaf-off at each site.

Site	BF leaf-on (°C)	BF leaf-off (°C)
HH	18.34 (3.26)	10.15 (2.19)
DH	17.68 (2.81)	9.00 (2.38)
RH	17.10 (2.79)	7.89 (1.22)

Stormflow mean temperatures were compared between BC and DC and during leaf-on and leaf-off. Stormflow stream temperatures did not significantly change ($\alpha = 0.05$) from baseflow conditions. Given these results, it was concluded that temperature fluctuations between BC and DC conditions were not due to construction activities but were instead influenced by seasonal variations.

These results indicate that water quality differences between BC and DC conditions are likely attributable to seasonal variations, not actual construction impacts. Trends were consistent between sites with respect to variations in seasons, which made it possible to conclude that FHP construction did not adversely affect water quality in these research watersheds. In other words, seasonal variability has a disproportionately large effect on the physical and chemical water quality parameters measured during this project when compared to those impacts that might possibly have resulted from Foothills Parkway construction.

CHAPTER 5 – CONCLUSIONS

The objectives of this research were to deploy and maintain a real-time remote monitoring system for three small watersheds below the Foothills Parkway in the Great Smoky Mountains. Water quality data was monitored over the course of a year to determine trends for baseflow and stormflow conditions for undisturbed and 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 research were as follows:

- There are advantages and disadvantages to using 5-min and 60-min sampling intervals. A 5-min interval would be most ideal during storm events, especially for turbidity data if regulations are imposed and numeric effluent standards must be met. Although such a small sampling interval created redundancy in baseflow data, a shorter frequency ensures accuracy in stormflow data analysis. A 60-min interval would be desirable while sampling during baseflow conditions. However, if storm events were to occur, severe increases in turbidity data would potentially be missed.
- A 16-hr turbidity alert system would be most practical for monitoring changes in stream turbidity. This would allow site managers to be notified of potential permit violations while still providing adequate time to reach sites in the event of

disturbance to assess the situation and decide an appropriate course of action for remediation.

- For baseflow conditions, HH generally had higher turbidity, pH, conductivity, and temperature. HH turbidity averaged 56.8 and 162.3 NTU for leaf-on and leaf-off, respectively. Mean turbidity at DH was 31.0 and 86.1 NTU respectively, for leaf-on and leaf-off. Mean RH turbidity was 71.2 and 55.6 NTU for leaf-on and leaf-off, respectively. Stormflow turbidity was highest at HH during leaf-on (285.5 NTU) but highest at DH during leaf-off (149.8 NTU). RH was consistently lowest turbidity during stormflow both for leaf-on (98.2 NTU) and leaf-off (77.1 NTU). During baseflow, mean pH at HH was 7.22, while DH and RH pH was 6.35 and 6.27, respectively for leaf-on. For leaf-off, mean pH at HH, DH, and RH was 7.10, 6.29, and 6.25, respectively. Mean baseflow conductivity during leaf-on at HH was 0.151 mS/cm, while at both DH and RH, mean conductivity was 0.075 and 0.075 mS/cm. During leaf-off, mean conductivity was 0.116, 0.044, and 0.032 mS/cm at HH, DH, and RH, respectively. These differences between HH and the other two sites were likely due to internal disturbances such as road cuts prior to monitoring. HH temperature was highest during leaf-on (18.34 °C) and leaf-off (10.15 °C). RH had lowest temperature during leaf-on (17.10 °C) and leaf-off (8.53 °C). This was most likely due to the sonde at HH consistently exposed to sunlight in the stream. RH flow length was relatively short above monitoring and was heavily influenced by groundwater temperature.

- Trends in pH, conductivity, and temperature during storm events were not conclusive, as parameter fluctuations ranged in equal magnitude in both positive and negative direction. Therefore, pH, conductivity, and temperature, did not significantly differ between baseflow and stormflow conditions.
- Seasonal variations existed in and influenced water quality data at each site. Turbidity at HH for stormflow was 285.5 and 62.0 NTU during leaf-on and leaf-off, respectively. DH mean turbidity for stormflow was 70.1 and 149.8 NTU during leaf-on and leaf-off, respectively. RH stormflow turbidity was 98.2 and 77.1 NTU during leaf-on and leaf-off, respectively. pH and conductivity were lower during leaf-off than during leaf-on at each site. Lower leaf-off pH was due to more atmospheric nitrogen and sulfur deposition because leaves weren't causing interception. Storm events transported more sediment during leaf-off, which was also due to interception being removed. Stormflow turbidity was higher at HH during leaf-on but higher at DH during leaf-off. DH drains more catchment area than HH, causing more sediment transport from the watershed, especially during periods when leaves weren't causing interception. Again, higher turbidity at HH was likely due to internal disturbances.
- Correlations were established between rainfall and change in turbidity for each site during leaf-on and leaf-off. Regression equations were created to predict change in turbidity given rain depth, days since last rainfall, and storm duration. Variables used to describe turbidity were transformed to determine best-fit relationships. R^2 values for prediction equations ranged from 0.56 at HH during

leaf-on to 0.81 at DH during leaf-off. One overall equation was generated for predicting change in turbidity in each site, which had an R^2 value of 0.62.

- Turbidity data revealed that at HH and RH, during-construction levels were lower than before-construction levels. HH turbidity BC was 248.8 NTU, while DC turbidity was 126.1 NTU. RH turbidity for BC was 100.7 NTU and 81.0 NTU for DC. Analysis of DH turbidity revealed the opposite: turbidity was higher for during construction timeframe than for before construction timeframe. This analysis was incorporated to determine seasonal effects on water quality. However, because no actual construction occurred in DH during this research, it was determined that impacts on water quality were due to seasonal fluctuations and not caused by highway construction. This was an important finding both for NPS and for private landowners, as streams flowed from below construction to landowner property.

This research outlines methodology for establishing real-time remote monitoring systems to assess water quality. Equations determined in this study could aid researchers in predicting water quality in remote streams for watersheds with similar characteristics to the ones in this research. However, to enhance the procedures and findings outlined in this study, research could be modified in the following ways:

- Rain data collection should be setup to coincide with collection of water quality data. If this is not done, inaccuracies may exist in establishing behavioral trends between rainfall and water quality data, as precipitation data must be included from another site, or may not exist at all. Validity of the use of rain data substitution is questionable, especially if research sites differ from the region where rain data is being included.

- When possible, air temperature and stream discharge should be measured to more accurately predict impacts of storm events on water quality parameters. Simply measuring rain depth may not be adequate to fully understand the hydrologic interactions of rainfall and stream water quality.
- Frequency of sonde calibration should be in accordance with manufacturer's specifications to ensure accurate and precise measurement of water quality data. This is especially critical during storm events, when water quality parameters are most likely to be affected and undergo fluctuations.

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APPENDICES

Appendix A – Sonde Calibration Schedule

Date	HH	DH	RH
5/20/10	Yes	Yes	Yes
10/26/10	Yes	No	No
10/27/10	No	Yes	No
12/8/10	Yes	Yes	Yes
1/20/11	Yes	Yes	Yes
2/24/11	Yes	Yes	Yes
3/15/11	Yes	Yes	Yes
4/28/11	Yes	No	Yes
5/19/11	Yes	Yes	Yes
6/9/11	Yes	Yes	No

Appendix B – Summary Water Quality Data for Watersheds

Hembree Hollow – Background Comparison

	Turbidity (NTU)	pH	Conductivity (mS/cm)	Temperature (°C)
Baseflow leaf-on	56.8 (157.3)	7.22 (0.24)	0.151 (0.054)	18.34 (3.26)
Stormflow leaf-on	285.5 (391.7)	7.18 (0.25)	0.145 (0.044)	N/A
Baseflow leaf-off	36.2 (77.9)	7.10 (0.23)	0.116 (0.032)	10.15 (2.19)
Stormflow leaf-off	62.0 (231.1)	7.05 (0.20)	0.106 (0.025)	N/A

Hembree Hollow – Construction Comparison

	Turbidity (NTU)	pH	Conductivity (mS/cm)	Temperature (°C)
Baseflow BC	50.5 (125.4)	7.27 (0.21)	0.161 (0.055)	19.92 (2.02)
Stormflow BC	248.8 (310.0)	7.32 (0.14)	0.156 (0.041)	N/A
Baseflow DC	49.0 (144.1)	7.11 (0.25)	0.118 (0.035)	11.21 (2.60)
Stormflow DC	126.1 (333.6)	7.02 (0.20)	0.110 (0.030)	N/A

Dunn Hollow – Background Comparison

	Turbidity (NTU)	pH	Conductivity (mS/cm)	Temperature (°C)
Baseflow leaf-on	11.5 (17.0)	6.35 (0.20)	0.075 (0.016)	17.68 (2.81)
Stormflow leaf-on	70.1 (228.2)	6.40 (0.20)	0.073 (0.014)	N/A
Baseflow leaf-off	23.0 (99.0)	6.29 (0.14)	0.044 (0.007)	9.00 (2.38)
Stormflow leaf-off	149.8 (374.0)	6.32 (0.14)	0.044 (0.007)	N/A

Dunn Hollow – Construction Comparison

	Turbidity (NTU)	pH	Conductivity (mS/cm)	Temperature (°C)
Baseflow BC	15.8 (62.0)	6.33 (0.18)	0.063 (0.020)	14.26 (5.00)
Stormflow BC	120.3 (328.7)	6.34 (0.17)	0.053 (0.017)	N/A
Baseflow DC	N/A	N/A	N/A	N/A
Stormflow DC	N/A	N/A	N/A	N/A

Rudd Hollow – Background Comparison

	Turbidity (NTU)	pH	Conductivity (mS/cm)	Temperature (°C)
Baseflow leaf-on	22.7 (54.3)	6.27 (0.12)	0.075 (0.074)	17.10 (2.79)
Stormflow leaf-on	98.2 (254.9)	6.27 (0.09)	0.061 (0.066)	N/A
Baseflow leaf-off	10.6 (0.8)	6.33 (0.09)	0.033 (0.002)	7.89 (1.22)
Stormflow leaf-off	5.2 (4.6)	6.34 (0.07)	0.034 (0.001)	N/A

Rudd Hollow – Construction Comparison

	Turbidity (NTU)	pH	Conductivity (mS/cm)	Temperature (°C)
Baseflow BC	24.4 (63.0)	6.33 (0.07)	0.057 (0.022)	19.00 (0.81)
Stormflow BC	100.7 (176.1)	6.33 (0.04)	0.088 (0.083)	N/A
Baseflow DC	14.6 (36.8)	6.21 (0.11)	0.031 (0.004)	10.21 (2.76)
Stormflow DC	81.0 (282.0)	6.30 (0.69)	0.032 (0.003)	N/A

Appendix C – SAS® Procedure Codes

Slope-intercept Regression

```
data one;   'names the data set'
input       'input parameters and values'
date mmddyy10.   HH_daily   DH_daily   RH_daily   CC_daily;
cards;
12/9/2010  0.32  0.09999999 0.03  0
12/10/2010 0     0     0     0
12/11/2010 0     0     0     0
12/12/2010 0.2   0.21  0.32  0.996062992
12/13/2010 0     0     0     0.035433071
12/14/2010 0.03  0     0     0
12/15/2010 0     0     0     0.05511811
12/16/2010 0.47  0.5   0.58  0.602362205
12/17/2010 0     0     0     0
12/18/2010 0     0     0     0
12/19/2010 0     0     0     0
12/20/2010 0     0     0     0
12/21/2010 0.14  0.1   0.11  0.098425197
12/22/2010 0.05  0.04  0.05  0.051181102
12/23/2010 0.01  0     0     0
12/24/2010 0     0     0     0
12/25/2010 0     0     0.03  0.476377953
12/26/2010 0     0     0     0.122047244
12/27/2010 0     0     0     0
12/28/2010 0.13  0     0     0
12/29/2010 0.04  0     0.09  0
12/30/2010 0.42  0.39  0.25  0.015748031
12/31/2010 0.12  0.15  0.01  0.011811024
1/1/2011   1.22999999 0.47  1.17  1.976377953
1/2/2011   0.04  0.09  0.03  0.082677165
1/3/2011   0     0     0     0
1/4/2011   0     0.17  0     0
1/5/2011   0.09  0.14  0.1   0.145669291
1/6/2011   0.14  0.12  0.13  0.137795276
1/7/2011   0.09  0.04  0.11  0.157480315
1/8/2011   0     0     0     0.051181102
1/9/2011   0     0     0     0
1/10/2011  0     0     0     0.440944882
1/11/2011  0     0     0     0.007874016
1/12/2011  0     0     0     0
1/13/2011  0.07  0     0     0
1/14/2011  0.15  0     0     0
1/15/2011  0.23  0     0.01  0
1/16/2011  0.08  0.22  0.18  0
1/17/2011  0.01  0.18  0.16  0
1/18/2011  0.18  0.37  0.24  0.248031496
```

1/19/2011	0.09	0.21	0.11	0.086614173
1/20/2011	0.01	0.01	0.01	0.05511811
1/21/2011	0.08	0	0	0
1/22/2011	0.01	0	0	0
1/23/2011	0.01	0.01	0.04	0
1/24/2011	0	0.03	0.05	0
1/25/2011	0.14	0.09	0.13	0.098425197
1/26/2011	0.55	0.54	0.51	0.704724409
1/27/2011	0.24	0.04	0.08	0
1/28/2011	0.01	0.11	0.12	0
1/29/2011	0	0	0	0
1/30/2011	0	0.01	0	0
1/31/2011	0	0	0	0
2/1/2011	0.35	0.25	0.28	0.421259843
2/2/2011	0	0.01	0	0
2/3/2011	0	0	0	0.003937008
2/4/2011	0.25	0.19	0.28	0.244094488
2/5/2011	0.03	0.04	0.05	0.023622047
2/6/2011	0	0	0	0
2/7/2011	0.12	0.11	0.1	0.153543307
2/8/2011	0.04	0.01	0.02	0
2/9/2011	0.02	0	0.01	0.031496063
2/10/2011	0.11	0	0.04	0.039370079
2/11/2011	0.01	0.03	0.03	0
2/12/2011	0	0.02	0.02	0
2/13/2011	0	0.01	0	0
2/14/2011	0	0	0	0
2/15/2011	0	0	0	0
2/16/2011	0	0	0	0
2/17/2011	0	0	0	0
2/18/2011	0.09	0.04	0.06	0.070866142
2/19/2011	0	0	0	0
2/20/2011	0.02	0.01	0.02	0
2/21/2011	0	0	0	0.007874016
2/22/2011	0.23	0.14	0.24	0.291338583
2/23/2011	0	0	0	0
2/24/2011	0.28	0.19	0.35	0.12992126
2/25/2011	0.79	0.69	0.77	0.716535433
2/26/2011	0	0	0	0
2/27/2011	0.1	0.02	0.15	0.007874016
2/28/2011	1.41	1.23	1.34	1.421259843
3/1/2011	0.01	0	0.01	0.003937008
3/2/2011	0	0	0	0
3/3/2011	0	0	0	0
3/4/2011	0	0	0	0
3/5/2011	0.18	0.24	0.31	0.606299213
3/6/2011	1.67999999	1.07	1.54	2.137795276
3/7/2011	0	0.01	0.02	
3/8/2011	0.01	0.01	0.01	0.047244094
3/9/2011	0.75999999	0.64	0.6	1.874015748
3/10/2011	1.41	0.95999999	1.26999999	1.637795276

3/11/2011	0.18		0.13	0.031496063
3/12/2011	0		0	0
3/13/2011	0		0	0
3/14/2011	0		0	0
3/15/2011	0.35	0.01	0.35	0.413385827
3/16/2011	0	0	0	0
3/17/2011	0	0	0	0
3/18/2011	0	0	0	0
3/19/2011	0	0	0	0
3/20/2011	0	0	0	0
3/21/2011	0	0	0	0
3/22/2011	0	0	0	0
3/23/2011	0.57	0.52	0.62	0.24015748
3/24/2011	0	0	0	0.003937008
3/25/2011	0.03	0.02	0.03	0.082677165
3/26/2011	0.23	0.18	0.21	0.342519685
3/27/2011	0.04	0.04	0.05	0.07480315
3/28/2011	0.31	0.31	0.3	0.283464567
3/29/2011	0.01	0	0	0
3/30/2011	0.64	0.51	0.59	0.661417323
3/31/2011	0.04	0.04	0.04	0.007874016
4/1/2011	0	0	0	0
4/2/2011	0.04	0	0.02	0
4/3/2011	0	0	0	0
4/4/2011	1.78999998	1.59	1.67	2.488188976
4/5/2011	0.69	0.55	0.62	0.287401575
4/6/2011	0	0	0	0
4/7/2011	0	0	0	0
4/8/2011	0.01	0.01	0	0
4/9/2011	0	0	0	0
4/10/2011	0	0	0	0
4/11/2011	0.09	0.06	0.1	
4/12/2011	0.47	0.53	0.58	0.700787402
4/13/2011	0.14	0	0	0
4/14/2011	0	0	0	
4/15/2011	0.68	0.54	0.63	1.503937008
4/16/2011	0.2	0.16	0.13	0.212598425
4/17/2011	0	0	0	0
4/18/2011	0	0	0	0
4/19/2011	0	0	0.01	0
4/20/2011	0.38	0.35	0.42	0.460629921
4/21/2011	0	0	0	0
4/22/2011	0	0	0	0
4/23/2011	0	0	0	0
4/24/2011	0	0	0	0
4/25/2011	0	0	0	0.003937008
4/26/2011	0.01	0	0.01	0.07480315
4/27/2011	0.17	0.35	0.5	0.468503937
4/28/2011	0.82	0.64	0.6	0.051181102
4/29/2011	0	0	0	0
4/30/2011	0	0	0	0

```
;
proc reg;  'runs regression procedure'
model rh_daily = hh_daily;  'specification of regression model'
test intercept=0,hh_daily=1;
run;  'runs procedure'
quit; 'stops calculations after completion of model run'

proc reg;
model rh_daily = dh_daily;  'comparing RH to DH'
test intercept=0,dh_daily=1;
run;
quit;

proc reg;
model hh_daily = dh_daily;
test intercept=0,dh_daily=1;
run;
quit;
```

Correlation Analysis

```
proc corr;  'runs correlation procedure'
var delta_turb rain_event DSLR dur;     'specify variables'
run;
```

Data Transformations

```
data RH1;   'new data set'
set RH;     'created from old data set'
lnturb=log(delta_turb);      'transforms data to natural log'
lnrain=log(rain_event);
lnDSLR=log(DSLR);
lndur=log(duration);
turb2=delta_turb**2;         'transforms data to squared'
rain2=rain_event**2;
DSLR2=DSLR**2;
dur2=duration**2;
srturb=sqrt(delta_turb);     'transforms data to square root'
srrain=sqrt(rain_event);
srDSLR=sqrt(DSLR);
srdur=sqrt(duration);
run;
```

Descriptive Statistics and Box-&-Whisker Plots

```
proc univariate data=RH;     'generates descriptive stats'
var delta_turb rain_event DSLR pH cond temp;  'specific variables'
run;
```

ANOVAs

```
data RH;    'creates data set from input lines'
input condition $ turb;      'specify labels and format of input'
datalines;      'input turbidity data comparing leaf-on and leaf-off'
ON    0.3
ON    0.3
ON    1.9
ON    8.5
ON    9.5
ON    4.4
ON    5.4
ON    7.4
ON    17.8
ON    6.7
ON    9.9
ON    5.3
ON    43.1
ON    12.2
ON    54.2
ON    204.2
ON    6.0
ON    578.9
ON    16.1
ON    53.2
ON    11.0
ON    0.7
ON    487.1
ON    38.7
ON    20.1
ON    47.6
ON    64.7
ON    26.2
ON    14.2
ON    17.2
ON    1271.2
OFF   0.6
OFF   0.3
OFF   0.0
OFF   0.2
OFF   0.1
OFF   125.2
OFF   0.9
```

```
OFF   0.5
OFF   0.2
OFF   0.1
OFF   1.3
OFF   3.9
OFF   0.6
OFF   0.3
OFF   0.6
OFF   0.4
OFF   0.1
OFF   0.8
OFF   1.5
OFF   1.1
OFF   2.0
OFF   0.4
OFF   0.1
OFF   2.1
OFF   3.2
OFF   6.0
OFF   8.0
OFF   2.0
OFF   3.3
OFF   1.4
OFF   1.7
OFF   3.4
OFF   0.2
OFF   45.7
OFF   4.1
OFF   0.5
OFF   1.5
OFF   370.3
OFF   10.2
OFF   4.1
OFF   15.2
OFF   3.2
OFF   6.5
OFF   9.8
OFF   3.1
OFF   5.7
OFF   1081.2
OFF   5.1
OFF   3.6
OFF   12.3
OFF   0.0
OFF   40.7
OFF   30.3
OFF   1227.3
OFF   1256.2
OFF   5.5
;
proc glm;   'runs glm (general linear model) procedure'
```

```
class condition;       'specify class or comparison of interest'
model turb = condition;      'specify model parameters'
means condition / hovtest=bf; 'Brown-Forsythe-Levene equal variance'
means condition / lsd tukey;    'LSD and Tukey multiple comparisons'
run;
quit;
```

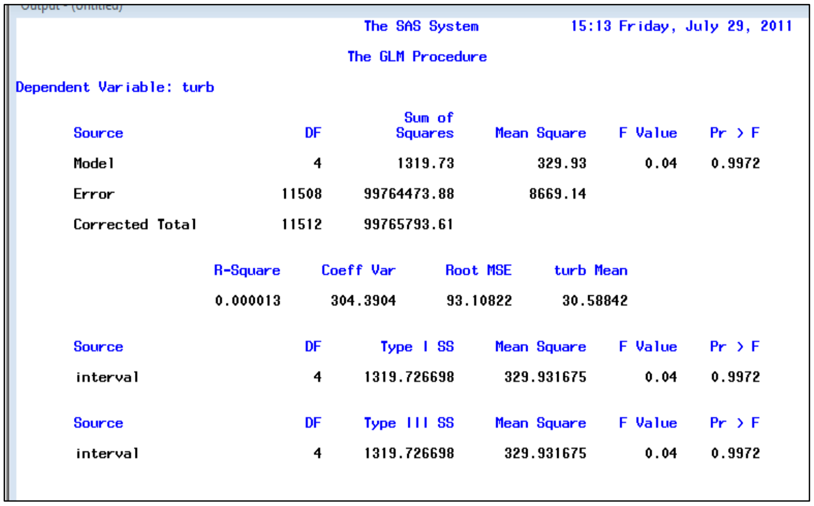
Multiple Regression

```
proc reg;   'runs regression procedure for multiple variables'
model turb2 = lnrain DSLR dur2;    'specify variables for model'
run;
quit;
```

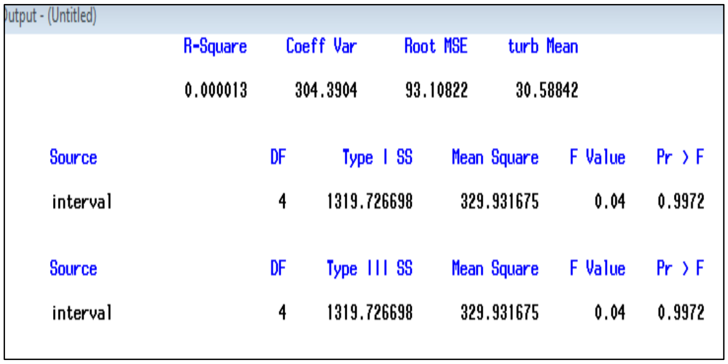
Appendix D – SAS® Output

Objective 1

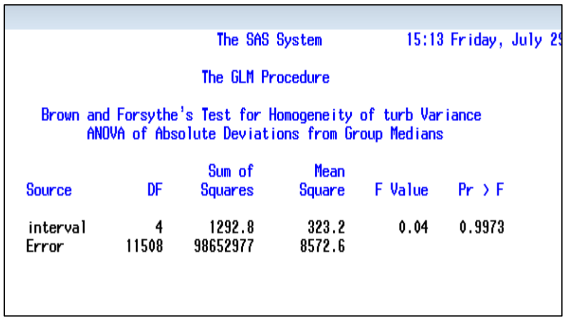
Sampling intervals:



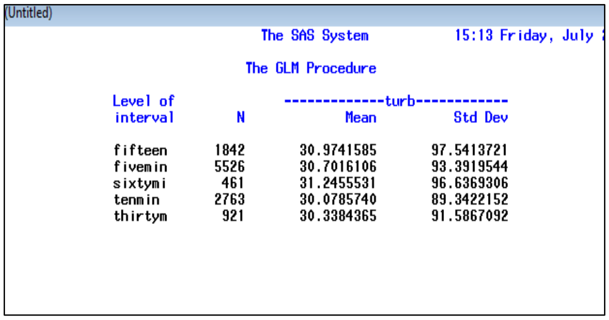
```
                                   The SAS System          15:13 Friday, July 29, 2011

                                 The GLM Procedure

Dependent Variable: turb

                                                Sum of
       Source                      DF          Squares     Mean Square    F Value    Pr > F

       Model                        4          1319.73          329.93       0.04    0.9972

       Error                    11508      99764473.88         8669.14

       Corrected Total          11512      99765793.61


                        R-Square     Coeff Var      Root MSE     turb Mean

                        0.000013      304.3904      93.10822      30.58842


       Source                      DF        Type I SS     Mean Square    F Value    Pr > F

       interval                     4      1319.726698      329.931675       0.04    0.9972


       Source                      DF      Type III SS     Mean Square    F Value    Pr > F

       interval                     4      1319.726698      329.931675       0.04    0.9972
```



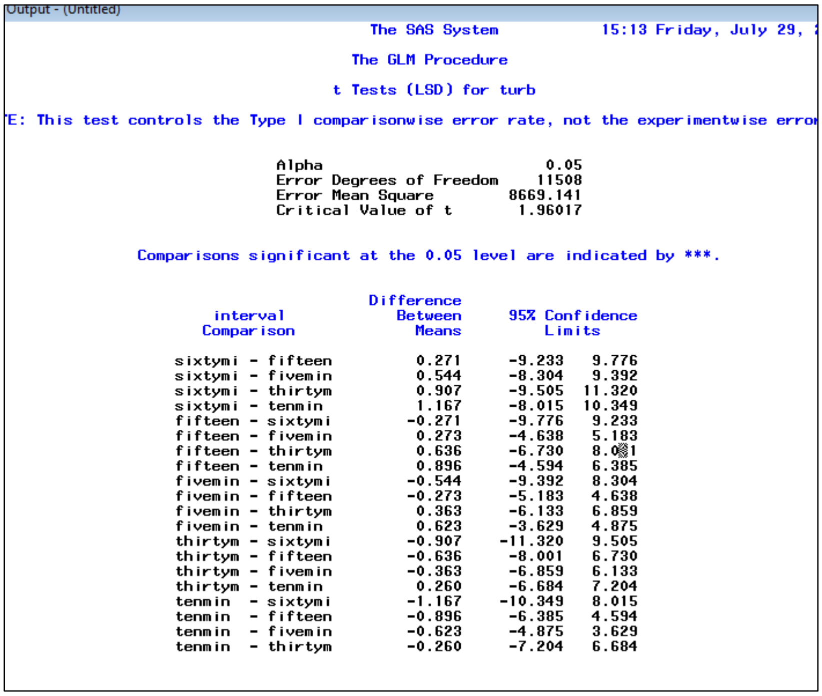
```
                        R-Square     Coeff Var      Root MSE     turb Mean

                        0.000013      304.3904      93.10822      30.58842


       Source                      DF        Type I SS     Mean Square    F Value    Pr > F

       interval                     4      1319.726698      329.931675       0.04    0.9972


       Source                      DF      Type III SS     Mean Square    F Value    Pr > F

       interval                     4      1319.726698      329.931675       0.04    0.9972
```



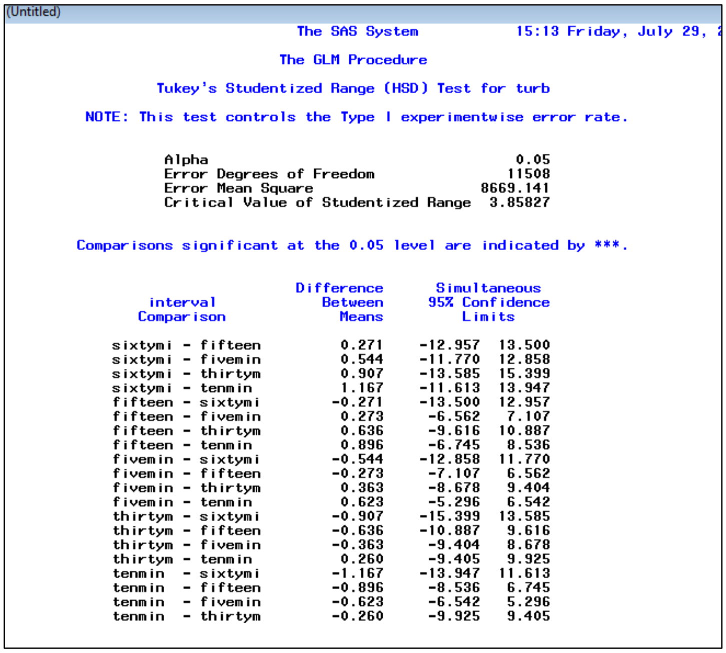
```
                      The SAS System          15:13 Friday, July 2

                     The GLM Procedure

   Brown and Forsythe's Test for Homogeneity of turb Variance
         ANOVA of Absolute Deviations from Group Medians

                            Sum of        Mean
 Source          DF        Squares      Square    F Value    Pr > F

 interval         4         1292.8       323.2       0.04    0.9973
 Error        11508       98652977      8572.6
```



```
                          The SAS System          15:13 Friday, July

                         The GLM Procedure

            Level of            -------------turb------------
            interval        N              Mean          Std Dev

            fifteen      1842        30.9741585       97.5413721
            fivemin      5526        30.7016106       93.3919544
            sixtymi       461        31.2455531       96.6369306
            tenmin       2763        30.0785740       89.3422152
            thirtym       921        30.3384365       91.5867092
```



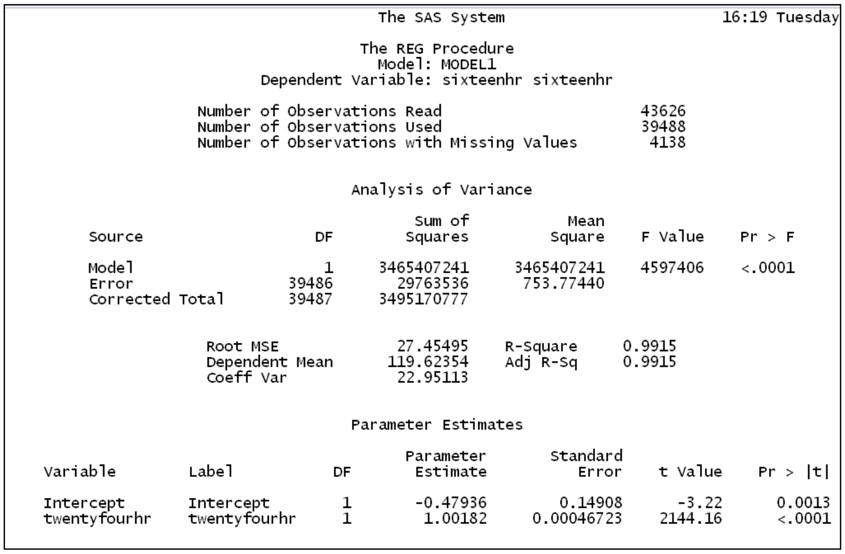
```
                              The SAS System          15:13 Friday, July 29,

                             The GLM Procedure

                            t Tests (LSD) for turb

E: This test controls the Type I comparisonwise error rate, not the experimentwise erro

                     Alpha                            0.05
                     Error Degrees of Freedom        11508
                     Error Mean Square            8669.141
                     Critical Value of t           1.96017


          Comparisons significant at the 0.05 level are indicated by ***.


                                    Difference
                 interval              Between     95% Confidence
                Comparison               Means         Limits

             sixtymi - fifteen           0.271     -9.233    9.776
             sixtymi - fivemin           0.544     -8.304    9.392
             sixtymi - thirtym           0.907     -9.505   11.320
             sixtymi - tenmin            1.167     -8.015   10.349
             fifteen - sixtymi          -0.271     -9.776    9.233
             fifteen - fivemin           0.273     -4.638    5.183
             fifteen - thirtym           0.636     -6.730    8.0[illegible]1
             fifteen - tenmin            0.896     -4.594    6.385
             fivemin - sixtymi          -0.544     -9.392    8.304
             fivemin - fifteen          -0.273     -5.183    4.638
             fivemin - thirtym           0.363     -6.133    6.859
             fivemin - tenmin            0.623     -3.629    4.875
             thirtym - sixtymi          -0.907    -11.320    9.505
             thirtym - fifteen          -0.636     -8.001    6.730
             thirtym - fivemin          -0.363     -6.859    6.133
             thirtym - tenmin            0.260     -6.684    7.204
             tenmin  - sixtymi          -1.167    -10.349    8.015
             tenmin  - fifteen          -0.896     -6.385    4.594
             tenmin  - fivemin          -0.623     -4.875    3.629
             tenmin  - thirtym          -0.260     -7.204    6.684
```



```
                         The SAS System           15:13 Friday, July 29,

                       The GLM Procedure

             Tukey's Studentized Range (HSD) Test for turb

      NOTE: This test controls the Type I experimentwise error rate.


                 Alpha                                  0.05
                 Error Degrees of Freedom              11508
                 Error Mean Square                  8669.141
                 Critical Value of Studentized Range  3.85827


     Comparisons significant at the 0.05 level are indicated by ***.


                               Difference       Simultaneous
            interval             Between       95% Confidence
           Comparison             Means           Limits

        sixtymi - fifteen         0.271     -12.957  13.500
        sixtymi - fivemin         0.544     -11.770  12.858
        sixtymi - thirtym         0.907     -13.585  15.399
        sixtymi - tenmin          1.167     -11.613  13.947
        fifteen - sixtymi        -0.271     -13.500  12.957
        fifteen - fivemin         0.273      -6.562   7.107
        fifteen - thirtym         0.636      -9.616  10.887
        fifteen - tenmin          0.896      -6.745   8.536
        fivemin - sixtymi        -0.544     -12.858  11.770
        fivemin - fifteen        -0.273      -7.107   6.562
        fivemin - thirtym         0.363      -8.678   9.404
        fivemin - tenmin          0.623      -5.296   6.542
        thirtym - sixtymi        -0.907     -15.399  13.585
        thirtym - fifteen        -0.636     -10.887   9.616
        thirtym - fivemin        -0.363      -9.404   8.678
        thirtym - tenmin          0.260      -9.405   9.925
        tenmin  - sixtymi        -1.167     -13.947  11.613
        tenmin  - fifteen        -0.896      -8.536   6.745
        tenmin  - fivemin        -0.623      -6.542   5.296
        tenmin  - thirtym        -0.260      -9.925   9.405
```

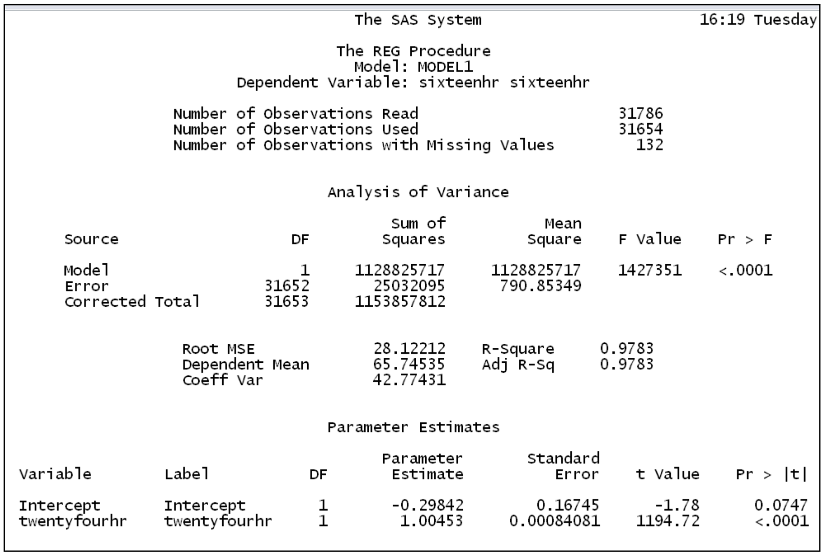
Turbidity Alert:

HH



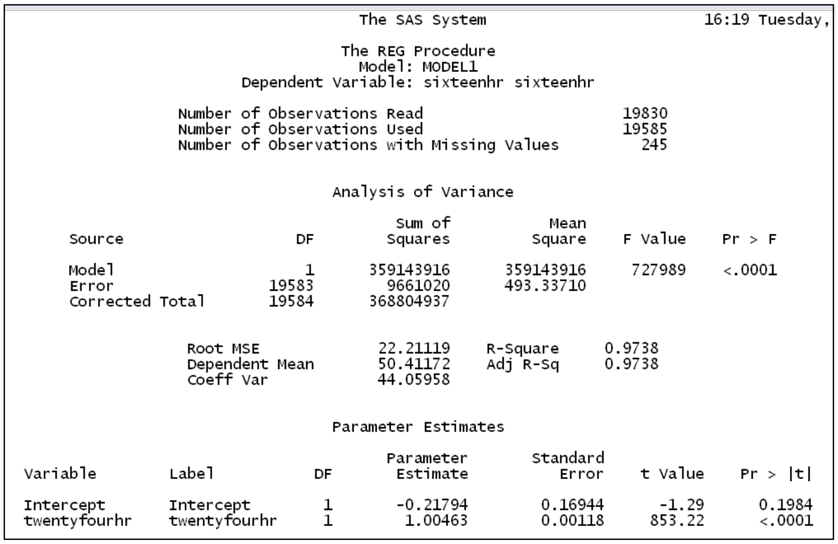
```
                                   The SAS System                        16:19 Tuesday

                                  The REG Procedure
                                    Model: MODEL1
                        Dependent Variable: sixteenhr sixteenhr

                  Number of Observations Read                        43626
                  Number of Observations Used                        39488
                  Number of Observations with Missing Values          4138


                                Analysis of Variance

                                          Sum of           Mean
        Source                   DF      Squares         Square    F Value    Pr > F

        Model                     1   3465407241     3465407241    4597406    <.0001
        Error                 39486     29763536      753.77440
        Corrected Total       39487   3495170777


                     Root MSE             27.45495    R-Square     0.9915
                     Dependent Mean      119.62354    Adj R-Sq     0.9915
                     Coeff Var            22.95113


                                Parameter Estimates

                                          Parameter       Standard
    Variable        Label           DF     Estimate          Error    t Value    Pr > |t|

    Intercept       Intercept        1     -0.47936        0.14908      -3.22      0.0013
    twentyfourhr    twentyfourhr     1      1.00182     0.00046723    2144.16      <.0001
```

DH



```
                                  The SAS System                      16:19 Tuesday

                                 The REG Procedure
                                  Model: MODEL1
                      Dependent Variable: sixteenhr sixteenhr

                Number of Observations Read                        31786
                Number of Observations Used                        31654
                Number of Observations with Missing Values           132


                               Analysis of Variance

                                       Sum of           Mean
     Source                  DF       Squares         Square    F Value    Pr > F

     Model                    1    1128825717     1128825717    1427351    <.0001
     Error                31652      25032095      790.85349
     Corrected Total      31653    1153857812


                 Root MSE             28.12212    R-Square     0.9783
                 Dependent Mean       65.74535    Adj R-Sq     0.9783
                 Coeff Var            42.77431


                               Parameter Estimates

                                          Parameter       Standard
Variable         Label            DF       Estimate          Error    t Value    Pr > |t|

Intercept        Intercept         1       -0.29842        0.16745      -1.78      0.0747
twentyfourhr     twentyfourhr      1        1.00453     0.00084081    1194.72      <.0001
```

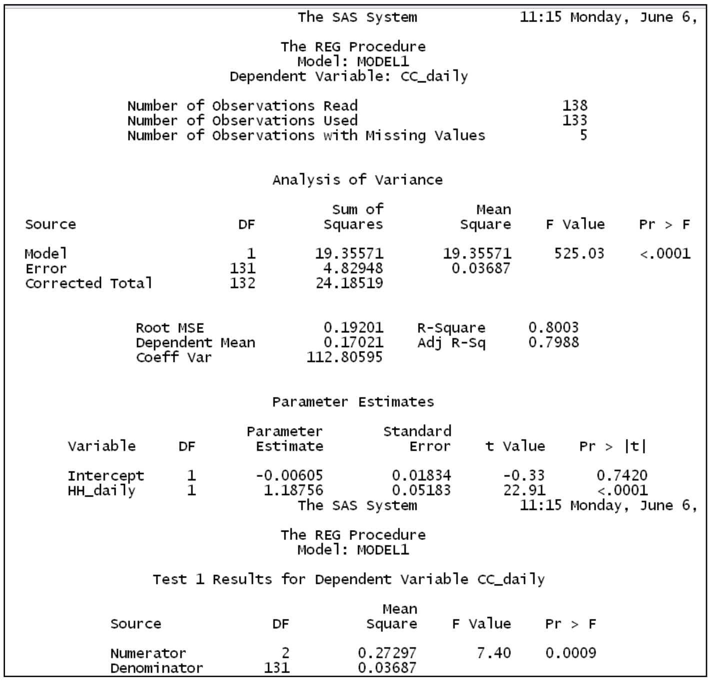
RH



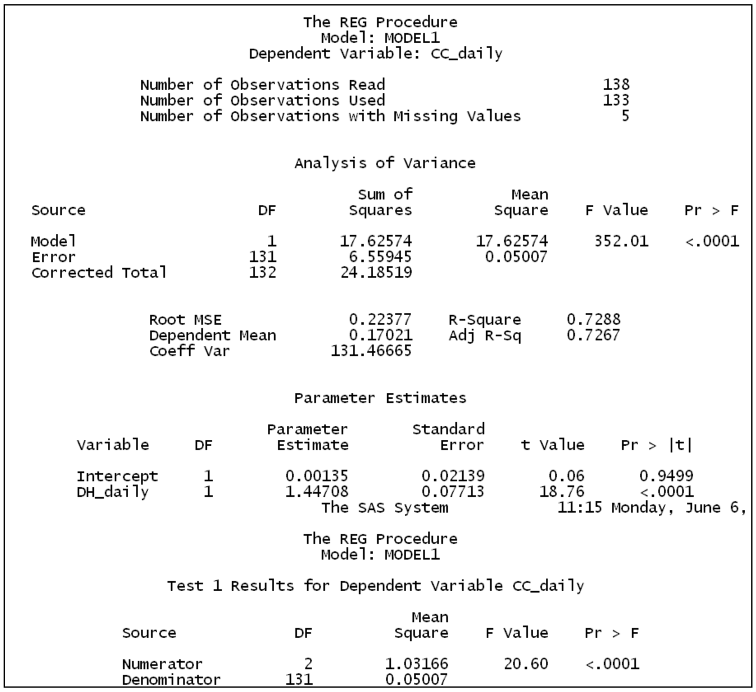
```
                                  The SAS System                      16:19 Tuesday,

                                 The REG Procedure
                                  Model: MODEL1
                      Dependent Variable: sixteenhr sixteenhr

                Number of Observations Read                        19830
                Number of Observations Used                        19585
                Number of Observations with Missing Values           245


                               Analysis of Variance

                                       Sum of           Mean
     Source                  DF       Squares         Square    F Value    Pr > F

     Model                    1     359143916      359143916     727989    <.0001
     Error                19583       9661020      493.33710
     Corrected Total      19584     368804937


                 Root MSE             22.21119    R-Square     0.9738
                 Dependent Mean       50.41172    Adj R-Sq     0.9738
                 Coeff Var            44.05958


                               Parameter Estimates

                                          Parameter       Standard
Variable         Label            DF       Estimate          Error    t Value    Pr > |t|

Intercept        Intercept         1       -0.21794        0.16944      -1.29      0.1984
twentyfourhr     twentyfourhr      1        1.00463        0.00118     853.22      <.0001
```

Objective 2

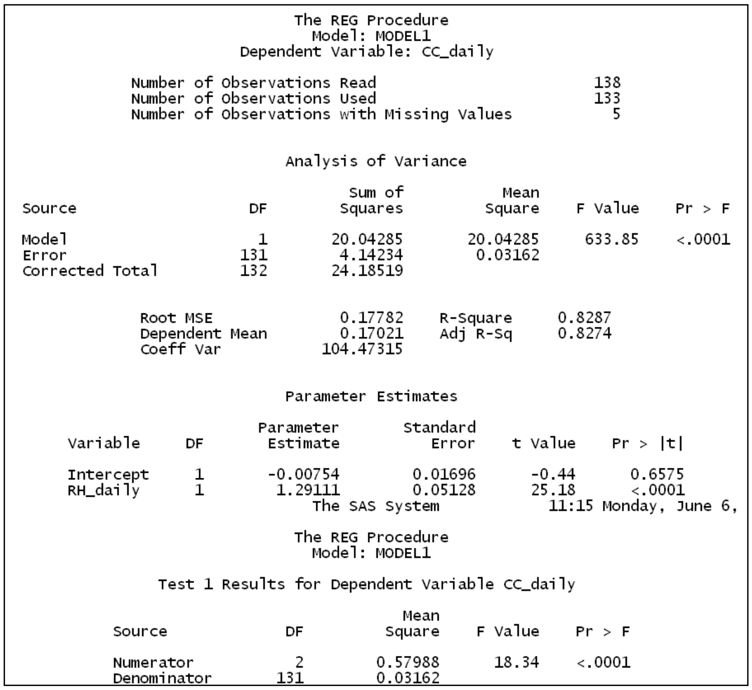
Rainfall comparisons:



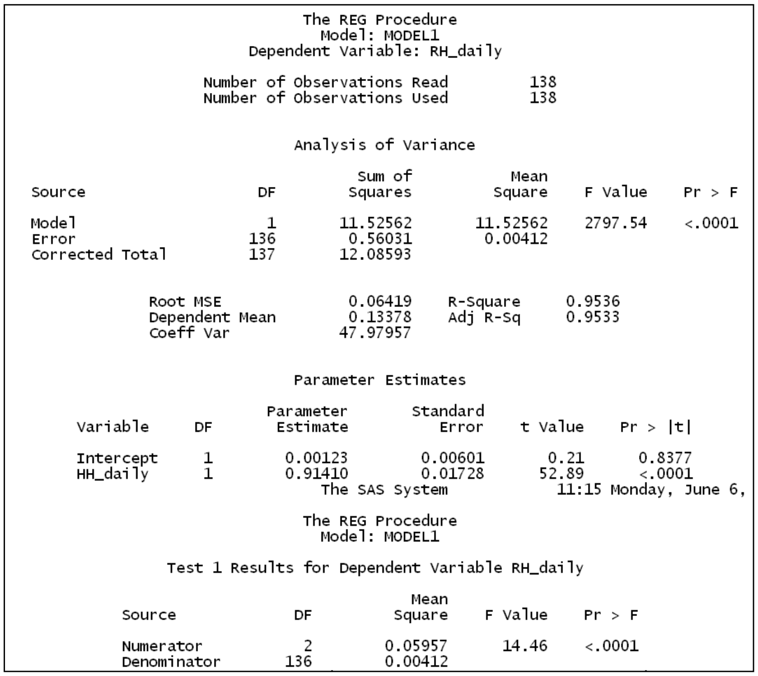
```
                                 The SAS System          11:15 Monday, June 6,

                               The REG Procedure
                                 Model: MODEL1
                          Dependent Variable: CC_daily

             Number of Observations Read                        138
             Number of Observations Used                        133
             Number of Observations with Missing Values           5


                              Analysis of Variance

                                      Sum of           Mean
  Source                   DF        Squares         Square    F Value    Pr > F

  Model                     1       19.35571       19.35571     525.03    <.0001
  Error                   131        4.82948        0.03687
  Corrected Total         132       24.18519


              Root MSE              0.19201    R-Square     0.8003
              Dependent Mean        0.17021    Adj R-Sq     0.7988
              Coeff Var           112.80595


                              Parameter Estimates

                              Parameter       Standard
       Variable     DF         Estimate          Error    t Value    Pr > |t|

       Intercept     1         -0.00605        0.01834      -0.33      0.7420
       HH_daily      1          1.18756        0.05183      22.91      <.0001
                                 The SAS System          11:15 Monday, June 6,

                               The REG Procedure
                                 Model: MODEL1

                Test 1 Results for Dependent Variable CC_daily

                                         Mean
          Source             DF        Square    F Value    Pr > F

          Numerator           2       0.27297       7.40    0.0009
          Denominator       131       0.03687
```



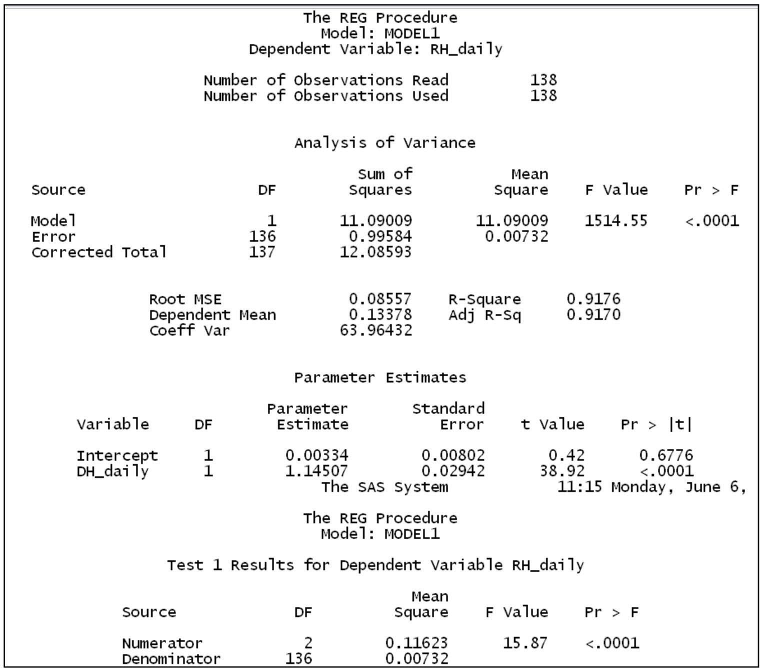
```
                               The REG Procedure
                                 Model: MODEL1
                          Dependent Variable: CC_daily

             Number of Observations Read                        138
             Number of Observations Used                        133
             Number of Observations with Missing Values           5


                              Analysis of Variance

                                      Sum of           Mean
  Source                   DF        Squares         Square    F Value    Pr > F

  Model                     1       17.62574       17.62574     352.01    <.0001
  Error                   131        6.55945        0.05007
  Corrected Total         132       24.18519


              Root MSE              0.22377    R-Square     0.7288
              Dependent Mean        0.17021    Adj R-Sq     0.7267
              Coeff Var           131.46665


                              Parameter Estimates

                              Parameter       Standard
       Variable     DF         Estimate          Error    t Value    Pr > |t|

       Intercept     1          0.00135        0.02139       0.06      0.9499
       DH_daily      1          1.44708        0.07713      18.76      <.0001
                                 The SAS System          11:15 Monday, June 6,

                               The REG Procedure
                                 Model: MODEL1

                Test 1 Results for Dependent Variable CC_daily

                                         Mean
          Source             DF        Square    F Value    Pr > F

          Numerator           2       1.03166      20.60    <.0001
          Denominator       131       0.05007
```



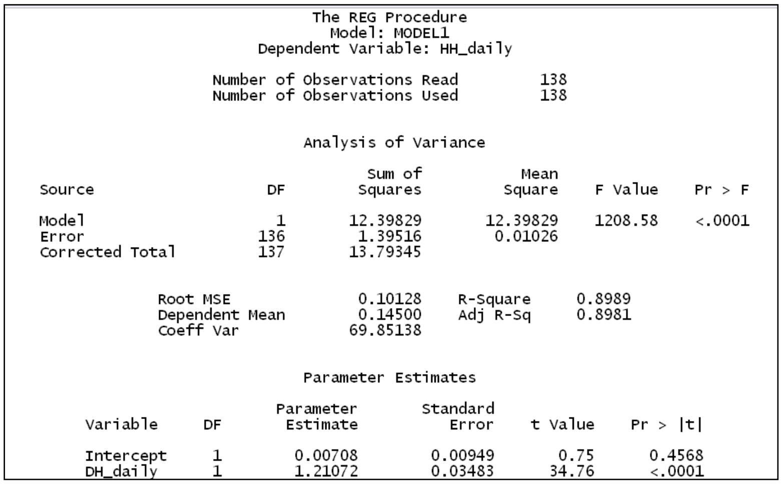
```
                             The REG Procedure
                               Model: MODEL1
                       Dependent Variable: CC_daily

          Number of Observations Read                          138
          Number of Observations Used                          133
          Number of Observations with Missing Values             5


                            Analysis of Variance

                                    Sum of           Mean
Source                   DF        Squares         Square    F Value    Pr > F

Model                     1       20.04285       20.04285     633.85    <.0001
Error                   131        4.14234        0.03162
Corrected Total         132       24.18519


             Root MSE              0.17782    R-Square     0.8287
             Dependent Mean        0.17021    Adj R-Sq     0.8274
             Coeff Var           104.47315


                            Parameter Estimates

                           Parameter       Standard
     Variable     DF        Estimate          Error    t Value    Pr > |t|

     Intercept     1        -0.00754        0.01696      -0.44      0.6575
     RH_daily      1         1.29111        0.05128      25.18      <.0001
                              The SAS System           11:15 Monday, June 6,

                             The REG Procedure
                               Model: MODEL1

               Test 1 Results for Dependent Variable CC_daily

                                          Mean
          Source              DF        Square    F Value    Pr > F

          Numerator            2       0.57988      18.34    <.0001
          Denominator        131       0.03162
```



```
                             The REG Procedure
                               Model: MODEL1
                       Dependent Variable: RH_daily

                 Number of Observations Read         138
                 Number of Observations Used         138


                            Analysis of Variance

                                    Sum of           Mean
Source                   DF        Squares         Square    F Value    Pr > F

Model                     1       11.52562       11.52562    2797.54    <.0001
Error                   136        0.56031        0.00412
Corrected Total         137       12.08593


             Root MSE              0.06419    R-Square     0.9536
             Dependent Mean        0.13378    Adj R-Sq     0.9533
             Coeff Var            47.97957


                            Parameter Estimates

                           Parameter       Standard
     Variable     DF        Estimate          Error    t Value    Pr > |t|

     Intercept     1         0.00123        0.00601       0.21      0.8377
     HH_daily      1         0.91410        0.01728      52.89      <.0001
                              The SAS System           11:15 Monday, June 6,

                             The REG Procedure
                               Model: MODEL1

               Test 1 Results for Dependent Variable RH_daily

                                          Mean
          Source              DF        Square    F Value    Pr > F

          Numerator            2       0.05957      14.46    <.0001
          Denominator        136       0.00412
```

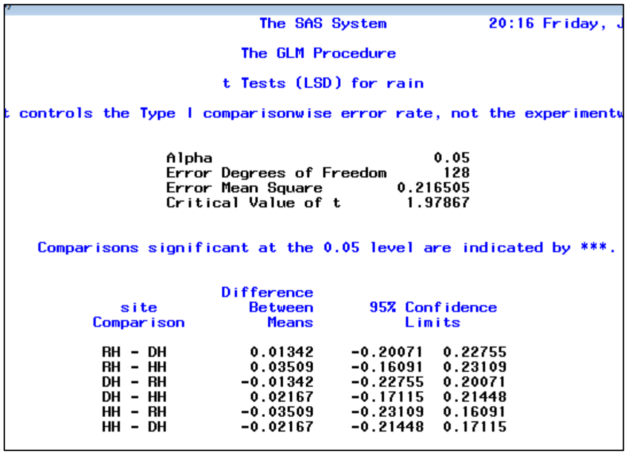


```
                              The REG Procedure
                                Model: MODEL1
                        Dependent Variable: RH_daily

                   Number of Observations Read         138
                   Number of Observations Used         138


                             Analysis of Variance

                                    Sum of           Mean
Source                   DF        Squares         Square     F Value     Pr > F

Model                     1       11.09009       11.09009     1514.55     <.0001
Error                   136        0.99584        0.00732
Corrected Total         137       12.08593


             Root MSE              0.08557    R-Square     0.9176
             Dependent Mean        0.13378    Adj R-Sq     0.9170
             Coeff Var            63.96432


                             Parameter Estimates

                          Parameter       Standard
     Variable     DF       Estimate          Error    t Value    Pr > |t|

     Intercept     1        0.00334        0.00802       0.42      0.6776
     DH_daily      1        1.14507        0.02942      38.92      <.0001
                                The SAS System            11:15 Monday, June 6,

                              The REG Procedure
                                Model: MODEL1

               Test 1 Results for Dependent Variable RH_daily

                                          Mean
          Source             DF         Square     F Value    Pr > F

          Numerator           2        0.11623       15.87    <.0001
          Denominator       136        0.00732
```

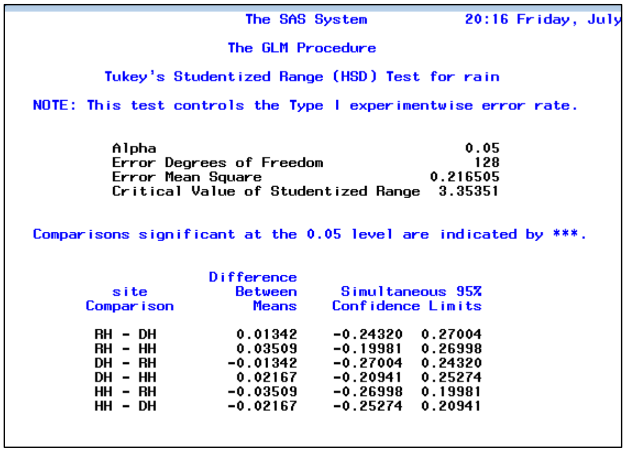


```
                              The REG Procedure
                                Model: MODEL1
                        Dependent Variable: HH_daily

                   Number of Observations Read         138
                   Number of Observations Used         138


                             Analysis of Variance

                                    Sum of           Mean
Source                   DF        Squares         Square     F Value     Pr > F

Model                     1       12.39829       12.39829     1208.58     <.0001
Error                   136        1.39516        0.01026
Corrected Total         137       13.79345


             Root MSE              0.10128    R-Square     0.8989
             Dependent Mean        0.14500    Adj R-Sq     0.8981
             Coeff Var            69.85138


                             Parameter Estimates

                          Parameter       Standard
     Variable     DF       Estimate          Error    t Value    Pr > |t|

     Intercept     1        0.00708        0.00949       0.75      0.4568
     DH_daily      1        1.21072        0.03483      34.76      <.0001
```

Rain leaf-on:

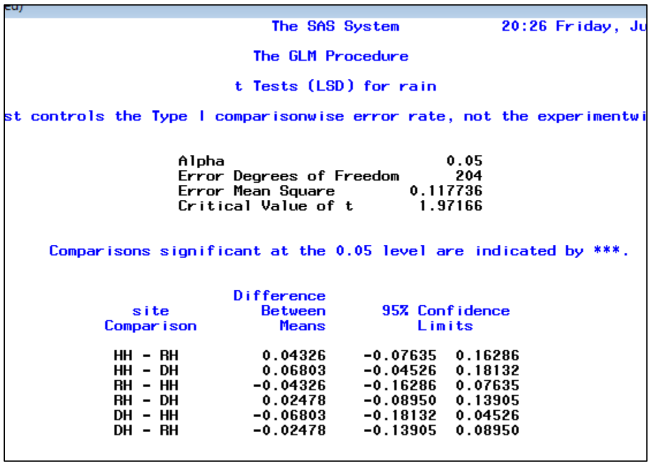


```
                         The SAS System           20:16 Friday, J

                       The GLM Procedure

                     t Tests (LSD) for rain

t controls the Type I comparisonwise error rate, not the experimentw


               Alpha                          0.05
               Error Degrees of Freedom        128
               Error Mean Square          0.216505
               Critical Value of t         1.97867


  Comparisons significant at the 0.05 level are indicated by ***.


                       Difference
         site           Between       95% Confidence
      Comparison         Means            Limits

       RH - DH          0.01342     -0.20071  0.22755
       RH - HH          0.03509     -0.16091  0.23109
       DH - RH         -0.01342     -0.22755  0.20071
       DH - HH          0.02167     -0.17115  0.21448
       HH - RH         -0.03509     -0.23109  0.16091
       HH - DH         -0.02167     -0.21448  0.17115
```

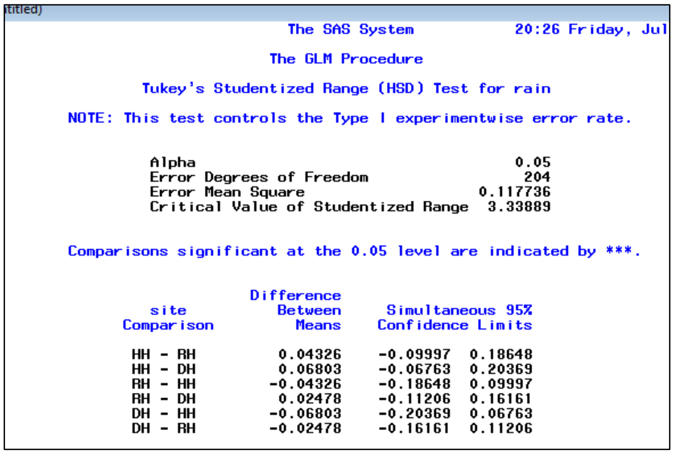


```
                         The SAS System           20:16 Friday, July

                       The GLM Procedure

            Tukey's Studentized Range (HSD) Test for rain

  NOTE: This test controls the Type I experimentwise error rate.


           Alpha                                      0.05
           Error Degrees of Freedom                    128
           Error Mean Square                      0.216505
           Critical Value of Studentized Range     3.35351


  Comparisons significant at the 0.05 level are indicated by ***.


                       Difference
         site           Between      Simultaneous 95%
      Comparison         Means       Confidence Limits

       RH - DH          0.01342     -0.24320  0.27004
       RH - HH          0.03509     -0.19981  0.26998
       DH - RH         -0.01342     -0.27004  0.24320
       DH - HH          0.02167     -0.20941  0.25274
       HH - RH         -0.03509     -0.26998  0.19981
       HH - DH         -0.02167     -0.25274  0.20941
```

Rain leaf-off:



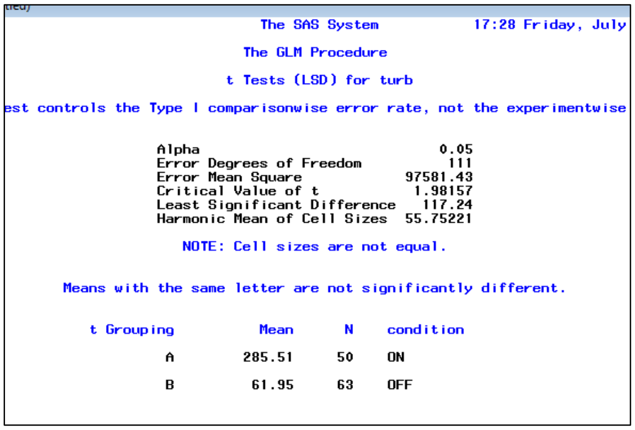
```
                         The SAS System           20:26 Friday, Ju

                       The GLM Procedure

                     t Tests (LSD) for rain

st controls the Type I comparisonwise error rate, not the experimentwi


               Alpha                          0.05
               Error Degrees of Freedom        204
               Error Mean Square          0.117736
               Critical Value of t         1.97166


  Comparisons significant at the 0.05 level are indicated by ***.


                       Difference
         site           Between       95% Confidence
      Comparison         Means            Limits

       HH - RH          0.04326     -0.07635  0.16286
       HH - DH          0.06803     -0.04526  0.18132
       RH - HH         -0.04326     -0.16286  0.07635
       RH - DH          0.02478     -0.08950  0.13905
       DH - HH         -0.06803     -0.18132  0.04526
       DH - RH         -0.02478     -0.13905  0.08950
```



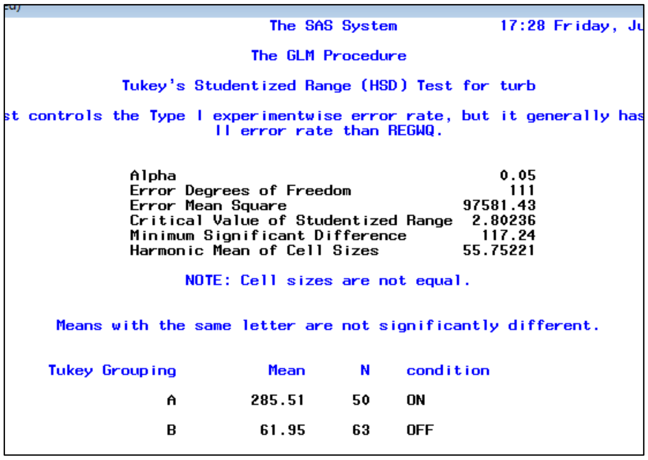
```
                         The SAS System            20:26 Friday, Jul

                      The GLM Procedure

           Tukey's Studentized Range (HSD) Test for rain

   NOTE: This test controls the Type I experimentwise error rate.


                Alpha                                       0.05
                Error Degrees of Freedom                     204
                Error Mean Square                       0.117736
                Critical Value of Studentized Range      3.33889


   Comparisons significant at the 0.05 level are indicated by ***.


                              Difference
                  site          Between      Simultaneous 95%
              Comparison          Means     Confidence Limits

               HH - RH          0.04326    -0.09997  0.18648
               HH - DH          0.06803    -0.06763  0.20369
               RH - HH         -0.04326    -0.18648  0.09997
               RH - DH          0.02478    -0.11206  0.16161
               DH - HH         -0.06803    -0.20369  0.06763
               DH - RH         -0.02478    -0.16161  0.11206
```

Turbidity:

HH

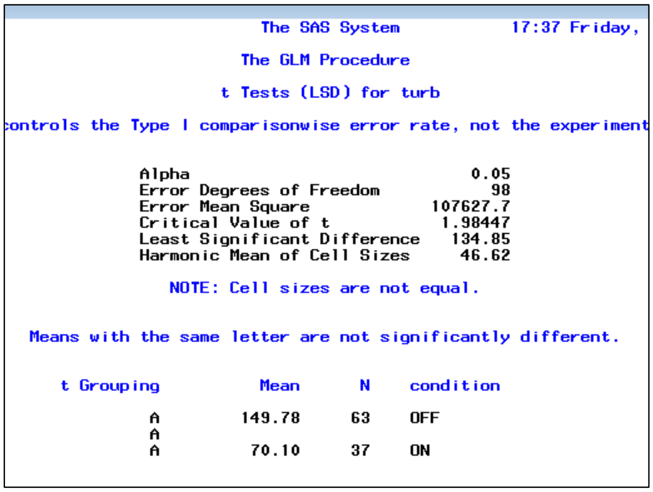


```
                       The SAS System            17:28 Friday, July

                    The GLM Procedure

                   t Tests (LSD) for turb

est controls the Type I comparisonwise error rate, not the experimentwise


               Alpha                               0.05
               Error Degrees of Freedom             111
               Error Mean Square               97581.43
               Critical Value of t              1.98157
               Least Significant Difference      117.24
               Harmonic Mean of Cell Sizes     55.75221

                 NOTE: Cell sizes are not equal.


     Means with the same letter are not significantly different.


         t Grouping          Mean       N    condition

                  A        285.51      50    ON

                  B         61.95      63    OFF
```

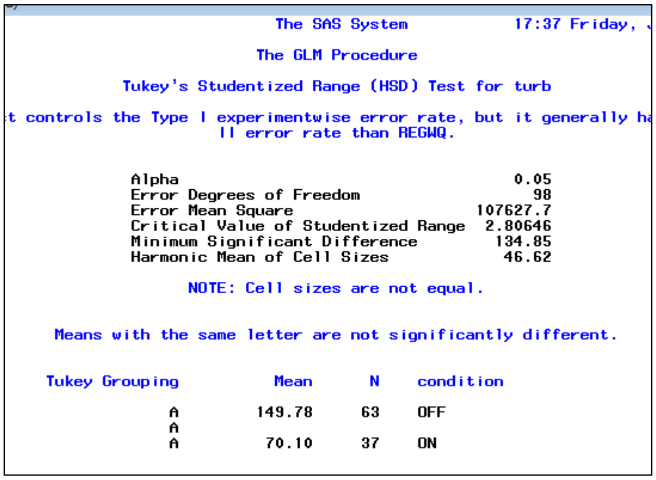


```
                         The SAS System            17:28 Friday, Ju

                      The GLM Procedure

             Tukey's Studentized Range (HSD) Test for turb

st controls the Type I experimentwise error rate, but it generally has
                    II error rate than REGWQ.


              Alpha                                       0.05
              Error Degrees of Freedom                     111
              Error Mean Square                       97581.43
              Critical Value of Studentized Range      2.80236
              Minimum Significant Difference            117.24
              Harmonic Mean of Cell Sizes             55.75221

                      NOTE: Cell sizes are not equal.


        Means with the same letter are not significantly different.


      Tukey Grouping           Mean       N    condition

                   A         285.51      50    ON

                   B          61.95      63    OFF
```

DH

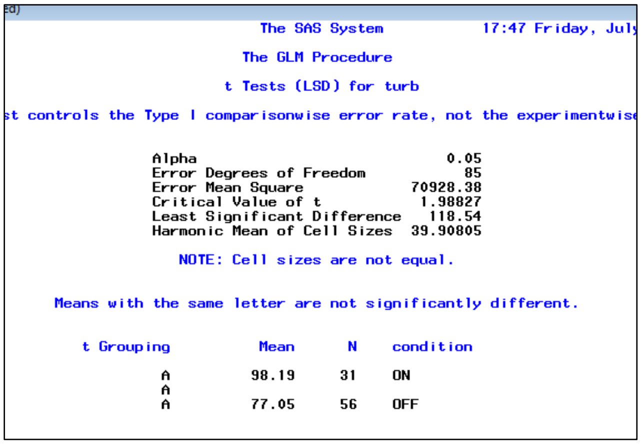


```
                         The SAS System          17:37 Friday,

                       The GLM Procedure

                     t Tests (LSD) for turb

controls the Type I comparisonwise error rate, not the experiment


            Alpha                               0.05
            Error Degrees of Freedom              98
            Error Mean Square               107627.7
            Critical Value of t              1.98447
            Least Significant Difference      134.85
            Harmonic Mean of Cell Sizes        46.62

                  NOTE: Cell sizes are not equal.


  Means with the same letter are not significantly different.


     t Grouping          Mean      N    condition

              A        149.78     63    OFF
              A
              A         70.10     37    ON
```

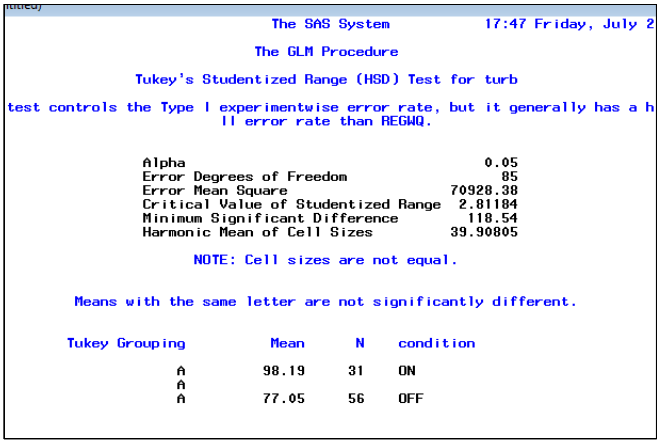


```
                         The SAS System          17:37 Friday,

                       The GLM Procedure

            Tukey's Studentized Range (HSD) Test for turb

t controls the Type I experimentwise error rate, but it generally ha
                   II error rate than REGWQ.


          Alpha                                        0.05
          Error Degrees of Freedom                       98
          Error Mean Square                        107627.7
          Critical Value of Studentized Range       2.80646
          Minimum Significant Difference             134.85
          Harmonic Mean of Cell Sizes                 46.62

                  NOTE: Cell sizes are not equal.


     Means with the same letter are not significantly different.


    Tukey Grouping          Mean      N    condition

                 A        149.78     63    OFF
                 A
                 A         70.10     37    ON
```

RH

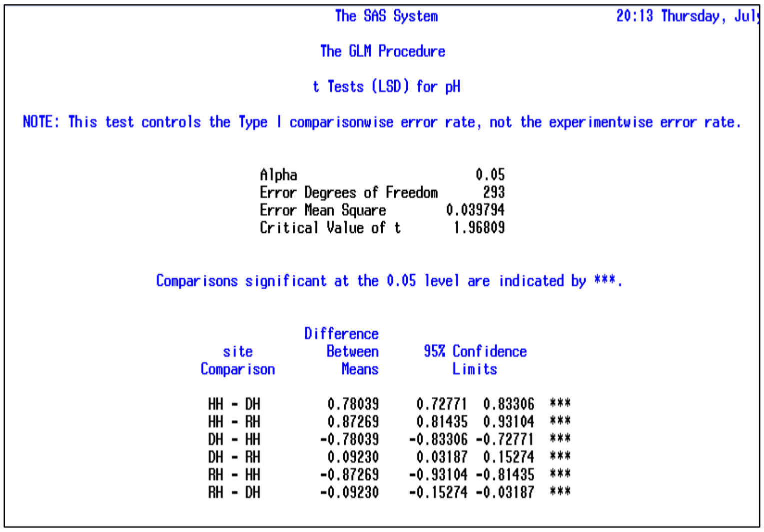


```
ed)
                              The SAS System           17:47 Friday, July
                            The GLM Procedure
                          t Tests (LSD) for turb
st controls the Type I comparisonwise error rate, not the experimentwis

                 Alpha                                0.05
                 Error Degrees of Freedom               85
                 Error Mean Square                70928.38
                 Critical Value of t               1.98827
                 Least Significant Difference       118.54
                 Harmonic Mean of Cell Sizes      39.90805

                    NOTE: Cell sizes are not equal.

         Means with the same letter are not significantly different.

            t Grouping          Mean       N    condition

                     A         98.19      31    ON
                     A
                     A         77.05      56    OFF
```

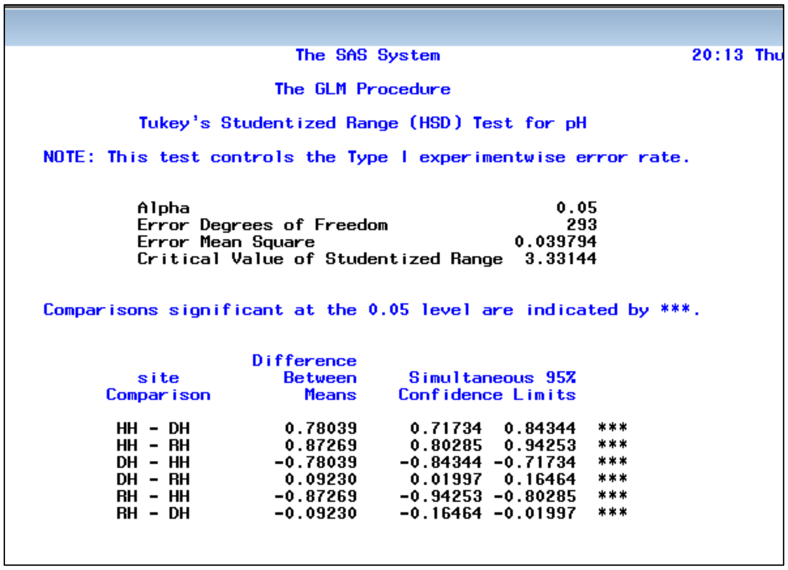


```
itled)
                              The SAS System          17:47 Friday, July 2
                             The GLM Procedure
                Tukey's Studentized Range (HSD) Test for turb
test controls the Type I experimentwise error rate, but it generally has a h
                        ll error rate than REGWQ.

               Alpha                                     0.05
               Error Degrees of Freedom                    85
               Error Mean Square                     70928.38
               Critical Value of Studentized Range    2.81184
               Minimum Significant Difference          118.54
               Harmonic Mean of Cell Sizes           39.90805

                    NOTE: Cell sizes are not equal.

         Means with the same letter are not significantly different.

          Tukey Grouping          Mean       N    condition

                       A         98.19      31    ON
                       A
                       A         77.05      56    OFF
```

pH:

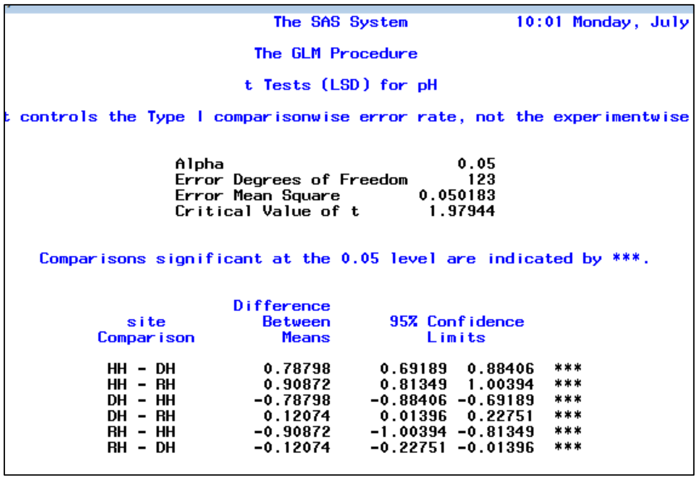


```
                          The SAS System                    20:13 Thursday, Jul

                        The GLM Procedure

                       t Tests (LSD) for pH

NOTE: This test controls the Type I comparisonwise error rate, not the experimentwise error rate.


                  Alpha                          0.05
                  Error Degrees of Freedom        293
                  Error Mean Square          0.039794
                  Critical Value of t         1.96809


          Comparisons significant at the 0.05 level are indicated by ***.


                            Difference
                  site         Between      95% Confidence
               Comparison        Means          Limits

                HH - DH        0.78039     0.72771  0.83306  ***
                HH - RH        0.87269     0.81435  0.93104  ***
                DH - HH       -0.78039    -0.83306 -0.72771  ***
                DH - RH        0.09230     0.03187  0.15274  ***
                RH - HH       -0.87269    -0.93104 -0.81435  ***
                RH - DH       -0.09230    -0.15274 -0.03187  ***
```

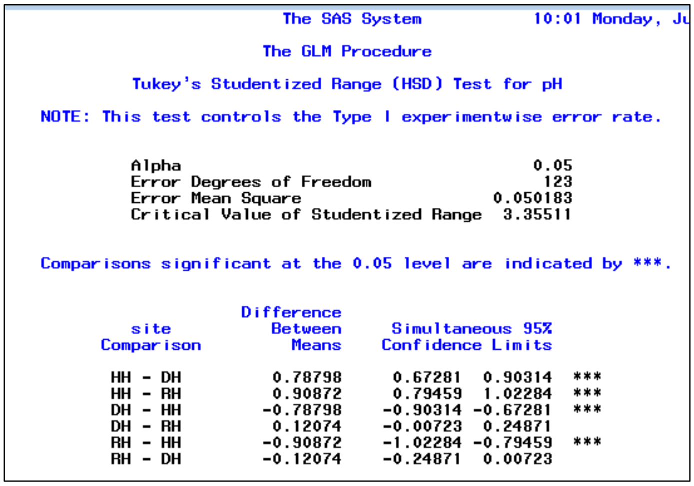


```
                    The SAS System                     20:13 Thu

                  The GLM Procedure

         Tukey's Studentized Range (HSD) Test for pH

 NOTE: This test controls the Type I experimentwise error rate.


          Alpha                                   0.05
          Error Degrees of Freedom                 293
          Error Mean Square                   0.039794
          Critical Value of Studentized Range  3.33144


 Comparisons significant at the 0.05 level are indicated by ***.


                      Difference
          site           Between     Simultaneous 95%
       Comparison          Means    Confidence Limits

        HH - DH          0.78039     0.71734  0.84344  ***
        HH - RH          0.87269     0.80285  0.94253  ***
        DH - HH         -0.78039    -0.84344 -0.71734  ***
        DH - RH          0.09230     0.01997  0.16464  ***
        RH - HH         -0.87269    -0.94253 -0.80285  ***
        RH - DH         -0.09230    -0.16464 -0.01997  ***
```

Leaf-on

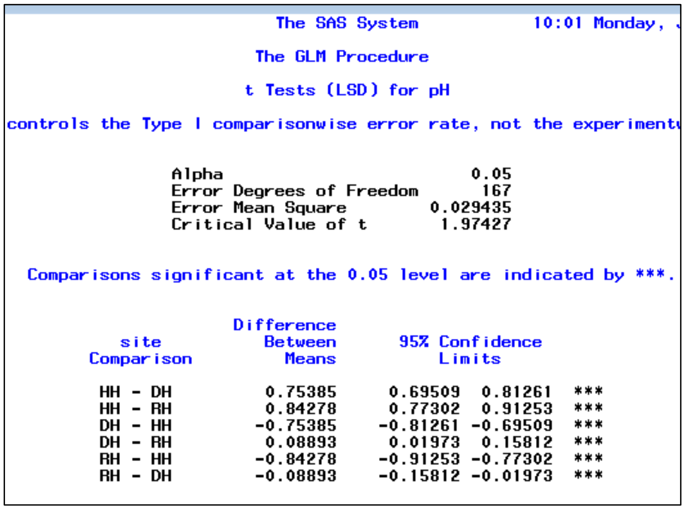


```
                     The SAS System            10:01 Monday, July

                   The GLM Procedure

                  t Tests (LSD) for pH

t controls the Type I comparisonwise error rate, not the experimentwise


                 Alpha                         0.05
                 Error Degrees of Freedom       123
                 Error Mean Square         0.050183
                 Critical Value of t        1.97944


   Comparisons significant at the 0.05 level are indicated by ***.


                          Difference
           site              Between       95% Confidence
        Comparison             Means           Limits

         HH - DH             0.78798     0.69189  0.88406  ***
         HH - RH             0.90872     0.81349  1.00394  ***
         DH - HH            -0.78798    -0.88406 -0.69189  ***
         DH - RH             0.12074     0.01396  0.22751  ***
         RH - HH            -0.90872    -1.00394 -0.81349  ***
         RH - DH            -0.12074    -0.22751 -0.01396  ***
```

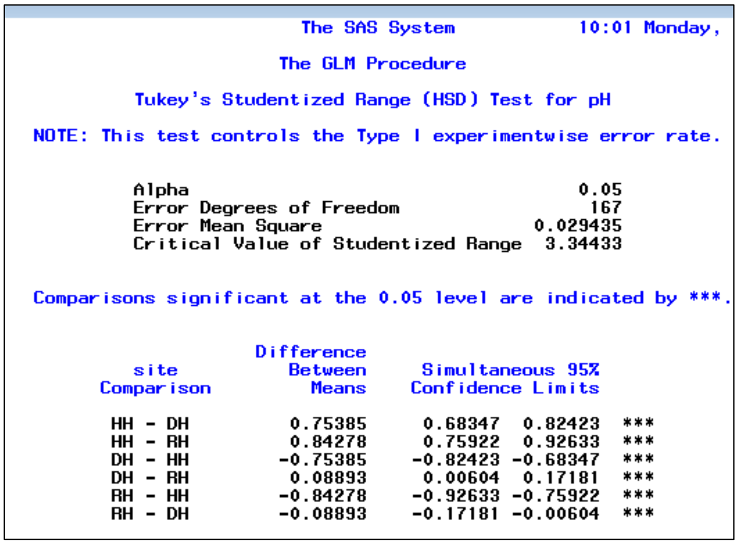


```
                     The SAS System            10:01 Monday, Ju

                   The GLM Procedure

         Tukey's Studentized Range (HSD) Test for pH

  NOTE: This test controls the Type I experimentwise error rate.


           Alpha                                       0.05
           Error Degrees of Freedom                     123
           Error Mean Square                       0.050183
           Critical Value of Studentized Range      3.35511


  Comparisons significant at the 0.05 level are indicated by ***.


                         Difference
          site              Between      Simultaneous 95%
       Comparison             Means     Confidence Limits

        HH - DH             0.78798     0.67281  0.90314  ***
        HH - RH             0.90872     0.79459  1.02284  ***
        DH - HH            -0.78798    -0.90314 -0.67281  ***
        DH - RH             0.12074    -0.00723  0.24871
        RH - HH            -0.90872    -1.02284 -0.79459  ***
        RH - DH            -0.12074    -0.24871  0.00723
```

Leaf-off



```
                         The SAS System           10:01 Monday,

                        The GLM Procedure

                      t Tests (LSD) for pH

controls the Type I comparisonwise error rate, not the experiment

                Alpha                            0.05
                Error Degrees of Freedom          167
                Error Mean Square            0.029435
                Critical Value of t           1.97427

  Comparisons significant at the 0.05 level are indicated by ***.

                        Difference
           site          Between        95% Confidence
        Comparison        Means            Limits

         HH - DH         0.75385      0.69509  0.81261  ***
         HH - RH         0.84278      0.77302  0.91253  ***
         DH - HH        -0.75385     -0.81261 -0.69509  ***
         DH - RH         0.08893      0.01973  0.15812  ***
         RH - HH        -0.84278     -0.91253 -0.77302  ***
         RH - DH        -0.08893     -0.15812 -0.01973  ***
```



```
                         The SAS System           10:01 Monday,

                        The GLM Procedure

          Tukey's Studentized Range (HSD) Test for pH

  NOTE: This test controls the Type I experimentwise error rate.

            Alpha                                     0.05
            Error Degrees of Freedom                   167
            Error Mean Square                     0.029435
            Critical Value of Studentized Range    3.34433

  Comparisons significant at the 0.05 level are indicated by ***.

                        Difference
           site          Between       Simultaneous 95%
        Comparison        Means        Confidence Limits

         HH - DH         0.75385      0.68347  0.82423  ***
         HH - RH         0.84278      0.75922  0.92633  ***
         DH - HH        -0.75385     -0.82423 -0.68347  ***
         DH - RH         0.08893      0.00604  0.17181  ***
         RH - HH        -0.84278     -0.92633 -0.75922  ***
         RH - DH        -0.08893     -0.17181 -0.00604  ***
```

HH leaf-on

The GLM Procedure

Level of condition	N	pH	
		Mean	Std Dev
BF	**57**	7.18385965	0.24576233
SF	**57**	7.17912281	0.24718617

t Tests (LSD) for pH

Note: This test controls the Type I comparisonwise error rate, not the experimentwise error rate.

Means with the same letter are not significantly different.			
t Grouping	**Mean**	**N**	**condition**
A	7.18386	57	BF
A			
A	7.17912	57	SF

Tukey's Studentized Range (HSD) Test for pH

Note: This test controls the Type I experimentwise error rate, but it generally has a higher Type II error rate than REGWQ.

Means with the same letter are not significantly different.			
Tukey Grouping	**Mean**	**N**	**condition**
A	7.18386	57	BF
A			
A	7.17912	57	SF

DH leaf-on

The GLM Procedure

Level of condition	N	pH	
		Mean	Std Dev
BF	**34**	6.39588235	0.28383860
SF	**34**	6.39794118	0.20239145

t Tests (LSD) for pH

Note: This test controls the Type I comparisonwise error rate, not the experimentwise error rate.

Means with the same letter are not significantly different.

t Grouping	Mean	N	condition
A	6.39794	34	SF
A			
A	6.39588	34	BF

Tukey's Studentized Range (HSD) Test for pH

Note: This test controls the Type I experimentwise error rate, but it generally has a higher Type II error rate than REGWQ.

Means with the same letter are not significantly different.

Tukey Grouping	Mean	N	condition
A	6.39794	34	SF
A			
A	6.39588	34	BF

DH leaf-off

Level of condition	N	pH	
		Mean	Std Dev
BF	**68**	6.31676471	0.14261357
SF	**68**	6.31544118	0.14129924

t Tests (LSD) for pH

Note: This test controls the Type I comparisonwise error rate, not the experimentwise error rate.

Means with the same letter are not significantly different.

t Grouping	Mean	N	condition
A	6.31676	68	BF
A			
A	6.31544	68	SF

Tukey's Studentized Range (HSD) Test for pH

Note: This test controls the Type I experimentwise error rate, but it generally has a higher Type II error rate than REGWQ.

Means with the same letter are not significantly different.			
Tukey Grouping	**Mean**	**N**	**condition**
A	6.31676	68	BF
A			
A	6.31544	68	SF

RH leaf-on

Level of condition	N	pH	
		Mean	Std Dev
BF	**35**	6.27514286	0.06218433
SF	**35**	6.26641155	0.08867499

t Tests (LSD) for pH

Note: This test controls the Type I comparisonwise error rate, not the experimentwise error rate.

Means with the same letter are not significantly different.			
t Grouping	**Mean**	**N**	**condition**
A	6.27514	35	BF
A			
A	6.26641	35	SF

Tukey's Studentized Range (HSD) Test for pH

Note: This test controls the Type I experimentwise error rate, but it generally has a higher Type II error rate than REGWQ.

Means with the same letter are not significantly different.			
Tukey Grouping	**Mean**	**N**	**condition**
A	6.27514	35	BF
A			
A	6.26641	35	SF

Conductivity

HH leaf-on

Level of condition	N	cond	
		Mean	Std Dev
BF	**48**	0.14460417	0.04935832
SF	**48**	0.14459555	0.04405289

t Tests (LSD) for cond

Note: This test controls the Type I comparisonwise error rate, not the experimentwise error rate.

Means with the same letter are not significantly different.			
T Grouping	**Mean**	**N**	**condition**
A	0.144604	48	BF
A			
A	0.144596	48	SF

Tukey's Studentized Range (HSD) Test for cond

Note: This test controls the Type I experimentwise error rate, but it generally has a higher Type II error rate than REGWQ.

Means with the same letter are not significantly different.			
Tukey Grouping	**Mean**	**N**	**condition**
A	0.144604	48	BF
A			
A	0.144596	48	SF

DH leaf-on

Level of condition	N	cond	
		Mean	Std Dev
BF	**32**	0.07462500	0.01335073
SF	**32**	0.07268750	0.01390390

t Tests (LSD) for cond

Note: This test controls the Type I comparisonwise error rate, not the experimentwise error rate.

Means with the same letter are not significantly different.			
t Grouping	**Mean**	**N**	**condition**
A	0.074625	32	BF
A			
A	0.072688	32	SF

Tukey's Studentized Range (HSD) Test for cond

Note: This test controls the Type I experimentwise error rate, but it generally has a higher Type II error rate than REGWQ.

Means with the same letter are not significantly different.			
Tukey Grouping	**Mean**	**N**	**condition**
A	0.074625	32	BF
A			
A	0.072688	32	SF

DH leaf-off

Level of condition	N	cond	
		Mean	**Std Dev**
BF	**67**	0.04429851	0.00730092
SF	**67**	0.04405970	0.00733378

t Tests (LSD) for cond

Note: This test controls the Type I comparisonwise error rate, not the experimentwise error rate.

Means with the same letter are not significantly different.			
t Grouping	**Mean**	**N**	**condition**
A	0.044299	67	BF
A			
A	0.044060	67	SF

Tukey's Studentized Range (HSD) Test for cond

Note: This test controls the Type I experimentwise error rate, but it generally has a higher Type II error rate than REGWQ.

Means with the same letter are not significantly different.			
Tukey Grouping	**Mean**	**N**	**condition**
A	0.044299	67	BF
A			
A	0.044060	67	SF

RH leaf-on

Level of condition	**N**	**cond**	
		Mean	**Std Dev**
BF	**35**	0.06148571	0.06415302
SF	**35**	0.06062857	0.06569228

t Tests (LSD) for cond

Note: This test controls the Type I comparisonwise error rate, not the experimentwise error rate.

Means with the same letter are not significantly different.			
t Grouping	**Mean**	**N**	**condition**
A	0.06149	35	BF
A			
A	0.06063	35	SF

Tukey's Studentized Range (HSD) Test for cond

Note: This test controls the Type I experimentwise error rate, but it generally has a higher Type II error rate than REGWQ.

Means with the same letter are not significantly different.			
Tukey Grouping	**Mean**	**N**	**condition**
A	0.06149	35	BF
A			
A	0.06063	35	SF

Temperature

HH leaf-on

Level of condition	N	temp	
		Mean	Std Dev
BF	**48**	17.3606250	3.30131657
SFmax	**48**	17.8270833	3.53054993
SFmin	**48**	16.9372917	3.34008074

t Tests (LSD) for temp

Note: This test controls the Type I comparisonwise error rate, not the experimentwise error rate.

Means with the same letter are not significantly different.

t Grouping	Mean	N	condition
A	17.8271	48	SFmax
A			
A	17.3606	48	BF
A			
A	16.9373	48	SFmin

Tukey's Studentized Range (HSD) Test for temp

Note: This test controls the Type I experimentwise error rate, but it generally has a higher Type II error rate than REGWQ.

Means with the same letter are not significantly different.

Tukey Grouping	Mean	N	condition
A	17.8271	48	SFmax
A			
A	17.3606	48	BF
A			
A	16.9373	48	SFmin

DH leaf-on

Level of condition	N	temp	
		Mean	Std Dev
BF	**35**	17.6508571	3.07021207
SFmax	**35**	17.9222857	2.91175921
SFmin	**35**	17.4942857	2.93850231

t Tests (LSD) for temp

Note: This test controls the Type I comparisonwise error rate, not the experimentwise error rate.

Means with the same letter are not significantly different.			
t Grouping	**Mean**	**N**	**condition**
A	17.9223	35	SFmax
A			
A	17.6509	35	BF
A			
A	17.4943	35	SFmin

Tukey's Studentized Range (HSD) Test for temp

Note: This test controls the Type I experimentwise error rate, but it generally has a higher Type II error rate than REGWQ.

Means with the same letter are not significantly different.			
Tukey Grouping	**Mean**	**N**	**condition**
A	17.9223	35	SFmax
A			
A	17.6509	35	BF
A			
A	17.4943	35	SFmin

DH leaf-off

Level of condition	N	temp	
		Mean	Std Dev
BF	**67**	9.40343284	2.26256997
SFmax	**67**	9.59388060	2.17859070
SFmin	**67**	9.26044776	2.18525460

t Tests (LSD) for temp

Note: This test controls the Type I comparisonwise error rate, not the experimentwise error rate.

Means with the same letter are not significantly different.			
t Grouping	**Mean**	**N**	**condition**
A	9.5939	67	SFmax
A			
A	9.4034	67	BF
A			
A	9.2604	67	SFmin

Tukey's Studentized Range (HSD) Test for temp

Note: This test controls the Type I experimentwise error rate, but it generally has a higher Type II error rate than REGWQ.

Means with the same letter are not significantly different.			
Tukey Grouping	**Mean**	**N**	**condition**
A	9.5939	67	SFmax
A			
A	9.4034	67	BF
A			
A	9.2604	67	SFmin

RH leaf-on

Level of condition	N	temp	
		Mean	Std Dev
BF	**36**	16.1536111	2.90607851
SFmax	**36**	16.7488889	3.30260571
SFmin	**36**	15.8919444	3.02228184

t Tests (LSD) for temp

Note: This test controls the Type I comparisonwise error rate, not the experimentwise error rate.

Means with the same letter are not significantly different.			
t Grouping	**Mean**	**N**	**condition**
A	16.7489	36	SFmax
A			
A	16.1536	36	BF
A			
A	15.8919	36	SFmin

Tukey's Studentized Range (HSD) Test for temp

Note: This test controls the Type I experimentwise error rate, but it generally has a higher Type II error rate than REGWQ.

Means with the same letter are not significantly different.			
Tukey Grouping	**Mean**	**N**	**condition**
A	16.7489	36	SFmax
A			
A	16.1536	36	BF
A			
A	15.8919	36	SFmin

Objective 3

Objective 4

HH BF turbidity

Level of condition	N	turb	
		Mean	Std Dev
BC	**32**	30.434375	48.398804
DC	**81**	177.288889	401.591783

t Tests (LSD) for turb

Note: This test controls the Type I comparisonwise error rate, not the experimentwise error rate.

Note: Cell sizes are not equal.

Means with the same letter are not significantly different.			
t Grouping	**Mean**	**N**	**condition**
A	177.29	81	DC
B	30.43	32	BC

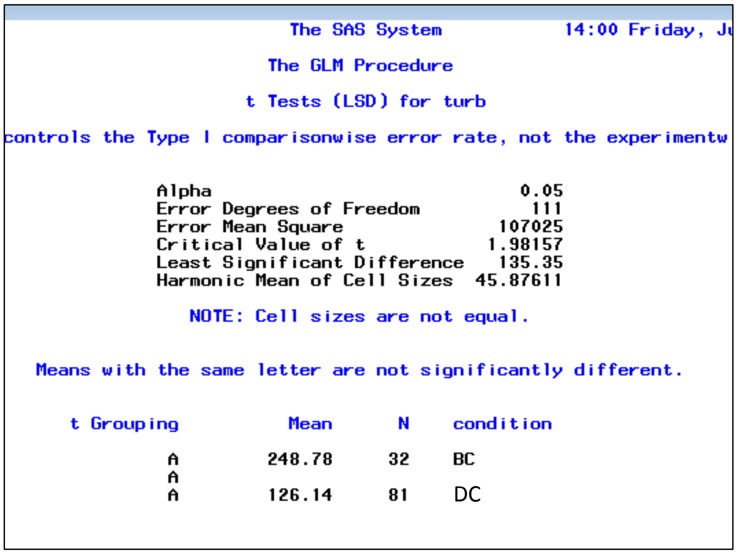
Tukey's Studentized Range (HSD) Test for turb

Note: This test controls the Type I experimentwise error rate, but it generally has a higher Type II error rate than REGWQ.

Note: Cell sizes are not equal.

Means with the same letter are not significantly different.			
Tukey Grouping	**Mean**	**N**	**condition**
A	177.29	81	DC
B	30.43	32	BC

HH SF turbidity



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                    The SAS System            14:00 Friday, Ju

                  The GLM Procedure

                 t Tests (LSD) for turb

controls the Type I comparisonwise error rate, not the experimentw

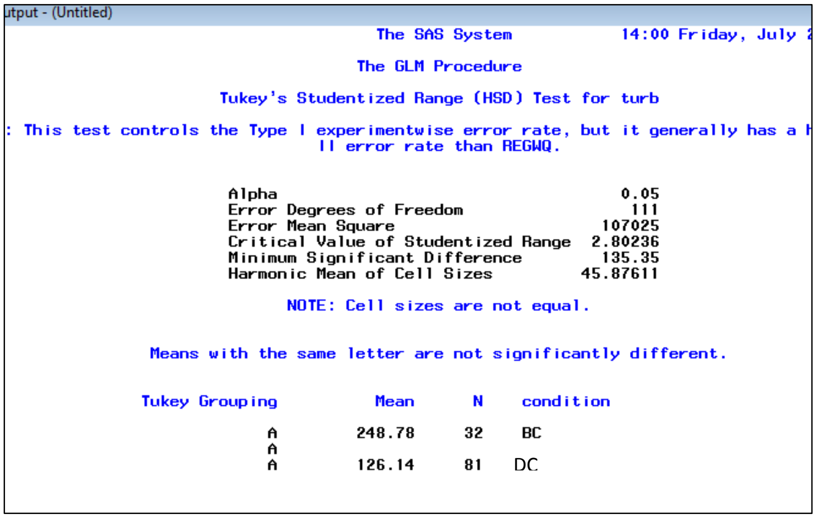

             Alpha                            0.05
             Error Degrees of Freedom          111
             Error Mean Square              107025
             Critical Value of t           1.98157
             Least Significant Difference   135.35
             Harmonic Mean of Cell Sizes  45.87611

                NOTE: Cell sizes are not equal.


   Means with the same letter are not significantly different.


      t Grouping          Mean      N     condition

               A        248.78     32     BC
               A
               A        126.14     81     DC
```



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utput - (Untitled)
                         The SAS System           14:00 Friday, July 2

                        The GLM Procedure

              Tukey's Studentized Range (HSD) Test for turb

: This test controls the Type I experimentwise error rate, but it generally has a h
                          II error rate than REGWQ.


                Alpha                                  0.05
                Error Degrees of Freedom                111
                Error Mean Square                    107025
                Critical Value of Studentized Range 2.80236
                Minimum Significant Difference       135.35
                Harmonic Mean of Cell Sizes        45.87611

                     NOTE: Cell sizes are not equal.


           Means with the same letter are not significantly different.


           Tukey Grouping          Mean      N     condition

                        A        248.78     32     BC
                        A
                        A        126.14     81     DC
```
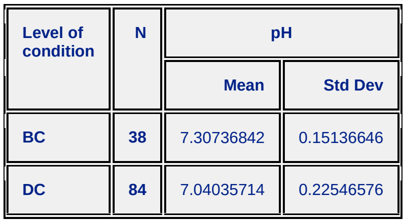

HH BF pH



Level of condition	N	pH	
		Mean	Std Dev
BC	38	7.30736842	0.15136646
DC	84	7.04035714	0.22546576

t Tests (LSD) for pH

Note: This test controls the Type I comparisonwise error rate, not the experimentwise error rate.

Note: Cell sizes are not equal.

Means with the same letter are not significantly different.			
t Grouping	**Mean**	**N**	**condition**
A	7.30737	38	BC
B	7.04036	84	DC

Tukey's Studentized Range (HSD) Test for pH

Note: This test controls the Type I experimentwise error rate, but it generally has a higher Type II error rate than REGWQ.

Note: Cell sizes are not equal.

Means with the same letter are not significantly different.			
Tukey Grouping	**Mean**	**N**	**condition**
A	7.30737	38	BC
B	7.04036	84	DC

HH SF pH

Level of condition	**N**	**pH**	
		Mean	**Std Dev**
BC	**38**	7.31842105	0.14018379
DC	**84**	7.01571429	0.20302701

t Tests (LSD) for pH

Note: This test controls the Type I comparisonwise error rate, not the experimentwise error rate.

Note: Cell sizes are not equal.

Means with the same letter are not significantly different.			
t Grouping	**Mean**	**N**	**condition**
A	7.31842	38	BC
B	7.01571	84	DC

Tukey's Studentized Range (HSD) Test for pH

Note: This test controls the Type I experimentwise error rate, but it generally has a higher Type II error rate than REGWQ.

Note: Cell sizes are not equal.

Means with the same letter are not significantly different.			
Tukey Grouping	**Mean**	**N**	**condition**
A	7.31842	38	BC
B	7.01571	84	DC

HH BF conductivity

Level of condition	**N**	**cond**	
		Mean	**Std Dev**
BC	**31**	0.15393548	0.05150206
DC	**82**	0.11258537	0.03211936

t Tests (LSD) for cond

Note: This test controls the Type I comparisonwise error rate, not the experimentwise error rate.

Note: Cell sizes are not equal.

Means with the same letter are not significantly different.			
t Grouping	**Mean**	**N**	**condition**
A	0.153935	31	BC
B	0.112585	82	DC

Tukey's Studentized Range (HSD) Test for cond

Note: This test controls the Type I experimentwise error rate, but it generally has a higher Type II error rate than REGWQ.

Note: Cell sizes are not equal.

Means with the same letter are not significantly different.			
Tukey Grouping	**Mean**	**N**	**condition**
A	0.153935	31	BC

Means with the same letter are not significantly different.			
Tukey Grouping	**Mean**	**N**	**condition**
B	0.112585	82	DC

HH SF conductivity

Level of condition	N	cond	
		Mean	Std Dev
BC	**31**	0.15620150	0.04096905
DC	**82**	0.10984796	0.03025173

t Tests (LSD) for cond

Note: This test controls the Type I comparisonwise error rate, not the experimentwise error rate.

Note: Cell sizes are not equal.

Means with the same letter are not significantly different.			
t Grouping	**Mean**	**N**	**condition**
A	0.156202	31	BC
B	0.109848	82	DC

Tukey's Studentized Range (HSD) Test for cond

Note: This test controls the Type I experimentwise error rate, but it generally has a higher Type II error rate than REGWQ.

Note: Cell sizes are not equal.

Means with the same letter are not significantly different.			
Tukey Grouping	**Mean**	**N**	**condition**
A	0.156202	31	BC
B	0.109848	82	DC

HH BF temperature

Level of condition	N	temp	
		Mean	Std Dev
BC	**31**	19.2458065	2.39335855
DC	**82**	10.6002439	2.41805348

t Tests (LSD) for temp

Note: This test controls the Type I comparisonwise error rate, not the experimentwise error rate.

Note: Cell sizes are not equal.

Means with the same letter are not significantly different.			
t Grouping	**Mean**	**N**	**condition**
A	19.2458	31	BC
B	10.6002	82	DC

Tukey's Studentized Range (HSD) Test for temp

Note: This test controls the Type I experimentwise error rate, but it generally has a higher Type II error rate than REGWQ.

Note: Cell sizes are not equal.

Means with the same letter are not significantly different.			
Tukey Grouping	**Mean**	**N**	**condition**
A	19.2458	31	BC
B	10.6002	82	DC

HH SF temperature

Level of condition	N	temp	
		Mean	Std Dev
BCmax	**31**	19.7822581	2.70368478
BCmin	**31**	18.9335484	2.16825052
DCmax	**82**	10.9557317	2.42888738
DCmin	**82**	10.2185366	2.32988482

t Tests (LSD) for temp

Note: This test controls the Type I comparisonwise error rate, not the experimentwise error rate.

Comparisons significant at the 0.05 level are indicated by ***.				
condition Comparison	**Difference Between Means**	**95% Confidence Limits**		
BCmax - BCmin	0.8487	-0.3522	2.0497	
BCmax - DCmax	8.8265	7.8296	9.8234	***
BCmax - DCmin	9.5637	8.5668	10.5606	***
BCmin - BCmax	-0.8487	-2.0497	0.3522	
BCmin - DCmax	7.9778	6.9809	8.9747	***
BCmin - DCmin	8.7150	7.7181	9.7119	***
DCmax - BCmax	-8.8265	-9.8234	-7.8296	***
DCmax - BCmin	-7.9778	-8.9747	-6.9809	***
DCmax - DCmin	0.7372	-0.0012	1.4756	
DCmin - BCmax	-9.5637	-10.5606	-8.5668	***
DCmin - BCmin	-8.7150	-9.7119	-7.7181	***
DCmin - DCmax	-0.7372	-1.4756	0.0012	

Tukey's Studentized Range (HSD) Test for temp

Note: This test controls the Type I experimentwise error rate.

Comparisons significant at the 0.05 level are indicated by ***.				
condition Comparison	**Difference Between Means**	**Simultaneous 95% Confidence Limits**		
BCmax - BCmin	0.8487	-0.7288	2.4262	
BCmax - DCmax	8.8265	7.5171	10.1360	***
BCmax - DCmin	9.5637	8.2543	10.8732	***
BCmin - BCmax	-0.8487	-2.4262	0.7288	
BCmin - DCmax	7.9778	6.6684	9.2873	***
BCmin - DCmin	8.7150	7.4056	10.0245	***
DCmax - BCmax	-8.8265	-10.1360	-7.5171	***
DCmax - BCmin	-7.9778	-9.2873	-6.6684	***
DCmax - DCmin	0.7372	-0.2327	1.7071	
DCmin - BCmax	-9.5637	-10.8732	-8.2543	***
DCmin - BCmin	-8.7150	-10.0245	-7.4056	***

Comparisons significant at the 0.05 level are indicated by ***.				
condition Comparison	**Difference Between Means**	**Simultaneous 95% Confidence Limits**		
DCmin - DCmax	-0.7372	-1.7071	0.2327	

DH BF turbidity HH timeframe

Level of condition	N	turb	
		Mean	**Std Dev**
BC	**24**	10.6166667	1.777264
DC	**76**	77.7855263	198.989033

t Tests (LSD) for turb

Note: This test controls the Type I comparisonwise error rate, not the experimentwise error rate.

Note: Cell sizes are not equal.

Means with the same letter are not significantly different.			
t Grouping	**Mean**	**N**	**condition**
A	77.79	76	DC
A			
A	10.62	24	BC

Tukey's Studentized Range (HSD) Test for turb

Note: This test controls the Type I experimentwise error rate, but it generally has a higher Type II error rate than REGWQ.

Note: Cell sizes are not equal.

Means with the same letter are not significantly different.			
Tukey Grouping	**Mean**	**N**	**condition**
A	77.79	76	DC
A			
A	10.62	24	BC

DH BF turbidity RH timeframe

Level of condition	N	turb	
		Mean	Std Dev
BC	**44**	10.078182	7.901998
DC	**56**	102.197500	227.249708

t Tests (LSD) for turb

Note: This test controls the Type I comparisonwise error rate, not the experimentwise error rate.

Note: Cell sizes are not equal.

Means with the same letter are not significantly different.			
t Grouping	**Mean**	**N**	**condition**
A	102.20	56	DC
B	10.08	44	BC

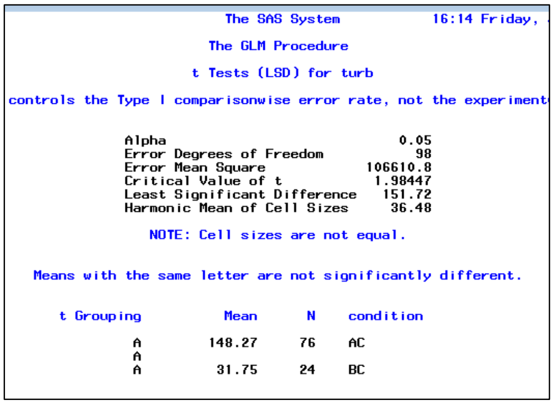
Tukey's Studentized Range (HSD) Test for turb

Note: This test controls the Type I experimentwise error rate, but it generally has a higher Type II error rate than REGWQ.

Note: Cell sizes are not equal.

Means with the same letter are not significantly different.			
Tukey Grouping	**Mean**	**N**	**condition**
A	102.20	56	DC
B	10.08	44	BC

DH SF turbidity HH timeframe



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                    The SAS System           16:14 Friday,

                  The GLM Procedure

                t Tests (LSD) for turb

controls the Type I comparisonwise error rate, not the experiment

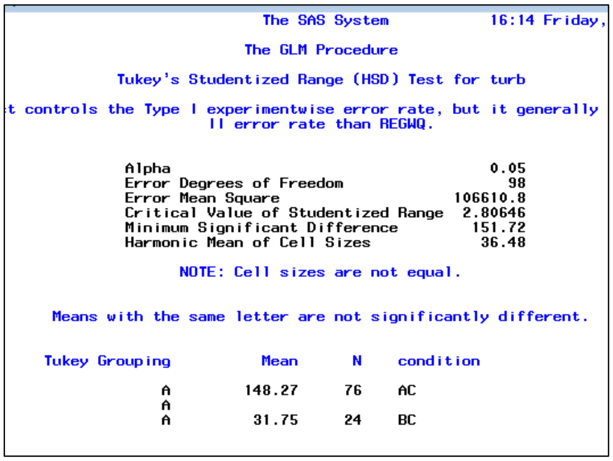
              Alpha                              0.05
              Error Degrees of Freedom             98
              Error Mean Square              106610.8
              Critical Value of t             1.98447
              Least Significant Difference     151.72
              Harmonic Mean of Cell Sizes       36.48

                 NOTE: Cell sizes are not equal.

   Means with the same letter are not significantly different.

      t Grouping          Mean      N    condition

               A        148.27     76    AC
               A
               A         31.75     24    BC
```



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                   The SAS System           16:14 Friday,

                 The GLM Procedure

          Tukey's Studentized Range (HSD) Test for turb

t controls the Type I experimentwise error rate, but it generally
                   II error rate than REGWQ.

            Alpha                                      0.05
            Error Degrees of Freedom                     98
            Error Mean Square                      106610.8
            Critical Value of Studentized Range     2.80646
            Minimum Significant Difference           151.72
            Harmonic Mean of Cell Sizes               36.48

                 NOTE: Cell sizes are not equal.

     Means with the same letter are not significantly different.

    Tukey Grouping          Mean      N    condition

                 A        148.27     76    AC
                 A
                 A         31.75     24    BC
```
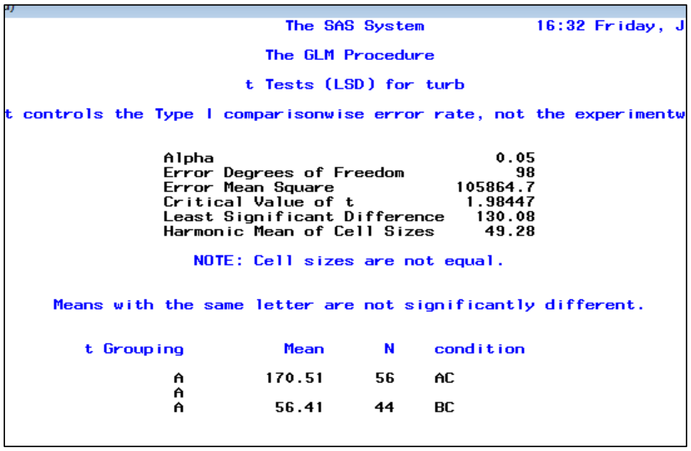

DH SF turbidity RH timeframe



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                   The SAS System            16:32 Friday, J

                 The GLM Procedure

               t Tests (LSD) for turb

t controls the Type I comparisonwise error rate, not the experimentw

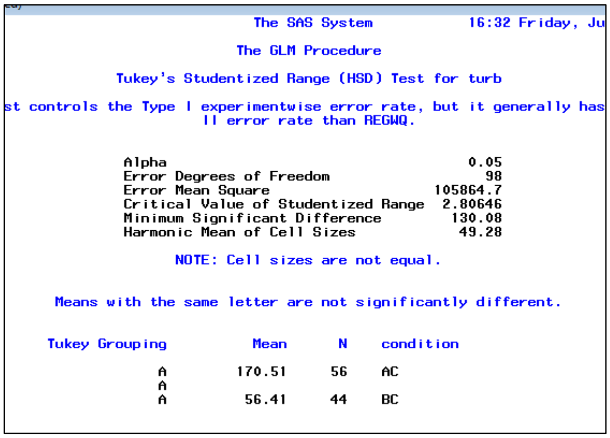
            Alpha                              0.05
            Error Degrees of Freedom             98
            Error Mean Square              105864.7
            Critical Value of t             1.98447
            Least Significant Difference     130.08
            Harmonic Mean of Cell Sizes       49.28

                 NOTE: Cell sizes are not equal.

    Means with the same letter are not significantly different.

      t Grouping          Mean       N    condition

               A        170.51      56    AC
               A
               A         56.41      44    BC
```



```
                    The SAS System            16:32 Friday, Ju

                  The GLM Procedure

     Tukey's Studentized Range (HSD) Test for turb

st controls the Type I experimentwise error rate, but it generally has
                  II error rate than REGWQ.


          Alpha                                    0.05
          Error Degrees of Freedom                   98
          Error Mean Square                    105864.7
          Critical Value of Studentized Range  2.80646
          Minimum Significant Difference         130.08
          Harmonic Mean of Cell Sizes             49.28

               NOTE: Cell sizes are not equal.


     Means with the same letter are not significantly different.


    Tukey Grouping           Mean       N     condition

                 A         170.51      56     AC
                 A
                 A          56.41      44     BC
```

DH BF pH HH timeframe

Level of condition	N	pH	
		Mean	Std Dev
BC	24	6.45458333	0.29802216
DC	78	6.30884615	0.14991756

t Tests (LSD) for pH

Note: This test controls the Type I comparisonwise error rate, not the experimentwise error rate.

Note: Cell sizes are not equal.

Means with the same letter are not significantly different.			
t Grouping	Mean	N	condition
A	6.45458	24	BC
B	6.30885	78	DC

Tukey's Studentized Range (HSD) Test for pH

Note: This test controls the Type I experimentwise error rate, but it generally has a higher Type II error rate than REGWQ.

Note: Cell sizes are not equal.

Means with the same letter are not significantly different.			
Tukey Grouping	Mean	N	condition
A	6.45458	24	BC
B	6.30885	78	DC

DH BF pH RH timeframe

Level of condition	N	pH	
		Mean	Std Dev
BC	**46**	6.31760870	0.26347410
DC	**56**	6.36410714	0.13380823

t Tests (LSD) for pH

Note: This test controls the Type I comparisonwise error rate, not the experimentwise error rate.

Note: Cell sizes are not equal.

Means with the same letter are not significantly different.			
t Grouping	**Mean**	**N**	**condition**
A	6.36411	56	DC
A			
A	6.31761	46	BC

Tukey's Studentized Range (HSD) Test for pH

Note: This test controls the Type I experimentwise error rate, but it generally has a higher Type II error rate than REGWQ.

Note: Cell sizes are not equal.

Means with the same letter are not significantly different.			
Tukey Grouping	**Mean**	**N**	**condition**
A	6.36411	56	DC
A			
A	6.31761	46	BC

DH SF pH HH timeframe

Level of condition	N	pH	
		Mean	Std Dev
BC	**24**	6.44541667	0.19575893
DC	**78**	6.31141026	0.14561758

t Tests (LSD) for pH

Note: This test controls the Type I comparisonwise error rate, not the experimentwise error rate.

Note: Cell sizes are not equal.

Means with the same letter are not significantly different.			
t Grouping	**Mean**	**N**	**condition**
A	6.44542	24	BC
B	6.31141	78	DC

Tukey's Studentized Range (HSD) Test for pH

Note: This test controls the Type I experimentwise error rate, but it generally has a higher Type II error rate than REGWQ.

Note: Cell sizes are not equal.

Means with the same letter are not significantly different.			
Tukey Grouping	**Mean**	**N**	**condition**
A	6.44542	24	BC
B	6.31141	78	DC

DH SF pH RH timeframe

Level of condition	**N**	**pH**	
		Mean	**Std Dev**
BC	**46**	6.31847826	0.19723610
DC	**56**	6.36303571	0.13770746

t Tests (LSD) for pH

Note: This test controls the Type I comparisonwise error rate, not the experimentwise error rate.

Note: Cell sizes are not equal.

Means with the same letter are not significantly different.			
t Grouping	**Mean**	**N**	**condition**
A	6.36304	56	DC
A			
A	6.31848	46	BC

Tukey's Studentized Range (HSD) Test for pH

Note: This test controls the Type I experimentwise error rate, but it generally has a higher Type II error rate than REGWQ.

Note: Cell sizes are not equal.

Means with the same letter are not significantly different.			
Tukey Grouping	**Mean**	**N**	**condition**
A	6.36304	56	DC
A			
A	6.31848	46	BC

DH BF conductivity HH timeframe

Level of condition	**N**	**cond**	
		Mean	**Std Dev**
BC	**23**	0.08117391	0.00663772
DC	**76**	0.04590789	0.00896836

t Tests (LSD) for cond

Note: This test controls the Type I comparisonwise error rate, not the experimentwise error rate.

Note: Cell sizes are not equal.

Means with the same letter are not significantly different.			
t Grouping	**Mean**	**N**	**condition**
A	0.081174	23	BC
B	0.045908	76	DC

Tukey's Studentized Range (HSD) Test for cond

Note: This test controls the Type I experimentwise error rate, but it generally has a higher Type II error rate than REGWQ.

Note: Cell sizes are not equal.

Means with the same letter are not significantly different.			
Tukey Grouping	**Mean**	**N**	**condition**
A	0.081174	23	BC

Means with the same letter are not significantly different.			
Tukey Grouping	**Mean**	**N**	**condition**
B	0.045908	76	DC

DH BF conductivity RH timeframe

Level of condition	N	cond	
		Mean	**Std Dev**
BC	**43**	0.06888372	0.01518334
DC	**56**	0.04275000	0.00696289

t Tests (LSD) for cond

Note: This test controls the Type I comparisonwise error rate, not the experimentwise error rate.

Note: Cell sizes are not equal.

Means with the same letter are not significantly different.			
t Grouping	**Mean**	**N**	**condition**
A	0.068884	43	BC
B	0.042750	56	DC

Tukey's Studentized Range (HSD) Test for cond

Note: This test controls the Type I experimentwise error rate, but it generally has a higher Type II error rate than REGWQ.

Note: Cell sizes are not equal.

Means with the same letter are not significantly different.			
Tukey Grouping	**Mean**	**N**	**condition**
A	0.068884	43	BC
B	0.042750	56	DC

DH SF conductivity HH timeframe

Level of condition	N	cond	
		Mean	Std Dev
BC	**23**	0.07969565	0.00625543
DC	**76**	0.04532895	0.00862305

t Tests (LSD) for cond

Note: This test controls the Type I comparisonwise error rate, not the experimentwise error rate.

Note: Cell sizes are not equal.

Means with the same letter are not significantly different.			
t Grouping	**Mean**	**N**	**condition**
A	0.079696	23	BC
B	0.045329	76	DC

Tukey's Studentized Range (HSD) Test for cond

Note: This test controls the Type I experimentwise error rate, but it generally has a higher Type II error rate than REGWQ.

Note: Cell sizes are not equal.

Means with the same letter are not significantly different.			
Tukey Grouping	**Mean**	**N**	**condition**
A	0.079696	23	BC
B	0.045329	76	DC

DH SF conductivity RH timeframe

Level of condition	N	cond	
		Mean	Std Dev
BC	**43**	0.06769767	0.01499767
DC	**56**	0.04226786	0.00620115

t Tests (LSD) for cond

Note: This test controls the Type I comparisonwise error rate, not the experimentwise error rate.

Note: Cell sizes are not equal.

Means with the same letter are not significantly different.			
t Grouping	**Mean**	**N**	**condition**
A	0.067698	43	BC
B	0.042268	56	DC

Tukey's Studentized Range (HSD) Test for cond

Note: This test controls the Type I experimentwise error rate, but it generally has a higher Type II error rate than REGWQ.

Note: Cell sizes are not equal.

Means with the same letter are not significantly different.			
Tukey Grouping	**Mean**	**N**	**condition**
A	0.067698	43	BC
B	0.042268	56	DC

DH BF temperature HH timeframe

Level of condition	**N**	**temp**	
		Mean	**Std Dev**
BC	**24**	19.4345833	1.35263986
DC	**78**	10.0176923	2.67885463

t Tests (LSD) for temp

Note: This test controls the Type I comparisonwise error rate, not the experimentwise error rate.

Note: Cell sizes are not equal.

Means with the same letter are not significantly different.			
t Grouping	**Mean**	**N**	**condition**
A	19.4346	24	BC
B	10.0177	78	DC

Tukey's Studentized Range (HSD) Test for temp

Note: This test controls the Type I experimentwise error rate, but it generally has a higher Type II error rate than REGWQ.

Note: Cell sizes are not equal.

Means with the same letter are not significantly different.			
Tukey Grouping	**Mean**	**N**	**condition**
A	19.4346	24	BC
B	10.0177	78	DC

DH BF temperature RH timeframe

Level of condition	**N**	**temp**	
		Mean	**Std Dev**
BC	**46**	16.2517391	3.66089200
DC	**56**	8.9326786	2.19994255

t Tests (LSD) for temp

Note: This test controls the Type I comparisonwise error rate, not the experimentwise error rate.

Note: Cell sizes are not equal.

Means with the same letter are not significantly different.			
t Grouping	**Mean**	**N**	**condition**
A	16.2517	46	BC
B	8.9327	56	DC

Tukey's Studentized Range (HSD) Test for temp

Note: This test controls the Type I experimentwise error rate, but it generally has a higher Type II error rate than REGWQ.

Note: Cell sizes are not equal.

Means with the same letter are not significantly different.			
Tukey Grouping	**Mean**	**N**	**condition**
A	16.2517	46	BC
B	8.9327	56	DC

DH SF temperature HH timeframe

Level of condition	N	temp	
		Mean	Std Dev
BCmax	**24**	19.6158333	1.48236273
BCmin	**24**	19.2325000	1.11014786
DCmax	**78**	10.2473077	2.63543716
DCmin	**78**	9.8867949	2.63854667

t Tests (LSD) for temp

Note: This test controls the Type I comparisonwise error rate, not the experimentwise error rate.

Comparisons significant at the 0.05 level are indicated by ***.				
condition Comparison	**Difference Between Means**	**95% Confidence Limits**		
BCmax - BCmin	0.3833	-0.9815	1.7482	
BCmax - DCmax	9.3685	8.2649	10.4721	***
BCmax - DCmin	9.7290	8.6254	10.8327	***
BCmin - BCmax	-0.3833	-1.7482	0.9815	
BCmin - DCmax	8.9852	7.8816	10.0888	***
BCmin - DCmin	9.3457	8.2421	10.4493	***
DCmax - BCmax	-9.3685	-10.4721	-8.2649	***
DCmax - BCmin	-8.9852	-10.0888	-7.8816	***
DCmax - DCmin	0.3605	-0.3966	1.1176	
DCmin - BCmax	-9.7290	-10.8327	-8.6254	***
DCmin - BCmin	-9.3457	-10.4493	-8.2421	***
DCmin - DCmax	-0.3605	-1.1176	0.3966	

Tukey's Studentized Range (HSD) Test for temp

Note: This test controls the Type I experimentwise error rate.

Comparisons significant at the 0.05 level are indicated by ***.				
condition Comparison	**Difference Between Means**	**Simultaneous 95% Confidence Limits**		
BCmax - BCmin	0.3833	-1.4099	2.1765	
BCmax - DCmax	9.3685	7.9185	10.8185	***

Comparisons significant at the 0.05 level are indicated by ***.				
condition Comparison	Difference Between Means	Simultaneous 95% Confidence Limits		
BCmax - DCmin	9.7290	8.2791	11.1790	***
BCmin - BCmax	-0.3833	-2.1765	1.4099	
BCmin - DCmax	8.9852	7.5352	10.4352	***
BCmin - DCmin	9.3457	7.8957	10.7957	***
DCmax - BCmax	-9.3685	-10.8185	-7.9185	***
DCmax - BCmin	-8.9852	-10.4352	-7.5352	***
DCmax - DCmin	0.3605	-0.6342	1.3552	
DCmin - BCmax	-9.7290	-11.1790	-8.2791	***
DCmin - BCmin	-9.3457	-10.7957	-7.8957	***
DCmin - DCmax	-0.3605	-1.3552	0.6342	

DH SF temperature RH timeframe

Level of condition	N	temp	
		Mean	Std Dev
BCmax	46	16.4663043	3.62045323
BCmin	46	16.1136957	3.54169850
DCmax	56	9.1539286	2.15711818
DCmin	56	8.7771429	2.10450661

t Tests (LSD) for temp

Note: This test controls the Type I comparisonwise error rate, not the experimentwise error rate.

Comparisons significant at the 0.05 level are indicated by ***.				
condition Comparison	Difference Between Means	95% Confidence Limits		
BCmax - BCmin	0.3526	-0.8298	1.5350	
BCmax - DCmax	7.3124	6.1840	8.4407	***
BCmax - DCmin	7.6892	6.5608	8.8175	***
BCmin - BCmax	-0.3526	-1.5350	0.8298	
BCmin - DCmax	6.9598	5.8314	8.0881	***

Comparisons significant at the 0.05 level are indicated by *.**

condition Comparison	Difference Between Means	95% Confidence Limits		
BCmin - DCmin	7.3366	6.2082	8.4649	***
DCmax - BCmax	-7.3124	-8.4407	-6.1840	***
DCmax - BCmin	-6.9598	-8.0881	-5.8314	***
DCmax - DCmin	0.3768	-0.6948	1.4484	
DCmin - BCmax	-7.6892	-8.8175	-6.5608	***
DCmin - BCmin	-7.3366	-8.4649	-6.2082	***
DCmin - DCmax	-0.3768	-1.4484	0.6948	

Tukey's Studentized Range (HSD) Test for temp

Note: This test controls the Type I experimentwise error rate.

Comparisons significant at the 0.05 level are indicated by *.**

condition Comparison	Difference Between Means	Simultaneous 95% Confidence Limits		
BCmax - BCmin	0.3526	-1.2008	1.9060	
BCmax - DCmax	7.3124	5.8299	8.7948	***
BCmax - DCmin	7.6892	6.2067	9.1716	***
BCmin - BCmax	-0.3526	-1.9060	1.2008	
BCmin - DCmax	6.9598	5.4773	8.4422	***
BCmin - DCmin	7.3366	5.8541	8.8190	***
DCmax - BCmax	-7.3124	-8.7948	-5.8299	***
DCmax - BCmin	-6.9598	-8.4422	-5.4773	***
DCmax - DCmin	0.3768	-1.0311	1.7847	
DCmin - BCmax	-7.6892	-9.1716	-6.2067	***
DCmin - BCmin	-7.3366	-8.8190	-5.8541	***
DCmin - DCmax	-0.3768	-1.7847	1.0311	

RH BF turbidity

Level of condition	N	turb	
		Mean	Std Dev
BC	**16**	17.6187500	33.608813
DC	**71**	49.3788732	159.081948

t Tests (LSD) for turb

Note: This test controls the Type I comparisonwise error rate, not the experimentwise error rate.

Note: Cell sizes are not equal.

Means with the same letter are not significantly different.			
t Grouping	**Mean**	**N**	**condition**
A	49.38	71	DC
A			
A	17.62	16	BC

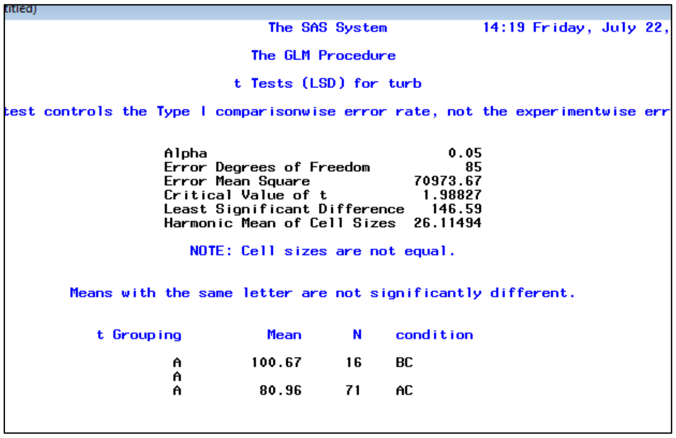
Tukey's Studentized Range (HSD) Test for turb

Note: This test controls the Type I experimentwise error rate, but it generally has a higher Type II error rate than REGWQ.

Note: Cell sizes are not equal.

Means with the same letter are not significantly different.			
Tukey Grouping	**Mean**	**N**	**condition**
A	49.38	71	DC
A			
A	17.62	16	BC

RH SF turbidity



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                              The SAS System          14:19 Friday, July 22,

                            The GLM Procedure

                          t Tests (LSD) for turb

test controls the Type I comparisonwise error rate, not the experimentwise err


                   Alpha                              0.05
                   Error Degrees of Freedom             85
                   Error Mean Square              70973.67
                   Critical Value of t             1.98827
                   Least Significant Difference     146.59
                   Harmonic Mean of Cell Sizes    26.11494

                      NOTE: Cell sizes are not equal.


        Means with the same letter are not significantly different.


           t Grouping          Mean      N     condition

                    A        100.67     16     BC
                    A
                    A         80.96     71     AC
```

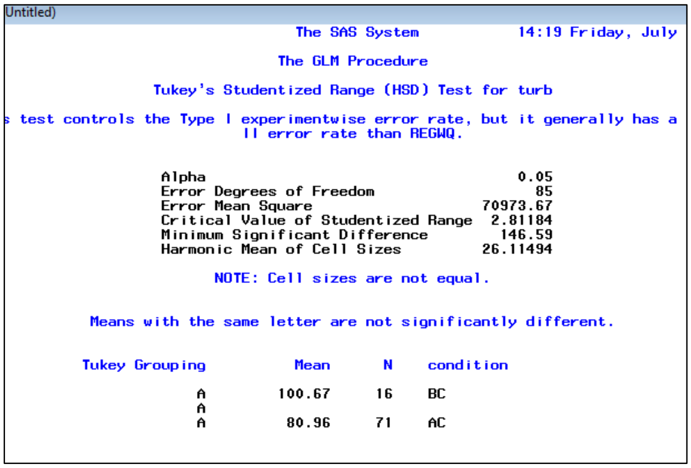

```
                              The SAS System          14:19 Friday, July

                            The GLM Procedure

                Tukey's Studentized Range (HSD) Test for turb

s test controls the Type I experimentwise error rate, but it generally has a
                    II error rate than REGWQ.


                 Alpha                                    0.05
                 Error Degrees of Freedom                   85
                 Error Mean Square                    70973.67
                 Critical Value of Studentized Range   2.81184
                 Minimum Significant Difference         146.59
                 Harmonic Mean of Cell Sizes          26.11494

                      NOTE: Cell sizes are not equal.


         Means with the same letter are not significantly different.


         Tukey Grouping          Mean      N     condition

                      A        100.67     16     BC
                      A
                      A         80.96     71     AC
```

RH BF pH

Level of condition	N	pH	
		Mean	Std Dev
BC	**18**	6.31333333	0.03199265
DC	**54**	6.23000000	0.09245090

t Tests (LSD) for pH

Note: This test controls the Type I comparisonwise error rate, not the experimentwise error rate.

Note: Cell sizes are not equal.

Means with the same letter are not significantly different.			
t Grouping	**Mean**	**N**	**condition**
A	6.31333	18	BC

Means with the same letter are not significantly different.			
t Grouping	**Mean**	**N**	**condition**
B	6.23000	54	DC

Tukey's Studentized Range (HSD) Test for pH

Note: This test controls the Type I experimentwise error rate, but it generally has a higher Type II error rate than REGWQ.

Note: Cell sizes are not equal.

Means with the same letter are not significantly different.			
Tukey Grouping	**Mean**	**N**	**condition**
A	6.31333	18	BC
B	6.23000	54	DC

RH SF pH

Level of condition	**N**	**pH**	
		Mean	**Std Dev**
BC	**18**	6.32502954	0.03609778
DC	**54**	6.29809199	0.69092473

t Tests (LSD) for pH

Note: This test controls the Type I comparisonwise error rate, not the experimentwise error rate.

Note: Cell sizes are not equal.

Means with the same letter are not significantly different.			
t Grouping	**Mean**	**N**	**condition**
A	6.3250	18	BC
A			
A	6.2981	54	DC

Tukey's Studentized Range (HSD) Test for pH

Note: This test controls the Type I experimentwise error rate, but it generally has a higher Type II error rate than REGWQ.

Note: Cell sizes are not equal.

Means with the same letter are not significantly different.			
Tukey Grouping	**Mean**	**N**	**condition**
A	6.3250	18	BC
A			
A	6.2981	54	DC

RH BF conductivity

Level of condition	**N**	**cond**	
		Mean	**Std Dev**
BC	**18**	0.08900000	0.08097567
DC	**75**	0.03208000	0.00338821

t Tests (LSD) for cond

Note: This test controls the Type I comparisonwise error rate, not the experimentwise error rate.

Note: Cell sizes are not equal.

Means with the same letter are not significantly different.			
t Grouping	**Mean**	**N**	**condition**
A	0.089000	18	BC
B	0.032080	75	DC

Tukey's Studentized Range (HSD) Test for cond

Note: This test controls the Type I experimentwise error rate, but it generally has a higher Type II error rate than REGWQ.

Note: Cell sizes are not equal.

Means with the same letter are not significantly different.			
Tukey Grouping	**Mean**	**N**	**condition**
A	0.089000	18	BC
B	0.032080	75	DC

RH SF conductivity

Level of condition	N	cond	
		Mean	Std Dev
BC	**18**	0.08811111	0.08341666
DC	**75**	0.03178667	0.00341813

t Tests (LSD) for cond

Note: This test controls the Type I comparisonwise error rate, not the experimentwise error rate.

Note: Cell sizes are not equal.

Means with the same letter are not significantly different.			
t Grouping	**Mean**	**N**	**condition**
A	0.088111	18	BC
B	0.031787	75	DC

Tukey's Studentized Range (HSD) Test for cond

Note: This test controls the Type I experimentwise error rate, but it generally has a higher Type II error rate than REGWQ.

Note: Cell sizes are not equal.

Means with the same letter are not significantly different.			
Tukey Grouping	**Mean**	**N**	**condition**
A	0.088111	18	BC
B	0.031787	75	DC

RH BF temperature

Level of condition	N	temp	
		Mean	Std Dev
BC	**18**	18.8133333	0.75534176
DC	**80**	9.8811250	2.39828525

t Tests (LSD) for temp

Note: This test controls the Type I comparisonwise error rate, not the experimentwise error rate.

Note: Cell sizes are not equal.

Means with the same letter are not significantly different.			
t Grouping	**Mean**	**N**	**condition**
A	18.8133	18	BC
B	9.8811	80	DC

Tukey's Studentized Range (HSD) Test for temp

Note: This test controls the Type I experimentwise error rate, but it generally has a higher Type II error rate than REGWQ.

Note: Cell sizes are not equal.

Means with the same letter are not significantly different.			
Tukey Grouping	**Mean**	**N**	**condition**
A	18.8133	18	BC
B	9.8811	80	DC

RH SF temperature

Level of condition	**N**	**temp**	
		Mean	**Std Dev**
BCmax	**18**	19.7916667	1.09588669
BCmin	**18**	18.7061111	0.71425106
DCmax	**80**	10.1510000	2.41754903
DCmin	**80**	9.6333750	2.29316924

t Tests (LSD) for temp

Note: This test controls the Type I comparisonwise error rate, not the experimentwise error rate.

Comparisons significant at the 0.05 level are indicated by ***.				
condition Comparison	**Difference Between Means**	**95% Confidence Limits**		
BCmax - BCmin	1.0856	-0.3428	2.5139	
BCmax - DCmax	9.6407	8.5228	10.7586	***
BCmax - DCmin	10.1583	9.0404	11.2762	***

Comparisons significant at the 0.05 level are indicated by *.**

condition Comparison	Difference Between Means	95% Confidence Limits		
BCmin - BCmax	-1.0856	-2.5139	0.3428	
BCmin - DCmax	8.5551	7.4372	9.6730	***
BCmin - DCmin	9.0727	7.9549	10.1906	***
DCmax - BCmax	-9.6407	-10.7586	-8.5228	***
DCmax - BCmin	-8.5551	-9.6730	-7.4372	***
DCmax - DCmin	0.5176	-0.1599	1.1952	
DCmin - BCmax	-10.1583	-11.2762	-9.0404	***
DCmin - BCmin	-9.0727	-10.1906	-7.9549	***
DCmin - DCmax	-0.5176	-1.1952	0.1599	

Tukey's Studentized Range (HSD) Test for temp

Note: This test controls the Type I experimentwise error rate.

Comparisons significant at the 0.05 level are indicated by *.**

condition Comparison	Difference Between Means	Simultaneous 95% Confidence Limits		
BCmax - BCmin	1.0856	-0.7913	2.9624	
BCmax - DCmax	9.6407	8.1718	11.1095	***
BCmax - DCmin	10.1583	8.6894	11.6272	***
BCmin - BCmax	-1.0856	-2.9624	0.7913	
BCmin - DCmax	8.5551	7.0862	10.0240	***
BCmin - DCmin	9.0727	7.6039	10.5416	***
DCmax - BCmax	-9.6407	-11.1095	-8.1718	***
DCmax - BCmin	-8.5551	-10.0240	-7.0862	***
DCmax - DCmin	0.5176	-0.3726	1.4079	
DCmin - BCmax	-10.1583	-11.6272	-8.6894	***
DCmin - BCmin	-9.0727	-10.5416	-7.6039	***
DCmin - DCmax	-0.5176	-1.4079	0.3726	