Phosphorus and Nitrogen Loading and Export

From

Rhodhiss Lake, North Carolina

prepared

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by

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for

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1. INTRODUCTION

As early as the 1950's, degraded water quality conditions, primarily attributed to point-source dischargers, were documented in streams in the Lenoir and Morganton areas (North Carolina State Department of Water Resources, 1961). Additionally, the United States Geological Survey (USGS) noted enriched tributaries in 1967. In 1975, the United States Environmental Protection Agency (USEPA) classified Rhodhiss lake as eutrophic due to high nutrient loadings from several tributaries in the watershed, but used the term "over-enriched" as a more appropriate description due to the relatively low chlorophyll a concentrations. Since that time, NCDEM (1982 and 1992) and NCDWQ (1995 and 1999) have reported various degradations due to excess nutrients and classified Rhodhiss as eutrophic.

In response to water quality concerns along the upper Catawba River, the Western Piedmont Council of Governments contracted with the USGS over a three-year period during the mid 1990s to conduct separate water quality investigations on Rhodhiss Lake and Lake Hickory. The lakes and selected tributaries were sampled over a 15-month period. The resultant data set was used to develop a calibrated two-dimensional hydrodynamic water quality model for each lake. Monitoring by the USGS (Giorgino and Bales, 1997) showed elevated nutrient concentrations in the upper end of Rhodhiss Lake and in Lower Creek. "In 1999, after reviewing the results of the USGS water quality modeling effort, DWQ committed to developing a watershed management strategy for controlling nutrient inputs to the reservoir" (NCDWQ, 2004). The Western Piedmont Council of Governments (WCOG) applied the Generalized Watershed Loading Functions Model (GWLF) to the Rhodhiss Lake Watershed to estimate current loadings and to evaluate future development in the watershed (Struve, 2003).

In 2000, NCDWQ classified this reservoir as mesotrophic and fully supporting all drinking water supply, aquatic life, and primary and secondary recreational uses, with no fish advisories

During the late spring of both 2000 and 2001, severe taste and odor problems were experienced in drinking water originating from Rhodhiss Lake. A special study conducted by DWQ in 2001 (Vander Borgh, 2001) indicated that moderate algal blooms within the Lake were dominated by two blue-green algae, *Anabaena* and *Aphanizomemon*, both of which have been implicated with taste and odor problems. A combination of factors, including elevated nutrient concentrations, abundant light, warm water temperatures and reduced flow through the reservoir appeared to contribute to the formation and persistence of these taste and odor producing genera. As a result of these two episodic events, municipalities with intakes on the lake (Granite Falls, Lenoir and Valdese) have either altered water treatment processes in their respective plants or are in the process of purchasing new equipment to better treat these algae. During the height of the blue-green algae bloom, the Town of Valdese estimated that treating with additional activated carbon at the Town's water treatment plant cost about $800 per week. In addition to these short-term costs, Granite Falls and Lenoir are investing over $1 million dollars collectively in improvements to their water treatment plants to help prevent future taste and odor problems.

In 2002 monitoring by DWQ identified frequent algal blooms and percent dissolved oxygen saturation values that exceeded state water quality standards (NCDWQ, 2004). By 2004, with six of seven water quality parameters identified as lake stressors (percent saturation DO, algae, chlorophyll a, pH, sediment, and taste and odor), NCDWQ reported that Rhodhiss Lake suffers from eutrophication and was impaired in its support of aquatic life. This classification was issued because of problems related to excessive nutrient concentrations in the lake (NCDWQ, 2004). Within the 2004 Basin-wide Plan the state recommended that a locally developed watershed management plan for Lake Rhodhiss be produced as a first step towards reducing nutrient loadings to the reservoir in the future.

In addition to nutrients, sediment is a pollutant of concern in much of the watershed. Several tributaries to the lake, including Muddy Creek and Lower Creek, have planning or implementation projects underway to address sediment concerns. Duke Energy has estimated that between 14,000 and 23,000 tons of sediment per year enters the Catawba River from Muddy Creek under typical flow conditions (NCDWQ, 1999). A turbidity total maximum daily load has been recently developed for Lower Creek (NCDWQ, 2004). Eroding stream banks have been identified as the major source of sediment loading to each of these two streams. Sediment loading to the reservoir has appeared to reduce the Lake's original storage capacity by as much as 34% according to recent bathymetric measurements conducted by the USGS (Giorgino and Bales, 1997).

In 2008, the North Carolina 303(d) list was updated to include Rhodhiss Lake for exhibiting high pH values (NCDWQ, 2008). In addition to Rhodhiss Lake, the following steam sections are also listed in the 303 (d) report (NCDWQ, 2008):

- 5.5 miles of Youngs Fork, tributary of N. Fork Muddy Creek: biological impairment
- 2.4 miles of Jacktown Creek, tributary of N. Fork Muddy Creek: biological impairment
- 7.4 miles of Hunting Creek: biological impairment
- 3.0 miles of Irish Creek (Warrior Fork): biological impairment, poor instream and riparian habitats
- 25.4 miles of Lower Creek (including tributaries): biological impairment, poor land use practices/sedimentation
- 3.9 miles of McGalliard Creek: biological impairment, lack of riparian vegetation in residential area

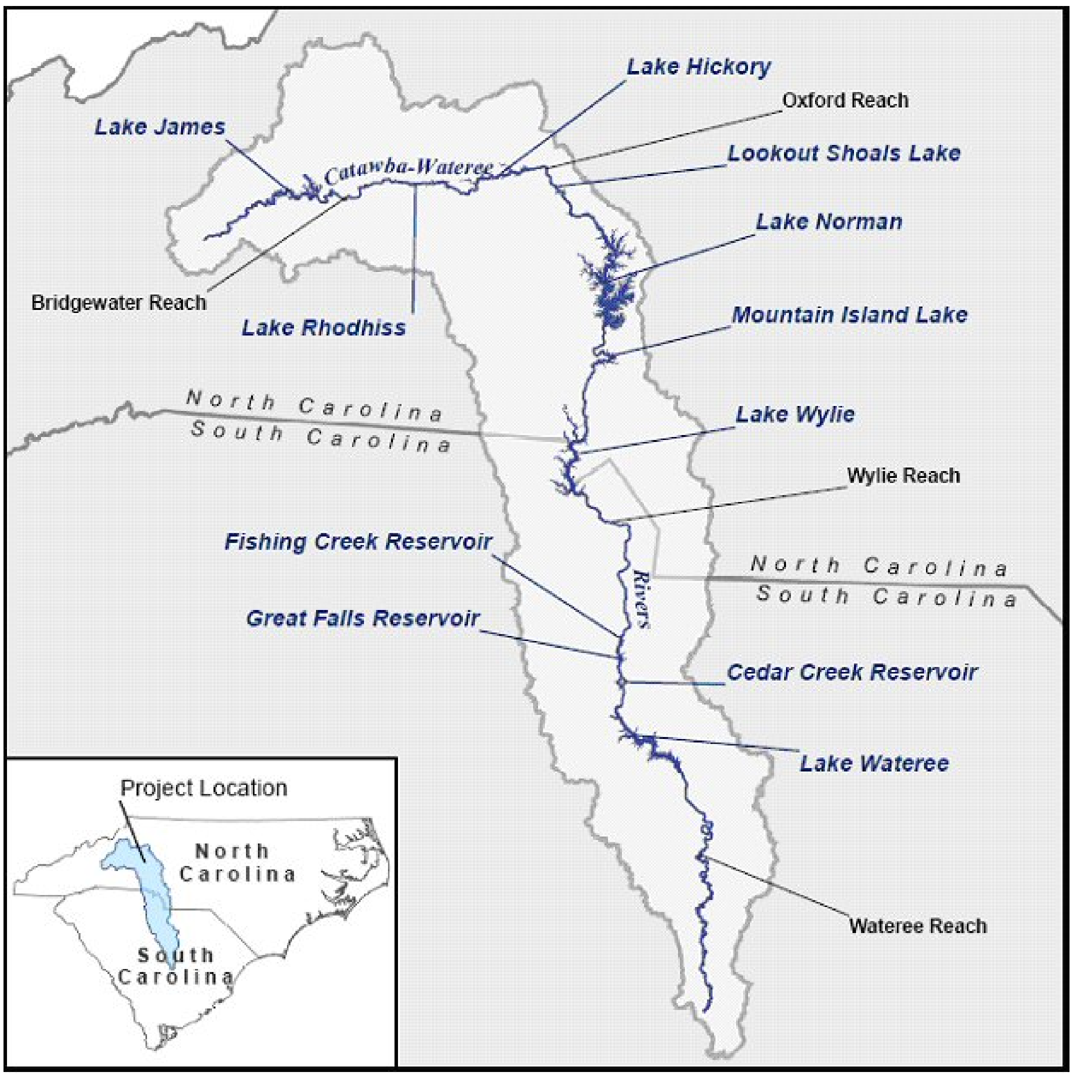
While the point sources of nutrients are known and available from the monthly reports of the municipal waste treatment plants, little quantitative data exists for nutrient and sediment loading from streams. The USEPA (1975) sampled various streams for nutrients and estimated flows in the streams. The NCDWQ has measured nutrient concentrations in some tributaries since the1980's, but has not measured stream discharge. The USGS (Giorgino and Bales, 1997) estimated flows and nutrient concentrations from one tributary and applied the data to other streams. In summary, to date, estimates of watershed loading to Rhodhiss Lake have relied on spot checks (measurement of nutrient concentrations) of a few tributaries and/or computer modeling of constituent parameters required for loading calculations.

Recognizing this lack of hard, comprehensive data collection to calculate the various sources of phosphorus, nitrogen, and sediment into Rhodhiss Lake, Carolina Land and Lakes RC&D, Inc. applied for and received a 319 Grant to measure the comprehensive nutrient loads to Rhodhiss Lake. Additionally, export of nutrients and sediment from Rhodhiss Lake was also planned. This report describes the results collected from ten streams, four point sources, and two hydro tailraces sampled for nutrient concentrations and measured for flow. The net result is a calculation of nutrient and sediment loading to Rhodhiss Lake and subsequent export from Rhodhiss Lake.

2. SITE DESCRIPTION

Rhodhiss Lake is the second most upstream reservoir on the Catawba River (Figure 1). Located between Lakes James and Hickory, Rhodhiss Lake was impounded in 1925 following the completion of Rhodhiss Dam and Powerhouse. Historically, Duke Energy used the hydroelectric station to generate electricity during periods of peak electrical demand and/or during periods of adequate inflows to maintain target lake elevations. In addition to hydropower production, the lake provides drinking water to the municipalities of Granite Falls, Morganton, Lenoir and Valdese. The lake is also popular among fishermen and boaters.

Figure 1. Impoundments on the Catawba River, North and South Carolina.



Rhodhiss Lake is characterized by a short retention time (14.5 days on average) (Table 1). With minimum storage capability, relatively high inflows, relatively shallow depths, and a large watershed, Lake Rhodhiss is dynamic and, at most times, inflow driven.

Table 1. Summary Characteristics of Rhodhiss Lake (updated from Duke Energy, 2007)

Parameter	Metric Units	English Units
NCDENR-DWQ Designated Use Classifications	WS-IV, B; CA	N/A
Full Pond (Spillway Elevation)	303.3 m-msl	995.1 ft-msl
Mean Lake Elevation[4]	302.2 m-msl	991.4 ft.msl
Surface Area[1]	1102 ha	2724 acres
Volume[1]	5.736 x 10^7 cubic meters	46,500 acre-feet
Maximum Depth[1]	18.0 meters	59 feet
Mean Depth[1]	6.3 meters	20.6 feet
Shoreline[1]	171.8 kilometers	106.8 miles
Total Watershed Area[2]	2823 sq. kilometers	1090 sq. miles
Reservoir Direct Watershed Area[3]	1827 sq. kilometers	703.5 sq. miles
Mean Inflow[4]	50.43 cubic meters per sec	1781 cubic feet per sec
Mean Outflow[4]	45.65 cubic meters per sec	1612 cubic feet per sec
Mean Retention Time[4]	14.5 days	N/A
Retention Time (Range)[4]	4 - 100 days	N/A

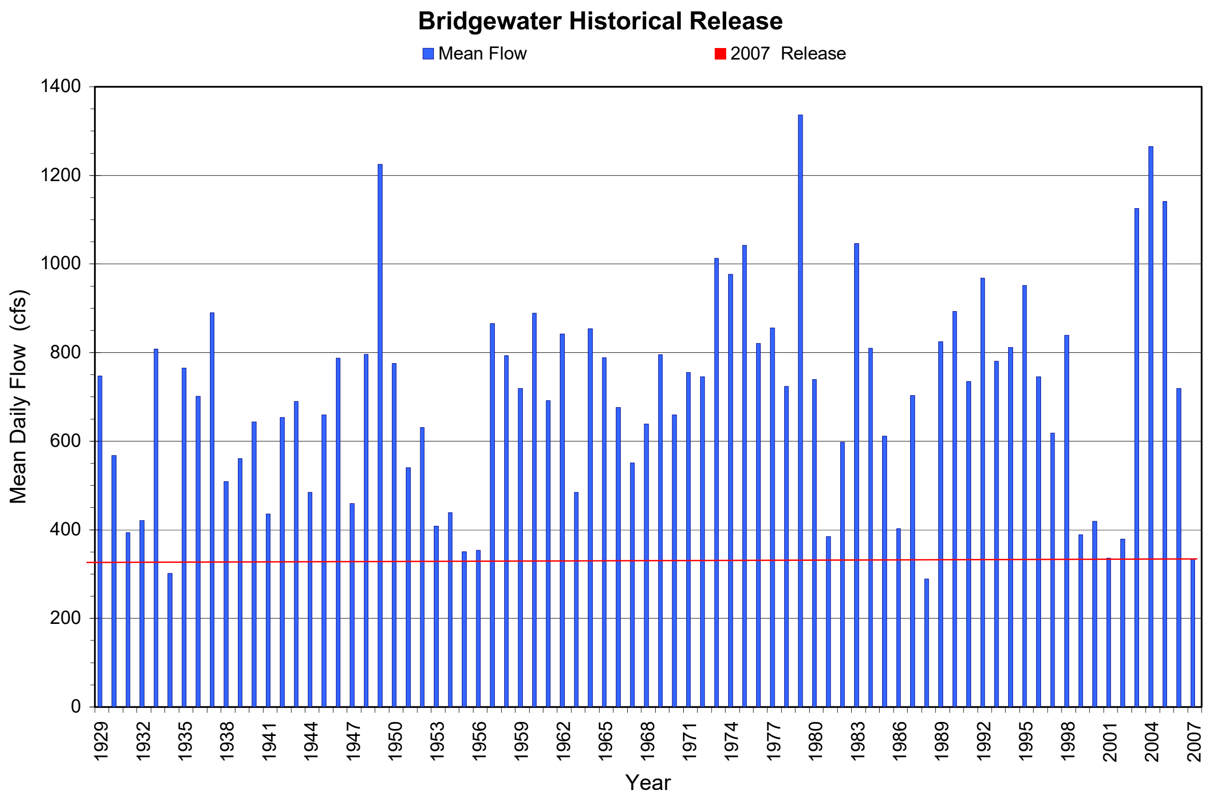
[1]Values Calculated from full pond (995.1 ft-msl)
[2]Up-stream Reservoir Included
[3]Does Not Include Up-stream Reservoir
[4]Based upon monthly averages from 1929 – 2003

Utilizing a calibrated two-dimensional hydrodynamic water quality model, the USGS (Giorgino and Bales, 1997) reservoir model was used to simulate a 30% reduced phosphorus load (measured from their ambient conditions) . The result predicted a 20% decrease in maximum algal concentrations, with the greatest reduction in late summer and early fall. A simulated 50 % reduction of phosphate released from the sediments (internal loading) resulted in a small reduction of algae. Similarly, an increase in phosphate load from the Valdese WWTP discharge (pipe on the bottom of the lake) had little impact on algal concentrations. But, when the increase was applied to a surface WWTP discharge, algal concentrations increased 2-3 times compared to the bottom discharge (the actual distribution of the effluent released on the lake bottom is a function of the relative temperature differences between the waste stream and the lake).

Duke Energy, as part of the water quality studies conducted for FERC relicensing of the Catawba Projects, commissioned the construction and calibration of a two-dimensional hydrodynamic water quality model (Jain and Ruane, 2006). Employing the W2 model illustrated that phosphorus patterns were very dynamic, and were driven by loadings that got diluted and redistributed by intermittent reservoir flow. In addition, phosphorus contributions due to point source and non-point discharges were not fully processed before being released from the dam. At high inflows, algal blooms were limited by short retention times. Low inflows (high retention times, high light penetration, and favorable nutrient concentrations) allowed algal blooms to develop and persist. These higher algal populations have triggered high pH and DO values. Additional modeling suggested that low dissolved oxygen occurred due to sediment oxygen demand along the bottom of the reservoir where residence times were longer (density inflow). Low dissolved oxygen was also predicted in the middle depths of the reservoir depths due to algal respiration. Low flow periods (i.e., long retention time), coupled with less diluted nutrient concentrations, produce the lowest DO levels within the reservoir and, subsequently, released from the reservoir.

Duke Energy calculated that the 703.5 square mile watershed that flows directly into Rhodhiss Lake (Table 1) produced, on the average, 1.54 cubic feet of water per second per square mile. This value agrees remarkably well to Giese and Mason's (1993) estimate for the Burke County region in North Carolina. The Duke Energy watershed yield ranged from 0.79 cfs to 2.58 cfs of water per square mile. An indicator of the variability of the range of flows into Rhodhiss, the mean daily Bridgewater releases for each year (1929 – 2007) (Figure 2) (Duke Energy, 2007) varied from 289 cfs in 1988 to 1337 cfs in 1979. As referenced in Table 1, this variability of inflow accounts for the tremendous range of water retention time (4 to 100 days) in the reservoir. And long retention times account for most of the degrading of water quality due to the length of time to accumulate products resulting from biological activity.

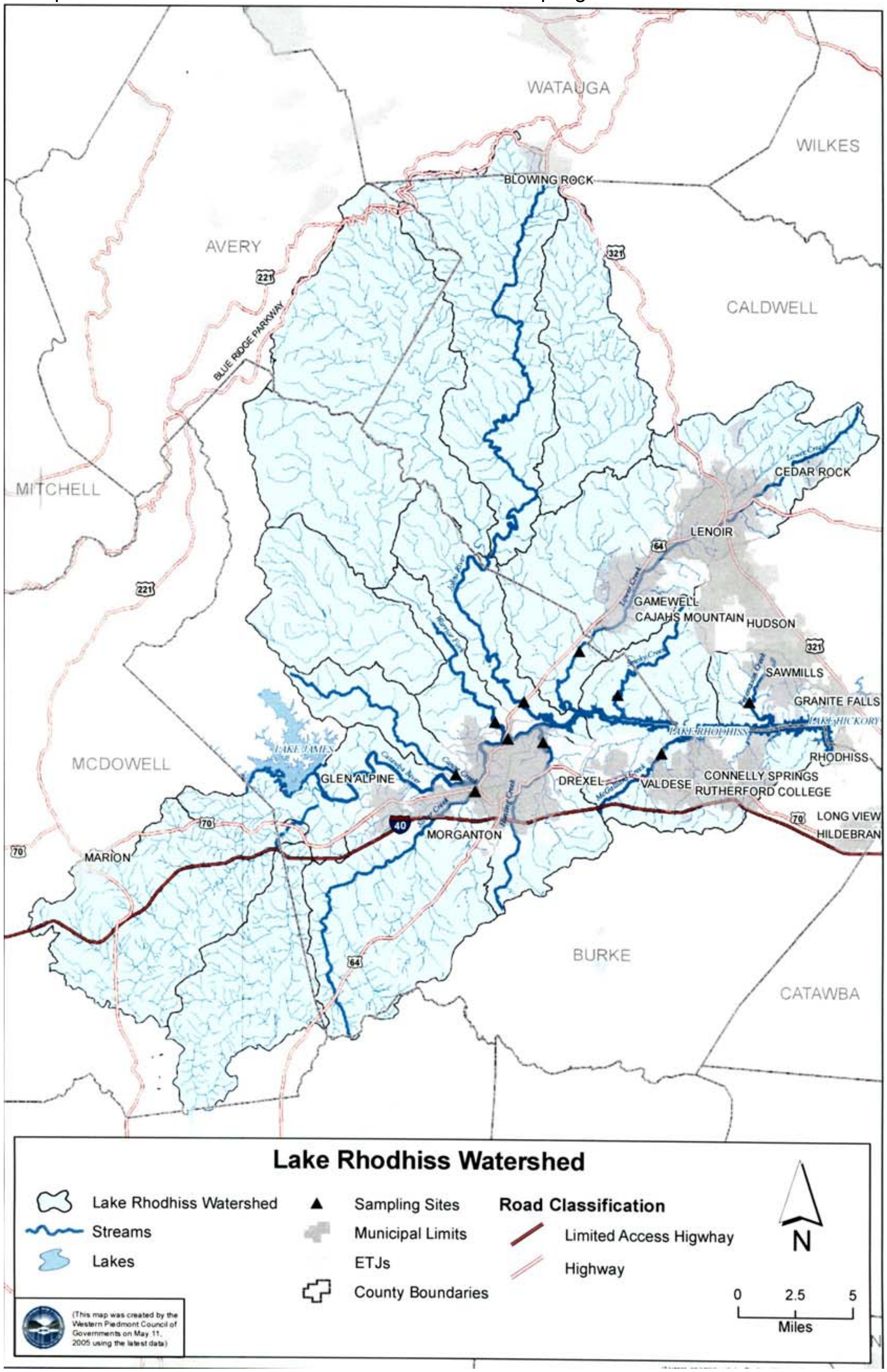
Figure 2. Annual Variability of Bridgewater Releases into Rhodhiss Lake (Duke Energy, 2007)



The flow record (Figure 2) indicates that 2007, the primary year of this study, was the third lowest flow year on record.

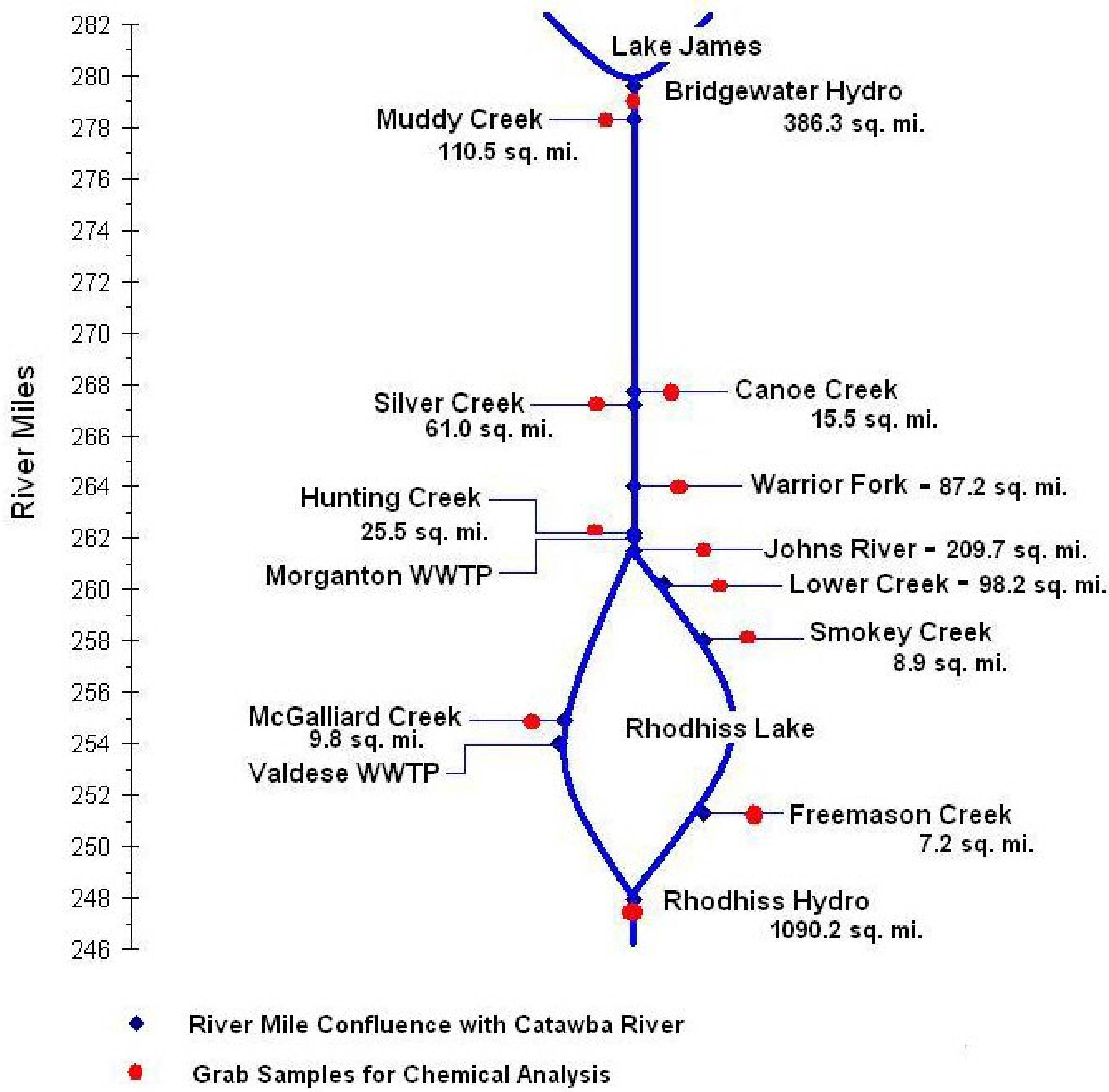
The watershed of Rhodhiss Lake, excluding Lake James, extends from the lower Blue Ridge Mountains into the Piedmont of North Carolina (Figure 3). The watershed consists of portions of Avery, Burke, Caldwell, McDowell and Watauga Counties in western North Carolina. The ultisol soils of the watershed are associated with high rainfall accelerating mineral decay into layer-latice silicate kaolinite clays with low cation-exchange capacity, low base saturation, and low organic content. The soils are weathered from Precambrian gneisses and schists, intensively leached, and easily erodible. These characteristics lead to surface waters with low ionic strength and potentially high total suspended solids (clays).

Figure 3. Map of the Rhodhiss Lake Watershed with 2007 Sampling Sites



A schematic of the Catawba River from Bridgewater Hydro to Rhodhiss Dam illustrates the proximity of the various tributaries and waste water treatment plants (WWTP) to each other as they enter the river (Figure 4). According to NCDWQ, Rhodhiss received heavy sediment and/or nutrient loads from Muddy Creek, Lower Creek, and the Johns River watersheds from agricultural activities. NCDWQ also identified Lake Rhodhiss as having heavy influence from urban centers via Hunting Creek, Silver Creek, and McGalliard Creek. In addition, nutrients from the Morganton and Valdese wastewater treatment plants discharge directly into the lake. While Lenoir's wastewater is received via Lower Creek and Marion WWTP discharged into the headwaters of Muddy Creek. The goal of this study was to systematically collect nutrient and flow data from all of the sources immediately prior to entering the Catawba River.

Figure 4. Schematic of the Rhodhiss Lake Watershed



The Western Piedmont Council of Governments (WPCOG) compiled the principal land use from each of the watersheds (Struve, 2003). A broadening of the various categories presented by the

WPCOG illustrated that the principal use of the land in all of the watersheds was as forest / wetland / upland herbaceous (Table 2).

Table 2. Land Use of the Rhodhiss Lake Watersheds (Struve, 2003)

Watershed	Land Use (% of Watershed)				
	Agricultural	Ornamentals	Forest / Wetland	Developed	Other
Hunting Creek	2.0	0.0	84.1	13.4	1.2
McGalliard Creek	0.4	0.0	89.8	8.2	1.6
Silver Creek	0.6	0.4	91.5	6.1	1.5
Lower Creek	6.3	0.3	94.6	3.2	0.5
Smokey Creek	0.1	0.0	97.2	2.4	0.3
Muddy Creek	8.9	0.2	87.9	2.2	0.7
Canoe Creek	1.1	0.9	96.9	0.7	0.5
Warrior Fork	0.5	1.2	97.3	0.5	0.5
Johns River	0.3	1.4	97.4	0.5	0.5
Freemason Creek	0.1	0.0	99.3	0.3	0.2

Urban areas, represented by all residential, industrial, and commercial groupings presented by Struve (2003), were a significant portion in half of the watersheds. Agricultural activities (all crops and livestock categories described by the WPCOG), excluding ornamental horticulture, was a significant use in Muddy and Lower Creek drainages. The growing of ornamental plants was greatest in the Johns River basin with 1.4% of the land used for that purpose. Each type of activity would have associated nutrient and sediment runoff, depending upon the severity of disturbance and mismanagement. However, the forest / wetland areas would be considered the use least apt to contribute to non-point runoff .

3. METHODS

3.1 Sampling Locations

Sampling consisted of collecting grab samples for laboratory analysis and stream level (stage) and flow measurements. For all streams sampled, a location was selected as near to the confluence with Lake Rhodhiss as feasible (Figures 3 and 4, Table 3). Typically this was the first bridge above the confluence or where easy access allowed sampling closer to the lake confluence, e.g. Warrior Fork. Samples for Muddy Creek were taken from the Highway 70 bridge, just upstream of the confluence with the Catawba River. The grab sample for the Lake James outflow (Bridgewater tailrace) was taken from the first bridge below the Bridgewater Power House. Grab samples at the Rhodhiss hydro were taken in the immediate tailrace.

Table 3. GPS Coordinates of Water Sample and Flow Measurement Locations with the Percentage of the Watershed Sampled

Watershed	Water Sample Location Latitude Longitude (deg, min)	Flow Measurement Location Latitude Longitude (deg, min)	Area of Watershed Upstream of Flow Measurement Location (%)
Bridgewater (Duke Energy Records)	35º 44.425'	35º 44.606'	100.00
	81º 50.091'	81º 50.291'	
Muddy Creek	35º 42.071'	35º 42.745'	99.83
	81º 49.392'	81º 51.111'	
Canoe Creek	35º 44.796'	35º 44.796'	99.98
	81º 43.787'	81º 43.787'	
Silver Creek	35º 44.162'	35º 43.861'	96.60
	81º 42.748'	81º 43.159'	
Warrior Fork	35º 46.809'	35º 46.809'	96.05
	81º 42.077'	81º 42.077'	
Hunting Creek	35º 46.086'	35º 46.086'	97.26
	81º 39.724'	81º 39.724'	
Johns River (USGS records)	35º 47.571'	35º 50.017'	95.87
	81º 40.651'	81º 42.717'	
Lower Creek	35º 45.815'	35º 49.910'	84.51
	81º 34.213'	81º 37.652'	
McGallard Creek	35º 45.815'	35º 45.815'	84.73
	81º 34.213'	81º 34.213'	
Smokey Creek	35º 47.937'	35º 47.937'	87.58
	81º 36.292'	81º 36.292'	
Freemason Creek	35º 47.843'	35º 47.843'	92.17
	81º 30.226'	81º 30.226'	
Inflow not Measured	N/A	N/A	9.96
Rhodhiss Hydro (Duke Energy Records)	35º 50.017'	35º 50.017'	100.00
	81º 42.717'	81º 42.717'	

3.2 Phosphorus, Nitrogen, and Suspended Solids

Beginning in April, 2007 and ending in May, 2008, grab samples were collected at monthly intervals. However, as low water conditions persisted, the sampling interval was increased (never more than six weeks between sampling). The increased interval was to allow additional flexibility with project funding to enable sample collection at higher flows. In addition, samples were collected from four streams at intervals throughout a storm event.

All samples were collected, processed, preserved, transported, and analyzed according to Prism Laboratories Quality Assurance Plan (2005). Chain-of-custody procedures and all appropriate Quality Assurance and Quality Control procedures were followed according to Prism Laboratories protocols. A summary of sample handling and analytical procedures are provided in Table 4.

Table 4. Summary of Sampling Protocols and Methodology

Parameter	Sampling Equipment	Sampling Method	Field Treatment	Preservatives	Description of Method	EPA Method Number	Method Detection Limit (mg/L)
Turbidity	glass	grab	measured	none	Nephelometric	180.1	0.042 NTU
Conductivity	plastic	grab or *in situ*	measured	none	Electrical Resistance	120.1	0.35 uSi
Total Kjeldahl Nitrogen	plastic	grab	raw water collected and transported	Sulfuric acid ice	Block Digestion Colorimetric	351.2	0.065
Filtered Kjeldahl Nitrogen	plastic	grab	field filtered, collected, and transported	Sulfuric acid ice	Block Digestion Colorimetric	351.2	0.065
Ammonia	plastic	grab	field filtered, collected, and transported	Sulfuric acid ice	Phenate	350.1	0.048
Nitrate-Nitrate	plastic	grab	field filtered, collected, and transported	Sulfuric acid ice	Cadmium Reduction	300	0.0099
Total Phosphorus	plastic	grab	raw water collected and transported	Sulfuric acid ice	Digestion Ascorbic Acid	365.3	0.0081
Filtered Total Phosphorus	plastic	grab	field filtered, collected, and transported	Sulfuric acid ice	Digestion Ascorbic Acid	365.3	0.0081
Ortho-Phosphorus	plastic	grab	field filtered, collected, and transported	Sulfuric acid ice	Ascorbic Acid	365.3	0.0049
Total Suspended Solids	plastic	grab	collected and transported	none	Filtration Gravimetric	160.2	0.94

Nutrient concentrations measured monthly during the period of study from the wastewater treatment facilities at Lenoir, Marion, Morganton, and Valdese were obtained from the DMR's reported to the NCDWQ.

3.3 Discharge Measurements and Calculations

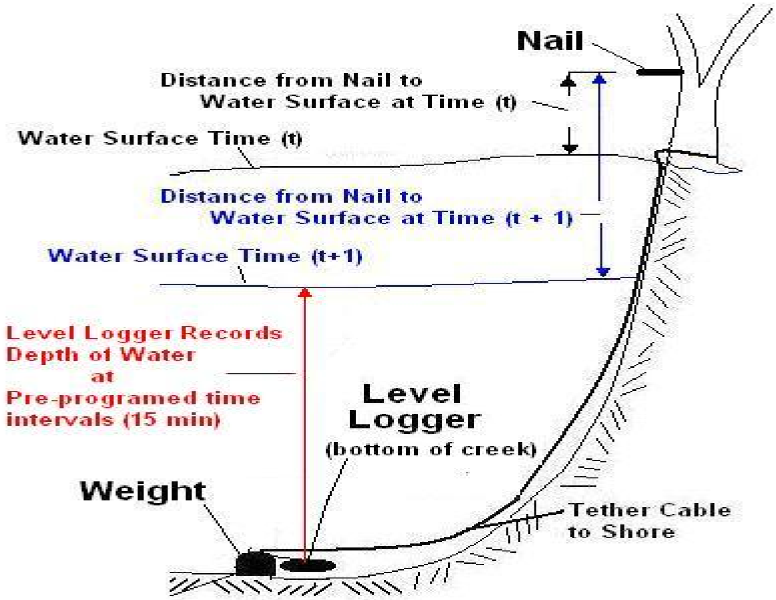
Stream discharge was calculated by the method described by Rantz (1982). Stream stage (water surface elevation) and flow (cubic feet per second) were measured and calculated for each stream at the locations specified in Table 3.

<u>Stage Measurement</u>

Relative water depth was recorded at 15-minute intervals with a Solinst Level Logger ®. The level loggers were placed in the streambed and tethered to shore with a stainless steel cable (Figure 5). At various time intervals throughout the study, the data from the level loggers were downloaded and a measurement of the water surface elevation relative to a permanent reference point (usually a nail in a tree) was taken. An additional level logger was hung in a tree at the Hunting Creek site (a central location of all the stream sampling locations) to measure changes in barometric pressure.

The first step in the calculation of stream stage was to subtract the barometric pressure changes (measured as centimeters of water) at each time step from the raw depth data

Figure 5. Measurement of Level Logger Placement and Correction of Level Logger Movement



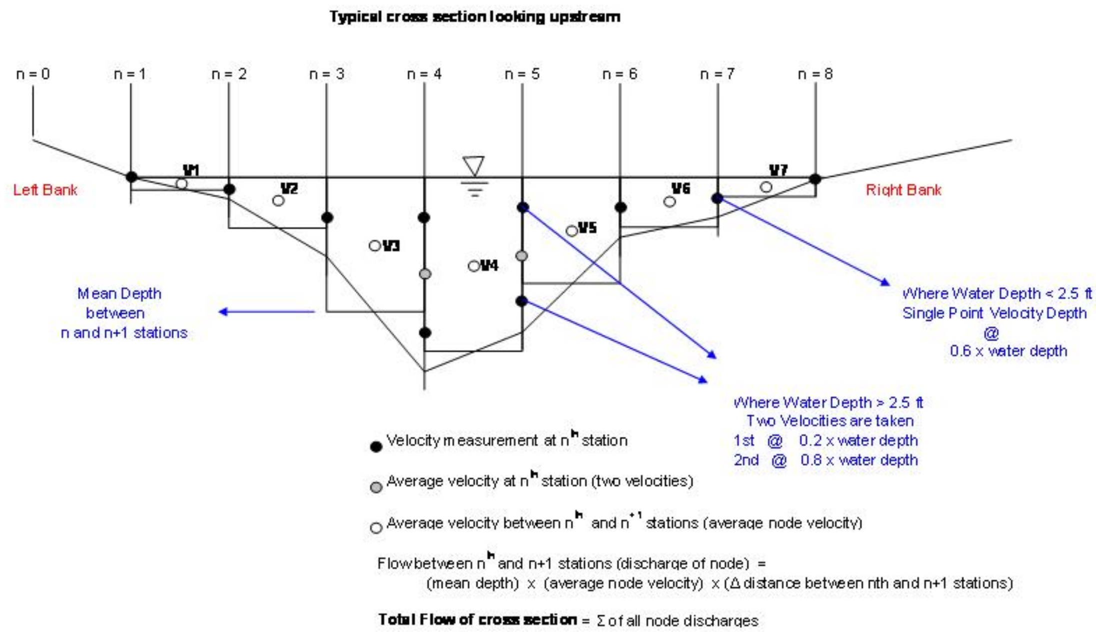
from the level logger's corresponding time. The second step involved comparing the corrected water depth to the nail-to-water measurements from the various times. This measurement allowed for correction of water depth recorded on the level logger in the event that the level logger was moved or disturbed. All corrected depth data were standardized to consistent nail-to-water distances. The reference point (nail) was arbitrarily set at an elevation of 100 ft and all stage data is presented as elevation relative to the reference point.

Flow Measurement

Stream flow was measured at each site (Table 3) where a level logger was placed. Flow measurements were taken at least at the different stream stages. Stream flow was measured according the manual method described by Rantz (1982). A transect perpendicular to the stream flow was chosen where obstructions, eddies, rocks, logs, etc. were non-existent or very minimal. Rebar was driven into each bank and a 'tag-line' delineated in 1-foot intervals was stretched across the channel and anchored to the rebar. Starting from one shoreline, the distance from the shoreline (station), the depth, and the mean column velocity were recorded at each transect station[1]. The flow (cubic feet per second) was calculated for each transect interval by averaging the depths and velocities measured from the interval stations and multiplying these values by the length of the interval. All intervals were summed to yield the total stream flow (cfs). These measurements and calculations are summarized in Figure 6.

Figure 6. Measurement of Stream Flow

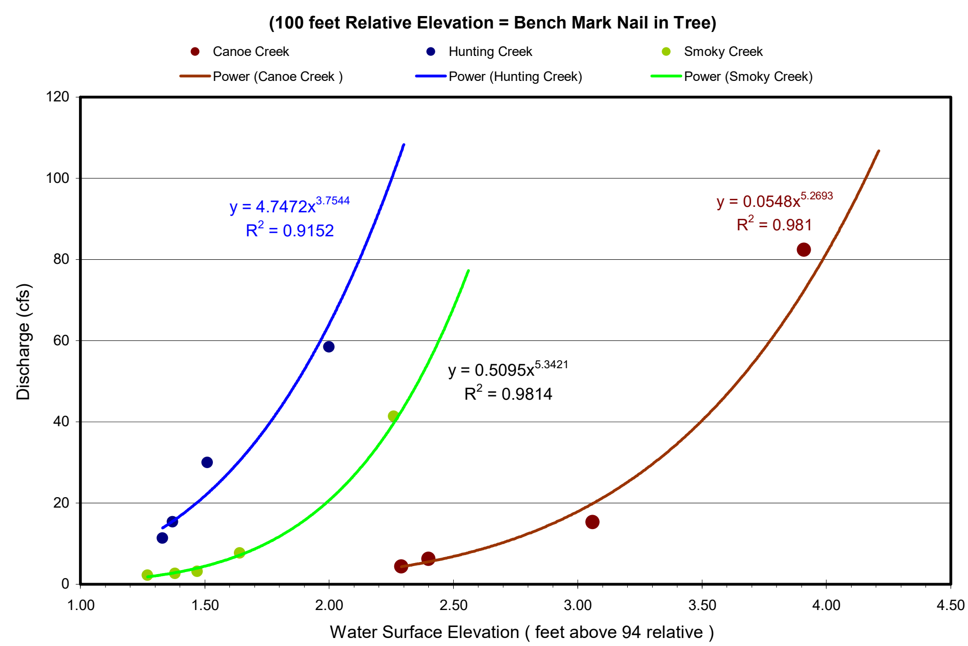
[1] Streams less than 15 feet wide, 1-foot intervals were used, stream widths greater than 15 feet, 2-foot intervals were used



Discharge Calculation

A rating curve was calculated for each stream by plotting the flow measurements against the stage measurement at the time of the flow measurement. A regression analysis was performed to yield an equation, usually a power function, which was used to calculate stream discharge at each measured stage throughout the study period (see Figure 7 for examples).

Figure 7. Example Rating Curves



The discharge from the Johns River was obtained from the 15-minute provisional data made available from the USGS (2008). All 15-minute discharge data (Johns River and calculated from all tributaries) were increased by the unmeasured portion of the watershed (Table 3).

The volume of water released from Bridgewater and Rhodhiss hydroelectric stations was provided by Duke Energy Carolinas, LTD. The flow was recorded at hourly intervals.

The daily average flow discharged from the four wastewater treatment plants were available from the DMR's submitted to NCDWQ.

4. RESULTS AND DISCUSSION

4.1 Phosphorus and Nitrogen Concentrations

Streams

The results of all analyses throughout the study period are itemized in Appendix A. The loading estimates calculated in Section 4.4 rely on measurements of total nitrogen and total phosphorus, however, fractionation of nitrogen and phosphorus is helpful to understand the characteristics of the nutrient loads and assumptions for calculating loading. Total nitrogen was calculated as the sum of total Kjelhahl nitrogen (TKN), which was measured from whole, unfiltered water samples, and nitrate-nitrite (NO_3), measured from filtered water. Additionally, a filterable Kjelhahl fraction was analyzed with a Kjelhahl digestion performed on a filtered water sample. Ammonia analysis was also performed on filtered water. Total Phosphorus (TP) was measured directly by digestion on a whole water sample and a digestion on a filtered sample yielded a filterable digested fraction. Analysis of ortho-phosphate was performed on a filtered water sample.

Nitrogen fractionation (Figure 8) revealed that ammonia concentrations were approximately equal from all streams, filterable Kjelhahl nitrogen was at the detection limit as was the TKN analysis. The result was that the total nitrogen in the streams was controlled by the nitrate levels.

Nitrate concentrations were lowest in the John's River and Warrior Fork and highest in Freemason Creek. Nitrogen concentrations did not exhibit any correlation with total suspended sediment nor conductivity values. Lower Creek, even though it received a wastewater discharge, exhibited nitrogen concentrations similar to other streams.

Phosphorus fractions (Figure 9) exhibited very different patterns than nitrogen. Ortho phosphate was at, or near, detection limits for all streams except for Lower Creek (which received a wastewater discharge from Lenoir contributing to the free ortho-P). The non-filterable and, to a lesser extent, the filterable digested phosphate dominated the phosphate concentrations in all of the streams except Lower Creek. Both digestible fractions of phosphate were highly correlated to total suspended solids (Figure 10). The relationship of the suspended solids to the non-filterable digestible fractions was not surprising since phosphorus has a high affinity for clay particles (primary constituent of the suspended solids) (Neubauer, 1988). However, the filterable digested fraction would normally be considered dissolved, but probably originated from extremely small clay particles, colloids derived from soil, and/or complex molecules derived from the soil solutions, but digestible with persulfate.

Figure 8. Mean Nitrogen Fractions from Rhodhiss Tributary Streams

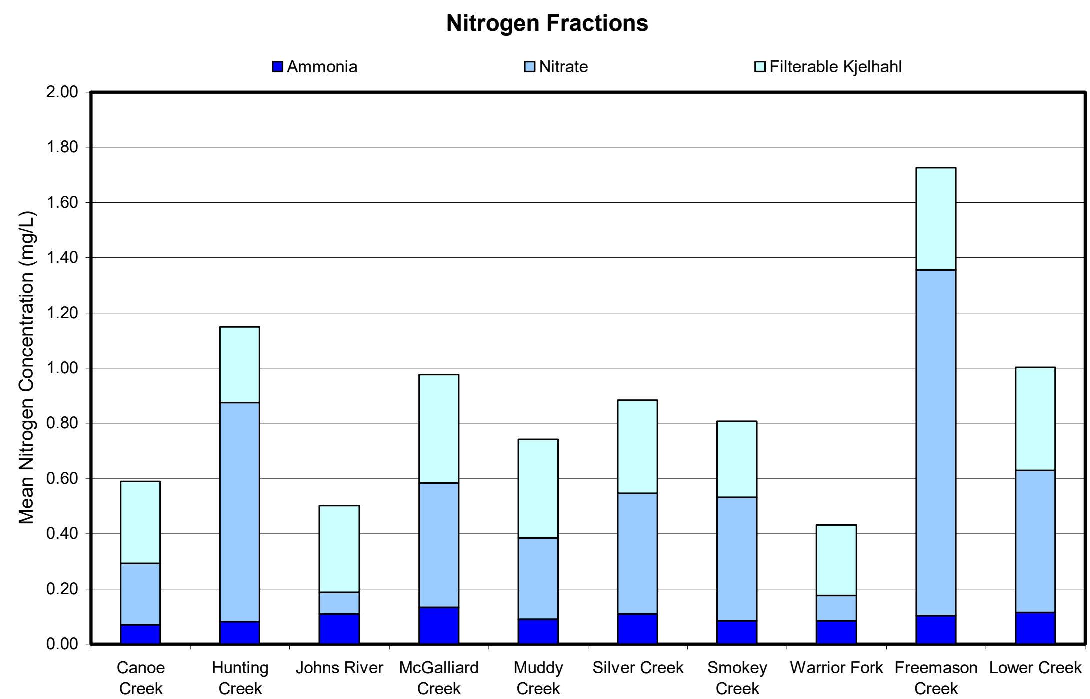
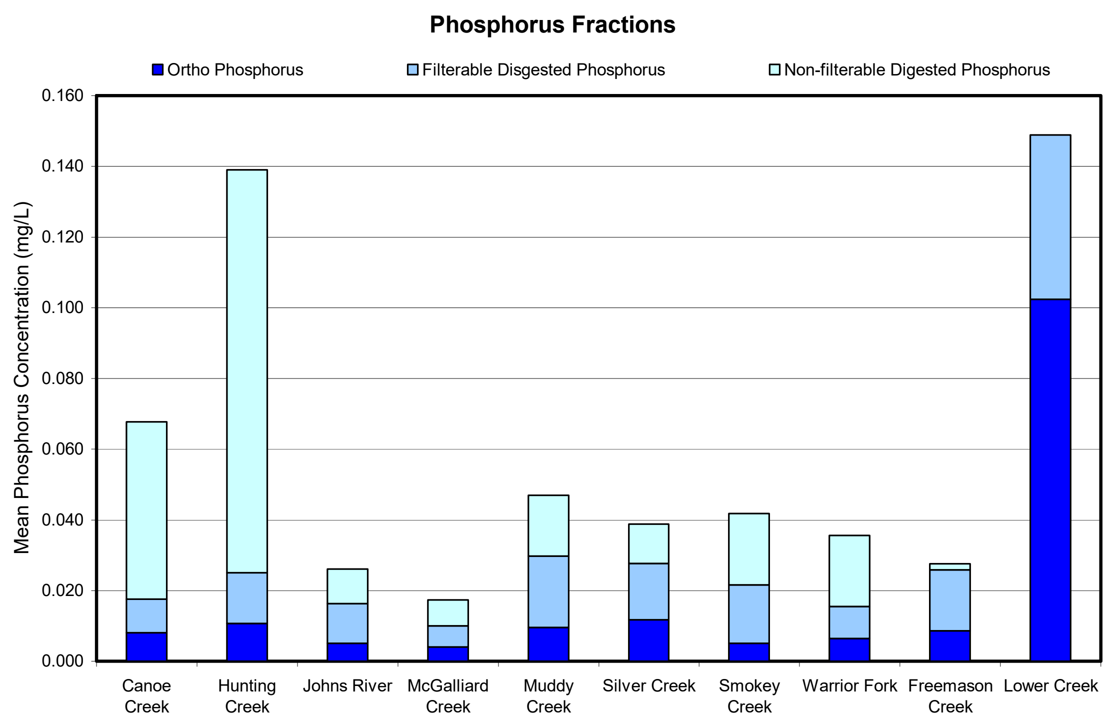
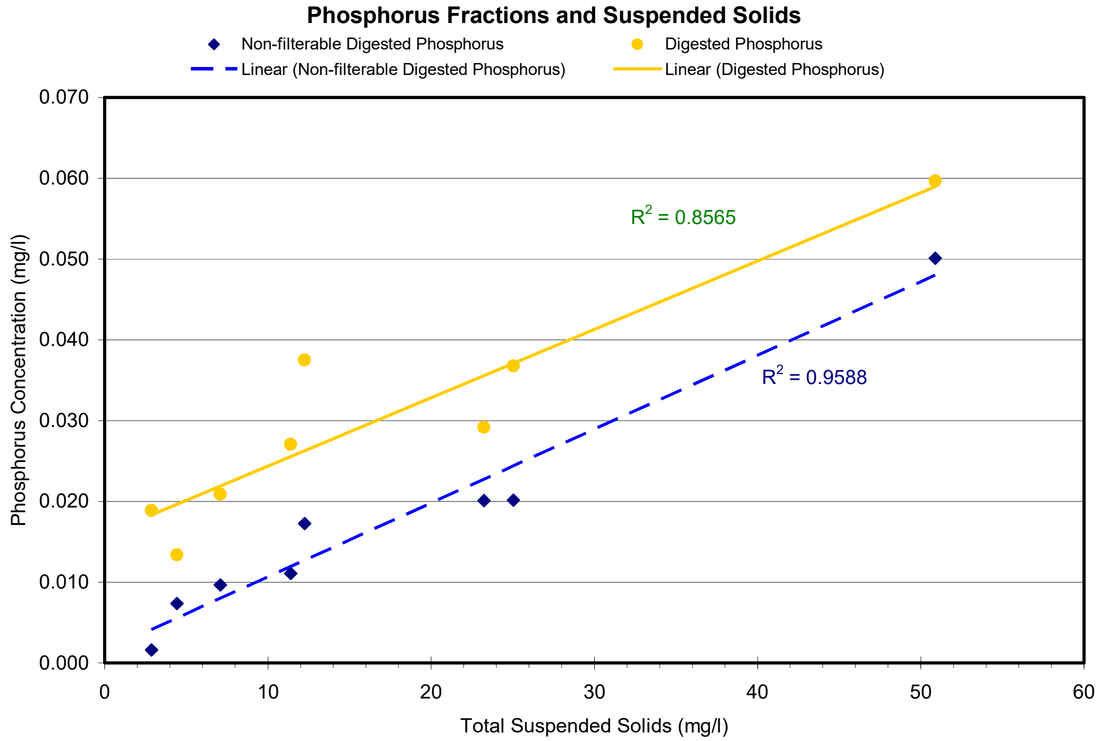


Figure 9. Mean Phosphorus Fractions from Rhodhiss Tributary Streams



The cumulative frequency distribution of total suspended solids, total Kjelhahl nitrogen, nitrate, and phosphorus (Figures 11 – 18) provide a direct comparison between tributaries and historical concentrations. Since concentrations of all nutrient species did not appear to be a function of seasonality (comparison of data from the raw nutrient data provided in Appendix A), a frequency distribution describes the probability of encountering a sample with a certain concentration.

Figure 10. Correlation of Digested Phosphate Fractions with Total Suspended Solids



Total suspended solids were generally highest in Lower Creek, followed by Canoe Creek and then Muddy and Silver Creek. McGalliard Creek and Johns River never exceeded 100 mg/L. The Bridgewater tailrace never exceeded 10 mg/L. As was typical of Piedmont streams, suspended solid concentrations increased during higher flows, with one Silver Creek sample exhibiting 350 mg/L. Compared to historical suspended solids concentrations, the tributaries in 2007 had fewer solids than the historical record (Figure 12). This tendency to suspend fewer solids was directly related to the low flows that occurred in 2007 (Figure 2). However, except at higher flows, Muddy Creek exhibited about the same concentration as the historical values.

As was mentioned previously, total Kjelhahl nitrogen concentrations in all of the streams were generally at or slightly greater than the detection limit (Figure 13). The distribution of concentrations was essentially the same for all of the tributaries with periodic spikes in nitrogen concentrations observed in each creek.   Rhodhiss tailrace TKN values were consistently greater than the TKN concentrations released from Bridgewater Hydro. Historical TKN were much higher in Lower Creek than in 2007 (Figure 14) whereas the 2007 concentrations in the Johns River and Muddy Creek had the same concentrations as historical values.

Nitrate concentrations varied significantly between tributaries but stayed relatively constant throughout the year in all of the tributaries (Figure 15). Unlike TSS, TKN, and total phosphorus concentrations, no spikes of high concentrations were observed in any of the creeks and rivers. Freemason Creek has twice to three times the nitrate concentration as any other tributary.

Hunting Creek exhibited the next greatest concentration, followed by Lower, Smokey, McGalliard, and Silver Creeks. The water released from Rhodhiss reservoir was had slightly more nitrate than the water released from Lake James.

Muddy Creek, Bridgewater tailrace, and Johns River nitrate concentrations were lower in 2007 than the historical values. Lower Creek exhibited higher nitrate concentrations in 2007, indicating that at least some of the nitrate originated from Lenoir's waste water treatment facility. Higher nitrate and lower TKN concentrations in 2007 compared to historical concentrations suggested that nitrogen originated from the Lenoir WWTP oxidized to a greater extent in the low flow year compared to historical higher flows. The magnitude of the nitrate concentrations dominated the concentrations of the nitrogen fractions observed from all of the Lake Rhodhiss tributaries.

Total phosphorus concentrations exhibited a very dynamic range of concentrations in all of the systems (Figure 17). Ortho-phosphorus was at or below the detection limits (Appendix A). Lower Creek generally exhibited concentrations 2-3 times that of other creeks. However, periodic total phosphorus spikes were observed in Hunting and Silver Creeks. The distribution of the total phosphorus concentrations resembled that of total suspended solids, again indicating an association of the two parameters. The water released from Lake Rhodhiss contained significantly higher concentrations of total phosphorus than that released from Lake James. These differences, coupled with little difference in nitrogen concentrations in the lake water indicated that phosphorus was retained in the lakes in preference to nitrogen, suggesting a non-biological mechanism of phosphorus retention.

A comparison of historical phosphorus concentrations to those collected in 2007 suggests a non-biological mechanism influencing the total phosphorus concentrations. Bridgewater tailrace, Lower Creek, and the Johns River all exhibited higher concentrations in 2007, the year of low flow. On the other hand, Muddy Creek exhibited lower concentrations in 2007. The phosphorus concentration released from Bridgewater was a function of the processes that occurred in the lower depths of Lake James, low flows through that reservoir would have a tendency to concentrate phosphorus compared to higher flows. Lower Creek, with the point source waste water treatment plant discharge, would exhibit lower concentrations of total phosphorus at higher flows since the higher flows would dilute the effluent. Generally, in all of the creeks and rivers, high flow would scour river banks adding suspended sediment carrying adsorbed phosphorus.

Figure 11. 2007 Cumulative Frequency Distribution of Total Suspended Solids

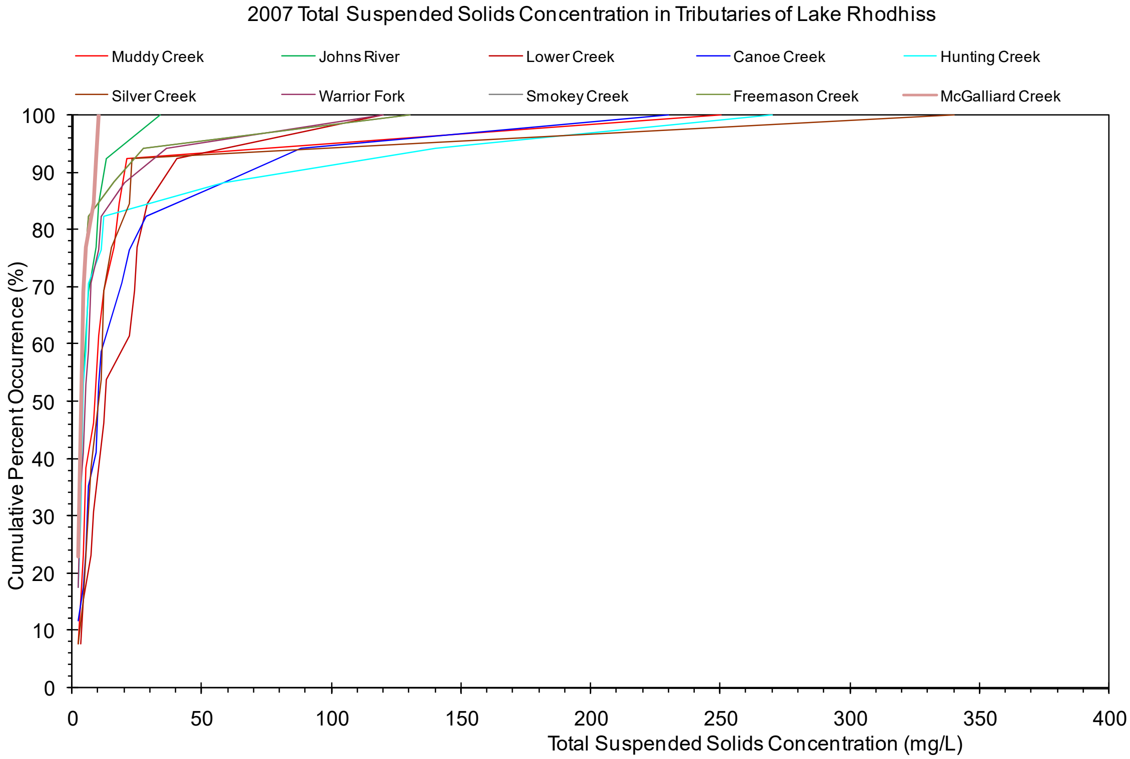


Figure 12. Cumulative Frequency Distributions of Historical and 2007 Total Suspended Solids

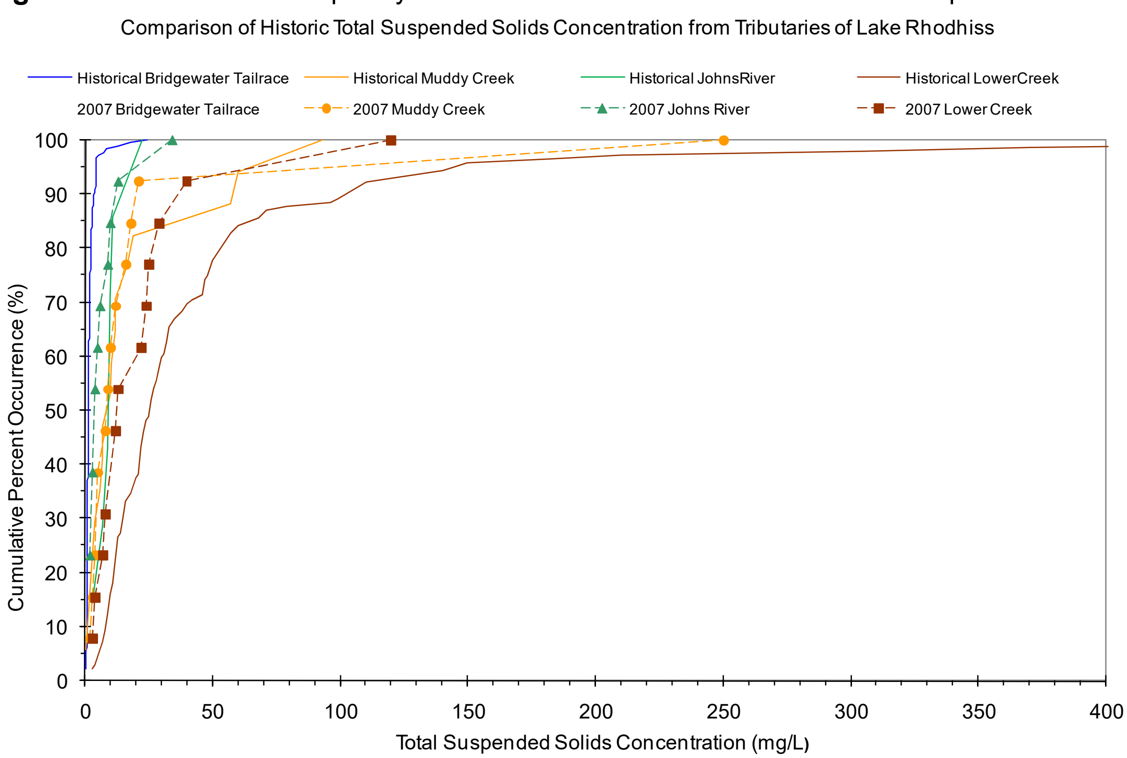


Figure 13. 2007 Cumulative Frequency Distribution of Total Kjelhahl Nitrogen

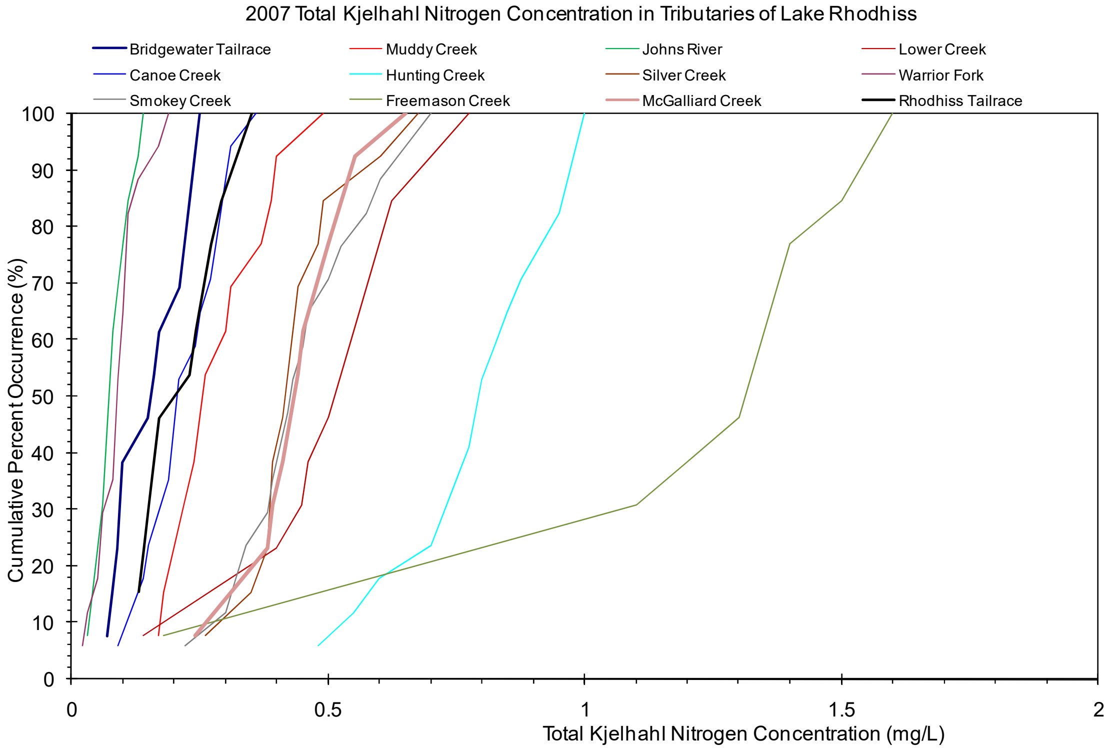


Figure 14. Cumulative Frequency Distributions of Historical and 2007 Total Kjelhahl Nitrogen

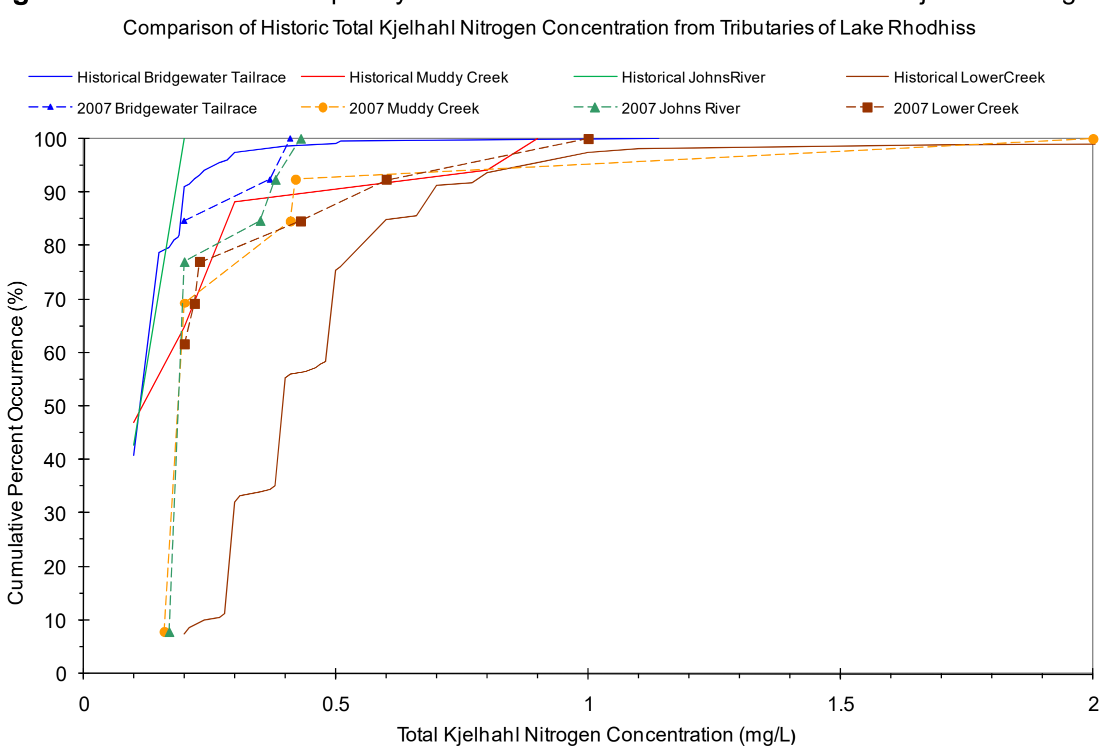


Figure 15. 2007 Cumulative Frequency Distribution of Nitrate Nitrogen

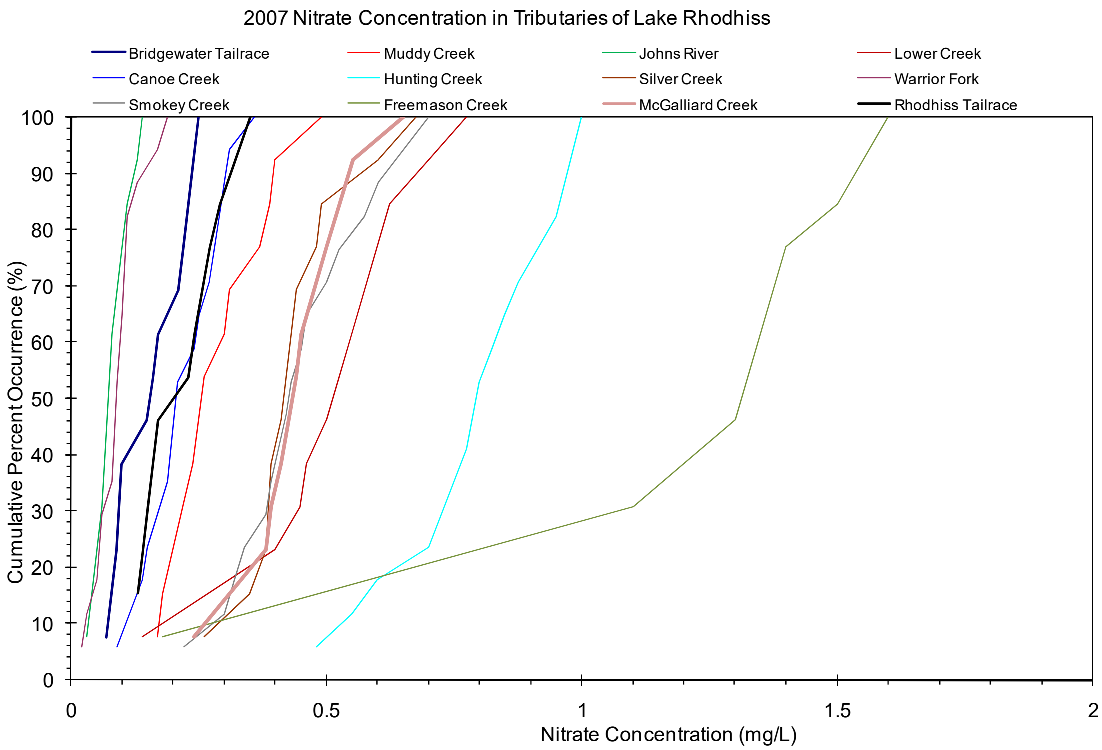


Figure 16. Cumulative Frequency Distributions of Historical and 2007 Nitrate Nitrogen

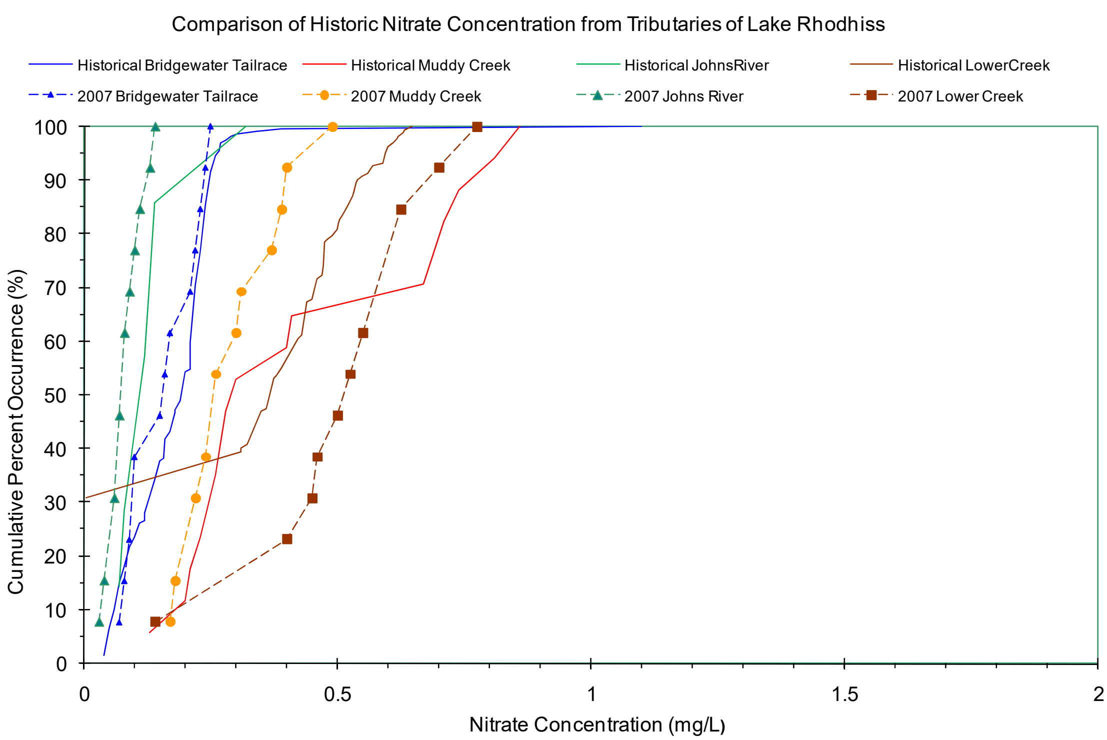


Figure 17. 2007 Cumulative Frequency Distribution of Total Phosphorus

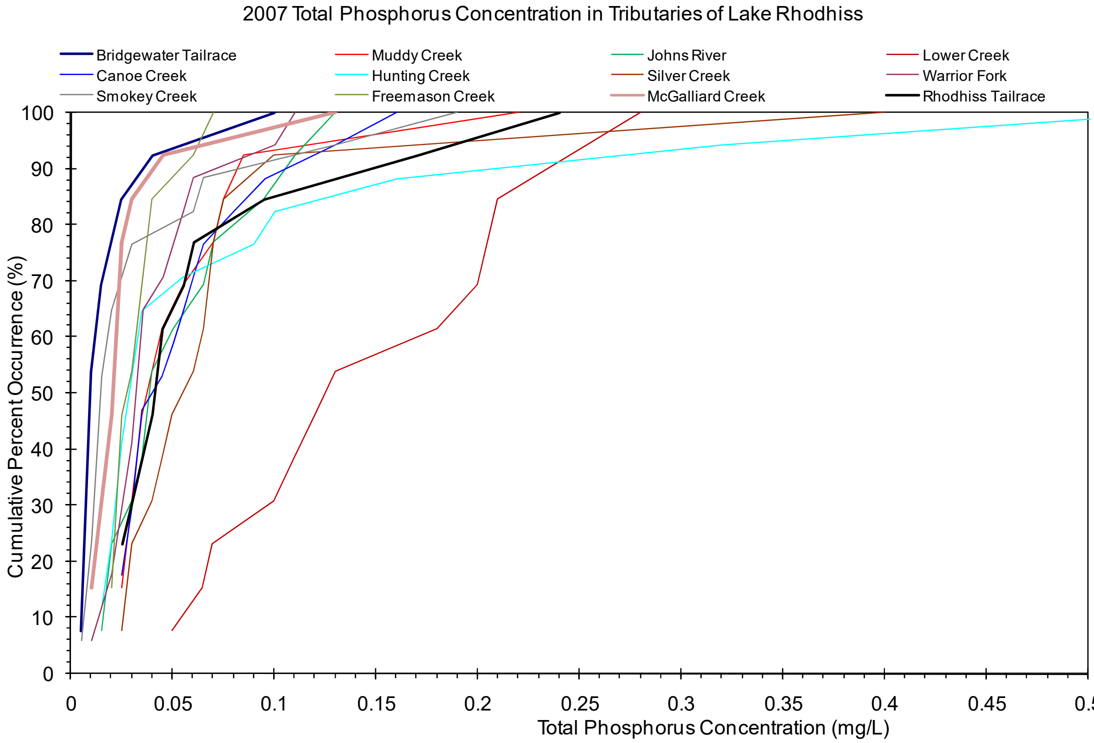
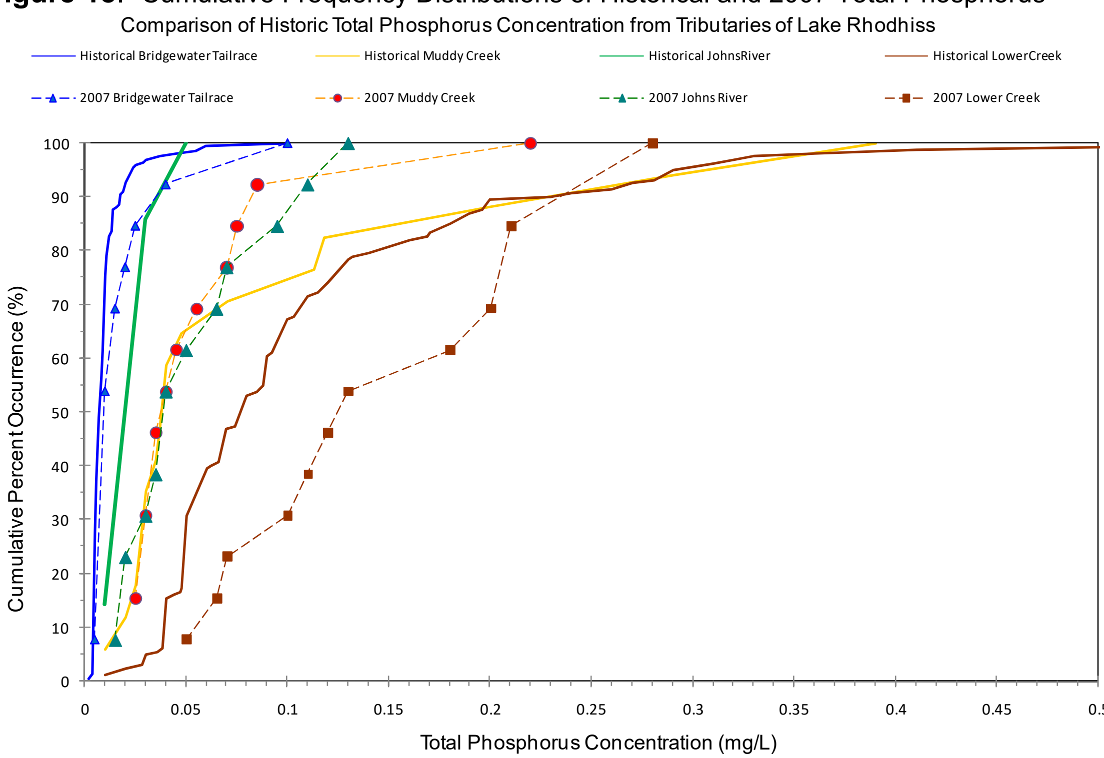


Figure 18. Cumulative Frequency Distributions of Historical and 2007 Total Phosphorus



Waste Water Treatment Plants

Phosphorus and nitrogen concentrations of the waste water discharged from the WWTP facilities exhibited varying patterns. Valdese and Morganton WWTP's had similar total phosphate concentrations with equal variability. Lenoir and Marion had, on the average, half as much phosphorus as Valdese and Morganton, but twice the variability throughout the year. Nitrogen concentrations in the discharges were very similar between Valdese, Lenoir, and Marion, but Morganton had over three times as much nitrogen as the other three.

Table 5. Monthly Nutrient Analysis from Wastewater Treatment Plants Discharging into the Rhodhiss Basin

Month / Year	Valdese		Morganton		Lenoir		Marion	
	TP (mg/l)	Total Nitrogen (mg/l)	TP (mg/l)	Total Nitrogen (mg/l)	TP (mg/l)	Total Nitrogen (mg/l)	TP (mg/l)	Total Nitrogen (mg/l)
Apr-07	2.85	9.65	2.14	11.30	0.99	22.80	1.26	5.20
May-07	3.35	6.57	2.62	17.80	2.96	8.50	0.40	1.70
Jun-07	3.15	6.65	3.00	10.70	3.20	3.31	2.62	4.80
Jul-07	3.53	8.57	3.55	13.40	4.50	2.99	4.61	5.20
Aug-07	3.67	3.43	3.31	15.68	0.20	5.99	0.56	0.64
Sep-07	3.13	8.09	1.97	7.52	0.75	4.06	0.32	1.70
Oct-07	2.53	7.69	2.86	9.20	0.60	3.61	1.30	5.50
Nov-07	4.20	2.64	3.37	13.00	0.78	5.17	0.78	9.35
Dec-07	2.48	5.32	3.60	19.20	0.52	3.56	1.00	16.20
Jan-08	2.15	6.32	3.30	24.10	0.90	7.37	3.30	13.30
Feb-08	1.90	13.60	2.32	57.40	0.35	7.72	1.90	6.90
Mar-08	1.73	5.22	4.64	60.20	0.80	5.31	1.30	9.50
Apr-08	3.10	1.25	1.51	26.70	0.37	5.76	1.70	9.50
Mean	2.90	6.54	2.94	22.02	1.30	6.63	1.62	6.88
Standard Deviation	0.72	3.21	0.83	17.26	1.35	5.17	1.24	4.59

4.2 Discharge Measurements

Streams

The hourly and daily flows of each tributary were calculated by applying the rating curve equation developed from the flow measurements (Section 3.2) to the 15-minute level logger (stage) data, determining the hourly mean from the 15-minute data, and calculating the daily mean flow from the hourly values. Annual mean flows were calculated from the daily averages.

Tributary hourly flows calculated from April, 2007, through April, 2008, (Figures 19–21) illustrated the storm driven hydrology of the watersheds. At the onset of a storm, the creeks experienced a very rapid increase in flow and, after the storm, a rapid decrease in flow. Hunting Creek (Figure 19) exhibited the greatest extreme in peak storm flows compared to base flow, while Freemason and McGalliard Creeks had the least fluctuation at the time of storm events. The difference in hydrology probably reflects the tendency for storm runoff to be intense, e.g. Hunting Creek, while

Figure 19. Hourly Stream Discharges Calculated From Smokey Creek, Canoe Creek, and Hunting Creek

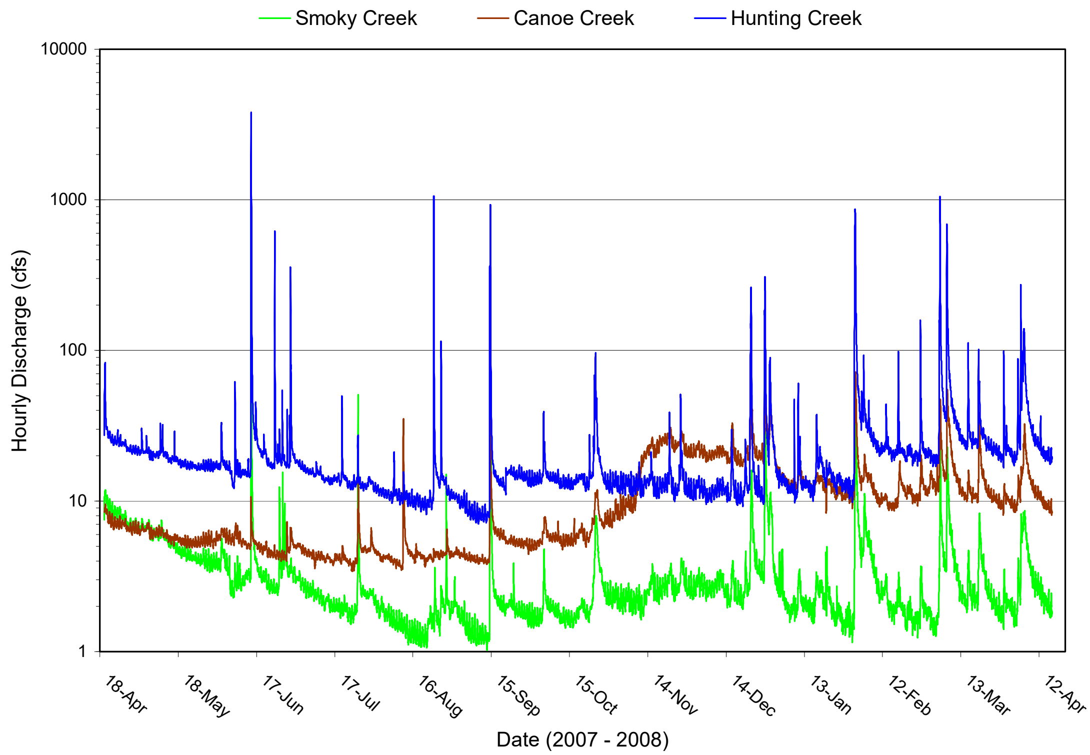


Figure 20. Hourly Stream Discharges Calculated From Freemason Creek, Warrior Fork, and Muddy Creek

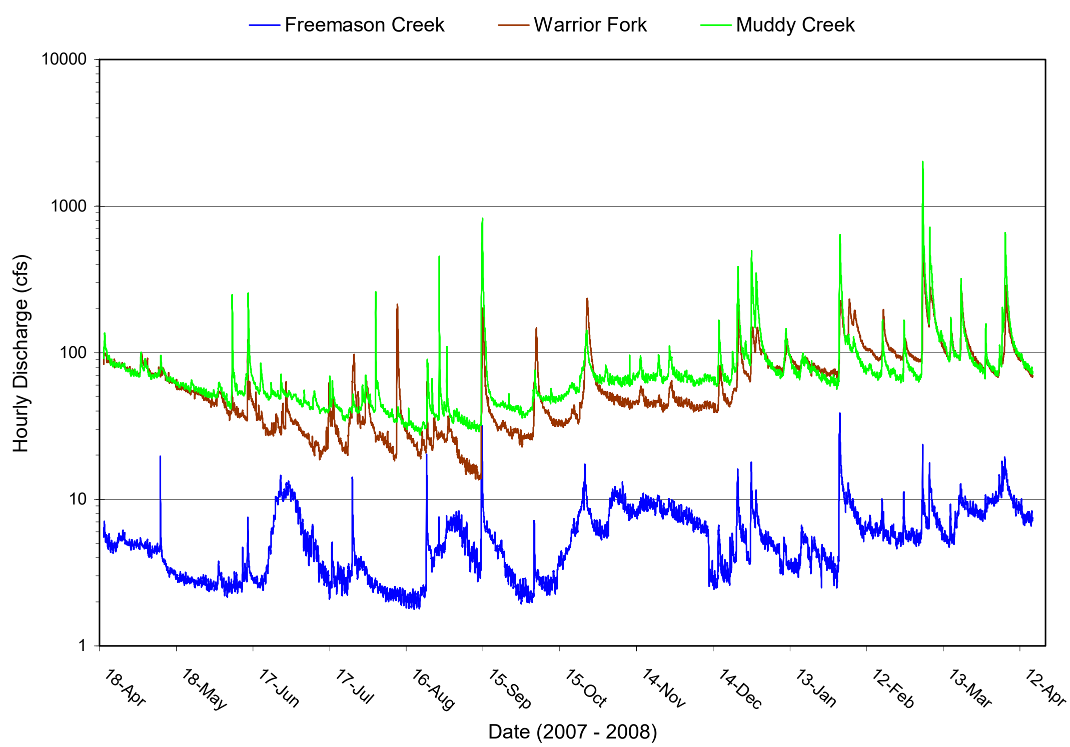
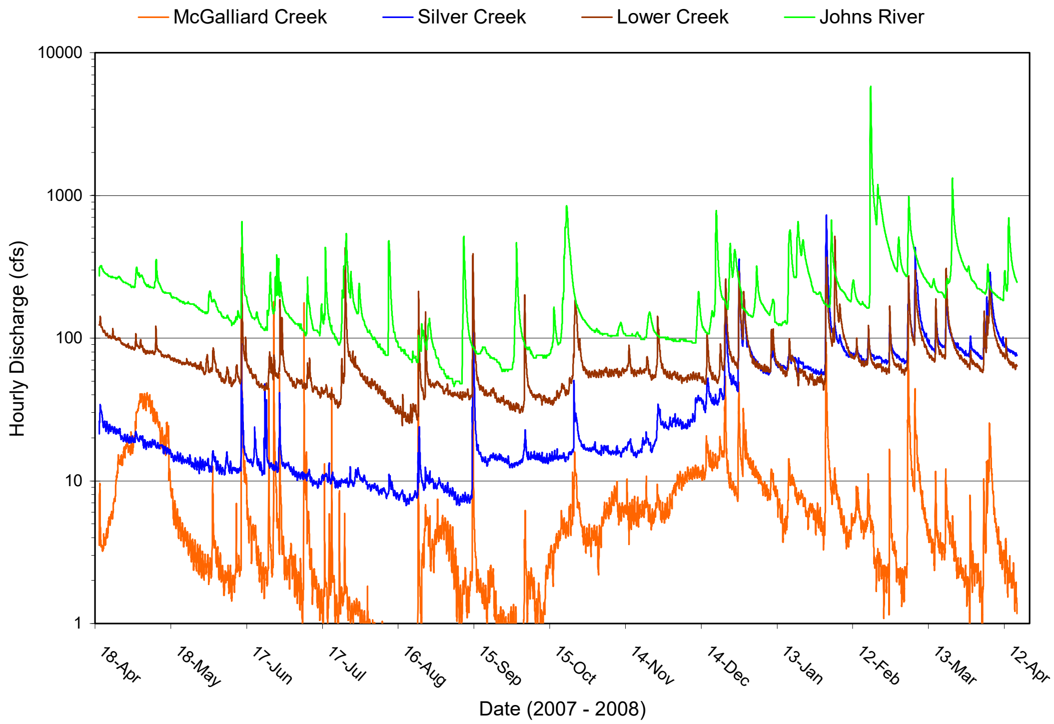


Figure 21. Hourly Stream Discharges Calculated From McGalliard Creek, Silver Creek, Lower Creek, and Johns River

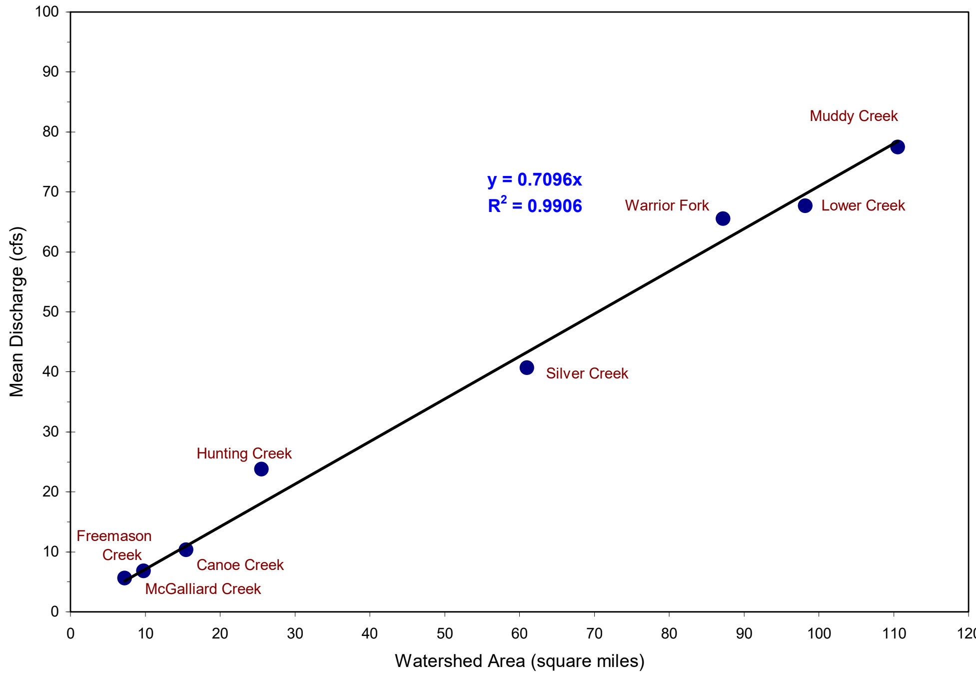


other watersheds had a higher infiltration rate which was reflected in reduced peaking of flows but increased baseline flow.

Indicative of the 2007 drought, the base flows from all of the watersheds continued to decrease from April, 2007, to September, 2007. After a significant September storm, and with more frequent rain events, the base flow increased from September, 2007 through December, 2007; after which it remained fairly constant.

As mentioned in Section 2, Duke Energy estimated that the watersheds that directly flow into Rhodhiss Lake historically produced, on the average, 1.54 cubic feet of water per second per square mile. The historical watershed yield ranged from 0.79 cfs to 2.58 cfs of water per square mile. During this investigation, the individual watersheds yielded very similar amounts of water (Figure 22), with an average yield of 0.71 cubic feet of water per second per square mile during the study period. The exception to this was the Johns River watershed, which yielded 0.93 cfs per square mile. These low values, relative to the Duke Energy and USGS estimates, were indicative of the 2007 drought.

Figure 22. Lake Rhodhiss Tributaries - Relationship Between Annual Mean Watershed Flow (2007 –2008) and Watershed Area



Waste Water Treatment Plants

The mean daily flows for the four waste water treatment plants (Table 6) total 10.48 mgd (16.2 cfs). These flows contribute very little in terms of 'new' water to the Rhodhiss system, especially since most of the water is pumped from the watershed, used, treated, and ultimately discharged back into the system. The Lenoir and Marion plants discharge directly into Lower Creek and Muddy Creek, with 3.6 cfs and 1.19 cfs, respectively. Morganton discharges 7.43 cfs directly into the Catawba River slightly upstream of the headwaters of Rhodhiss Lake. Valdese WWTP discharges 3.98 cfs directly into Lake Rhodhiss.

Table 6. Daily Average Flows from Wastewater Treatment Plants Discharging into the Rhodhiss Basin

Month / Year	Valdese	Morganton	Lenoir	Marion
	Flow (mgd)	Flow (mgd)	Flow (mgd)	Flow (mgd)
Apr-07	2.448	4.598	2.527	0.870
May-07	2.708	4.599	2.037	0.728
Jun-07	2.695	5.154	2.047	0.685
Jul-07	2.121	5.440	2.103	0.598
Aug-07	2.684	5.596	2.124	0.696
Sep-07	2.674	5.900	2.152	0.697
Oct-07	2.718	5.002	2.093	0.797
Nov-07	2.658	4.127	2.080	0.730
Dec-07	2.200	4.102	2.508	0.771
Jan-08	2.684	4.206	2.498	0.756
Feb-08	2.706	4.274	2.716	0.810
Mar-08	2.579	4.674	2.800	0.967
Apr-08	2.607	4.738	2.627	0.869
Mean	2.58	4.80	2.33	0.77

4.3 Nutrient Relationships to Flow

The monthly grab samples do not show any relationship to flow, primarily because the timing of sample collection was predetermined according to a sampling schedule irrespective of the flow in the creeks. In fact, the probability of sampling at higher flows with a predetermined sampling schedule diminishes as drought conditions persist, as in the beginning of this study. Therefore, designed into this study was the plan to sample representative creeks throughout a storm event. In other words, samples would be collected throughout a storm and those samples analyzed would be at the beginning, the rise, the peak, and the fall, and the tail of the hydrograph. This section describes those results.

River stage, conductivity, total suspended solids (turbidity), and nutrients (TKN, NO_3, and TP) were collected over a 3-4 day period corresponding to the beginning, rising, peaking, and receding of the water in four creeks. The steady rainfall of the February storm occurred over a 16 hour period, resulting in a total rainfall of 1.54 inches (recorded at Silver Creek Observatory, 2009). Rainfall and the creek hydrograph (stage) were plotted for the four creeks (Figures 23 – 30). Suspended solids and conductivity (surrogate for dissolved solids) were also plotted for each stream through out the storm spate. Most striking was the similarity of the response of all parameters through out the hydrographs of all of the streams.

Suspended solids increased dramatically during the rising water, but dropped significantly after the peak runoff. Within this pattern, only the concentrations of suspended solids differed between the streams, probably indicative of the land use within the watershed. Conductivity, on the other hand, changed slightly in Warrior Fork and Canoe Creek, or, as in Hunting Creek and Smokey Creek, decreased during the initial river rise and returning to pre-storm levels immediately after the hydrograph peak. The nitrate concentrations in all streams followed the conductivity trend. This is not surprising since nitrate is extremely soluble and would follow the dissolved solids pattern.

Total nitrogen and total phosphorus exhibited a very strong correlation to suspended solids concentrations, indicating both are associated with the particulate component of the water solution. As runoff from the watershed increased, particulate material, both inorganic (clays, silts, etc.) and organic were washed into the stream; as the runoff decreased, so did the particulate fractions. As mentioned in section 4.1, monthly phosphorus levels were correlated with suspended solids (clay fractions) but nitrogen compounds were not. However, this storm data indicates that both nitrogen and phosphorus are associated with the particulate material washed into the creeks from the watershed.

Figure 23. Warrior Fork – Total Phosphorus, TSS, Conductivity, and Stage Through Out Storm Event

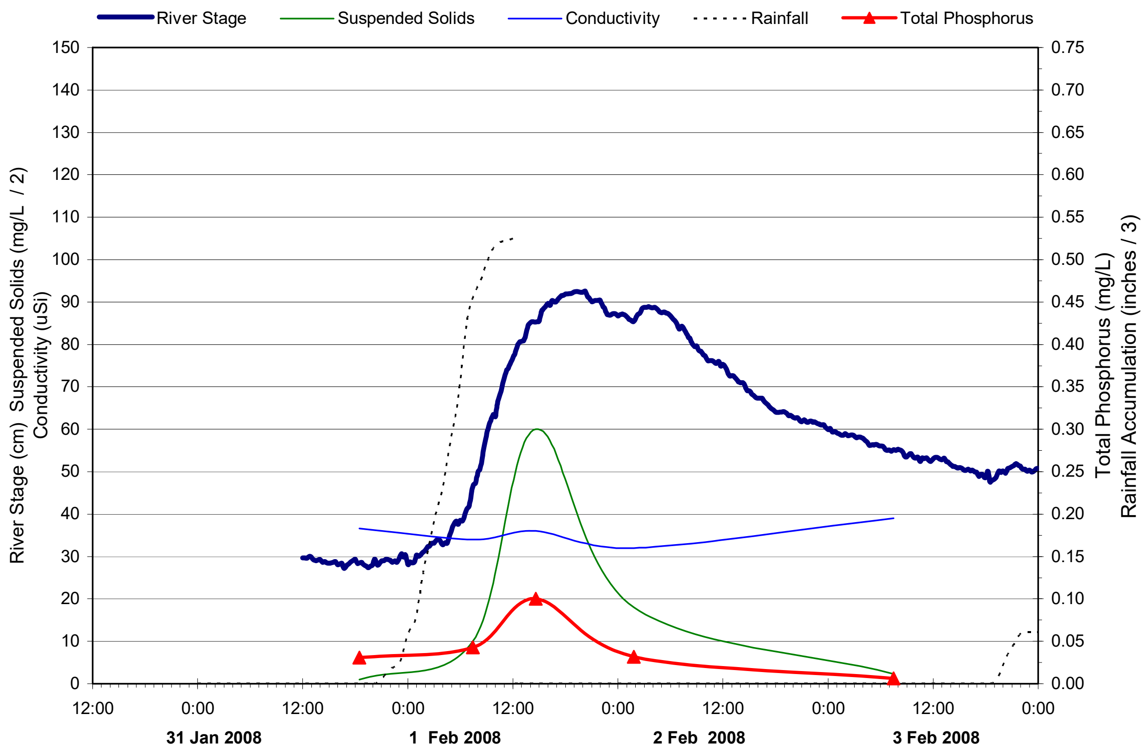


Figure 24. Warrior Fork – TKN Nitrogen, Nitrate, TSS, Conductivity, and Stage Through Out Storm Event

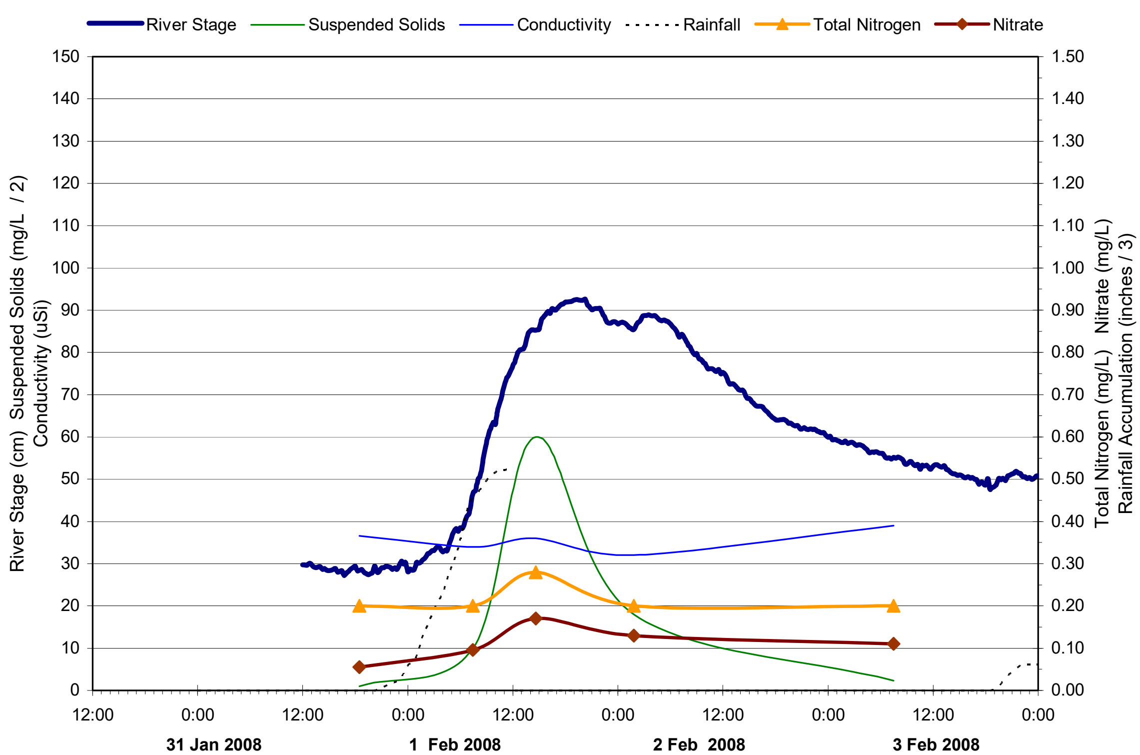


Figure 25. Canoe Creek – Total Phosphorus, TSS, Conductivity, and Stage Through Out Storm Event

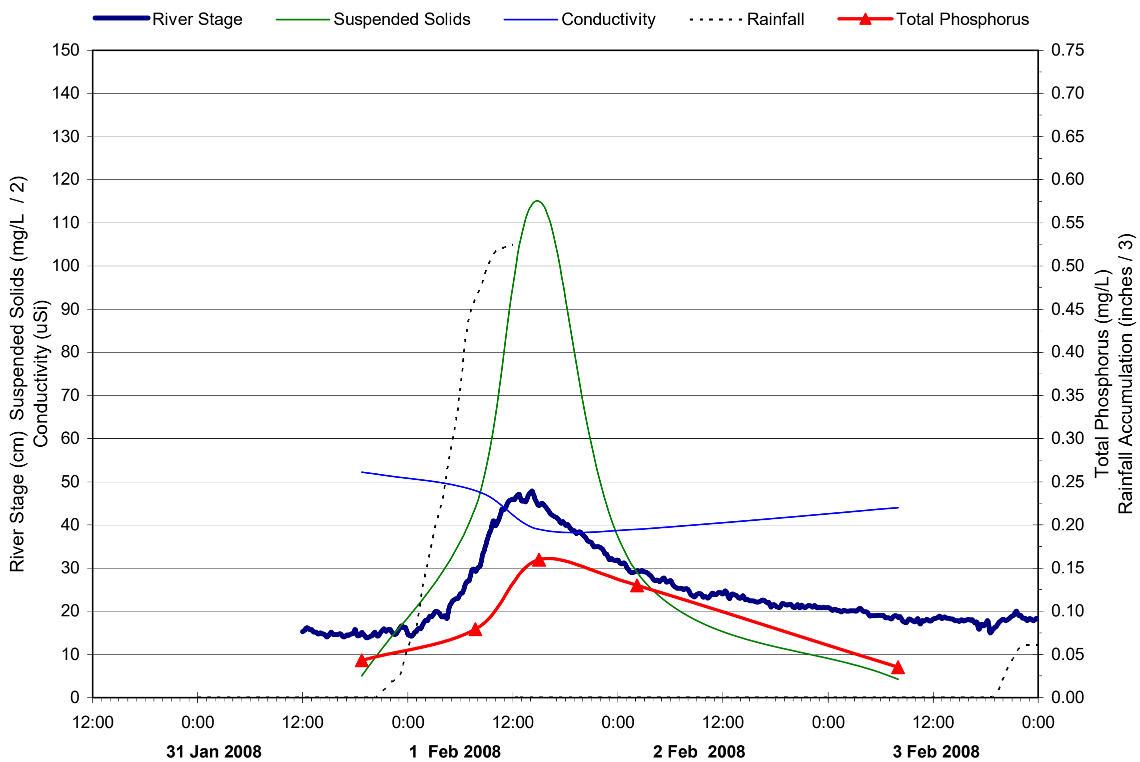


Figure 26. Canoe Creek–TKN Nitrogen, Nitrate, TSS, Conductivity, and Stage Through Out Storm Event

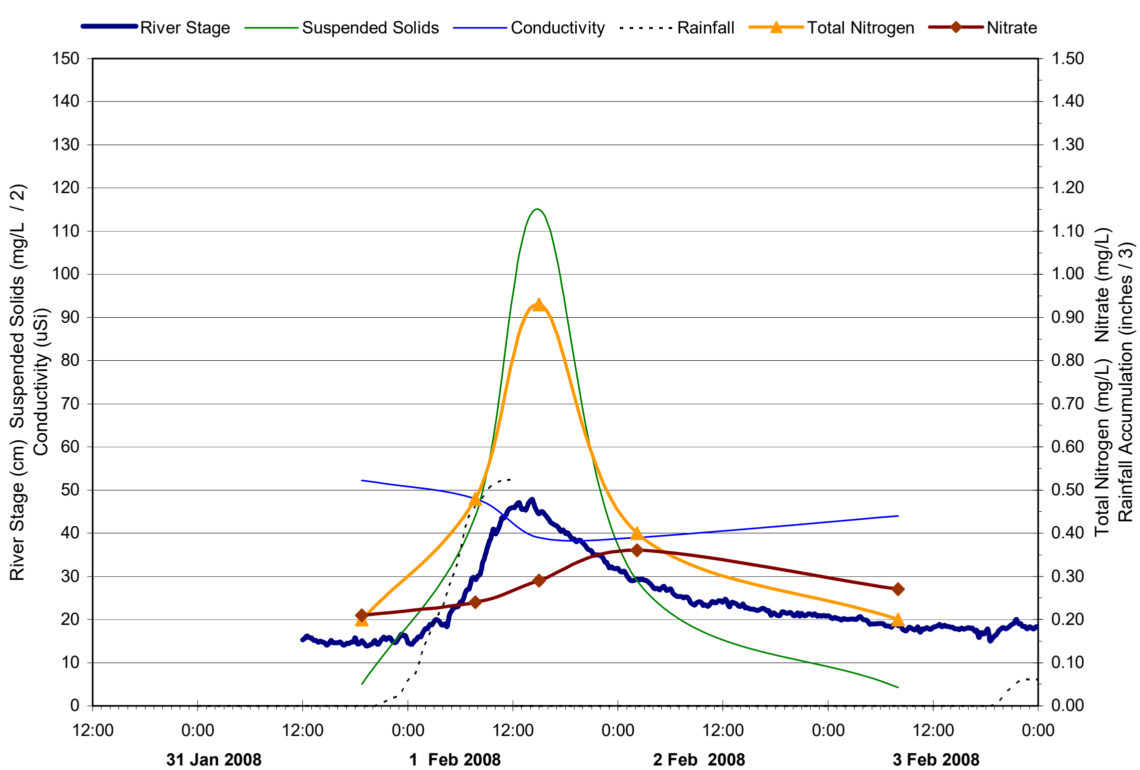


Figure 27. Hunting Creek – Total Phosphorus, TSS, Conductivity, and Stage Through Out Storm Event

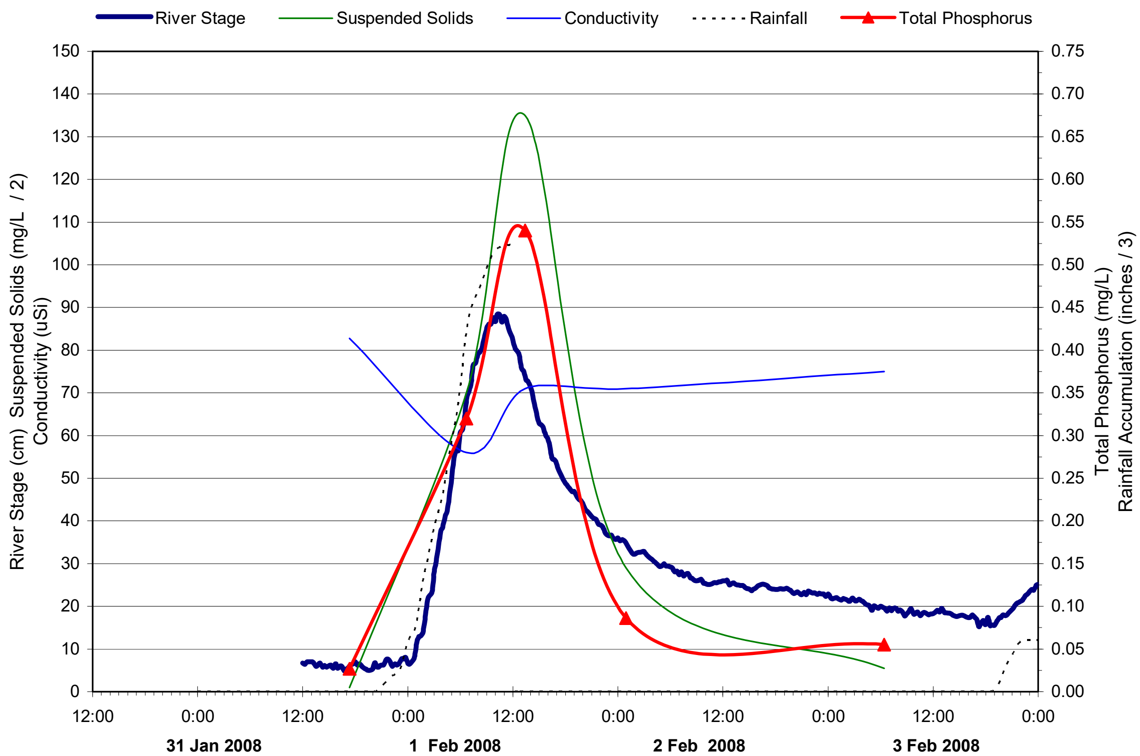


Figure 28. Hunting Creek–TKN Nitrogen, Nitrate, TSS, Conductivity, and Stage Through Out Storm Event

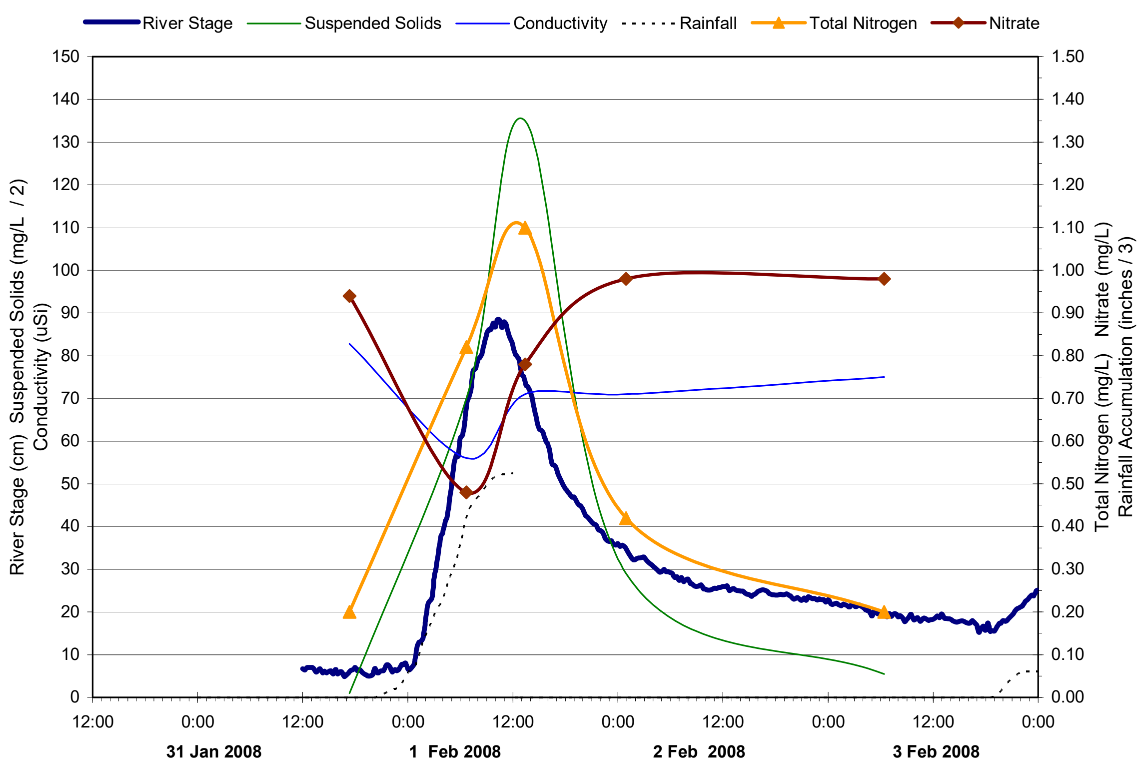


Figure 29. Smokey Creek – Total Phosphorus, TSS, Conductivity, and Stage Through Out Storm Event

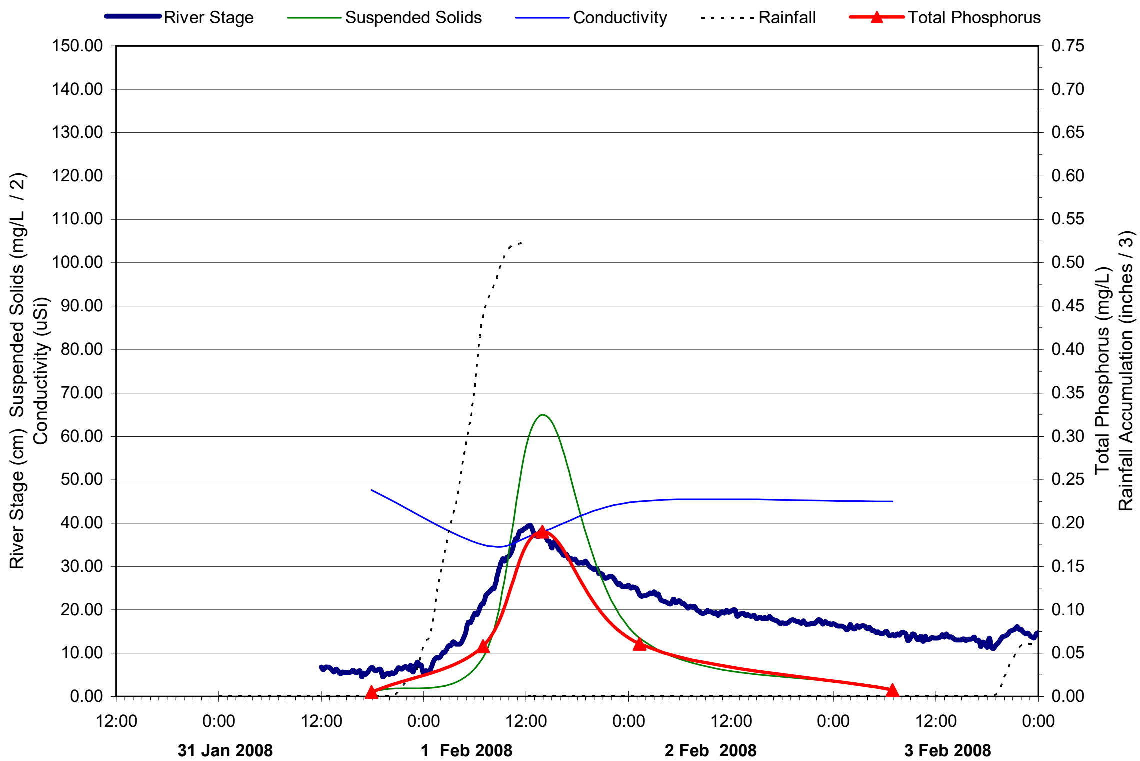
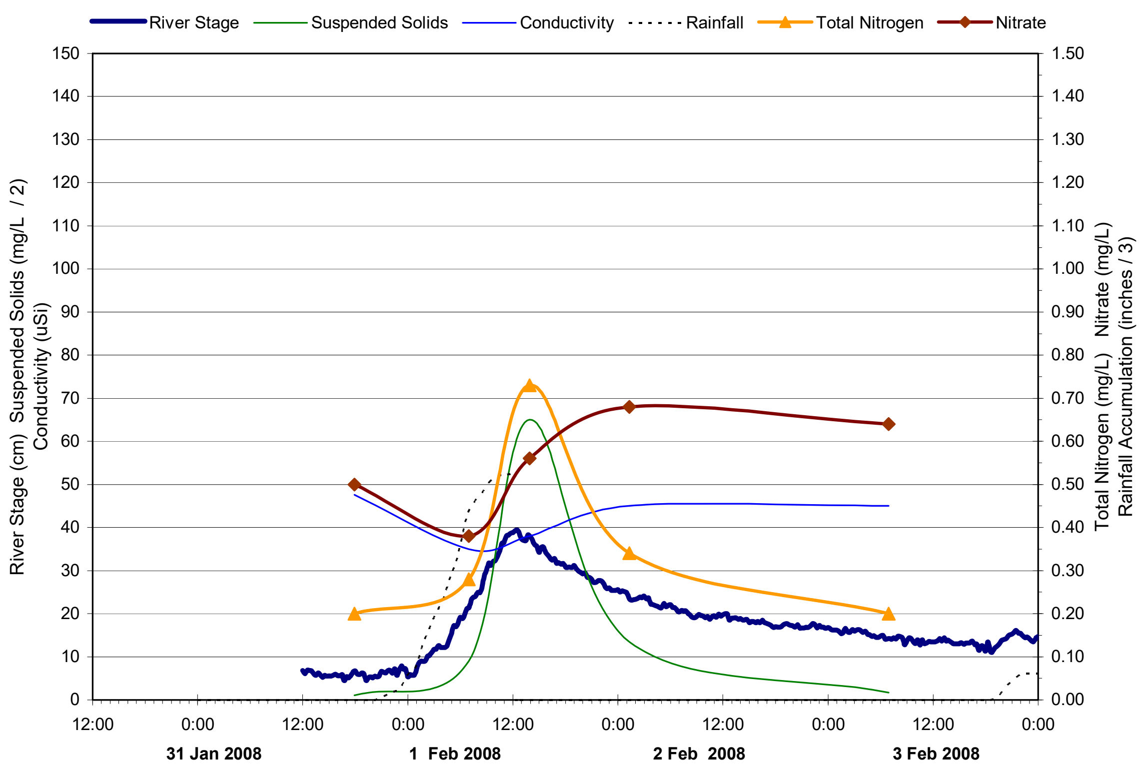


Figure 30. Smokey Creek–TKN Nitrogen, Nitrate, TSS, Conductivity, and Stage Through Out Storm Event



Even though the nutrient concentrations exhibited the same trend through out the storm spate in the four streams, the concentrations varied little compared to the total transport of nutrients (Figures 31 -33). Total nutrient transport (loading) was determined for each 15-minute interval by calculating the flow from the stage measurements using the established rating curves. Nutrient concentrations were then calculated for each 15-minute interval by using a lineal rate of change of the concentration vs. time between the sampling times. Transport rates were finally calculated for each 15-minute interval by the product of the concentration (g/m^3) and flow (m^3/min). This method of calculating loading did not assume any relationship between flow and nutrient concentration since the nutrient concentrations were measured directly during the storm at an average frequency of 48 stage measurements per nutrient sampling. The resultant transport rates clearly illustrated elevated nutrient runoff rate in the Hunting Creek drainage. Ratios of

Figure 31. Sediment Transport Rate during February, 2009, Storm Event

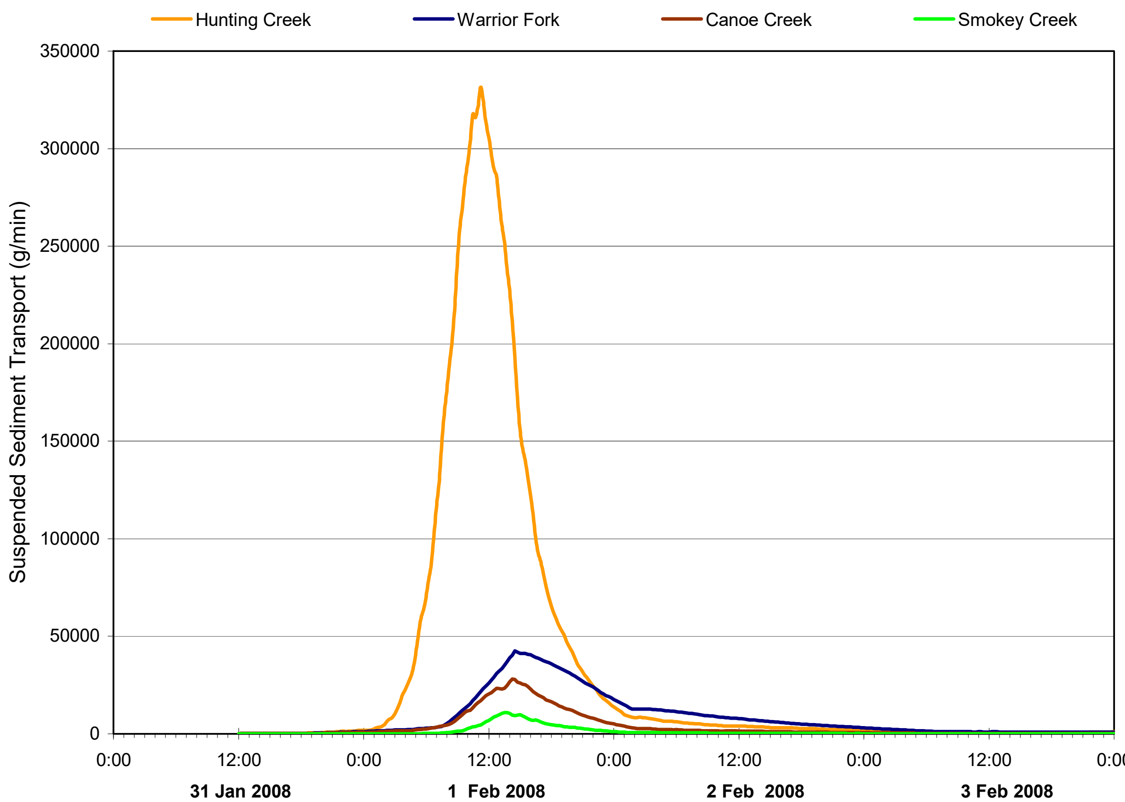


Figure 32. Nitrogen Transport Rate during February, 2009, Storm Event

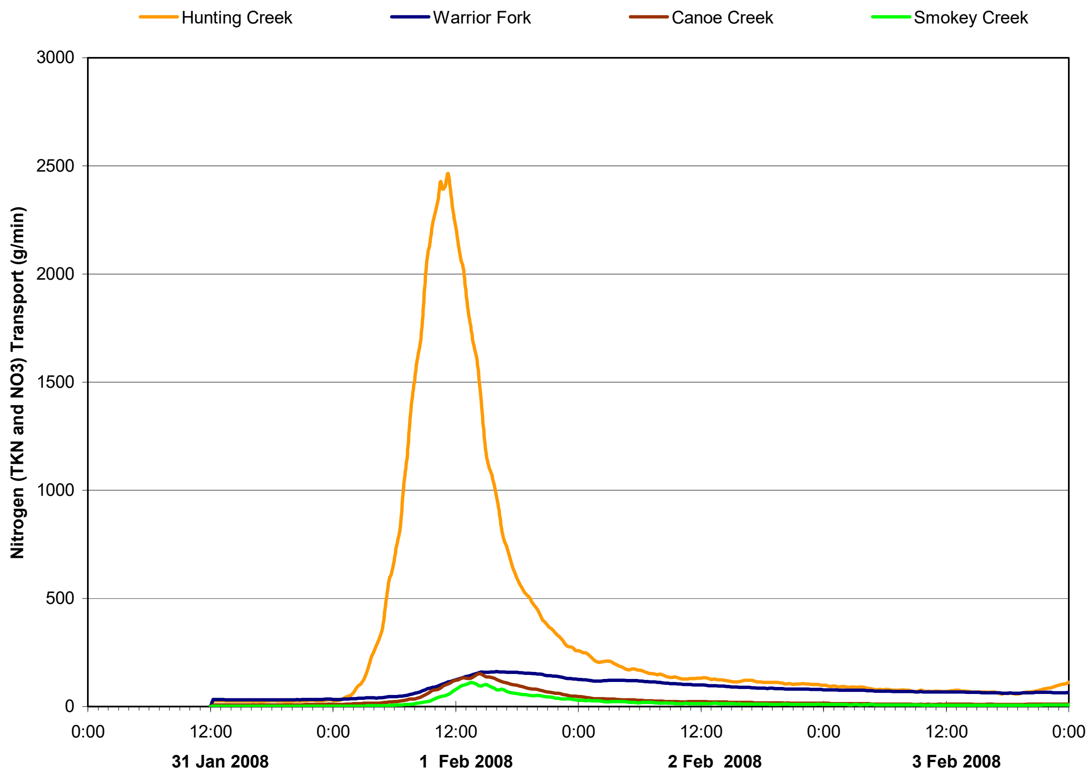
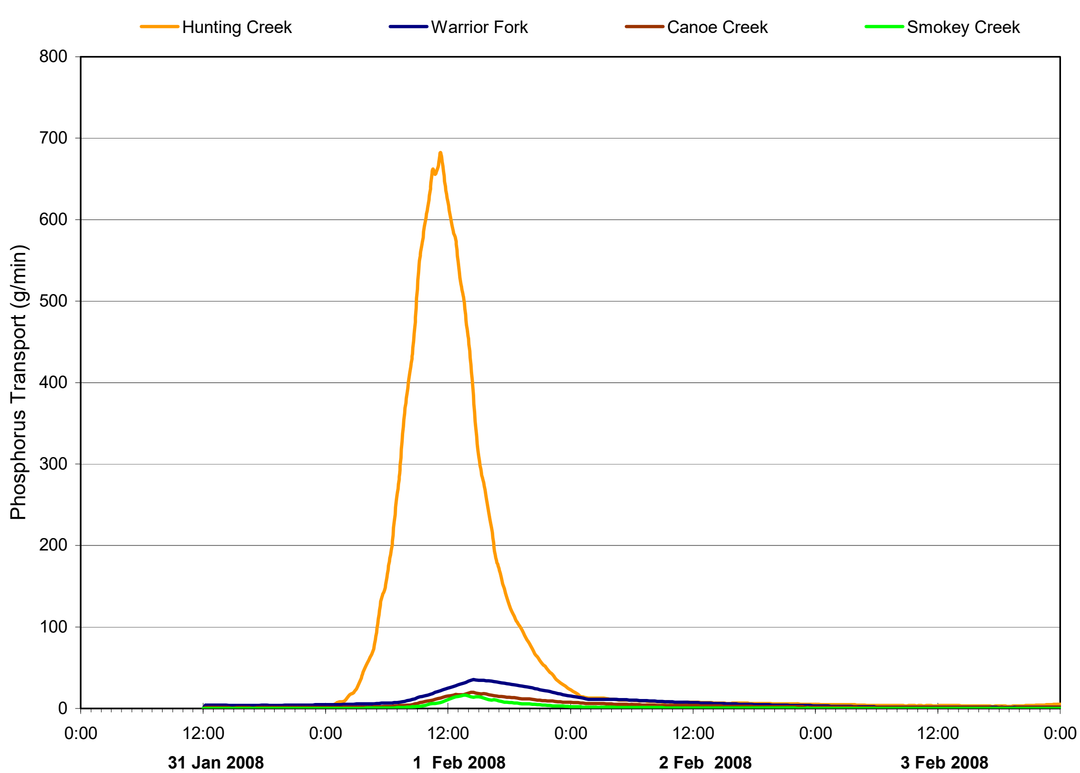


Figure 33. Phosphorus Transport Rate during February, 2009, Storm Event



the mass of sediment and nutrient transport increased due to the storm event probably indicate the impact of development within the watershed. Canoe Creek and Warrior Fork are primarily agricultural while Hunting Creek is the most urban of the watersheds while Smokey Creek was more developed than Canoe Creek or Warrior Fork (Table 2). Sediment increase during the storm was highest in the agricultural drainages while nitrogen and phosphorus increases were highest in the developed watersheds. Giorgino and Bales (1997) also noted a correlation of greater non-point source loading (total phosphorus) during storm events.

Table 7. Sediment and Nutrient Transport During a 48 hour Periods of a February, 2009, Storm Event

Tributary	Time	Total Sediment Transport		Total Nitrogen Transport		Total Phosphorus Transport	
		Kg	Ratio $Kg_{storm}:Kg_{prior\ to\ storm}$	Kg	Ratio $Kg_{storm}:Kg_{prior\ to\ storm}$	Kg	Ratio $Kg_{storm}:Kg_{prior\ to\ storm}$
Canoe Creek	48 Hours **Prior to** Storm	23	767	23	6	2	7
	48 Hours **During** Storm	17913		133		18	
Warrior Fork	48 Hours **Prior to** Storm	39	1027	91	3	11	3
	48 Hours **During** Storm	39637		294		37	
Hunting Creek	48 Hours **Prior to** Storm	1468	116	74	21	5	76
	48 Hours **During** Storm	169653		1535		348	
Smokey Creek	48 Hours **Prior to** Storm	31	164	6	15	0.1	93
	48 Hours **During** Storm	5161		82		8	

4.4 Nutrient and Sediment Loading

Calculation

The estimation of nutrient load relies on a simple calculation, namely:

$$N_i = (\Sigma\, (n_i \cdot q_i)_t) \cdot c$$

where,

N_i = Total mass of nutrients (kg) from all inflows per unit time
n_i = nutrient concentration (mg/l) of individual inflow
q_i = flow (cfs) of individual inflow
c = constant (mg/L to kg/m^3 and ft^3/sec to m^3/t)
t = time interval

However, the ideal solution for the equation is for each flow (qi), a corresponding nutrient concentration (n_i) would have been collected. But, as mentioned in the previous section, the collection of a nutrient sample for each flow (stage) was not only very impractical, but also extremely cost prohibitive.

LI, et.al (2003) have investigated various approaches to estimating loading using calculations and assumptions with varying frequencies of data collection. They report that the frequency and subsequent accuracy of the stream-flow is the single most important factor for the calculation of nutrient load. They present eight methods of calculation, ranging from simple average concentrations and flows to using the nearest time interval method to employing average concentrations and flows in various sample segments. All of the methods assume a statistical approach using means and flow-weighted means.

In this study, high frequency (15-minute) intervals of stream flow and numerous discharge measurements at various levels of stage maximized the accuracy of the stream flow estimates. However, unlike the relative high frequency of nutrient sampling during the storm event (one nutrient sample per 48 stage measurements), the routine nutrient sampling conducted at roughly monthly intervals resulted in an average of 2241 stage measurement for every nutrient sample. Also, one or more storm events also occurred between sample collections, further reducing any assumptions about linear transformations or normal distributions of nutrient data relative to stream flow.

The use of median nutrient concentrations calculated from cumulative frequency distributions of nutrients (Figures 12 -18) assumes no specific distribution of the data, but rather relies on the equal probability of concentrations being greater than or less than the median. The loading calculations from the 10 stream sites are based upon the following statistics:

- Cumulative Frequency Distribution of Each Nutrient
  - Median Concentration (upper and lower 25% quartile concentrations)
- Cumulative Frequency Distribution of Hourly Flow
  - Median Concentration (upper and lower 25% quartile concentrations)

Two methods based upon these statistics are used to estimate annual loading into Lake Rhodhiss:

1. The individual hourly flows multiplied by the median nutrient concentration, and,
2. The individual hourly flows multiplied by the either the upper, median, or lower quartile nutrient concentration;

The application of the second method utilizes the results of the storm event (Section 4.3). Suspended solids, total Kjelhahl nitrogen, and total phosphorus concentrations increased with the storm spate while dissolved solids, including nitrate, initially decreased as the flow began to rise. Based upon these characteristics, if the individual hourly flow was greater than the 75% quartile flow (Table 8), the 75% quartile nutrient concentration was applied for TSS, TKN, and TP, but the 25% quartile concentration for nitrate was applied. Conversely, if the individual hourly flow was less than the 25 % quartile flow, the 25 % quartile concentration for the particulate nutrient fractions were used in the calculation, but the 75% quartile nitrate concentration was used. If the individual hourly flow was between the 25 and 75 % quartile flow, the median concentration was applied for all the nutrient parameters. These methods of calculation takes into account the general statistical pattern of nutrient distribution as a function of flow, rather than the traditional season assumptions. The actual nutrient loadings probably fall between these two estimates.

Method 1 was used to calculate the nutrient mass released from Bridgewater and Rhodhiss hydro stations. Point source loading (WWTP) was calculated from the product of the annual flow and annual mean concentration available from DMR's submitted to NCDWQ. All nutrient loads are expressed as metric tons per year.

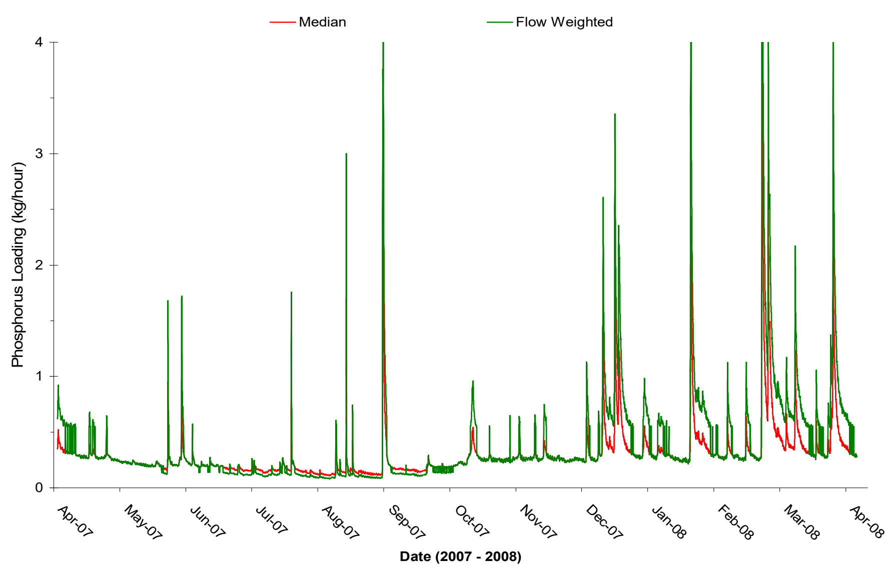
Table 8. Quartile and Median Values for All Flows, Nitrogen, Phosphorus, and Suspended Solids

Concentrations Used to Calculate Lake Rhodhiss Nutrient Loadings

Tributary (inflows)	Flow (cfs)			Total TKN Nitrogen (mg/L)			Nitrate (mg/L)			Total Phosphorus (mg/L)			Suspended Sediment (mg/L)		
	25% Quartile	Median	75% Quartile	25% Quartile	Median	75% Quartile	25% Quartile	Median	75% Quartile	25% Quartile	Median	75% Quartile	25% Quartile	Median	75% Quartile
Muddy Creek	49.1	66.3	80.5	0.19	0.20	0.28	0.21	0.26	0.36	0.028	0.038	0.066	4.1	8.5	15.0
Canoe Creek	5.1	7.4	13.2	0.19	0.20	0.37	0.16	0.21	0.28	0.029	0.040	0.064	5.1	9.8	21.3
Silver Creek	12.8	17.6	67.8	0.19	0.20	0.23	0.38	0.42	0.47	0.036	0.058	0.069	4.8	5.3	9.3
Warrior Fork	34.3	51.4	85.0	0.19	0.20	0.21	0.06	0.09	0.11	0.023	0.032	0.049	2.4	4.8	9.3
Hunting Creek	12.6	15.5	21.2	0.19	0.20	0.30	0.71	0.79	0.90	0.020	0.029	0.081	2.6	3.9	9.8
Johns River	104.8	158.6	236.8	0.19	0.19	0.20	0.05	0.07	0.10	0.023	0.039	0.069	2.1	3.8	8.3
Lower Creek	47.9	59.5	75.1	0.19	0.20	0.23	0.41	0.51	0.59	0.093	0.125	0.204	7.3	12.5	24.8
Smokey Creek	1.6	2.5	3.6	0.19	0.20	0.27	0.35	0.43	0.52	0.010	0.015	0.029	1.4	3.1	4.8
McGalliard Creek	2.2	4.3	8.0	0.19	0.20	0.20	0.38	0.43	0.49	0.013	0.021	0.025	2.1	3.2	4.8
Freemason Creek	3.2	5.1	7.5	0.19	0.20	0.29	0.87	1.31	1.39	0.011	0.028	0.037	1.1	2.8	5.5
Direct (unmeasured)	35.1	46.4	69.7	0.19	0.20	0.28	0.16	0.37	0.57	0.021	0.031	0.058	2.5	4.6	10.2
Reservoir Releases	**Flow (cfs)**			**Total TKN Nitrogen (mg/L)**			**Nitrate (mg/L)**			**Total Phosphorus (mg/L)**			**Suspended Sediment (mg/L)**		
	min	mean	max	25% Quartile	Median	75% Quartile	25% Quartile	Median	75% Quartile	25% Quartile	Median	75% Quartile	25% Quartile	Median	75% Quartile
Bridgewater	25	335	2313	0.17	0.20	0.20	0.09	0.16	0.22	0.007	0.009	0.019	0.7	1.1	1.8
Rhodhiss	60	861	6961	0.19	0.21	0.30	0.14	0.20	0.27	0.026	0.041	0.064	3.1	4.2	6.4

An example of the comparison of the resultant computations is provided by plotting the hourly loading values from Muddy Creek (Figure 34). As expected, the flow-weighted method provided greater loading rates during the high flow periods; conversely, during low, base-flow periods, the method of employing the median concentrations resulted in greater loading estimates. The rate of loading plot also provides an excellent example of the extremely high rates of nutrient loading, albeit short lived, resulting from storms. Rather than supplying a continuous source of nutrients to the lake, these storm events supply a "pulse" of nutrients to Lake Rhodhiss at a frequency and intensity relative to the weather patterns.

Figure 34. Comparison of Two Methods of Calculating Total Phosphorus Loading from Muddy Creek



<u>Tributary Annual Loading and Watershed Yield</u>

The integration of the hourly loading rates from the tributary inputs to Lake Rhodhiss resulted in an estimate of annual mass loading of suspended solids, total nitrogen, and total phosphorus (Figures 37 – 42). The method utilizing the median concentration, when applied to all hourly flows, probably underestimated the total nutrients entering the system from storm events. The flow-weighted method, by applying higher concentrations to higher hourly flows, may have overestimated the total mass transferred to the system since the duration of the high flow event was not considered in the calculations. The two methods probably bracket the actual loading values and the difference between the two methods probably reflects of the uncertainty of the loading estimates for the specific year.

The magnitudes of annual tributary loadings (metric tons per year, Figures 37, 39, and 41) and the annual watershed yield of nutrients (kg per square mile per year, Figures 38, 40, and 42) reflected the size of the watershed, but may also may be influenced by activities within the basin (land use). If all of the basins exhibited identical sediment and nutrient dynamics, the magnitudes and trends of the annual loads and yields would follow the water contributions from each basin (Figures 35 and 36). This appears to be the case with nitrogen loads from most basins. The contribution of nitrogen from each basin (Figures 37) parallels the magnitude of total annual discharge (Figure 35), indicating that nitrogen, primarily as nitrate, remains in solution with little biological or chemical reactions impacting the amount of nitrogen. The water yields (Figure 36) and nitrogen yields (Figure 40) also follow similar trends, except for Hunting Creek and Freemason Creek. These two watersheds have over twice the nitrogen yield as any other watershed. Both of these watersheds have different land uses (Table 2). Hunting Creek is an urban watershed and the source of nitrate may be runoff from fertilizers. The Freemason Creek basin is almost exclusively forest/wetland and exhibited the greatest nitrogen yield. With the exception of these two basins, nitrogen loading, in summary, appears to be primarily a function of the amount of water flowing through the basin with little influence from the land use.

Unlike nitrogen, sediment and phosphorus loadings exhibited very different patterns than the amount of water flowing through the watersheds. The patterns of sediment and phosphorus loading were very similar, again suggesting that phosphorus was associated with the suspended sediment fraction rather than the dissolved portion. Moreover, the mechanism of suspending sediment in the creeks also mobilized the phosphorus fractions.

The Bridgewater releases from Lake James exhibited moderate total suspended sediment and phosphorus loads due to the high volume of water passing through the lake. But, those hydro releases exhibited the lowest sediment and phosphorus yields from the watershed. These low yields were indicative of the characteristics of reservoirs to act as settling basins for many materials, particularly suspended sediment and associated adsorbed compounds, i.e. phosphorus (Duke Energy, 2007).

Johns River, Lower Creek, and Muddy Creek had the highest sediment loading rates and the greatest watershed yield of sediment (Figures 37 and 38), phosphorus loading from these watersheds also ranked 1, 2, and 3, respectively. However, the phosphorus yield from the Muddy Creek watershed was much less than the sediment yield would suggest. Muddy Creek and Lower Creek had the greatest proportion of agricultural activities (Table 2), but the Johns River basin had minimal agriculture. The percentage of developed land between the three watersheds was not consistent with the sediment or phosphorus loading.

Figure 35. Annual Water Contribution from the Tributary Inflows to Lake Rhodhiss

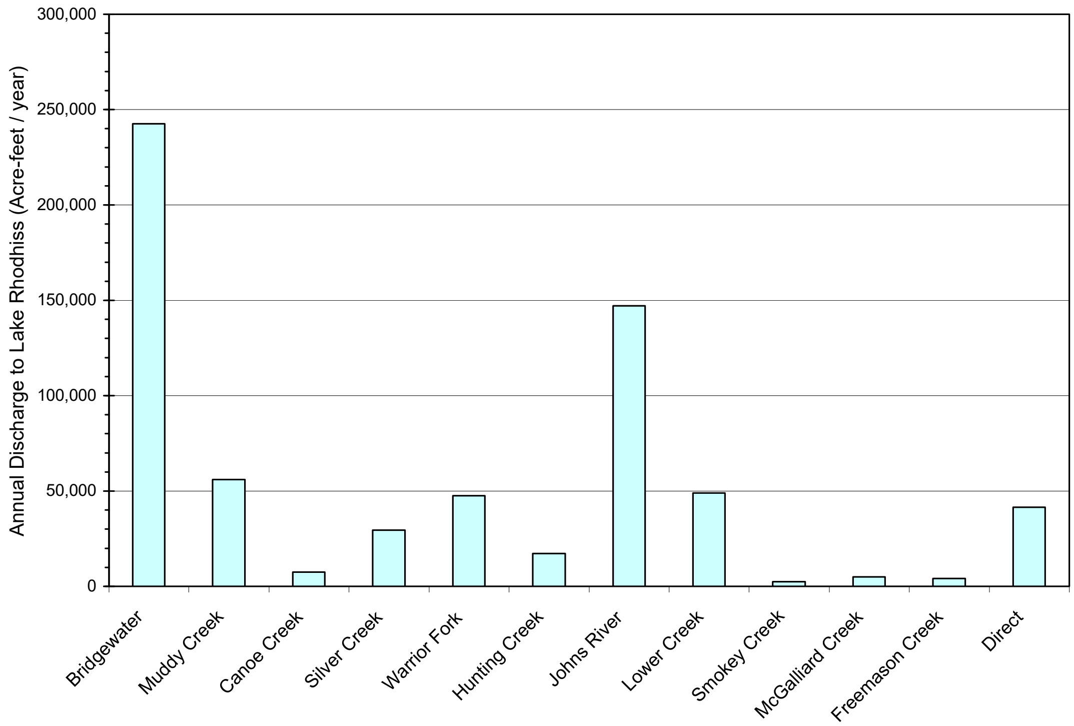


Figure 36. Annual Water Yield of Tributary Basins

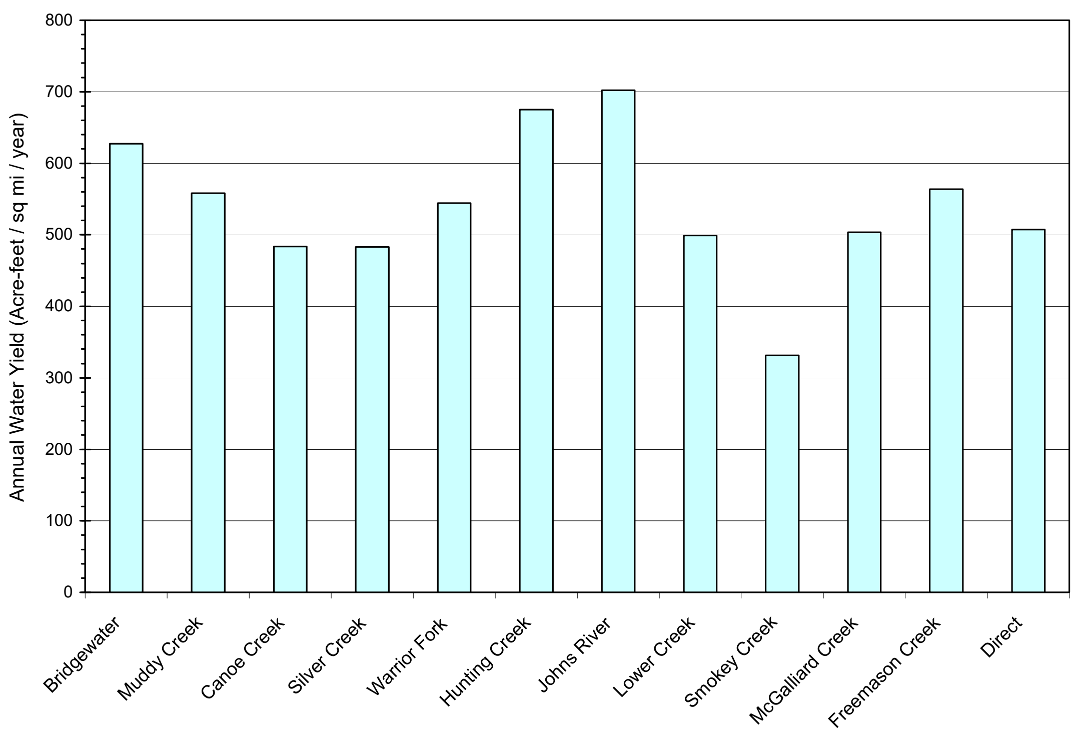


Figure 37. Annual Suspended Sediment Loading from the Tributary Inflows to Lake Rhodhiss

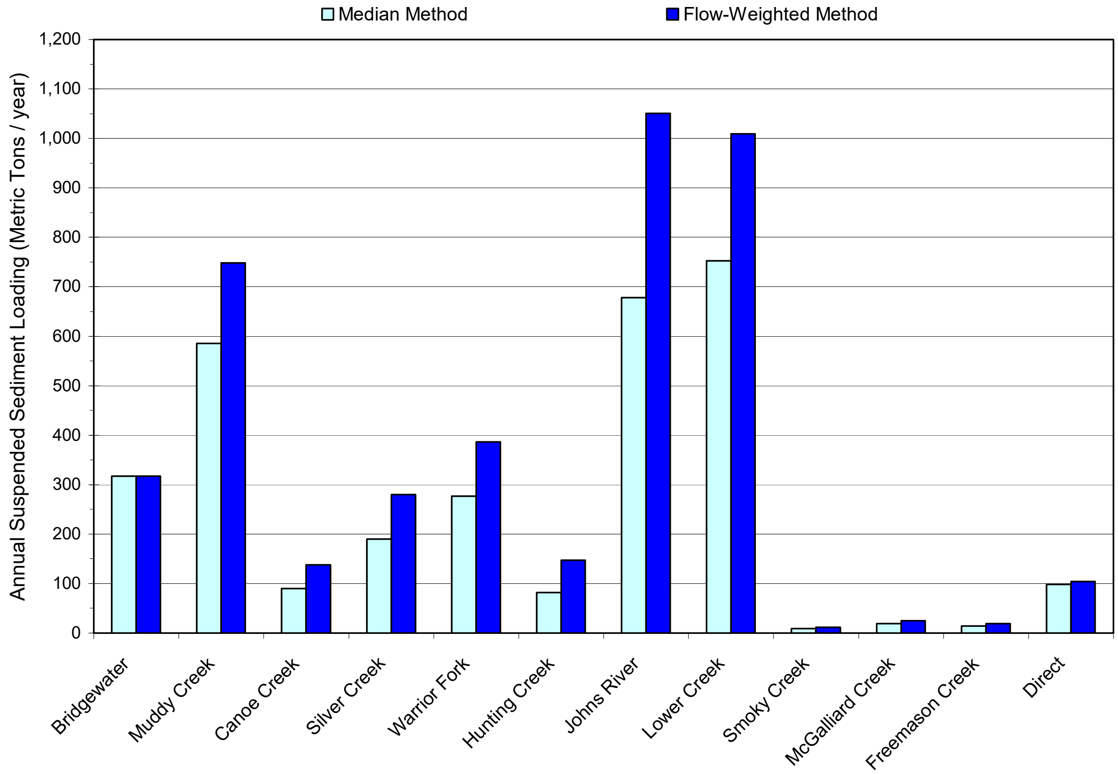


Figure 38. Annual Watershed Yield of Suspended Solids

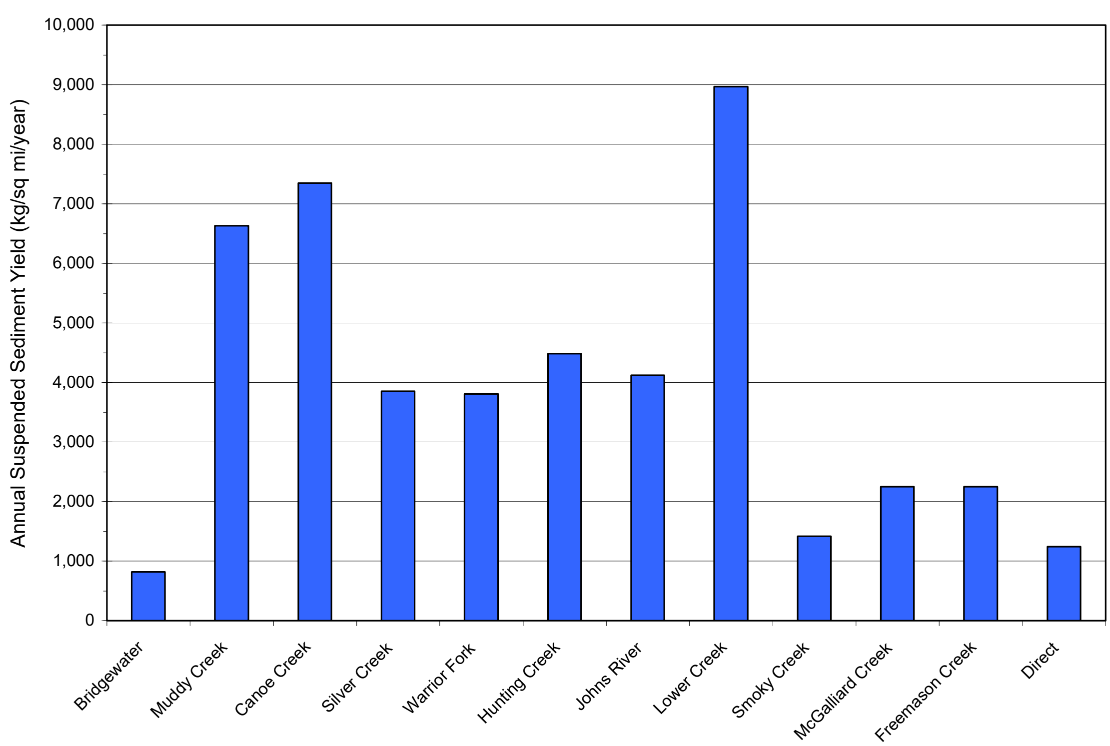


Figure 39. Annual Nitrogen Loading from the Tributary Inflows to Lake Rhodhiss (WWTP Loads Subtracted from Muddy Creek and Lower Creek)

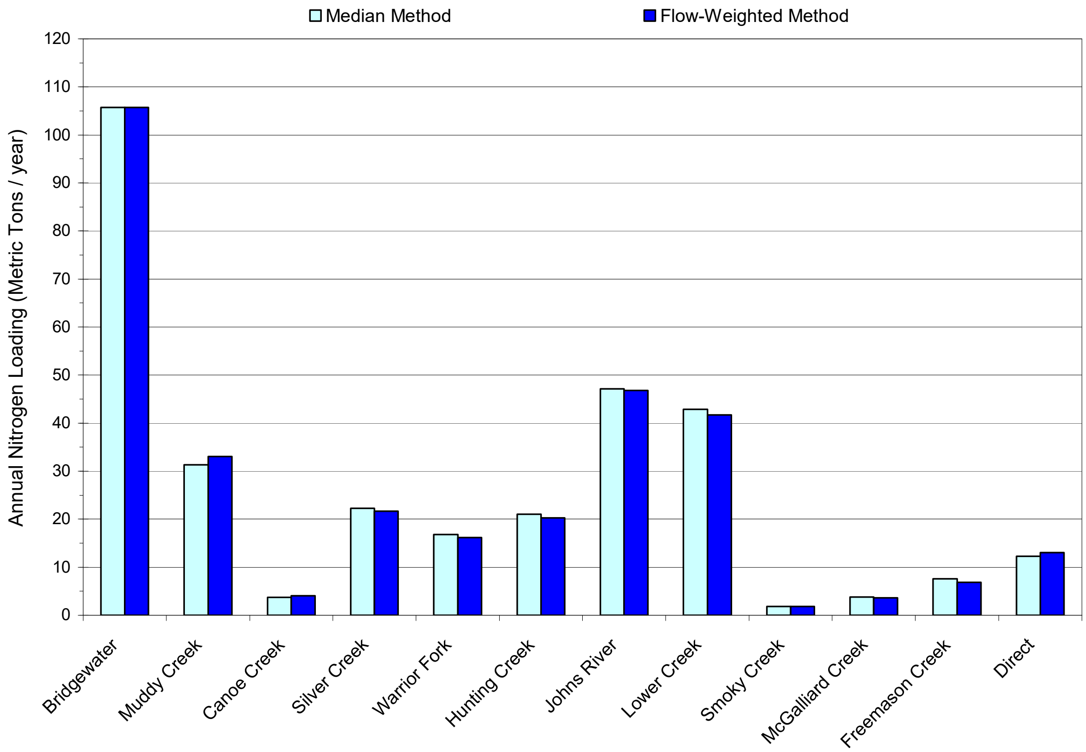


Figure 40. Annual Watershed Yield of Nitrogen

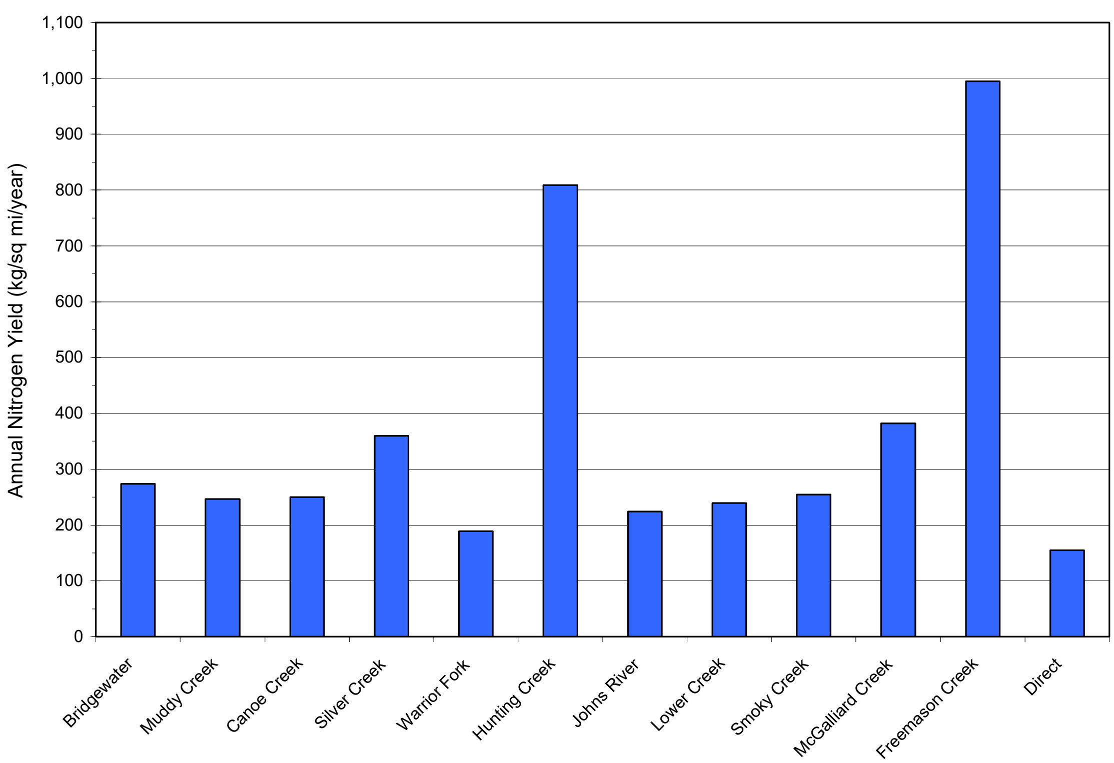


Figure 41. Annual Phosphorus Loading from the Tributary Inflows to Lake Rhodhiss

(WWTP Loads Subtracted from Muddy Creek and Lower Creek)

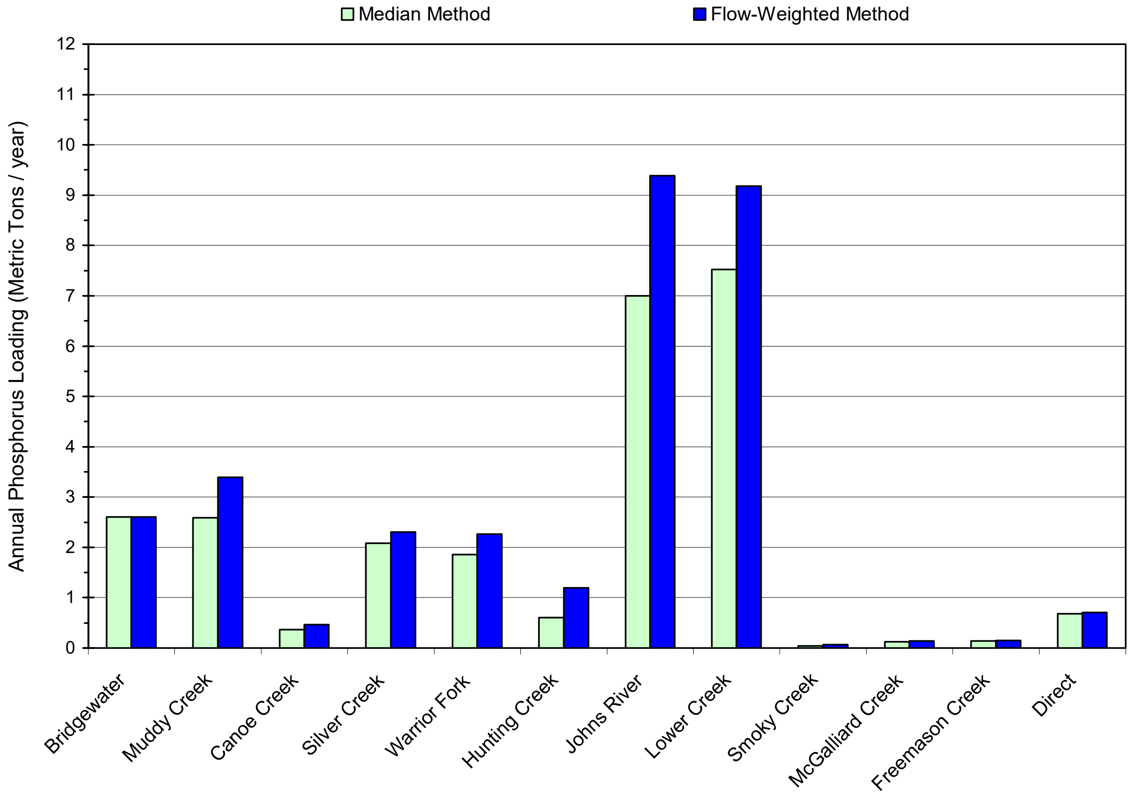
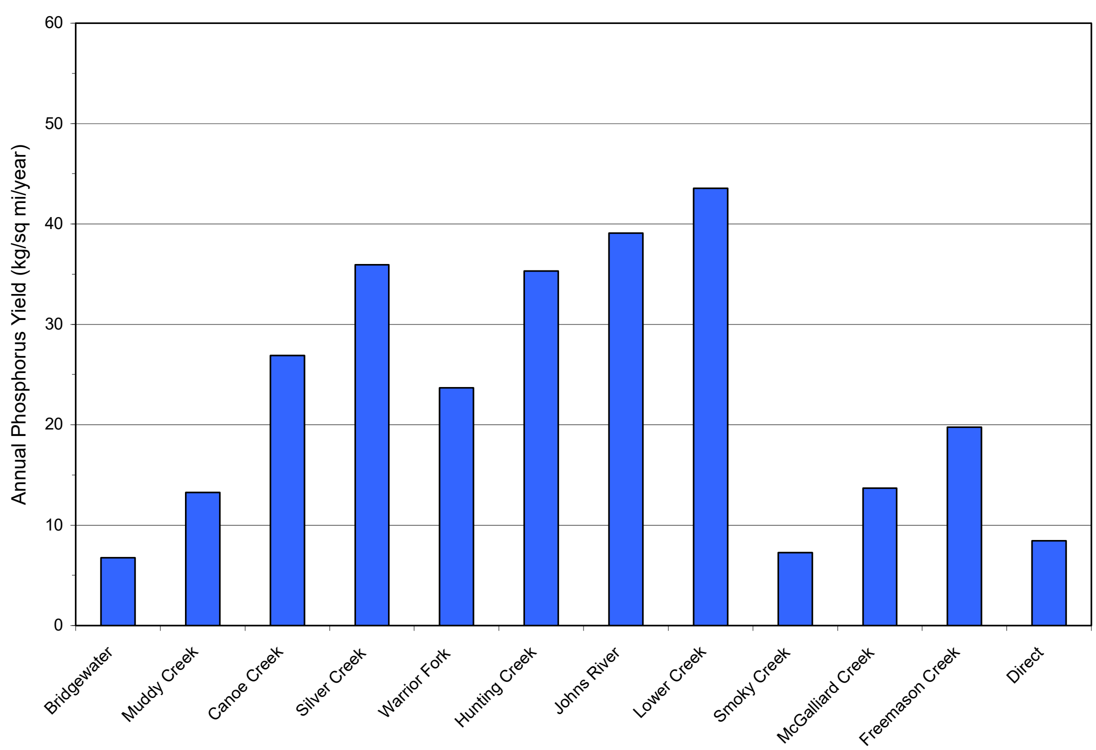


Figure 42. Annual Watershed Yield of Phosphorus



Hunting Creek, the most urban of the watersheds, had moderate sediment loading but relatively low phosphorus loading, but higher than average sediment and phosphorus yields. The next most developed watershed, McGalliard Creek (Table 2), had relatively low sediment and phosphorus loads and yields. Freemason Creek, which had similar proportions of agricultural and developed areas to the Johns River and Warrior Fork, had similar phosphorus yields as Warrior Fork, but half that of the Johns River. Silver Creek, which was the third most developed watershed, exhibited higher sediment and phosphorus loads than Hunting Creek, but similar watershed yields of sediment and phosphorus.

Based upon these data, no consistent trend between total sediment and phosphorus loading and/or watershed yields with gross land use was apparent. Rather than generalized land use patterns, the differences of actual nutrient loading between the basins was probably a result of localized, but significant activities within the basin. Examples of such local activities may include:

- Erosion control and runoff events from individual fields
- Construction and/or land disturbance and local control of runoff
- Storm drainage systems, especially road runoff
- Topography and associated erosion rates
- Stream bank scouring and/or stabilization
- Soil types and associated permeability
- Amount and timing of fertilizer application relative to runoff characteristics and events
- Retention ponds from developments or construction activities

Waste Water Treatment Plant Loading

The total annual nitrogen and phosphorus loading of the wastewater treatment plants were 191.59 metric tons and 36.04 metric tons, respectively (Table 9). However, the impact to Lake Rhodhiss from these facilities probably varies greatly. For example, the Marion and Lenoir WWTP discharged relatively low amounts of nutrients in the headwaters of Muddy Creek and Lower Creek, respectively. The nitrogen and phosphorus have a relatively long period of time to interact with inorganic and organic material that has washed into the creek. The extended travel time allows significant processing by physical, chemical, and biological activity until the nutrients reach Lake Rhodhiss. Phosphorus, to a large extent, is probably adsorbed on the clays from Muddy Creek and probably not to the same extent from Lower Creek. Morganton WWTP and, in particular, Valdese WWTP, discharge directly into Lake Rhodhiss. The nutrients, especially phosphorus, are readily available to the algae in the lake, whereas phosphorus washed in from the watersheds was usually associated with the suspended sediment and not quite as available to the lake algae.

Table 9. Annual Point Source Loading from Waste Water Treatment Plants in the Lake Rhodhiss Basin

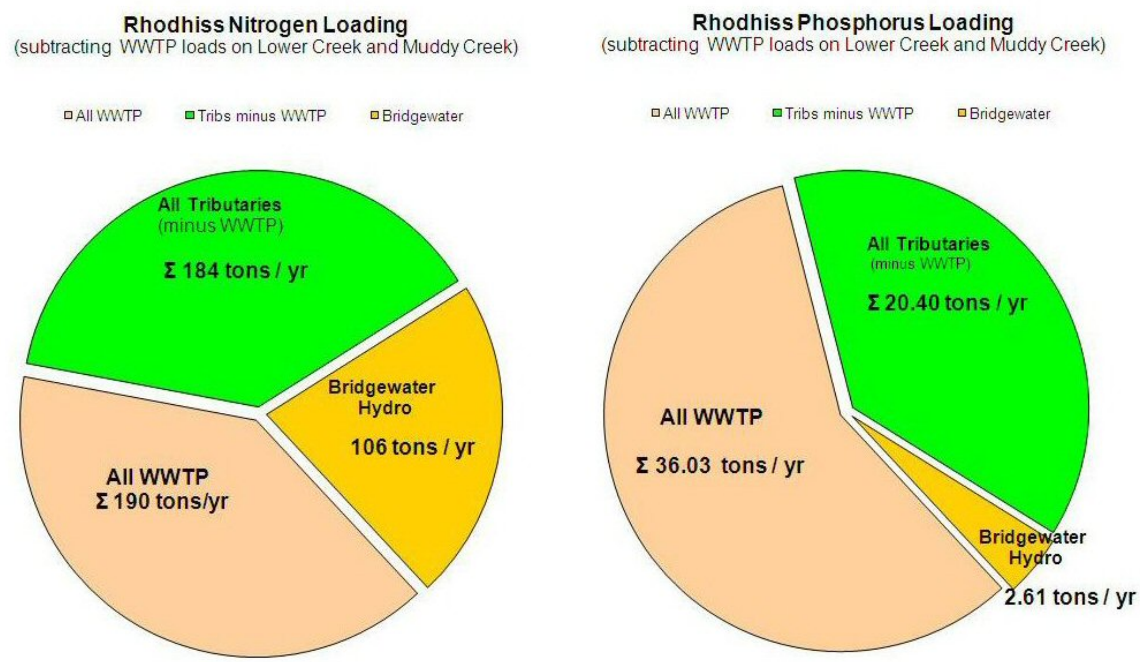
Facility	TN (metric tons / yr)	TP (metric tons / yr)
Morganton WWTP	142.21	20.03
Valdese WWTP	23.23	10.27
Lenoir WWTP	18.76	4.08
Marion WWTP	7.39	1.65
Total	191.59	36.04

Point vs. Non-point Source Loading

The accounting for all of the nitrogen and phosphorus entering Lake Rhodhiss is summarized in Figure 43. All of the tributaries (non-point sources) and all of the wastewater treatment plants (point sources) contributed equal amounts of nitrogen, mostly as nitrate. Bridgewater releases from Lake James contributed about 20% of the nitrogen entering Rhodhiss.

Phosphorus loading, however, was dominated by the point sources. During the year long study, 61% of the phosphorus entered Rhodhiss from point source discharge. Of this amount, 85% entered directly (or almost directly) into Lake Rhodhiss.

Figure 43. Relative Contributions of Nitrogen and Phosphorus from Point and Non-Point Sources



4.5 Nutrient Budget for Rhodhiss Lake

The annual total of inflowing water, sediment, nitrogen, and phosphorus were calculated to estimate the total loads to Lake Rhodhiss. In addition, the total releases from the Rhodhiss Hydro into Lake Hickory were also calculated (Table 10). The net result was, on the average, a loss of 4% of the water from evaporation. In addition, the lake retained 12% of the inflowing sediment, 35 % of the nitrogen, and 38% of the phosphorus. The suspended solids with associated adsorbed phosphorus, was lost from the water column to the lake bottom through coagulation and settling. Nitrogen was probably lost by biological de-nitrification reactions. The net result was the Lake Rhodhiss retained a significant portion of the material derived from the watersheds and processed some of the nutrients discharged from the wastewater treatment plants.

Table 10. Nutrient, Suspended Sediment, and Water Budget for Lake Rhodhiss, 2007-08

Inflows	**Water** (1000 acre-ft per yr)	**Suspended Sediment** (metric tons per yr)	**Nitrogen** (metric tons per yr)	**Phosphorus** (metric tons per yr)
Bridgewater Hydro	243	317	106	2.6
All Tributaries	407	3356	184	20.4
Point Sources	N/A	N/A	192	36.0
Total Inflow	**649**	**3673**	**481**	**59.0**

Outflows	**Water** (1000 acre-ft per yr)	**Suspended Sediment** (metric tons per yr)	**Nitrogen** (metric tons per yr)	**Phosphorus** (metric tons per yr)
Rhodhiss Hydro	623	3226	310	31.6
Total Outflow	**623**	**3226**	**310**	**31.6**

4.6 Comparison to Other Estimates of Nutrient Loading

A compilation of the nutrient loadings (nitrogen and phosphorus) from both the median method and the flow-weighted method used in this study are compared basin by basin to the other estimates of loading made by the USEPA (1973), Giorgino & Bales (1997), and Struve (2003)[2].

The reported loading values from the various sources differed significantly (Tables 11 and 12) from each other, but most significantly from this study. A brief discussion is warranted summarizing the various approaches used to estimate the Lake Rhodhiss nutrient budget.

- Advantages that this study had were:
    - First, this is the only study that measured both the nutrient concentrations and the flow from all of the non-point sources (tributaries) to Rhodhiss. These measurements, especially creek stage, were made at high frequencies that captured all of the low flows and storm events for a 1-year period of time.
    - Second, this study used actual DMR data collected at the wastewater treatment facilities, rather than estimates based on per capita waste.
    - Third, this study was conducted as a comprehensive approach where all inflows and outflows were conducted simultaneously with the same frequency of sample collection associated with creek stage measurements.
    - Fourth, this is the only study that measured the actual nutrient concentrations throughout a storm event in multiple systems.
- Disadvantages that occurred during this study were:
    - The year was an extreme low-flow year (drought) that may have reduced the loading due to low flows and altered normal nutrient concentrations
    - The low flow conditions contributed to minimal sampling of higher flows, potentially altering the median concentrations in the creeks

[2] The updated report from the Western Piedmont Council of Governments (2009) had estimates of loading essentially identical to Struve (2003).

The concept of nutrient loading is relatively simple, namely the mathematical product of the amount of water (Flow) and the amount of nutrient (concentration). A complete review and discussion of each report is beyond the scope of this report, however, some observations are as follows:

1. USEPA (1975) -
    a. The year sampled (1973) had twice as much water as this study, loading rates would be higher
    b. All flows were estimated from mean monthly flows from tributary sites (?) closest to the lake
    c. Rhodhiss outflow was 30% greater than inflow, suggests that flows were grossly in error
    d. Point Source loadings were estimated from average Nitrogen and Phosphorus waste per capita per year
    e. Catawba River downstream of Morganton WWTP was sampled for N and P, then total loading from Morganton subtracted, this sampling probably grossly overestimated Catawba River loading
    f. McGalliard Creek total phosphorus concentrations were 100 to 1000 times greater than reported for this study, also, EPA reported significant point sources on McGalliard Creek
    g. Freemason Creek total phosphorus concentrations were 2 to 3 times greater in 1973 than in 2007
    h. Lower Creek and Johns River total phosphate concentrations were similar to those measured in this study, however, TKN values were 3 – 5 times greater in 1973 than in 2007.
    i. Hunting Creek concentrations and flows are not presented
2. Giorgino and Bales (1997)
    a. The year sampled (1993) had approximately twice as much water as this study, loading rates would be higher
    b. Only the Catawba River at Hoffman Bridge and Lower Creek were sampled as tributaries
    c. Concentrations of total phosphate and nitrate in Lower Creek were similar in 1993 to those in 2007. However, TKN values were significantly higher in 1993
    d. Catawba River downstream of Morganton WWTP was sampled for N and P, this sampling probably grossly overestimated Catawba River loading
    e. The means to calculate constituent loading for the Lower Creek and Catawba River sites involved using a regression relationship between stream flow and concentrations. This relationship was used to compute hourly, daily, and monthly loads. (This method was never presented in more detail than just described).
    f. NPDES reporting requirements (DMR) were used to calculate WWTP loadings
3. Struve (2003)
    a. Utilized the Generalized Watershed Loading Functions (QWLF) computer model to calculate loads
    b. Basin selection was not consistent with river/creek systems, overlap in some areas
    c. Assume DMR data from NCDWQ for point source loading calculations

Table 11. Comparison of Annual Nitrogen Loading Estimates to Lake Rhodhiss from Various Sources

Note: All values are Metric Tons per year		This Study: Median Method	This Study: Flow-Weighted Method	USEPA (1975)	Giorgino & Bales (1997)	Struve (2003)
Inputs	**Total of Tributaries** (non-point Source)	**290**	**289**	**1205**	**1007**	**613**
	Catawba River			723.93		
	Catawba River - Site 20				878.50	
	Bridgewater	105.73	105.73	Included in Catawba River	Included in Site 20	24.44
	Muddy Creek	23.96	25.65			82.93
	Canoe Creek	3.74	4.01			13.13
	Silver Creek	22.24	21.68			56.79
	Warrior Fork	16.80	16.17			14.74
	Hunting Creek	21.03	20.28	168.42		35.96
	Johns River	47.14	46.79	125.05		154.33
	Lower Creek	24.11	22.95	106.65	128.81	63.23
	Smokey Creek	1.84	1.84	9.45		24.03
	McGalliard Creek	3.82	3.65	15.98		
	Freemason Creek	7.56	6.84	14.72		
	Other					143.19
	Direct (unmeasured drainages)	12.32	13.02			
	Hoyle Creek	included in Direct	included in Direct	6.54		
	Howard Creek			9.03		
	Stafford Creek			11.68		
	Bristol Creek			13.59		
	Total of WWTP (point Source)	**192**	**192**	**123**	**310**	**167**
	Morganton	142.21	142.21	46.34	163.20	
	Marion	7.39	7.39	11.34	33.60	
	Lenoir	18.76	18.76	50.01	48.48	
	Valdese	23.23	23.23		64.72	
	Valdese #1			3.61		
	Valdese #2			7.22		
	Drexel			4.87		
Outlet	Rhodhiss Hydro	**310.06**	**310.06**	**1268.72**		

Table 12. Comparison of Annual Phosphorus Loading Estimates to Lake Rhodhiss from Various Sources

	Note: All values are Metric Tons per year	This Study		USEPA (1975)	Giorgino & Bales (1997)	Struve (2003)
		Median Method	Flow-Weighted Method			
Inputs	**Total of Tributaries** (non-point Source)	**20**	**26**	**159**	**120**	**51**
	Catawba River			63.77		
	Catawba River - Site 20				105.47	
	Bridgewater	2.61	2.61	Included in Catawba River	Included in Site 20	1.55
	Muddy Creek	0.93	1.74			5.95
	Canoe Creek	0.37	0.47			0.92
	Silver Creek	2.08	2.30			3.10
	Warrior Fork	1.86	2.27			1.66
	Hunting Creek	0.61	1.20	63.48		2.74
	Johns River	7.00	9.39	7.16		13.93
	Lower Creek	3.45	5.11	5.76	14.57	5.51
	Smokey Creek	0.04	0.06	0.32		1.94
	McGalliard Creek	0.13	0.14	11.65		
	Freemason Creek	0.14	0.15	0.62		
	Other					13.48
	Direct (unmeasured drainages)	0.68	0.71			
	Hoyle Creek	included in Direct	included in Direct	3.83		
	Howard Creek			0.87		
	Stafford Creek			0.49		
	Bristol Creek			0.68		
	Total of WWTP (point Source)	**36**	**36**	**41**	**48**	**48**
	Morganton	20.03	20.03	15.45	16.88	
	Marion	1.65	1.65	3.78	2.62	
	Lenoir	4.08	4.08	16.68	4.44	
	Valdese	10.27	10.27		24.40	
	Valdese #1			1.21		
	Valdese #2			2.41		
	Drexel			1.63		
Outlet	Rhodhiss Hydro	**31.58**	**31.58**	**106.66**		

5. SUMMARY AND CONCLUSIONS

In 2008, the North Carolina 303(d) list was updated to include Rhodhiss Lake for exhibiting high pH values (NCDWQ, 2008). Presumably, the high pH values in the lake were due to high algal production rates stimulated by high nutrient levels, especially phosphorus.

Even though attempts made in 1973, 1993, and 2003 to estimate nutrient contributions to Lake Rhodhiss, no systematic, direct approach to measure nutrient concentrations and flows in most of the tributaries and point-source discharges had been attempted. As Struve (2003) pointed out, “loading estimates are lacking for most streams in the watershed for a couple of reasons”, namely, ‘time and expense collecting and analyzing nutrient samples over a wide range of conditions, and, primarily, the cost of stream gages to measure stage at high frequency intervals and develop rating curves to calculate flow at those stage measurements'. The reasonable cost of installing temporary stream gages, the development of rating curves for those gages, and routine and storm event nutrient sampling allowed direct loading measurements of 10 tributaries to Lake Rhodhiss.

Findings:

- The study year, April 2007 – April 2008 was an extremely low flow year (drought) which probably contributed to lower nutrient loading than would have occurred during an average or above average water year
- Nutrient (nitrogen and phosphorus fractions) were similar to NCDWQ historical values, with some concentrations slightly higher (low flows not diluting point source effluents) and some streams exhibiting lower concentrations (decreased non-point sources from reduced scouring and runoff)
- Phosphorus concentrations were very closely coupled with suspended sediment concentrations
- Nitrate concentrations dominated the nitrogen speciation. Concentrations varied little between creeks and between flow (Freemason Creek and Hunting Creeks had significantly higher nitrate concentrations). Since nitrate concentrations varied little, nitrogen loading was primarily a function of the flow rates.
- Flow patterns in all streams and creeks exhibited small variations in base flow (ground water was the major contributor). All creeks had rapidly rising and falling hydrographs during storm events. (Hunting Creek exhibited the greatest rate of rise and fall of water)
- The majority of the all nutrient loading occurred during storm events and provided "pulses" of nutrients to Lake Rhodhiss.
- Generally, the streams with the largest watershed exhibited the greatest nutrient loading. However, total loading (metric tons per year) nor nutrient yields (kg per square mile per year) could be related to generalize land use patterns.
- Unlike previous estimates, the point source nutrient loading was greater than the contributions of nutrients from all of the watersheds.
- Unlike the "pulsed" inputs of nutrients from the watersheds due to storm events, the Morganton and especially the Valdese WWTP facilities provide a continuous supply of nutrients to Lake Rhodhiss.
- The inflow of water to Lake Rhodhiss was 4% greater than the outflow, the similarity of these measurements, including the 4% attributable to evaporation, provided a high level of confidence in the accuracy of the individual flow measurements.
- Lake Rhodhiss retained significant amounts of sediment and phosphorus while probably loosing nitrogen by denitrification

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APPENDIX A

Analytical Laboratory Results of All Water Samples

Collected During the Study Period

April 2007 through April 2008

Sample Location	Collection Date	TOTAL KJELDAHL NITROGEN (COLORIMETRIC) (mg/L)	TOTAL DISSOLVED (Filtered) KJELDAHL NITROGEN (COLORIMETRIC) (mg/L)	AMMONIA (COLORIMETRIC) (mg/L)	NITRITE + NITRATE (COLORIMETRIC) (mg/L)	TOTAL PHOSPHORUS (COLORIMETRIC) (mg/L)	TOTAL DISSOLVED (Filtered) PHOSPHORUS (COLORIMETRIC) (mg/L)	O-PHOSPHATE (COLORIMETRIC) (mg/L)	SUSPENDED SOLIDS DRY WEIGHT (mg/L)	Temp (ºC)	SpCond (uS/cm)	Turbidity (NTU)
Bridgewater Tailrace	4/19/2007 11:16	0.20			0.160	0.007				10.8		
Bridgewater Tailrace	5/10/2007 11:08	0.20			0.170	0.007				14.8		
Bridgewater Tailrace	6/21/2007 10:26	0.37			0.210	0.009				14.2		
Bridgewater Tailrace	7/18/2007 10:41	0.20			0.230	0.003				14.5		
Bridgewater Tailrace	8/28/2007 10:41	0.20			0.250	0.007				15.4		
Bridgewater Tailrace	9/20/2007 11:17	0.20			0.240	0.008				19.3		
Bridgewater Tailrace	10/18/07 11:08	0.20			0.220	0.010				12.9		
Bridgewater Tailrace	11/14/07 11:01	0.20			0.067	0.019				16.5		
Bridgewater Tailrace	12/19/07 11:27	0.20			0.071	0.015				10.8		
Bridgewater Tailrace	1/1/08 9:06	0.20			0.095	0.039				1.5		
Bridgewater Tailrace	2/1/2008 16:51	0.20			0.085	0.014				10.0	54	3
Bridgewater Tailrace	2/27/2008 8:15	0.41			0.094	0.024					55	3
Bridgewater Tailrace	4/2/2008 11:52	0.20			0.150	0.097			2.0			
Rhodhiss Tailrace	4/19/2007 16:07	0.19			0.130	0.240				13.1		
Rhodhiss Tailrace	5/10/2007 15:30	0.21			0.160	0.021				20.2		
Rhodhiss Tailrace	6/21/2007 14:43	0.49			0.150	0.041				24.9		
Rhodhiss Tailrace	7/18/2007 15:15	0.27			0.270	0.027				24.0		
Rhodhiss Tailrace	8/28/2007 14:15	0.41			0.140	0.023				25.4		
Rhodhiss Tailrace	9/20/2007 14:48	0.31			0.130	0.037				24.4		
Rhodhiss Tailrace	10/18/07 14:58	0.19			0.170	0.037				20.1		
Rhodhiss Tailrace	11/14/07 14:16	0.16			0.270	0.045				18.6		
Rhodhiss Tailrace	12/19/07 14:30	0.20			0.240	0.170				11.2		
Rhodhiss Tailrace	1/1/08 14:18	0.20			0.290	0.095				1.5		
Rhodhiss Tailrace	2/2/2008 9:35	0.20			0.350	0.052				9.3	67	11
Rhodhiss Tailrace	2/27/2008 13:05	0.43			0.350	0.058					61	16
Rhodhiss Tailrace	4/2/2008 15:16	0.24			0.230	0.025			4.4			
Canoe Creek	4/19/2007 11:44	0.20	0.18	0.130	0.140	0.021	0.010	0.004	22.0	12.9	48	
Canoe Creek	5/10/2007 11:35	0.20	0.23	0.220	0.210	0.021	0.009	0.005	3.4	17.1	42	
Canoe Creek	6/21/2007 10:58	0.41	0.75	0.050	0.300	0.064	0.024	0.005	10.0	19.4	52	
Canoe Creek	7/18/2007 11:05	0.20	0.20	0.065	0.280	0.056	0.008	0.007	28.0	22.0	56	
Canoe Creek	8/28/2007 11:00	0.20		0.051	0.310	0.048		0.018	11.0	23.3	49	
Canoe Creek	9/20/2007 11:38	0.20		0.020	0.190	0.053		0.009	19.0	19.9	48	
Canoe Creek	10/18/07 11:27	0.20		0.050	0.140	0.029		0.009	4.7	18.2	46	
Canoe Creek	11/14/07 11:27	0.20			0.082	0.026			1.6	13.8	45	
Canoe Creek	12/19/07 11:47	0.20			0.150	0.022			2.0	5.2	47	
Canoe Creek	1/1/08 8:22	0.20			0.250	0.031			5.8	1.5	38	
Canoe Creek	1/31/2008 18:46	0.20	0.24	0.05	0.21	0.043	0.009	0.007	10	7.85	52.2	11
Canoe Creek	2/1/2008 7:44	0.48	0.21	0.050	0.24	0.079	0.0062	0.014	88	5.13	48	103
Canoe Creek	2/1/2008 15:00	0.93	0.46	0.050	0.29	0.16	0.0097	0.0083	230	7.43	39	457
Canoe Creek	2/2/2008 2:12	0.40	0.20	0.05	0.36	0.13	0.0059	0.005	58	6.06	39	95
Canoe Creek	2/3/2008 8:00	0.20	0.20	0.05	0.27	0.035	0.005	0.005	9	8.27	44	22
Canoe Creek	2/27/2008 9:13	0.49			0.210	0.092			19.0		50	56
Canoe Creek	4/2/2008 12:13	0.26			0.170	0.034			5.6	16.7	46	

Sample Location	Collection Date	TOTAL KJELDAHL NITROGEN (COLORIMETRIC) (mg/L)	TOTAL DISSOLVED (Filtered) KJELDAHL NITROGEN (COLORIMETRIC) (mg/L)	AMMONIA (COLORIMETRIC) (mg/L)	NITRITE + NITRATE (COLORIMETRIC) (mg/L)	TOTAL PHOSPHORUS (COLORIMETRIC) (mg/L)	TOTAL DISSOLVED (Filtered) PHOSPHORUS (COLORIMETRIC) (mg/L)	O-PHOSPHATE (COLORIMETRIC) (mg/L)	SUSPENDED SOLIDS DRY WEIGHT (mg/L)	Temp (ºC)	SpCond (uS/cm)	Turbidity (NTU)
Freemason Creek	4/19/2007 15:40	0.18	0.27	0.240	0.180	0.017	0.010	0.004	1.6	13.1	48	
Freemason Creek	5/10/2007 15:04	0.30	0.42	0.230	1.400	0.036	0.022	0.006	2.8	20.8	42	
Freemason Creek	6/21/2007 14:19	0.49	0.59	0.050	1.300	0.033	0.022	0.006	3.3	21.9	53	
Freemason Creek	7/18/2007 14:48	0.20	0.20	0.064	1.100	0.024	0.015	0.009	3.8	24.3	50	
Freemason Creek	9/20/2007 14:20	0.24		0.020	1.400	0.030		0.011	6.2	20.4	48	
Freemason Creek	10/18/07 14:33	0.20		0.037	1.600	0.023		0.009	2.0	19.5	41	
Freemason Creek	11/14/07 13:52	0.20			1.100	0.024			3.0	15.0	47	
Freemason Creek	12/19/07 14:10	0.20			1.400	0.016			2.0	5.8	46	
Freemason Creek	12/31/07 16:10	0.20			1.500	0.068			2.0	1.5	52	
Freemason Creek	2/2/2008 9:58	0.20			1.600	0.023			5.2	5.9	63	13
Freemason Creek	2/27/2008 12:09	0.45			1.400	0.037			2.0		55	6
Freemason Creek	4/2/2008 14:52	0.56			1.200	0.060			9.2	16.9	47	
Freemason Creek.	8/28/2007 13:47	0.20		0.086	1.100	0.035		0.015	6.2	24.2	48	
Hunting Creek	4/19/2007 12:53	0.20	0.02	0.260	0.730	0.160	0.010	0.003	2.2	13.7	80	
Hunting Creek	5/10/2007 12:33	0.20	0.23	0.160	0.930	0.013	0.004	0.005	3.2	17.9	67	
Hunting Creek	6/21/2007 11:47	0.33	0.49	0.050	0.810	0.032	0.015	0.005	12.0	19.6	82	
Hunting Creek	7/18/2007 12:10	0.20	0.20	0.059	0.790	0.018	0.013	0.009	5.4	22.2	88	
Hunting Creek	8/28/2007 11:34	0.20		0.066	0.590	0.030		0.009	5.2	23.9	76	
Hunting Creek	9/20/2007 12:18	0.20		0.020	0.750	0.023		0.009	3.8	20.1	74	
Hunting Creek	10/18/07 12:21	0.20		0.042	0.690	0.014		0.005	3.0	18.7	75	
Hunting Creek	11/14/07 12:00	0.20			0.550	0.018			2.0	13.5	73	
Hunting Creek	12/19/07 12:33	0.20			0.850	0.024			2.0	7.4	70	
Hunting Creek	1/1/08 13:05	0.20			1.000	0.100			4.6	1.5	65	
Hunting Creek	1/31/2008 17:20	0.20	0.20	0.05	0.94	0.027	0.023	0.005	2	6.96	82.8	3
Hunting Creek	2/1/2008 6:40	0.82	0.41	0.096	0.48	0.32	0.036	0.030	140	6.92	56	173
Hunting Creek	2/1/2008 13:23	1.10	0.51	0.072	0.78	0.54	0.019	0.025	270	6.89	71	396
Hunting Creek	2/2/2008 0:57	0.42	0.20	0.05	0.98	0.086	0.0050	0.012	58	4.73	71	82
Hunting Creek	2/3/2008 6:25	0.20	0.20	0.05	0.98	0.055	0.005	0.005	11	5.32	75	23
Hunting Creek	2/27/2008 11:04	0.34			0.870	0.022			3.2		73	13
Hunting Creek	4/2/2008 12:50	0.20			0.770	0.031			3.6	17.3	76	
Johns River	4/19/2007 13:45	0.17	0.23	0.240	0.063	0.013	0.009	0.002	3.8	13.6	34	
Johns River	5/10/2007 13:27	0.20	0.24	0.230	0.110	0.018	0.009	0.005	3.0	19.7	53	
Johns River	6/21/2007 12:46	0.43	0.59	0.050	0.130	0.038	0.016	0.005	13.0	24.8	42	
Johns River	7/18/2007 13:03	0.20	0.20	0.056	0.058	0.035	0.011	0.008	8.6	25.4	38	
Johns River	8/28/2007 12:23	0.35		0.130	0.074	0.040		0.006	10.0	27.0	32	
Johns River	9/20/2007 13:05	0.20		0.020	0.075	0.028		0.005	5.4	22.6	34	
Johns River	10/18/07 13:09	0.20		0.042	0.058	0.018		0.005	3.7	19.6	34	
Johns River	11/14/07 12:40	0.20			0.027	0.065			2.0	14.2	34	
Johns River	12/19/07 13:06	0.20			0.033	0.110			2.0	6.3	29	
Johns River	1/1/08 11:32	0.20			0.063	0.049			2.0	1.5	71	
Johns River	2/2/2008 1:45	0.20			0.094	0.095			34.0	7.5	33	48
Johns River	2/27/2008 9:55	0.38			0.085	0.130			4.2		33	10
Johns River	4/2/2008 13:32	0.20			0.140	0.069			2.8	16.1	30	

Sample Location	Collection Date	TOTAL KJELDAHL NITROGEN (COLORIMETRIC) (mg/L)	TOTAL DISSOLVED (Filtered) KJELDAHL NITROGEN (COLORIMETRIC) (mg/L)	AMMONIA (COLORIMETRIC) (mg/L)	NITRITE + NITRATE (COLORIMETRIC) (mg/L)	TOTAL PHOSPHORUS (COLORIMETRIC) (mg/L)	TOTAL DISSOLVED (Filtered) PHOSPHORUS (COLORIMETRIC) (mg/L)	O-PHOSPHATE (COLORIMETRIC) (mg/L)	SUSPENDED SOLIDS DRY WEIGHT (mg/L)	Temp (ºC)	SpCond (uS/cm)	Turbidity (NTU)
Lower Creek	4/19/2007 14:07	0.20	0.20	0.280	0.400	0.048	0.013	0.005	12.0	13.9	87	
Lower Creek	5/10/2007 13:46	0.22	0.29	0.260	0.510	0.110	0.011	0.005	40.0	19.2	84	
Lower Creek	6/21/2007 13:02	0.43	0.80	0.019	0.500	0.210	0.098	0.260	24.0	21.6	110	
Lower Creek	7/18/2007 13:18	0.20	0.20	0.091	0.610	0.130	0.064	0.057	12.0	24.4	130	
Lower Creek	8/28/2007 12:51	0.20		0.058	0.140	0.280		0.180	13.0	25.0	110	
Lower Creek	9/20/2007 13:17	0.20		0.032	0.760	0.280		0.110	29.0	20.6	110	
Lower Creek	10/18/07 13:28	0.20		0.064	0.700	0.210		0.100	7.0	19.4	110	
Lower Creek	11/14/07 12:53	0.20			0.550	0.180			3.0	14.7	99	
Lower Creek	12/19/07 13:18	0.20			0.450	0.069			3.2	6.2	110	
Lower Creek	1/1/08 11:20	0.20			0.610	0.120			22.0	1.5	47	
Lower Creek	2/2/2008 13:35	0.98			0.610	0.200			120.0	7.1	76	123
Lower Creek	2/27/2008 10:23	0.60			0.460	0.100			25.0		89	45
Lower Creek	4/2/2008 13:46	0.23			0.400	0.065			7.8	16.5	92	
McGalliard Creek	4/19/2007 15:12	0.20	0.42	0.260	0.450	0.010	0.005	0.001	1.6	12.8	73	
McGalliard Creek	5/10/2007 14:37	0.20	0.25	0.360	0.650	0.014	0.005	0.005	2.2	18.4	66	
McGalliard Creek	6/21/2007 13:53	0.46	0.70	0.012	0.500	0.021	0.009	0.005	3.9	21.2	83	
McGalliard Creek	7/18/2007 14:19	0.20	0.20	0.075	0.440	0.025	0.005	0.004	10.0	24.3	74	
McGalliard Creek	8/28/2007 13:29	0.20		0.110	0.380	0.023		0.004	4.2	24.7	88	
McGalliard Creek	9/20/2007 14:00	0.20		0.020	0.500	0.030		0.005	7.4	21.4	87	
McGalliard Creek	10/18/07 14:10	0.20		0.100	0.380	0.018		0.004	4.0	18.3	95	
McGalliard Creek	11/14/07 13:31	0.20			0.240	0.013			3.0	14.4	82	
McGalliard Creek	12/19/07 13:52	0.20			0.390	0.130			2.0	6.2	71	
McGalliard Creek	12/31/07 14:49	0.20			0.530	0.024			2.0	1.5	53	
McGalliard Creek	2/2/2008 10:25	0.20			0.550	0.006			8.4	6.2	65	15
McGalliard Creek	2/27/2008 11:25	0.37			0.440	0.020			3.4		72	12
McGalliard Creek	4/2/2008 14:31	0.22			0.410	0.042			2.8	17.3	75	
Muddy Creek	4/19/2007 10:36	0.16	0.20	0.240	0.220	0.033	0.017	0.005	5.0	13.0	54	
Muddy Creek	5/10/2007 10:44	0.20	0.21	0.210	0.260	0.028	0.012	0.002	5.0	17.7	51	
Muddy Creek	6/21/2007 9:47	0.41	0.82	0.050	0.240	0.073	0.036	0.007	21.0	19.8	62	
Muddy Creek	7/18/2007 10:17	0.20	0.20	0.062	0.300	0.054	0.016	0.014	18.0	22.2	76	
Muddy Creek	8/28/2007 10:21	0.20		0.026	0.220	0.038		0.016	9.8	23.6	61	
Muddy Creek	9/20/2007 11:02	0.20		0.020	0.260	0.044		0.012	9.0	19.6	60	
Muddy Creek	10/18/07 10:51	0.42		0.027	0.180	0.026		0.010	4.0	18.8	72	
Muddy Creek	11/14/07 10:41	0.20			0.170	0.021			3.0	13.8	64	
Muddy Creek	12/19/07 11:10	0.20			0.310	0.021			2.0	4.9	70	
Muddy Creek	1/1/08 9:25	0.20			0.400	0.070			12.0	1.5	48	
Muddy Creek	2/1/2008 16:33	2.0			0.490	0.220			250.0	7.9	74	222
Muddy Creek	2/27/2008 7:50	0.41			0.390	0.081			16.0		60	35
Muddy Creek	4/2/2008 11:33	0.20			0.370	0.031			7.2	16.1	73	

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Silver Creek	4/19/2007 12:07	0.20	0.27	0.270	0.380	0.021	0.013	0.006	4.4	13.6	59	
Silver Creek	5/10/2007 11:54	0.20	0.26	0.250	0.490	0.030	0.013	0.004	6.2	17.9	51	
Silver Creek	6/21/2007 11:17	0.41	0.62	0.050	0.430	0.067	0.025	0.009	23.0	20.4	62	
Silver Creek	7/18/2007 11:27	0.20	0.20	0.061	0.410	0.037	0.013	0.010	12.0	22.2	52	
Silver Creek	8/28/2007 11:13	0.20		0.070	0.350	0.066		0.022	22.0	23.2	61	
Silver Creek	9/20/2007 11:53	0.20		0.020	0.390	0.063		0.014	11.0	19.9	57	
Silver Creek	10/18/07 11:47	0.20		0.038	0.390	0.046		0.017	6.0	18.3	60	
Silver Creek	11/14/07 11:41	0.20			0.260	0.026			3.2	14.0	57	
Silver Creek	12/19/07 12:00	0.20			0.430	0.045			2.0	6.3	56	
Silver Creek	1/1/08 7:56	0.20			0.580	0.073			12.0	1.5	46	
Silver Creek	2/1/2008 17:10	1.10			0.670	0.400			340	7.1	48	377
Silver Creek	2/27/2008 8:48	0.39			0.480	0.059			15.0		58	31
Silver Creek	4/2/2008 12:29	0.24			0.440	0.097			8.6	16.7	57	
Smokey Creek	4/19/2007 14:30	0.23	0.25	0.240	0.340	0.008	0.006	0.001	2.6	13.1	42	
Smokey Creek	5/10/2007 14:07	0.20	0.20	0.230	0.510	0.011	0.005	0.005	2.0	19.8	34	
Smokey Creek	6/21/2007 13:23	0.40	0.71	0.050	0.430	0.024	0.110	0.005	6.0	21.4	42	
Smokey Creek	7/18/2007 13:49	0.20	0.20	0.062	0.390	0.011	0.004	0.005	4.3	24.2	38	
Smokey Creek	8/28/2007 13:06	0.20		0.071	0.300	0.015		0.009	2.6	23.7	37	
Smokey Creek	9/20/2007 13:34	0.20		0.020	0.420	0.015		0.005	3.2	20.4	38	
Smokey Creek	10/18/07 13:46	0.20		0.030	0.320	0.012		0.005	3.7	19.3	36	
Smokey Creek	11/14/07 13:09	0.20			0.220	0.030			2.0	15.1	36	
Smokey Creek	12/19/07 13:33	0.20			0.450	0.017			2.0	6.2	36	
Smokey Creek	12/31/07 16:50	0.20			0.580	0.016			2.0	1.5	37	
Smokey Creek	1/31/2008 17:54	0.20	0.20	0.05	0.50	0.005	0.005	0.005	2	5.18	47.6	4
Smokey Creek	2/1/2008 6:58	0.28	0.20	0.050	0.38	0.058	0.005	0.005	18	3.87	35	38
Smokey Creek	2/1/2008 13:55	0.73	0.32	0.05	0.56	0.19	0.005	0.005	130	9.32	38	232
Smokey Creek	2/2/2008 1:18	0.34	0.20	0.05	0.68	0.061	0.0050	0.005	27	4.38	45	56
Smokey Creek	2/3/2008 6:55	0.20	0.20	0.05	0.64	0.0076	0.005	0.005	3	4.43	45	16
Smokey Creek	2/27/2008 10:40	0.36			0.460	0.130			3.4		38	15
Smokey Creek	4/2/2008 14:06	0.20			0.420	0.007			2.2	17.2	38	
Warrior Fork	4/19/2007 13:22	0.20	0.22	0.290	0.083	0.024	0.009	0.006	4.8	13.6	36	
Warrior Fork	5/10/2007 13:05	0.21	0.15	0.210	0.110	0.022	0.011	0.005	6.4	19.1	29	
Warrior Fork	6/21/2007 12:15	0.36	0.57	0.020	0.190	0.033	0.016	0.001	6.2	22.4	41	
Warrior Fork	7/18/2007 12:39	0.20	0.20	0.076	0.088	0.029	0.020	0.009	9.1	25.1	38	
Warrior Fork	8/28/2007 11:59	0.39		0.094	0.110	0.031		0.013	2.0	26.0	34	
Warrior Fork	9/20/2007 12:43	0.20		0.020	0.080	0.027		0.008	3.2	21.3	31	
Warrior Fork	10/18/07 12:52	0.20		0.028	0.052	0.019		0.005	2.7	19.1	37	
Warrior Fork	11/14/07 12:27	0.20			0.029	0.017			2.0	14.4	33	
Warrior Fork	12/19/07 12:56	0.20			0.050	0.060			5.8	6.7	32	
Warrior Fork	1/1/08 10:55	0.20			0.086	0.051			2.2	1.5	25	
Warrior Fork	1/31/2008 18:29	0.20	0.22	0.05	0.06	0.031	0.005	0.005	2	5.39	36.6	2
Warrior Fork	2/1/2008 7:26	0.20	0.20	0.050	0.096	0.04	0.005	0.005	20	3.87	34	23
Warrior Fork	2/1/2008 14:37	0.28	0.33	0.050	0.17	0.10	0.25	0.01	120	6.56	36	91
Warrior Fork	2/2/2008 1:50	0.20	0.20	0.05	0.13	0.032	0.0052	0.0051	36	4.18	32	26
Warrior Fork	2/3/2008 7:28	0.20	0.20	0.05	0.11	0.0063	0.005	0.005	5	3.87	39	7
Warrior Fork	2/27/2008 9:34	0.39			0.020	0.110			11.0		31	12
Warrior Fork	4/2/2008 13:15	0.20			0.100	0.052			3.0	16.9	37	

Sample Location	Collection Date	TOTAL KJELDAHL NITROGEN (COLORIMETRIC) (mg/L)	TOTAL DISSOLVED (Filtered) KJELDAHL NITROGEN (COLORIMETRIC) (mg/L)	AMMONIA (COLORIMETRIC) (mg/L)	NITRITE + NITRATE (COLORIMETRIC) (mg/L)	TOTAL PHOSPHORUS (COLORIMETRIC) (mg/L)	TOTAL DISSOLVED (Filtered) PHOSPHORUS (COLORIMETRIC) (mg/L)	O-PHOSPHATE (COLORIMETRIC) (mg/L)	SUSPENDED SOLIDS DRY WEIGHT (mg/L)	Temp (ºC)	SpCond (uS/cm)	Turbidity (NTU)
Field Blank	5/10/2007 12:56	0.20	0.20	0.027	0.020	0.005	0.005	0.005	2.0			
Field Blank - Client	7/18/2007 11:42	0.20	0.20			0.005		0.004				
Field Blank - Prism	7/18/2007 11:42	0.20	0.20	0.057	0.014	0.005	0.007	0.004	2.5			
Field Blank	8/28/2007 11:52	0.20		0.054	0.014	0.005		0.006	2.0			
Field Blank	9/20/2007 12:38	0.20		0.020	0.020	0.005		0.005	2.0			
Field Blank	10/18/07 12:41	0.20		0.023	0.017	0.005		0.002	3.3			
Field Blank	11/14/07 12:22	0.20			0.014	0.005						
Field Blank	12/19/07 12:50	0.20			0.020	0.021						
Field Blank	1/1/08 6:30	0.20			0.020	0.024						
Field Blank	2/2/2008 11:30	0.20			0.020	0.008						
Field Blank	2/3/2008 9:55	0.20	0.20	0.050	0.020	0.005	0.005	0.005	2.0			
Field Blank	2/27/2008 13:30	0.27			0.020	0.160						
Field Blank	4/2/2008 13:08	0.20			0.020	0.005						