To the Graduate Council:

I am submitting herewithin a thesis written by Tiffany Foster Day entitled "Water quality in two east Tennessee watershed." I have examined the final paper copy of this thesis for form and content and recommend that in be accepted in partial fulfillment of the requirements for the degree of Master of Science, with a major in Plant and Soil Sciences.

Joanne Logan, Major Professor

We have read this thesis
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Vice Provost and Dean of Graduate Studies

Water Quality in Two East Tennessee Watershed

A Thesis Presented for the Masters of Science Degree
The University of Tennessee, Knoxville

Tiffany Foster Day
May 2002

AG-VET-MED.
Thesis
2002
.D39

DEDICATION

I dedicate this thesis to my parents, Jerry and Sandra Foster, who instilled in me the love of learning and the importance of a positive outlook. Their love, faith, and support has been an amazing constant in my life. Through their encouragement and example, I have been able to achieve many of my goals and prepare myself for future challenges. I also dedicate this thesis to my husband, Stuart Bradley Day, whose patience and support has been of tremendous help. Thanks for believing in me.

ACKNOWLEDGEMENTS

The author would like to acknowledge the following persons:

Dr. Joanne Logan, my major professor, for her positive attitude, generous spirit, and constant encouragement. Without her help, I would not be likely finishing my masters degree at the University of Tennessee.

Dr. Michael Mullen, committee member, for his willingness to share his insights and knowledge. Under his guidance, I was able to complete my graduate work and gain a greater appreciation for science.

Dr. Forbes Walker, committee member, for his enthusiasm for this project and constant quest for more funding. Without his dedication and determination, this project might have never been realized.

Galina Melnichenko, University of Tennessee, water quality scientist, whose patience, knowledge, and kindness made this project a great learning experience. Her instruction, assistance, and skill were exceptional.

Jonathon Burr, biologist with Water Pollution Control, TDEC, whose expertise was called upon on numerous occasions. Generosity of his time, guidance, and equipment proved invaluable to the completion of this project.

Melody Ann Sasser, project colleague, for her organizational skills and enthusiasm for this project. With her help, I have learned many valuable lessons.

Warren Downe Devine, Doctoral candidate, for his willingness to participate in numerous sampling events and his dedication to all things mechanical.

Lauren Boettcher and David Mathis, undergraduate research assistants, for their wonderful attitude, dependability, and assistance in water sampling.

ABSTRACT

As part of the Clean Water Act of 1972, all states are required to establish water quality standards, develop a list of impaired waterbodies called the 303(d) list, and create Total Maximum Daily Loads (TMDLs) for these impaired waters (Hession et al., 2000). A TMDL is a calculation of the maximum amount of a pollutant that a waterbody can receive and still meet water quality standards described by the section 303 of the CWA. Water quality is greatly affected by land use (USEPA, 2001b). In Tennessee, agriculture, forestry, and urban land use are predominant nonpoint sources, with top impairments cited as sediments and nutrients. Reduction of nonpoint source pollutants may be accomplished by implementing best management practices (BMP). When correctly installed and maintained, buffers have the capacity to remove up to 50 percent or more of nutrients and up to 75 percent of sediments. Two watersheds were chosen for this project, each containing an impaired stream from the 303(d) list. The first watershed land use was predominantly dairy Pond Creek. The second watershed, Crooked Fork-Emory, had mixed land use. There were two primary objectives for this study: 1) collection and analysis of water samples within two east Tennessee watersheds, Pond Creek (HUC 06010201) and Crooked Fork-Emory (HUC 06010208), and 2) the examination of land use as related to nonpoint source pollutants. Water analysis showed nutrient levels in both watersheds to be greater than ecoregion reference stream data. Overall, nutrient and solids concentrations were higher in the agricultural watershed, with highest concentrations located along the more intensive agricultural land use areas. Crooked Fork-Emory

watershed also showed high concentrations of nutrient and sediments. Residential, commercial, and some agricultural land use are all built on the floodplain, which increases the likelihood of impairment. Water quality improvements could be seen with implementation of BMPs in both Pond Creek and Crooked Fork-Emory watersheds.

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Introduction and Objectives

The establishment of the water quality standards resulted from the Clean Water Act of 1972 (CWA). Under the CWA, all states are required to establish water quality standards, develop a list of impaired waterbodies called the 303(d) list, and create Total Maximum Daily Loads (TMDLs) for these impaired waters (Hession et al., 2000). A TMDL is a calculation of the maximum amount of a pollutant that a waterbody can receive and still meet water quality standards described by Section 303 of the CWA. Tennessee Department of Environment and Conservation (TDEC) is using the BASINS 3.0 (Better Assessment Science Integrating point and Nonpoint Sources) computer model to predict pollutant loading and to develop TMDL criteria for each impaired watersheds (USEPA, 2001a).

TMDL development in Tennessee addresses both point and nonpoint source pollution. Nonpoint source pollutants such as nutrients and sediment contribute greatly to the water impairment in Tennessee, with agriculture cited as the primary source (USEPA, 2001b). Excess nutrients are a concern due to possible eutrophication of surface waters (Aschmann et al., 1999). Other dominant sources of water quality degradation are channelization, urban runoff, land development and contaminated sediments (Stone et al., 1995; USEPA, 2001b). The reduction of pollutants from all of these sources will improve water quality and is a goal of TMDL development.

TDEC has adopted a regional watershed approach to evaluate and develop standards for water quality (TDEC, 2001a). Using this watershed approach allows for consideration of the variance in soils, topography, climate, vegetation, and land use across the state. Tennessee is divided in 54 watersheds that correspond to the eight-digit hydrologic unit code (HUC) numbering system developed by United States Geological Survey (USGS) (Griffith et al., 1999a). These watersheds are divided into five groups for water quality planning, monitoring, and assessment. These five groups are placed on a five-year permitting and monitoring cycle in order to thoroughly assess water quality and develop the appropriate TMDLs (TDEC, 2001b). Currently TDEC has relatively few TMDLs completed and approved by the USEPA (TDEC, 2001b). Lack of monitoring data has delayed TMDL development for some impaired waters.

The current study was conducted to gather water quality monitoring data and determine any relationships between the level of water quality impairment, type of impairment, source of impairment, and land use surrounding the water sampling sites. This data could be useful to TDEC in TMDL development for Pond Creek and Crooked Fork-Emory watersheds. The data could also be useful to land owners in both watersheds.

This project had two primary objectives.

1) The collection and analysis of water samples within two east Tennessee watersheds, Pond Creek (HUC 06010201) and Crooked Fork-Emory (HUC 06010208).
2) The examination of land use as related to nonpoint source pollutants.

Chapter 1
Literature Review

Water Quality and the Clean Water Act

Recently United States Environmental Protection Agency (USEPA) reported that of all waterways assessed, 44% of rivers and streams and 49% of lakes are impaired or threatened. The term impaired refers to a body of water that cannot support its designated use, while the term threatened distinguishes a water body that could fail to support its use (Griffith et al., 1999a). Designated use is a classification system of waters and refers to the manner in which the waterway might be used. Waters not supporting their designated use are considered polluted. Water quality standards and improved water quality monitoring could improve water quality.

Over the past few decades, several key pieces of legislation have been created to protect and improve the water quality in the United States. Beginning in 1956 with the Federal Water Pollution Control Act, the US government has enacted a series of regulations in an effort to improve the water quality for its citizens. The 1956 Act focused on providing funds to publicly owned water treatment centers. Later, the Water Quality Act of 1965 mandated states to develop water quality standards for interstate waters. In 1972, water quality regulations were increased in the form of the Federal Water Pollution Control Act Amendments (PL92-500), better known as the Clean Water Act (CWA) of 1972.

The Clean Water Act (CWA) established the federal permitting program known as the National Pollutant Discharge Elimination System (NPDES), as well as providing significant funds for wastewater treatment and state water quality programs (USEPA, 2001c; USEPA, 2001d). The CWA set requirements for all states to identify and report all polluted waters that do not comply with water quality standards initially established by the EPA (Hession et al., 2000). This act was reauthorized in 1977, 1982, and 1987 (Ribaudo and Kuch, 1999). While the original legislation did not specifically address nonpoint pollution, however the amended CWA of 1987 require states to examine nonpoint sources, as well as wetlands and water quality standards (USEPA, 2001d).

Inputs from both point and nonpoint sources degrade water quality. According to the CWA Section 502, point sources are "any discernable, confined and discrete conveyance, including, but not limited to any pipe, ditch, channel, ...concentrated animal feeding operation...from which pollutants are or may be discharged." Examples of point sources are industrial and municipal discharges. Nonpoint source can be described as polluted runoff that enters the waters not from a specific point like a pipe, but dispersed over a larger area. Nonpoint source pollution contaminates surface and ground waters. Nonpoint sources include inputs from agricultural activities, construction sites, and urban runoff. Often, cropland, pasture, concentrated animal feeding operations (CAFO), and rangelands are lumped together as agricultural contributors (Parry, 1998). The inclusion of CAFOs within the nonpoint source agricultural activities category is misleading because CAFOs are regarded as point source pollutants according to the CWA (USEPA, 2001e).

In accordance with the CWA, states are required to address water quality issues of their waterways. It is necessary for each state to develop water quality standards to use as a reference to assess the condition of the waters at present time and in the future. The standards that the individual states develop are subject to approval of the EPA (USEPA, 2001f). In addressing the water quality issues of individual States, are required to assess waters and assign designated uses, develop water quality criteria, and develop and enforce standards and regulations for water quality improvements (figure 1). All figures and tables for this thesis can be found in the appendix section.

Initially, states must assess waterways and assign a designated use. The term "designated use" refers to the manner in which the waterway might be used. The waterway may or may not be in use for that particular activity at the time, but the quality of the water should be maintained so as to allow that use at a later date. Waters might be set aside for possible future uses such as water supply, navigation, or recreation. Second, states must develop criteria that can be used as a standard to judge water quality in each water body. These criteria can be qualitative or quantitative, and the values are often based on EPA standards published for water quality criteria. This step is where many states, including Tennessee, are having difficulty in assigning a working, realistic value for water quality parameters. The final step is development and enforcement of standards and regulations to prevent further pollution into these waters (Parry, 1998).

Water quality that is less than optimal, or not fully supporting its designated use, can affect many aspects of the watershed community. Aspects affected include aquatic life, recreational opportunities, public safety, and economic issues. Nationally, 303 (d) lists show over 218 million Americans live within 16 km of an impaired water body

(USEPA, 2001f). The primary factors causing water impairment are excess sediments, excess nutrients, and microorganisms (USEPA, 2002a).

Aquatic life is threatened in many areas where water quality standards have not been meet and habitat alterations have occurred. Many streams and lakes which once had a vast number of aquatic life species have seen the diversity decline rapidly. This decline of aquatic species can be used as an indicator of possible poor watershed health.

Nationally, one-third of the freshwater fish and approximately 72% of native freshwater mussels are threatened, endangered, or of special concern. Amphibians and crayfish do not fair any better, with 51% of crayfish and 40% of amphibians listed as imperiled or vulnerable. In Tennessee, at least 56 fish taxa are reported as threatened, endangered, or of special concern (Griffith et al., 1999a).

Aquatic life may also be threatened due to excess sediment in waters. Increased sediments loads can decrease light penetration, which can influence water temperature and dissolved oxygen levels. Also as sediment enters the waters, it brings with it nutrients such as nitrogen and phosphorous that are attached to soil colloids. Excess nutrient levels in surface waters may enhance eutrophication processes (Figure 2). Large increases in nutrients can greatly increase algal growth. Numerous algal populations impair water quality by causing drinking water to taste bad, blocking out light for aquatic organisms, clogging water-intake pipes, and decreasing the aesthetic value of the water body (Mueller and Helsel, 2001). As the algae die off and decomposition begins, the waters may become depleted of dissolved oxygen which can result in fish kills (Correll, 1998). Some algal blooms are more problematic, and may cause harm or death to humans, fish, shellfish, and other wildlife (USEPA, 1998a).

Tourism may also be negatively affected by impaired water quality. The decline in local waterway quality may threaten activities such as fishing, boating, swimming, water sports, camping, and hiking. Currently several reservoirs and streams in Tennessee have fish advisories posted, where consumption of either specific fish or in some cases all fish is warned against (TDEC, 2001c). Fishing has been halted in certain rivers and lakes in an effort to repopulate the regions as fish numbers have declined (Tennessee Wildlife Resources Agency, 2002). In some waterways, TDEC has determined that the level of contaminants, often pathogens, might pose a health risk to humans. Other deterrents to recreational water use are associated with odor, taste, and visual appearance. Often water quality is judged on appearance alone, which may be deceptive. However, studies indicate that if confronted with unpleasant odor or appearance, people will likely not want to frequent that waterway or live in an area that is considered to have "water problems" (House, 1996).

Impaired water quality may negatively affect human health. Waterborne pathogens, such as Cryptosporidium may pose great health risks, even at low exposure (Gostin et al., 2000). Outbreaks due to microorganisms may increase in the presence of excess nutrients in the waters (Mallin, 2000). Water pollutants such as heavy metals, disinfectants, inorganic chemicals, organic chemicals, and radionuclides can also pose human health risks. Exposure to these contaminants may cause the following health risks: increased cancer risk, nervous system effects, reproduction problems, liver or kidney problems, circulatory problems, and immune system problems (USEPA, 1999). Excess nutrient levels, primarily nitrogen and phosphorus, may also create problems in drinking water. Reports have shown of nitrate concentrations greater than 10 mg/L or

nitrite concentrations greater than 1 mg/L in drinking water may cause methemoglobinemia or "Blue baby syndrome" in infants less than six months. This condition is life threatening if immediate medical attention is not given (USEPA, 2002b). No negative health effects have been contributed directly to phosphorus concentrations in drinking water. However, phosphorus has been related to toxic algal blooms or anoxic conditions of surface waters that can harm humans and animals (Carpenter et al., 1998). The presence of algal blooms in drinking waters requires the use of disinfectants. Some of the disinfectants used result in potentially carcinogenic disinfection by-products, such as trihalomethanes to be released in the waters (USEPA, 2002c).

Economics also plays a role in water quality and regulations. It is commonly believed that it is cheaper to prevent the pollution than remediate the pollution. A case study of a municipal water treatment plant showed that impaired water quality increased the overall cost of water treatment. The dollar amount spent in chemical treatment increased along with the raw water contamination (Dearmont et al., 1998). Improvements in water quality that allow new recreational and commercial fishing use add to the economic benefits associated with water quality. Lake Erie provides an example of improved water quality and increased economic benefits (USEPA, 1998b).

In Tennessee, the Division of Pollution Prevention and Environmental Assistance collaborates with industrial and government leaders to find ways to minimize waste output and locate a place for the waste that is created before it reaches the waters (TDEC, 2001d). Nationally, funding and incentives are available to industry in an effort to entice them to comply with current or even future pollution regulations and criteria (Copeland, 2001). For agricultural pollution, both federal and state funds are made available to aid

in the development and implementation of techniques to limit the inputs of nutrients, pesticides, and sediments into the water (USEPA, 1998b).

Tennessee has greater than 60,000 stream miles and 540,000 acres of lakes. TDEC reports that 74% of the streams assessed have excellent water quality (TDEC, 1998a). However, many water bodies do not meet the designated use and are considered polluted. In Tennessee, nutrients and sediment inputs are among the top five water quality impairments. Agriculture is cited as the number one source of nutrients both in Tennessee (USEPA, 2001b) and across the United States, (Griffith et al., 1999a; Parry, 1998;). Other prevalent sources of water quality degradation are channelization, urban runoff, land development, and contaminated sediment (Stone et al., 1995).

Regionalized water quality management practices encompassing assessment, monitoring, analysis, reporting are needed. TDEC sets water quality standards and performs assessments every two years to determine if the waters are meeting water quality standards. During the initial assessment and evaluation of Tennessee waters four major categories were examined: natural and scenic beauty, recreational boating, recreational fishing, and water quality. In addition to these categories, cultural resources and navigation were also taken into account. The streams and lakes of Tennessee are assigned a classification based on use, such as drinking, wildlife and livestock watering, industrial water supply, fish and aquatic life, recreation, irrigation, and navigation. This evaluation was accomplished with cooperation of many groups and agencies as well as private consulting firms (TDEC, 1998b).

The water quality assessment is divided into four supporting classes and one "not assessed" class. The four identified classes are: "1. fully supporting designated uses

assigned to it by the Water Quality Control Board, 2. Fully supporting designated use but threatened, 3. Partially supporting designated use. 4. Does not support designated use. Currently, agencies are working to decrease the number of unassessed waterways. Every two years the Water Pollution Control (WPC) division of TDEC publishes water quality data in a 305(b) report, The Status of Water Quality in Tennessee (TDEC, 1998b).

After the streams are assessed, TDEC compiles a report called the 303(d) list of all the streams that are either impaired, might be impaired in the near future, or might need more stringent pollution control measures. The 303(d) list is used rank in order of need streams which qualify to be involved in a more intensive water quality project called a Total Maximum Daily Load (TMDL). The 303(d) section of the Clean Water Act requires that states perform TMDL studies on each stream that is listed on the 303(d) list (TDEC, 1998c).

Part of water quality assessment involves judging stream quality. Comparisons between streams and lakes to a reference water body can provide a starting point in evaluating water quality. For comparisons to have meaning, reference water bodies must be reasonably similar to the water that is being studied. For this comparison, ecoregions are well suited. The concept of ecological regions (ecoregions) framework has been studied and strengthened since the 1970s in the U.S., New Zealand, the Netherlands, Canada, Australia, and other countries. Ecoregion classifications have been used to assess and develop standards for water quality and biological criteria, as well as environmental resources. Ecoregion classification is a hierarchal scheme that uses Roman numerals to delineate the levels. The most broad level is Level I. Fifteen Level I ecoregions are contained within North America. Level II divides North America into 52

ecoregions. Level III classification recognizes 98 ecoregions within the continental United States. States across the U.S. have further divided the Level III classes into Level IV subecoregions. The decision to develop subecoregions was based on the need to account for differences across Level III ecoregions. Multiple factors were considered in developing the ecoregions such as geology, soils, physiography, land use, vegetation, climate, and water quality (Griffith et al., 1997).

Tennessee is divided into eight Level III ecoregions and 25 Level IV subecoregions (Figure 3). Within each subecoregion, state agencies have identified reference streams that will serve as a basis for comparison in biological criteria and water quality evaluations (Arnwine et al., 2000). These streams may not be pristine when compared to other areas, but they are generally considered to be the least impacted waters within the region. The hope is to establish a reference stream to serve as a benchmark for the level of water quality attainable in that ecoregion (Griffith et al., 1997).

Point source pollutant load reductions have been successful in reducing loads into waterways. However, reducing the point source pollutant load is only part of the solution. According to the EPA, point source pollutants are responsible for approximately 10% of pollutants in waterways, while nonpoint sources contribute up to 43% of the pollutants causing impairment in the 303(d) listed waters (USEPA, 2000a). Clearly, focus needs to be placed on lessening the impact of nonpoint source pollutants to the waterways. The amended CWA in 1987, section 319 specifies that nonpoint source pollution be managed on a watershed basis (Hession et al., 2000). The implementation of watershed management plans and TMDLs is necessary to target both nonpoint and point source related water quality problems.

Land use attributes can greatly affect water quality by influencing additions of nonpoint source pollutants such as sediment and nutrient to waterways. There is a correlation between land use and pollutant loading into streams. Impairment of water quality can be reduced by good land use management practices (Basnyat et al., 2000). Across the nation, agriculture, contributing 15% of nonpoint source pollution, is the leading source of nonpoint pollution (Table 1).

In Tennessee, agriculture, forestry, and urban land use are the predominant nonpoint sources. Recent studies show agricultural runoff from pastures is a significant contributor to excess nutrients and sediments to surface waters. Concentrated Animal Feeding Operations (CAFO), which are classified as point sources, can impair water quality. EPA reports show CAFO effluent runoff contributes 26% of all surface water impairments. Crop and animal agricultural pollution was indicated in 72% of assessed rivers and streams in EPA reports (Glover, 1996).

Pasture animals can destabilize the stream banks causing undercuts to the bank. This may allow for the introduction of pollutants such as nutrients and sediments. Additional inputs of nutrients occur when animal feed lots and pens are located close to waters. Animal waste from these lots or pens can pollute local waterways either by runoff due to precipitation or spraying off during routine cleaning. Nutrients are also added to the stream by direct input of waste from animals in the water (Lory, 1999).

Tennessee has approximately 13 million acres of forest, 80% of which is privately owned (Read, 2001). Within forested areas, removal of streamside vegetation, road use and construction, and timber harvesting may contribute to nonpoint source pollution. Ninety percent of the total sediment pollution in forested land areas may be directly

related to road use and road construction (EPA, 1997). In the Yazoo Basin uplands in Mississippi, forested areas demonstrated lower sediment loads (200kg/ha/yr) than agricultural lands. However, these pollutant loadings are responsible for about 47-76% of P and N added to the watershed (Schreiber et al., 2001).

Some urban nonpoint source pollutants are similar to nonpoint source pollutants in agricultural areas. These pollutants include sediment, excess nutrients, oxygen demanding organic materials, and bacteria. Failure of septic systems, leaking sewage pipes, and overflow of public sewer systems contribute pollutants such as nutrients and bacteria (Aschmann et al., 1999). Storm water runoff in urban areas contributes to nonpoint source pollution. Within the urban landscape, the amount of pollutants carried by runoff is influenced by the surface perviousness as well as the contaminants the runoff comes in contact with (Bhaduri et al., 2000).

It is clear that inputs of nutrients and sediment negatively impact water quality across the United States. Reports show excess nutrient inputs, riparian degradation and sediment loading associated with agricultural practices and urbanization are largely responsible for water quality degradation. In the US, although some locales have shown a downward trend in farming, the intensification of farm production has dramatically increased. High intensity farming, especially animal production, can severely degrade the land and local watershed. The USDA and EPA both note the correlation between the increase in animal production operation and the decrease in water quality on a watershed basis (USEPA, 2000b).

Best Management Practices

Reduction of nonpoint source pollutants may be accomplished by implementing best management practices (BMP) in agricultural areas, forests, and urban land. In agricultural areas nutrient management planning, no-till farming, buffer zones, pasture management, hardened stream crossings, strategic fencing, and alternative livestock watering systems can be effective in reducing sediments and nutrients loading to streams. Nutrient management planning can benefit both the producer and water quality. Nutrient management plans can be used to evaluate field conditions by considering inputs of all nutrient sources, both man-made fertilizer and manure, along with all nutrient outputs (Sharpley and Withers, 1994). Nutrient management plans allow the producer to consider multiple aspects of his farm operation and develop a management plan that will strive for maximum productivity, reasonable cost, and reduced water quality impairment. Effective fertilization techniques could help prevent nutrient loads to the waters and be cost effective for crop producers. Other fertilizer management practices such as accurate soil testing, well-timed fertilizer applications, and applying crop required amount of fertilizer could reduce the amount of fertilizer and nutrients that are available to enter surface and ground waters (Sims et al., 2000).

No-till farming practices aid in reduction of surface runoff and erosion, therefore nutrient and sediment loading to surface waters is reduced. Research in the Yazoo Basin uplands in Mississippi with conventional farming has shown sediment loads to the upland watershed to be approximately 19,000 kg/ha/yr. This accounts for 77-96% of P and N in transport in this region. In comparison, no-till operations showed sediment loads to be

500 kg/ha/yr, which contribute 31% of P and N moving into waterways. In areas with conventional tillage, one storm event can produce loading rates equal to the annual pollutant loads (Schreiber et al., 2001). In Tennessee, studies have shown no-till to be effective in sediment load reductions. Seven-fold reductions of sediment concentrations were seen in Beaver Creek watershed in west Tennessee.

Another BMP is buffer zones that consist of permanently vegetated areas, usually in small strips adjacent to waterways that are intended to capture pollutants, such as pesticides, nutrients, or sediments, and stabilize streamside land. Examples of buffers include: riparian buffers, filter strips, cross-wind strips, shallow water areas for wildlife, field borders, alley cropping, herbaceous wind barriers, and vegetative barriers. Studies finding agree that buffers can be affective in reducing nutrient and sediment inputs to streams, but differ on the degree of effectiveness. Studies performed by the Natural Resource Conservation Service (NRCS) state that when correctly installed and maintained, buffers have the capacity to remove up to 50 percent or more of nutrients and pesticides, up to 60 percent or more of certain pathogens and up to 75 percent or more of sediment (NRCS, 2000). An urban area study shows buffer zones can be used effectively in nonagricultural environments in reducing the nitrate loading (Basnyat et al., 2000). Studies have shown riparian buffer strips effective management techniques for removal of nitrate, with near 80% efficiency ratings (Jordan et al., 1993).

Other examples of BMPs that relate directly to livestock management are pasture management, hardened stream crossings, strategic fencing, and alternative livestock watering systems. Pasture management refers to many combined management practices aimed at balancing forage production and animal grazing needs. Efforts are taken to

reduce the risk of overgrazing which could result in soil erosion or nutrient runoff. Techniques such as rotational grazing and alternative hay feeding can reduce grazing pressure in areas of low forage growth. Hardening stream crossings provide a solid path for animals to travel across a stream in a pasture setting. Geotextile fabric and gravel are used to construct the crossing, with fencing placed on both sides of the crossing to prevent animals from wandering in the stream. Hardening stream crossings can reduce the direct inputs of nutrients and bacteria, along with reducing stream bank destabilization that occurs as animals cross streams (Johnson, 2001).

Reducing pollutant loading can also be accomplished by fencing. The placement of fencing within a pasture area is used to keep the animals out of the water and away from the stream banks. This can prevent bank destabilization and minimize the amount of animal waste directly entering the water, thus reduce nutrient and sediment inputs. If livestock is fenced out of waterways, water must be provided from another source. Alternative watering systems such as AC electric pumps, gravity pumps, and sling pumps can benefit both water quality and animal producers. Water quality is improved by keeping the animals out of the streams, thus reducing pollutant loading. Producers may benefit by a reduction in soil erosion, flexibility in pasture rotational management, and reduction of possible animal injury from watering in stream (Johnson, 2001).

Best management practices are also available for urban areas with nonpoint pollution. Failed sewer and septic systems, new construction and habitat alterations are some of the primary sources of water pollution associated with urban land use. Some of these pollutant sources are easier to address than others. Faulty waste removal systems can lead to excess bacteria and nutrients in the water. Much of this occurs due to

networks of old underground pipes that form many city sewer systems. The pipes are made of terra cotta, which over time have developed leaks and cracks. This type of public sewer system is found throughout the state of Tennessee. The problem will likely remain because it does not seem feasible to dig up all pipes across a city and replace them with new PVC piping (Burr, 2001).

However, there are BMPs that could be utilized to improve the pollutant loading in urban areas. Reduction of nitrogen and phosphorus to streams in residential areas could be accomplished by adequate, not excess fertilizer applications. Often homeowners fertilize lawns and gardens without the benefit of soil testing. Soil tests can help to determine the nutrient needs of the soil, giving homeowners a guide on how much fertilizer can be utilized by the land. Excess fertilizer not only wastes money and time, but the nutrients in the excess fertilizer can leach through the soils or wash off during precipitation events and eventually reach surface waters. Management practices of street sweeping and litter control can help reduce contaminants available to be carried by runoff or washed down storm drains. The reduction of impervious areas will also help control nonpoint source pollution by reducing the area from which water can runoff and increasing infiltration (Bhaduri et al., 2000). Erosion control measures, such as silt fencing and seed mats, can reduce sediment loading at construction sites. The addition of greenways to urban areas provides water filtration as opposed to runoff, and may provide a catchment for pollution (Carpenter et al., 1998).

Forestry best management practices have been developed to lessen the impact of nonpoint source pollution. Maintaining or installing buffer zones along stream banks reduce sediment and nutrient loads. To reduce the nonpoint source impacts from erosion,

proper management of road construction and maintenance is also essential. Ideally, roads should follow the natural contours of the land, avoiding steep gradients and waterways. If timber harvesting is to occur within the forested area, steps should be taken to minimize land disturbance that could increases sediment and nutrient loads (NRCS, 2000).

Total Maximum Daily Loads (TMDLs)

The Clean Water Act requires states to develop Total Maximum Daily Loads (TMDL) for water bodies not meeting their designated use. A TMDL is a calculation of the maximum amount of a pollutant that a waterbody can receive and still meet water quality standards described by the section 303 of 1972 Clean Water Act (USEPA, 2001f). The EPA further defines TMDL as a "mechanism for determining a cost –effective combination of steps that will result in a polluted water body being restored and attaining water quality standards."(USEPA, 2000c). The purpose of the TMDL plan is to improve the water quality by: allowing the states to identify areas in need of pollution reduction within their state, make available an inclusive register of all of the polluted waters in the US, take into account all possible pollution sources and the possible cleanup options (TDEC, 1998c). A simplified flow chart of the steps involved in TMDL development is shown in figure 4.

Each state in the US is required to adopt pollutant criteria for waterways. States may use the EPA's water quality standards to set qualitative or quantitative concentration levels for each pollutant or create their own standards subject to EPA approval. If states have criteria for pollutants and they are still not meeting their water quality goals, new criteria or permit limits need to be set. The idea is that with lowering the allowable

amount of pollutant in the water body, the water will be able to meet the standard for water quality. TMDLs are developed to give states new permit limits when water bodies are not meeting the water quality standards set forth by the existing point source permits.

The following equation shows the factors considered to develop TMDLs for each pollutant in each stream segment.

$$\sum WLA + \sum LA + MOS = TMDL = \text{Loading Capacity}$$

The WLA refers to waste load allocations of point sources contributing the pollutant of interest within the stream segment. The LA identifies load allocations for nonpoint sources and natural background levels pertaining to the particular pollutant within the stream segment. Both the WLA and LA include existing and future pollutant loadings. The margin of safety (MOS) that is factored into the TMDL attempts to account for the lack of knowledge on exactly how much of a pollutant is too much before the stream becomes impaired and on the variability of natural background levels (USEPA, 2002c). In development of the MOS, both actual and possible pollutant inputs are considered along with naturally occurring or background levels of some pollutants (Parry, 1998). Two approaches for MOS values are available: the implicit approach which uses assumptions from conservative model or the explicit approach which reserves a part of the total TMDL as the MOS and uses the rest for allocations (USEPA, 2002c).

Although Clean Water Act provisions were passed in 1972, most states have done little to address the problem or adhere to the regulations set forth. Activism of citizens and environmental groups has returned the focus to the TMDLs and the 303(d) section of the Clean Water Act. Recently, these groups have filed suit against individual states for not complying with the CWA and with the EPA for not enforcing compliance with the

laws and regulations pertaining to the development of TMDLs and the formation of 303(d) lists (Leclair, 1997). As a result of legal actions taken, in many states the EPA is required by the court to guarantee that TMDLs are being developed in a timely manner (Parry, 1998).

Currently, 38 states have had legal action brought against them because of failure to develop TMDLs or make progress towards their development. If the states are not capable of developing the water quality standards and TMDLs, the EPA must step in and perform the tasks (TDEC, 1998c; Parry, 1998). Tennessee is one of the states that has been pressured by legal action taken to complete more TMDLs. According to TDEC's own website, they have fallen behind in their TMDL development schedule. Thirty-four TMDLs from high priority watersheds were to be developed in 2000 and 2001. By the end of year 2002, 46 TMDLs of high priority are to be completed (TDEC, 2002a). The total number of TMDLs completed and approved by EPA as of April 2002 is only 17, 16 for fecal coliform and 1 for copper (USEPA, 2002d). Less than adequate funding and few staff members contribute greatly to the failure to meet TMDL development schedules (Burr, 2001).

Under the TMDL rule, states are required to produce a report every four years listing the water bodies that are polluted and the schedule for clean up. States may also include waters that are threatened. In regards to the TMDL final rule, the states will be given ten years to produce a cleanup schedule for impacted water bodies, a five year extension will be provided if needed. The EPA is asking that polluted waters used for drinking supplies or that provide habitat for endangered species be given top priority. If

this is not implemented, the states must justify to the EPA why this step is not necessary (USEPA, 2000a).

There will be certain key components that each TMDL will contain such as the name and location of the water body, the acceptable amount of pollutant, the load reduction needed to be in compliance, the pollutant source, point source waste load allocation, runoff or nonpoint source waste load allocation, and an implementation plan. In addition, each TMDL will include a margin of safety factored into the, "consideration of seasonal variation; and allowance for reasonably foreseeable increases in pollutant loads." In order to allow the addition of new TMDL factors at a later time, a transitional period is in place. Before the states submit the TMDLs to the EPA, citizens will be provided opportunity to review the priority and completeness of the waters listed, the methods used to assess the waters, and the TMDL reports (USEPA, 2000a). Once the state has developed a TMDL plan for a body of water, the state submits the plan to the EPA. The EPA then decides whether the plan meets the required goals or if revisions are necessary. The EPA retains the power to redo the TMDLs entered by the state if it feels they are inadequate (USEPA, 2001f).

Continuing evaluation of the clean up processes should be noted and adjustments made if the TMDL plan in place is not providing the desired results. The TMDL plan should also cite the date that the standards for water quality will be reached (should be within ten years). Lastly, within five years of the start of the TMDL plan, any runoff controls that might be needed should be implemented (USEPA, 2000a).

The TMDL final rule also spells out the steps to implement the TMDL plan. This would likely begin with an outline of measures to be taken to reduce or eliminate the

pollution inputs along with a schedule for accomplishing these tasks. This TMDL plan should take into consideration both nonpoint and point pollution sources as well as other pollutants that may not fit into either category. With the plan, it should be implied that the states would follow through with the clean up plans. This is referred to "reasonable assurance" and can be examined by looking at point and nonpoint sources of pollution. For point source, this reasonable assurance will come about by the use of the already established National Pollutant Discharge and Elimination System (NPDES) permits. For nonpoint source pollutants and any other pollutants, EPA requires that for each TMDL the load allocations must follow certain rules. The loadings need to apply to the specific pollutant, be employed quickly, use effective programs, and have adequate water quality funding (USEPA, 2000a).

Revised TMDL regulations were issued in 1985. This step called for nonpoint source and load allocations to be addressed. Later in 1992, a revision was made that required the states to report the 303(d) lists every two years. In 1999, more changes to TMDL and NPDES rules were proposed. The latest version of the rules, currently called the Final Rule was issued on July 13, 2000. The implementation of these rules cannot be fully realized due to a rider that Congress placed on one of its appropriations bill, this rider disallows the funding of this rule 2000. The rider makes it so the EPA cannot spend the FY2000 and FY2001 money to employ this new rule (USEPA, 2000a).

TMDLs can provide a means for states and the EPA to work together to develop ways to improve the water quality and prevent further degradation. A major benefit of the TMDL plan is that the State controls much of the process. This allows the State to implement a plan fit specifically for their needs. In addition, this gives individual states

the opportunity to develop incentive or reward based plans to entice polluters or potential polluters to reduce pollutant outputs (USEPA, 2000a).

Many states have adopted the watershed approach to address TMDL development and water quality assessment (Figure 5). In 1996, TDEC decided to use a regional watershed approach to evaluate and develop standards for water quality in an effort to comply with the 1972 Clean Water Act (TDEC, 1998c). A watershed can be defined as "an area that drains to a particular lake or stream" (TDEC, 1998a). Using a watershed approach allows for the consideration of the variance in soils, topography, climate, vegetation, and land use across the state. Also, using the watershed approach allows TDEC to take a broader approach and consider inputs from all sources. The watershed approach incorporates the idea that what is going on in one stream or lake within the same watershed can have a profound influence on the other streams or lake within the watershed. Land use activities and disturbances to the land in one part of the watershed play a role in the quality of the watershed downstream.

Nutrients and Solids

According to EPA Office of Water Division, April 2000, the top three pollutants are sediments, pathogens, and nutrients. The sediment category includes entries for turbidity, sediment, and siltation. The nutrient category includes nitrogen, phosphorus, algae, and aquatic weeds. Twelve states in the US have a narrative criterion for nutrients; these standards were formed primarily to examine the unwanted growth of algae and weeds. For some pollutants, such as phosphorus, the EPA has developed numerical criteria for marine and estuary waters, but not for fresh water or drinking waters. Some states have developed their own phosphorus criteria, while almost half of the states have

no set limit on phosphorus inputs (Parry, 1998). EPA standards for nitrate concentration in drinking water have been adopted and are set at 10 mg/L. Standard drinking water levels for nitrite are 1 mg/L (USEPA, 2002c). However, criteria for nitrogen in general use water systems are not in place (Stewart et al., 2001).

Nutrient additions to waterways by human activities account for an appreciable amount of pollutants. EPA reports contributions from urban runoff contain 3-10 mg N/L and 0.2-1.7 mg P/L, livestock operations: 6-800 mg organic N/L and 4-5 mg P/L, atmospheric depositions: 0.9 mg N/L and 0.015 mg P/L, untreated wastewater: 35 mg N/L and 10 mg P/L, treated wastewater: 30 mg N/L and 10 mg P/L (USEPA, 2002c).

Nitrogen exists in different states in nature, continually cycling (Figure 6). Nitrogen can be found as organic nitrogen, inorganic nitrogen, or gaseous nitrogen. Atmospheric nitrogen gas accounts for the largest pool of nitrogen and N_2 is not immediately available to life forms and requires conversion be to biological usable. In terrestrial or aquatic environments, conversion of nitrogen gas occurs via three general processes: nitrogen fixation, ammonification, and nitrification. A fourth process, denitrification, converts different forms of nitrogen into a gaseous form. The state of nitrogen in the environment is dependent on factors such as pH, oxygen, and moisture levels (Flite et al., 2001).

Biological nitrogen fixation involves organisms such as cynobacteria, *Rhizobium*, and *Azobacteria* that can convert nitrogen gas into NH_4^+ and NH_3. Ammonification relies on decomposer organisms to metabolize organic materials such as wastes and non-living organic tissue to produce ammonia. The third process, nitrification, is a two-step process that is also assisted by microbes. *Nitrosomonas* work to oxidize NH_4^+ into

nitrite. This process leads to the further oxidation of nitrite to form nitrate by *Nitrobacters* (USEPA, 2002e). The generalized term, mineralization, refers to the conversion of organic nitrogen into inorganic nitrogen with the help of microbes as described in the ammonification and nitrification processes.

Nitrate in soils can undergo denitrification. This process can occur in aerobic or anaerobic conditions. Under anaerobic conditions, nitrate is reduced to N_2O, N_2, and NO and then enters the atmosphere. This gaseous form can return to the soils and water environments through acid deposition (Brady and Weil, 1999).

Nitrogen can exist in several forms in terrestrial and aquatic environments: dissolved nitrogen gas (N_2), ammonium (NH_4^+), ammonia (NH_3), nitrite (NO_2^-), nitrate (NO_3^-), and organic nitrogen (USEPA, 2002c). Organic nitrogen is the form most commonly found in animal and human waste. Ammonium is also found in waste and is immediately available, but accounts for a much smaller amount of the nitrogen. In dairy manures, organic N accounts for much of the manure. Manure produced by livestock varies with breed, weight, feed, gender, and other factors. Average manure outputs for one average weight (450 kg) dairy cow is 36 kg/day (NRCS, 2001).

Much of the organic nitrogen is converted into inorganic nitrogen (NH_4^+, NO_2^- and NO_3^-), but some will be temporarily held in organic materials with the possibility of transport to surface waters. In soils, plants can use some of the NH_4^+, and the remainder is available for other processes such as nitrification, clay fixation, or volatization. Gaseous forms of nitrogen allow for the addition of nitrogen to surface water from atmospheric deposition and the loss of nitrogen from soil or water to atmosphere from volatization. Volatization can occur at soil surfaces when ammonia is not incorporated

into the soil or readily taken up by biota, the process can also occur along the water-air interface of surface waters. The nitrogen ratio of the soil can affect volatization rates. Exposure to environmental factors such as high temperature and high winds, as well as the concentration of NH_3 in the atmosphere can influence volatization rates.

NH_4^+ can also be adsorbed onto clay colloids, which can account for some inorganic nitrogen movement into surface waters during runoff events. The NH_4^+ moves with the eroded soil and can be released in the water. NH_4^+ fixation can also occur. Due to the small size of the ion, NH_4^+ can become trapped or fixed within an expanding clay, such as vermiculite. Inorganic nitrogen can also be converted into organic nitrogen by immobilization. This process is often described as the reverse of mineralization, with immobilization being dominant in environments with high (greater than 30:1) carbon:nitrogen ratio (Brady and Weil, 1999).

The majority of NH_4^+ undergoes nitrification. Once in the nitrate form, many paths are possible. Nitrate can be assimulated by both plant and microbial organisms. Leaching may also occur because nitrate does not readily bind with soil or organic matter so nitrate not utilized by biota is available to move through the unsaturated zone of soil (USEPA, 2002c). Once nitrate moves below the root zone, chance of nitrogen entering the ground water via subsurface flow or lateral flow into surface waters increases. Soluble organic nitrogen, the second most prevalent nitrogen form, can also enter ground water. The presence of nitrate in ground water, subsurface flow, or lateral flow areas provide a potential contamination source for wells and surface water (Bottcher and Rhue, 2001).

Nitrogen in surface waters can be found as dissolved nitrogen gas (N_2), ammonia (NH_4^+ and NH_3), nitrite (NO_2^-), nitrate (NO_3^-), and organic nitrogen. Immediately available forms such as NH_4^+, NO_2^-, and NO_3^- can have the most significant impact on water quality. High concentration of these forms of nitrogen can enhance eutrophication. These forms of inorganic nitrogen can be used by aquatic organisms, which later die and give off ammonia during decomposition. The ammonia ions continue to cycle through the aquatic environment and can be converted into nitrate and nitrite, available for uptake by aquatic organisms.

The cycling of nitrogen through the aquatic environment shows seasonal variations, largely due to the influence of temperature and its affect on aquatic life and dissolved oxygen concentrations. Factors such as pH, precipitation, land management also affect the forms and concentrations of nitrogen in surface and ground waters. Usually nitrate concentrations accumulate in the soil during fall and summer, when plant uptake is lower (Tate et al., 1999). This could lead to increased nitrate concentrations available for leaching into ground water or surface runoff. Surface waters can become contaminated due to surface runoff, erosion, atmospheric deposition, subsurface flows, and ground water inflows. Sources of nitrogen that contaminate water are runoff from fertilizer on both agricultural fields and residential landscapes, leaching from septic tanks, leaking sewage lines, sewage system overflows or failures, animal inputs, and erosion of natural deposits (Stewart et al., 2001).

High levels of nitrogen in surface or ground waters can negatively affect water quality. Nitrate levels above 10 mg/L present in drinking waters can cause methemoglobinemia, or blue baby syndrome, which can be a life-threatening syndrome

for infants. Levels of nitrate greater than 100 mg/L can cause a bitter taste in drinking waters and cause physiological distress (USEPA, 2002e). Aquatic life can be poisoned by ammonium concentrations greater than 2.5 mg/L. The occurrence of this is not as frequent as other nitrogen problems due to rapid conversion of ammonia into nitrite and nitrate. The addition of nitrogen has been seen to cause great damage to water quality as evidenced by areas such as the Gulf of Mexico. This area is sometimes referred to as the Dead Zone because it has been depleted of oxygen to the extent that aquatic life cannot survive. In this case, both humans and aquatic life are directly affected by eutrophication (Gburek et al., 2000).

Phosphorus is a naturally occurring element with rocks and natural phosphate deposits being the primary source of phosphorus. Activities such as weathering, leaching, erosion, and mining can release phosphorus from its sinks. Additional phosphorus enters the environment through rainwater, plant residues, additions of fertilizer (both organic and non-organic), and animal and municipal wastes.

Like nitrogen, phosphorus is cyclic in nature (Figure 7). Phosphorus can exist in organic or inorganic states and is often described in terms of dissolved and solid or particulate fractions. In most soils, inorganic phosphorus contributes two-thirds of the soil phosphorus, while organic phosphorus makes up the remaining one-third (Urban, 2000). Organic phosphorus can be either dissolved or particulate forms and is found in microbial tissue, plant tissue, and municipal and animal waste. Inorganic phosphorus occurs in dissolved forms such as $H_2PO_4^-$, HPO_4^{2-}, and PO_4^{3-} and particulate forms. The soluble inorganic fraction exists as $H_2PO_4^-$, HPO_4^{2-}, and PO_4^{3-}. This group of phosphorus ions is also refered to as soluble reactive phosphorus (SRP). In highly acidic soils (pH 4-

6), $H_2PO_4^-$ is the most prevalent species. More alkaline soils (greater than pH 7) tend to favor HPO_4^{2-} and PO_4^{3-}. In soils with relatively neutral pH, $H_2PO_4^-$ and HPO_4^{2-} are found in equal amounts. The term inorganic phosphorus particulate refers to labile and fixed phosphorus. Labile phosphorus is loosely held, exchangeable phosphorus attached to calcium, iron or aluminum. The fixed fraction is tightly held and is found in compounds such as Al-phosphates, Fe-phosphates, Ca-phosphates (Brady and Weil, 1999).

Organic phosphorus can undergo mineralization with the aid of microbes, which converts the organic fraction into inorganic phosphorus that is readily available for biotic use. Inorganic become immobilized due to bonding with calcium or iron. Inorganic phosphorus can be converted into organic phosphorus in a process called immobilization, however this process is not as prevalent as mineralization.

Phosphorous in water can be adsorbed to sediments in the water column or to substrate making it temporarily unavailable. Phosphorus can settle on the stream bottom and remain here until an increase in stream flow or disturbance of the stream bed causes it to be resuspended. Microbes can assimilate inorganic phosphorus and when the microbes are ingested or die, this organic phosphorus can be transformed back into SRP (USEPA, 2002e).

Phosphorus movement from soils occurs in various forms and by different transport methods. Particulate phosphorus, attached to soil particles, moves with soil erosion brought on by precipitation or wind. Plant uptake is responsible for removal of some of the dissolved inorganic phosphorus. More dissolved phosphorus is transported away from the soil by surface runoff (Sharpley and Withers, 1994). In soils with already high levels of phosphorus, dissolved phosphorus can be lost by leaching. Soils seen in

areas of intensive animal agriculture such as Rhode Island have experienced leaching of phosphorus due to continued inputs of manure on phosphate rich soils. The leached phosphorus has the possibility of entering ground water and subsurface flows, which could eventually reach surface waters. Additional phosphorus is associated with fine particulates in the atmosphere and can enter waterways by precipitation events or dryfall (USEPA, 2002e). Additions of phosphorus can cause water quality degradation, with the most notable result being enhanced eutrophication.

The extent of phosphorus movement varies with several factors such as land use, soils, pH, climate, and topography. Generally on farmland soils, phosphorus is transported in the particulate form attached to soil particles (Tate et al., 1999). In areas of grasslands and forests, the majority of P is in the dissolved form that is transported by runoff (Lemunyon and Gilbert, 1993). The source factors of phosphorus movement are functions of soil type, crop nutrient requirements, pH and land management. Phosphorus transport factors are surface runoff, erosion, and subsurface flow. Usually watershed areas that have both high soil test phosphorus and historically contribute water to the nearby streams in the way of surface runoff are capable of transporting phosphorus. Additionally, the timing and techniques of manure or other fertilizer applications play a large role on the land's ability to utilize all of the phosphorus placed on it and determine if there is a risk of the phosphorus moving to surface waters (Sharpley and Withers, 1994).

Agricultural phosphorus is believed to be one of the highest sources of the additional phosphorus found in polluted waters. Much of the problem is believed to stem from the over-application of phosphorus to fields in the form of manure. Manure is

currently applied to land on a nitrogen-based rate (Sharpley et al., 1994). The addition of manure to soils can increase all forms of phosphorus, with inorganic phosphorus showing a greater increase than organic. This phosphorus can contribute to water quality impairment.

In agricultural settings, there is a greater risk of phosphorus movement due to the N: P ratio of manure ranges from 2:1 to 6:1 while the crop uptake generally ranges from 7:1 to 11:1. This imbalance in the ratios is a problem because in order for growers to get enough N on their crops, they will apply nutrients in manure form by the N rate. This leads to a build up of P in the soil. If the conditions are right, this excess P can be transported away from the application site and end up in waters, potentially causing problems (Gburek et al., 2000).

Excess solids in surface waters pose problems also. High sediment loads can become problematic when sunlight is blocked from the water surface. This can affect water temperature, gas exchange, decompostion rates, and photosynthetic processes. Additions of sediment can further degrade water quality by increasing nutrient levels, transporting metals and organics, and clogging gills of aquatic life (Denton et al., 2000). The term solids can be used to describe sediment, as well as mineral (calcium and magnesium) and organic matter in waters. Total solids refers to total sediments in surface waters. Total solids are measured without filtration of water sample. Suspended solids refers to sediment that is suspended within the water column and can be filtered from the water sample (Greenberg et al., 1992). Dissolved solids can be experimental defined as any mineral, organic, or sediment material that passes through a specified filter during analysis.

Surface runoff is the primary factor controlling sediment loadings to the stream. Agricultural practices such as tillage can increase erosion by removing plant cover and leaving soil exposed (Stone et al., 1995). Drinking water standards for total dissolved solids (TDS) are set at 500 mg/L. Waters with solid loads above this concentration have hardness, scaly deposits, cloudy or colored water, unpleasant odor, staining for materials that come in contact, salty or bitter taste (Stewart et al., 2001).

Water Sampling

Agencies formulating TMDLs use surface water quality samples to assess current conditions as well as chart water quality improvements from reductions of pollutant loading. Water sampling can be performed by surface grab sample or cross-sectionally, integrated flow composite. EPA determined that grab sampling in a representative area of the stream would be suitable to assess water quality. Many states have adopted this method because of lower cost, simplified operations, and less equipment needs (Martin et al., 1992). According to standard protocol of TDEC, surface waters should be sampled by grab sampling methods and collected a minimum of 10-12 times per year. Nitrogen, phosphorus, and solids are examined because these are primary water quality impairments in Crooked Fork-Emory and Pond Creek watersheds according the 303(d) list.

In evaluating watershed water quality, samples are gathered at the top or headwater of each watershed, then along the main stream within the watershed at points above and below probable sources of nonpoint pollutant loading. These nonpoint pollutant sources can be dairy farms, sod farms, leaking septic tanks, floodplain development, abandoned mine drainage ponds. Additional samples can be taken at the

bottom of each watershed and along incoming tributaries thought to have significant impacts. Samples may also be taken along stream sections where visible damage to the riparian zone is noted (Burr, 2001).

Samples taken during or immediately following storm events have shown to vary from samples collected prior to event. Storm events generally produce higher levels of pollutants in streams, primarily nutrients and sediments and can be helpful in determining seasonal variations of pollutant loadings. A study showed that timing and frequency of the sampling were very important in getting an accurate assessment of the nature of the watershed. Parameters examined were turbidity, suspended solids, ammonium (NH_4-N), nitrate (NO_3-N), and orthophosphate (PO_4-P). The study stated large storm events are capable of transporting nonpoint source pollutants, such as nutrients, out of watersheds so it would be important to record levels before and immediately following storm events. This study showed an increase in nitrate concentrations associated with storm events, which lowered after the event ended. Most phosphorus is transported out of the watershed by attachment to suspended solids. This phosphorus movement is influenced by seasonal variability because the amount of most suspended solids is affected by the precipitation intensity and the surface runoff. It has been shown that nitrate levels are highest at the first storm event of the year and become lower throughout the remainder of the year. Sampling only late in the season could result poor nitrogen inputs interpretation and incorrectly assume that nitrogen does not play a role here. Sampling only during storm events or peak flows or conversely sampling only during low flows could lead to misinterpretation of the sediment interactions within the watershed (Tate et al., 1999).

Determining stream velocity is important to pollutant loading. Examining the load allows for consideration of the concentrations of the pollutant and the volume of water associated with it. Tate et al. (1999) believes that to adequately assess water quality improvements, even several years may not give a thorough picture of trends developing or to note the differences that BMP are having on a watershed verses just seasonal or weather influences (Tate et al., 1999). Studies show that for nutrient TMDL development, stream flow parameters need to be considered because they directly influence depth, velocity, turbulence, reaeration, and volatilization in the stream, which can have a direct influence on the nitrogen and phosphorus species found in the waters (USEPA, 2002c). Paired watershed studies have shown to be beneficial in some cases when examining possible causes of water impairment and remediation techniques in the watershed (Tate et al., 1999).

Computer Modeling Tools

Geographic Information Systems (GIS) and Global Positioning Systems (GPS) technology has advanced greatly in recent years. Many aspects of daily living have been influenced by GIS/GPS. Growing use of GIS/GPS systems is seen in agricultural and environmental fields. Precision agricultural, land development, soil mapping, resource management, and water quality management are some areas that this technology has proven useful. Precision agriculture utilizes GPS/GIS in many aspects. Precision agriculture has influenced the crop production business greatly. Having access to soil information in GIS format has lead to improvements in land management and farm productivity. Computer technology has also allowed producers to relate simple soil characteristics, such as texture, organic matter content, and bulk density to more complex

characteristics, such as hydraulic conductivity and moisture retention (Bouma, 1999). GPS farming systems can assist farmer in applying fertilizer or herbicides only where needed to obtain maximum yield. Planting rates can also be assessed by GPS systems. Overall, utilizing GPS/GIS systems in precision agriculture can reduce waste and increase productivity for farmers (Trimble Corporation, 2000).

GIS technology is utilized in soil mapping. The National Cooperative Soil Survey (NCCS) is updating soil survey maps across the United States. Historically, the maintenance of soil surveys was delegated to individual counties and soil surveys were performed on a county basis. The updated soil surveys will be based on Major Land Resource Areas (MLRAs) and use GIS. This switch will provide greater accuracy and consistency to the soil maps, as well as giving users easier access to the soils data (Brannon and Hajek, 2000). Resource management and land use often use GPS/GIS to enhance the understanding of a landscape. Using GIS data layers such as STATSGO, SSURGO, DEM, and LULC (land-use/land cover) can aid managers in land use planning (Wu et al., 2001).

To assess water quality and develop solutions, identification of nonpoint source pollutants and loadings is necessary. There is a growing trend to move away from the simple monitoring of the concentrations of nutrients and other pollutants in the waters to an overall assessment of the watershed (Chen et al., 1999). This would allow for future predictions of watershed quality and possibly help determine the most effective and best placement of BMPs to control or improve water quality. Attempting to assess water quality on a watershed scale requires consideration of many parameters. Existing data such as climatic data, like precipitation patterns, storm events, temperatures, humidity,

stream flow, biological data, and benthic organisms will be useful in water quality assessment. Historical and current land use, as well as BMP treatments, past known pollutant input concentrations and sources, point source inputs, water use classification, will also assist watershed management. Using computer software programs, data can be organized, managed and analyzed competently (Mattikalli et al., 1996).

Most models addressing watershed assessment incorporate the use of GIS and GPS technology. Some of the models currently in use by state and federal agencies are GLEAMS, AGNPS, WASP, EPIC, SWAT, and BASINS (Table 2).

Watershed Ecosystem Nutrient Dynamics (WEND) is a computer-based model that utilizes the computer language STELLA to evaluate the inputs, outputs and events associated with phosphorus within a watershed. STELLA is noted for being user friendly and easily adaptable to individual needs. The WEND model is being developed with the cooperation of USDA/NRCS, Watershed Science Institute (WSSI), and other parties. This model will be used to look at all possible pathways for phosphorus to enter and exit the watershed, and will be capable of evaluating various management practices that would affect the levels of phosphorus in the watershed over time (Aschmann et al., 1999).

The GLEAMS (ground water loading effects of agricultural management system) is a mathematical water quality model that can be used on the field scale to predict the possible movement of phosphorus and nitrogen, as well as pesticides on agricultural lands. The GLEAMS model uses hydrology, sediment and erosion yields, and chemical transport submodels (Yoon et al., 1994). By examining the local data for weather, crop and land use, soil type, field conditions, the model has been used to imitate the transport

of nutrients and chemicals from the land by way of runoff, leaching, and subsurface flow (Boisvert et al., 1997).

Many studies have utilized GIS/GPS systems in examining water quality and watershed management. One model, long-term hydrologic impact assessment nonpoint source (L-THIA/NPS GIS), has been used in a watershed in Indiana. This model uses long-term climatic records, soil data, and land use data to compute average annual runoff and nonpoint pollution in response to land use changes in the watershed (Bhaduri et al., 2000). An Alabama study was conducted using GIS software to correlate nitrate concentration levels in waters to local land use. This study helped identify potential problems of urban build up and water impairment and demonstrated that reductions in nitrate levels could be reduced by buffer zones (Basnyat et al., 2000).

The computer model to be used in this study will be BASINS 3.0 (Better Assessment Science Integrating point and Nonpoint Sources). The configuration of BASINS is conducive to developing TMDLs on a watershed basis, using ArcView as a framework. The first version of BASINS was created in 1996 by Tetra Tech Corporation for the EPA's Office of Water. BASINS was developed to assess environmental information, analyze ecosystems, and give a basis for ecological management possibilities on a watershed level. The second release of the BASINS model, called BASINS 3.0, was in 1998. BASINS 2.0 and 3.0 along with the data sets and tutorials are available free of charge on the EPA website or copies of BASINS and the data can be requested from EPA on CD-rom (USEPA, 2001a).

The BASINS model uses the powerful technology of GIS to perform complex tasks and make available a multitude of databases. Using ArcView GIS as the model's

framework allows great spatial organization and gives the user the ability to overlay georeferenced data from outside sources. With BASINS, users can query environmental data from national databases, locate sensitive land areas, and run ecological models. The BASINS data available are grouped into three categories; spatially distributed data, environmental monitoring data, and point source data. Some of the databases available are land use, digital elevation models, counties outlines, weather data, gauging station data, nutrient concentrations, biological data, roads, toxic release inventories, water quality parameters, and soil surveys. With the databases available for BASINS, it is possible to perform water quality analysis of selected watersheds and develop maps, charts, and reports showing the results (USEPA, 2001a).

Environmental modeling assessment tools available within BASINS that use an ArcView GIS environment are, TARGET, ASSESS, and DATA MINING. These tools are used to evaluate water quality and examine point source loading on small or large-scale projects. Simulations of pollutant loading and transport with the BASINS model can be useful in developing TMDLs and determining where best management practices would be most effective. WinHSPF (Windows Hydrologic Simulation Program-Fortran) and SWAT (Soil and Water Assessment Tool) are watershed loading and transport models within BASINS 3.0 (USEPA, 2001g).

The SWAT modeling tool was developed by Jeff Arnold for the Agricultural Research Service. SWAT is a physically based, continuous time model that was created to predict land management effects on water quality and agricultural chemical and sediment yields in watersheds. The model is able to predict events occurring within the watershed by allowing many different physical processes to be simulated at once. This

model draws from many of the earlier models, such as CREAMS, GLEAMS, and EPIC. SWAT is directly related to the SWRRB (Simulator for Water Resources in Rural Basins). SWAT has undergone many transformations and improvements, such as better accuracy in nutrient cycling predictions and increased land management options for simulations.

Watershed or site specific inputs of weather, soil properties, topography, vegetation, and land management practices are required by SWAT and allow for greater accuracy during simulations. Direct modeling of physical processes such as water movement, sediment movement, crop growth, and nutrient cycling are accomplished by SWAT. Improvements in SWAT have brought many benefits. One benefit is that watersheds that do not have monitoring data can be modeled using the other specified parameters. Changes of land management and climate or weather events can be quantified (DiLuzio et al., 2001).

While BASINS and the technology associated with it have great possibilities, much work is needed to determine the field accuracy of the model's predictions. To determine if this computer model is giving realistic assessments, field trials over an extended period are needed. Opinions of BASINS as a useful water assessment tool were favorable in a recent report in the Journal of the American Water Resources Association. However, it was noted that some of the tools within BASINS could be faulty and further enhancement of the program was needed (Whittemore and Beebe, 2000).

Chapter 2
Methods

Methodology for this study included water sampling and analysis within two east Tennessee watersheds, analysis of water quality data with a statistical computer program, and utilization of BASINS and SWAT to examine land use as related to water quality data.

Site Selection

Two streams were selected from TDEC's 303(d) list of impaired waterways, with the help of Jonathon Burr from Water Pollution Control, TDEC. The primary streams are listed as partially supporting their designated uses. The first stream, Pond Creek, is located in Pond Creek watershed. The second stream, Crooked Fork, is located in Crooked Fork-Emory watershed. Eight sampling sites within each watershed were selected with TDEC. Factors influencing site selection are reported in table 3.

Watershed and Site Descriptions

Pond Creek watershed

Pond Creek is located in the Upper Tennessee River Basin, within the Watts Barr/Fort Loudon watershed (HUC 06010201) as shown in figure 8. Pond Creek is the smaller of the two watersheds, with an approximate area of 8090 ha. It is located mostly in Loudon County, where dairy operations are the dominant land use (Figure 9). The topography of this watershed shows gently rolling hills, with many meandering

tributaries. Elevations range from 239 meters to 336 meters. Pond Creek watershed is contained within the Ridge and Valley ecoregion IV (ecoregion 67) shown in figure 10. The study site is located within subecoregion 67f. Details of subecoregion 67f are presented in table 4. Figure 11 shows that STATSGO classifications of soils in this region are predominantly Ultisols.

Figure 12 shows the location of Pond Creek sampling sites and table 5 provides detailed information regarding land use, soils, and site description. By convention, water sampling sites are numbered starting with the lower, most downstream site of the primary sampling stream and assigning this site number one and then work your way up stream, numbering stream sites. Site numbering in Pond Creek varies slightly from this in that sites 7 and 8 are tributaries to Pond Creek. Site 8, along Mud Creek, is the most upstream of all segments studied, and it joins Pond Creek above site 6. Site 7 is located on Greasy Creek and joins Pond Creek just downstream of site 6 before reaching site 5 (figure 12). Figure 13 shows the Pond Creek watershed stream network and proximity to the Tennessee River. According to the 303(d) list, Pond Creek is partially supporting due to pollution from nutrients, sediments, and habitat alterations. Impairment sources are listed as removal of riparian zones and nonpoint source concentrated animal feeding operations.

Crooked Fork-Emory watershed

The second watershed included in this study is Crooked Fork-Emory, located in Morgan County (Figure 14). Within the Emory River watershed (HUC 06010208) and Clinch River basin, this watershed is approximately 12, 960 ha and with mixed land use (Figure 15). Table 6 shows soils in this watershed are mostly Ultisols, with a presence of

Inceptisols and Alfisols. Distribution of the soils can be seen in figure 16. Mountains dominate the topography in this area, with elevations range of 364 m to 977m. Figure 17 shows the location of Crooked Fork-Emory sampling sites and table 6 provides detailed information regarding land use, soils, and site description. Sites in this watershed are numbered by identifying the primary stream, Crooked Fork, and numbering the downstream segment as site 1, and then working up the stream for sites 2-6. Sites 7 and 8 are located along a tributary to Crooked Fork, called Flat Fork. The upper reach of Flat Fork was assigned site 8 and the downstream of this reach was assigned site 7. Flat Fork enters Crooked Fork downstream of site 2 (Figure 17). The larger stream network can be seen from figure 18. This watershed falls within two Level IV ecoregions, Southwestern Appalachians (ecoregion 68) and Central Appalachians (ecoregion 69). These ecoregions are further subdivided into subecoregions, with Crooked Fork-Emory watershed spanning 68a, the Cumberland Plateau, and 69d, Cumberland Mountains (Figure 19). Table 4 gives a more detailed look at both of these subecoregions.

Much of the development in this area is concentrated along the river that runs along the valley of the mountainous area. The rapid development has created problems as people have built homes, businesses, and roads along the floodplains in this region. Impairments for Crooked Fork-Emory River are nutrients, habitat alteration, and siltation. TDEC lists the pollutant sources as pastureland, channelization, and abandoned mines.

Water Sampling

Water sampling began May 2001 and continued through February 2002. Selection of the subwatersheds and water sampling sites was performed with Tennessee Department of Environment and Conservation (TDEC). Water sampling is performed by grab sampling method, and follows TDEC sampling protocol. Two types of sample bottles were used, amber colored glass and high-density polyethylene. Grab sampling refers to manually collecting water samples with single bottles by submerging a bottle under water approximately 15 cm, with the mouth of the bottle facing up stream, until the bottle is full. Sample bottle is then removed from the stream, capped, and chilled. Grab samples from eight sites in each watershed are collected monthly, with sample duplicates collected at each site. Samples are collected mid-channel, in free flowing streams. Before samples were collected, bottles were cleaned thoroughly and dried. At the sample site, the bottles were rinsed three times with the sample water to be collected before the actual sample was obtained. This helped ensure a less contaminated sample (Buurman et al., 1996).

To begin sampling, flow direction of the water body was determined. Collection was upstream of the sampler so as to not contaminate the water collected. Sample bottles were completely submerged (approximately 15 cm below the surface), with the mouth of the bottle facing upstream. Once the sample bottles were filled and capped, they were labeled immediately in order to ensure proper record keeping. We were careful not to contaminate the sample by contacting the water sample itself, the inside of the sample bottle, or cap. If the stream volume was too low to have continuous flow, this was noted in the field book and no water sample was taken. Each water sample was labeled with the site location, time and date, and then placed in ice coolers. Cooling of

samples can help reduce biodegradation and conversion of nutrients before the sample is analyzed. Water samples were not allowed to freeze because this might change the pH reading or cause a separation of the dissolved organics in the water sample. Once in the lab, samples were kept at 4 degrees C in a refrigeration unit (Buurman and Velthorst, 1996).

The following parameters were observed in the field at each sampling site: water temperature, pH, dissolved oxygen, specific conductivity, ambient temperature, relative humidity, flow, stream width, stream depth, and weather conditions. The YSI 600XL Multiparameter probe (YSI Incorporated, Yellow Springs, OH) was used to determine pH, conductivity, water temperature, and dissolved oxygen. The need for field analysis is related to the time factor (Tate et al., 1999).

Flow measurements were made perpendicular the stream channel, using a portable flow meter. Eight to ten flow measurements were taken at each sampling site. The distance between the individual flow measurements varied with the width of the stream. Two different meters were used throughout the study period, Swoffer Portable flow meter and Marsh-McBirney Flo-Mate model 2000. Ideally, one flow meter would have been used for the duration of the experiment, however due to equipment failure, the Marsh-McBirney was not usable to several sampling events. During some sampling events, no flow was recorded due to complete failure of the meters and the lack of a reliable backup. On occasions when no usable flow meter was available, estimates of flow were taken. Estimations were performed by marking off 6 m along the stream bank and using a stop watch to time the length of time it took an object, such as a leaf, to go the 6 m distance. This was repeated three times and an average taken. Comparison of

the two flow meters showed that the Marsh-McBirney flow meter was better suited to the needs of this study. This meter was more sensitive for very low flows and was able to measure negative flows that sometimes occurred in areas along the stream bank. Data for flow is recorded in Table 7. This data can be used to calculate the loading of each pollutant to the stream segment.

Laboratory Analysis

Samples were analyzed in the University of Tennessee Department of Biosystems Engineering and Environmental Science Departmental laboratories immediately upon returning from the field. The following laboratory analyses were performed on each sample: total Kjedahl nitrogen (TKN), total phosphorus (TP), nitrate, nitrite, phosphate (soluble reactive phosphorus), total solids, suspended solids, dissolved solids, turbidity, BOD-5 day, COD, TOC, and NH_3-N. Nitrogen, phosphorus, and solids are examined because these are water quality impairments in Crooked Fork-Emory and Pond Creek watersheds according TDEC's 303(d) list. Analyses of chemical and physical parameters were performed within the allotted time frame. Concentrations of nitrate and ammonium can change drastically over a relatively short time period. Due to the instability of these compounds, ammonium, nitrate, and sulfate analyses were conducted as soon as possible. Portions of each sample were preserved by freezing for future comparison.

Total Kjedahl Nitrogen (TKN) analysis reports the sum of organic nitrogen and ammonia. Analyses for TKN were performed in accordance with the Standard Methods (Greenberg et al., 1992). For this study, analyses of TKN utilized the LACHAT

QuikChem Method 10-107-06-2-E (Diamond, 1992). Water samples were prepared by block digestion and analyzed by colorimetry. This method is capable of determining nitrogen levels within the range of 0.1 to 5.0 mg N/L in drinking water, ground and surface waters, domestic and industrial wastes. Sulfuric acid is added to the water samples for digestion, mercuric oxide is also added as a catalyst. After digestion, samples are diluted with 20 mL of deionized water before analyzed by colorimetry. The procedure changes biological forms of nitrogen, such as amino acids, proteins, and peptides to ammonium. The ammonium is heated with salicylate and hypochlorite to give a blue color that is proportional to the amount of ammonium in the sample. Adding sodium nitroprusside intensifies the color. This ammonium is measured by flow injection analysis into a colorimetric detector. Determining the concentration of ammonium is achieved by comparing the absorbance of the sample to a standard absorbance curve. The stock standard is made from ammonium chloride dissolved in deionized water. The standard curve uses concentrations of 5.00, 2.00, 1.00, 0.50, 0.25, 0.10, and 0.0 mg N/L (Diamond, 1992). This measurement relates to the amount of TKN in the water sample.

Analysis for total phosphorus (TP) also uses block digestion and the LACHAT QuikChem. TP analysis utilizes the LACHAT QuikChem Method 10-115-01-1-C (Liao, 1993). This method is applicable in the range of 0.01-5.0 mg P/L, with a detection limit of 0.005 mg P/L. Six standards were used to create the standard absorbance curve for phosphorus. Water samples were prepared by block digestion and analyzed by colorimetry. During block digestion, organic phosphorus in the water sample is converted to orthophosphate. A complex is formed by a reaction with ammonium molybdate, antimony potassium tartrate and the orthophosphate anion (PO_4^{3-}). This

complex is reduced by ascorbic acid and forms a blue complex that absorbs light at 880 nm. Colorimetric absorbance correlates with the amount of orthophosphate in the sample (Liao, 1993).

Ammonia analyses were performed using the HACH 2500 spectrophotometer, Method 8038, Nessler Method. The spectrophotometer measures the ammonia concentration in water samples by using 425 nm wavelengths. This procedure was adapted from Standard Methods for the Examination of Water and Wastewater, SM 4500-NH_3 C (Greenberg et al., 1992). The estimated detection limit is 0.06 mg NH_3-N/L. The Twenty-five mL of each sample were mixed with a mineral stabilizer, polyvinyl alcohol-dispersing agent, and Nessler reagent. The sample mixture is placed in a clean, non-scratched glass cell and placed in the spectrophotometer. Blanks were prepared by using deionized water with the reagents. The blank was used to "zero out" the spectrophotometer and set a base line for ammonia measurements. This base line was set at the start of each analysis period. The mineral stabilizer, zinc sulfate, reacts and complexes with the calcium to inhibit precipitation of residual calcium ions. Precipitation can occur when the Nessler reagent is added to the sample because of the alkaline nature of the Nessler reagent. The polyvinyl alcohol-dispersing agent helps produce the color in the reaction of the Nessler reagent and ammonium ions. The intensity of the yellow color corresponds to the ammonia concentration. A greater intensity relates to a higher ammonia concentration (HACH, 1995).

Determination of nitrate (NO_3^-), nitrite (NO_2^-), and phosphate (PO_4^{3-}) was accomplished by ion chromatography, SM4500C from the Standard Methods for the Examination of Water and Wastewater 18th edition (Greenberg et al., 1992). In

preparation, water samples were passed through a 0.45 μm pore diameter filter to remove particles that could interfere with the procedure Using ion chromatography allows for the evaluation of multiple anions at once. An anion separator column can determine concentrations of nitrate, nitrite, phosphate, sulfate, chloride, bromide, and fluoride. Ion chromatography works by injecting the sample into a stream of bicarbonate eluent and passing it through ion exchangers. The anions become separated according to their affinity for a low capacity, strongly basic anion exchanger. The anions then are converted into a highly conductive form within a fiber suppressor column. The carbonate-bicarbonate eluent is changed into a poorly conducting carbonic acid. The anions can then be measured by their conductivity as determined by peak areas. Different anions will remain on the column for different lengths of time, so it is possible to determine which peak belongs to which anion. The area under the peak measures anion concentration (Greenberg et al., 1992).

Measurement of total solids, dissolved solids, and suspended solids was performed according to Standard Methods for the Examination of Water and Wastewater 18th edition, SM2540C, SM2540D, and SM2540D respectively (Greenberg et al., 1992). Total solids refer to material residue remaining in the dish after drying and evaporation of water sample for a set time. Total solids include dissolved and suspended solids. Dissolved solids refer to solids that pass through a 2.0 μm pore glass filter. Dissolved solids can be estimated by subtracting the suspended solids from the total solids. Suspended solids are the portions of the solids that remain on the filter. All solids test samples were dried in an oven at 103-105 degrees C and then desiccated. This varies

from the Standard Methods for the Examination of Water and Wastewater 18th edition, which requires dissolved solids to be dried at an oven temperature of 180 degrees C. The temperature for drying solids in our lab is set at the lower temperature after repeated solid analyses were performed and shown to be as accurate as the 180-degree ovens. For total solids analysis, a sample volume of 25 ml provided sufficient residues (Greenberg et al., 1992). For dissolved solids and suspended solids, a 25 ml of sample water was also used and filtered once through a glass fiber filter. Successive washing were not performed after determination of this method not producing good results.

Ecoregion Comparison

Ecoregion reference stream data for each watershed were compared with water quality data from our water sampling sites. Eight month mean watershed composite water sampling data for each watershed was compared with ecoregion reference stream data for each watershed. Pond Creek watershed in located in ecoregion 67, Central Appalachian Ridge and Valleys (Figure 10), and was compared with the ecoregion 67 reference stream. Crooked Fork-Emory watershed spans two ecoregions, ecoregion 68 is Southern Appalachians and ecoregion 69 is the Central Appalachians (Figure 19). The Crooked Fork-Emory data was compared with reference streams in the two ecoregions. Ecoregion data provided information for the following parameters: pH, total phosphorus, suspended solids, total dissolved solids, total Kjedahl nitrogen, and ammonia.

Statistical Analysis

Data from nutrient, solids, and BOD-5 day analysis were evaluated using statistical computer software SAS, version 8.1. Pearson correlation procedures for total solids, suspended solids, dissolved solids, total P, phosphate, TKN, nitrate-N, ammonia-N, BOD-5 day, and pH were performed with $\alpha = 0.05$ for each watershed. General Linear Mean (GLM) regression analysis were performed for each watershed examining total solids, suspended solids, dissolved solids, total P, phosphate, TKN, nitrate-N, ammonia-N, BOD-5 day, and pH. The GLM procedure was used to compare water quality parameter values by site in each watershed and to compare storm event sampling values with non-storm event sampling values for each watershed.

BASINS Computer Model

The BASINS 3.0 computer model with the SWAT watershed tool was used to examine several features within Pond Creek and Crooked Fork-Emory watershed. Within BASINS, separate projects for each watershed were developed using HUC data sets for each watershed provided on the EPA BASINS 3.0 website (USEPA, 2001a). These data sets (Table 8), provide georeferenced, spatial data that can be helpful during watershed assessment and watershed land use characterization. These data sets were downloaded, extracted, and projected according to the BASINS manual. The data sets in the individual projects are referred to as themes and appear in the BASINS view window as map-like features. Additional data of National Hydrologic stream data and digital elevation grids were used to enhance the data sets. Exact sampling site locations were

obtained using GPS coordinates obtained from a Trimble GPS Geoexplorer II unit at each sample site. This information was processed in a dbf file format and then added as manually added sampling points or outlets to the project data in the BASINS view. The procedures used for setting up the projects and running BASINS and SWAT followed the BASINS 3.0 users manual and the SWAT 2000 users guide (USEPA, 2001g; DiLuzio et al., 2001).

BASINS and SWAT tools were used to gather information from the data sets pertaining to our study areas. Delineation of Pond Creek and Crooked Fork-Emory study areas was performed using the BASINS manual delineation tool, resulting in a new watershed theme in each project. These delineated watersheds were used to form a "mask area" within each project. The mask area was used to define the study area from the larger HUC data set. With the mask area set, the Watershed Delineation management tool was used to input outlet points along the stream segments within each watershed. The outlet points used were the 8 sampling sites points that were in each watershed. BASINS uses this information to divide the watersheds into subbasins dependent on the digital elevation themes, outlet and inlet points. Each subbasin represents the drainage area pertaining to an individual sampling site, so there are 8 subbasins that relate to 8 sampling sites. Up to this point, BASINS 3.0 was used. The following information pertains to using the SWAT model interfaced with BASINS. The SWAT model houses the land use and soil distribution tool. This tool was used to determine land use and soil distribution, along with elevation data within each subbasin (USEPA, 2001g; DiLuzio et al., 2001). Reports were generated showing total land area,

elevation, land use classifications, soil classes and descriptions data for each watershed as a whole and for each of the 8 subbasins BASINS defined.

Chapter 3
Results and Discussion

Evaluation of water quality data was performed for each watershed. A computer statistical program was used to perform comparisons among sampling sites and contrast storm event sampling results and nonstorm event sampling results. BASINS 3.0 and SWAT land use and subbasin delineation data was used to examine possible land use effects on water quality parameters within each watershed. Comparisons were made between reference stream data for each watershed and water sampling results.

Comparison of both watersheds

Although this study was not conducted as a paired watershed study due to differences in study areas, some general comparisons were made regarding the eight month mean site composite data for each watershed (Tables 9 and 10) and the overall land use within each watershed (Tables 5 and 6). Most parameters were found in greater concentrations in Pond Creek watershed than in Crooked Fork-Emory watershed. Heavy agricultural land use seen throughout Pond Creek is likely the cause of greater concentrations in nutrients, and total and dissolved solids. These finding are consistent

with previous studies showing animal production contributes higher nutrient and sediment loads to streams when compared with other land uses (McFarland and Hauck, 1999).

Comparisons of Pond Creek watershed eight month mean sampling data with the Ridge and Valley (ecoregion 67) reference stream values show water sampling concentration results for all parameters greater than the ecoregion reference stream data (Table 9). This result is not surprising because Pond Creek is listed on the 303(d) list for nutrient and sediment pollutants (USEPA, 2002b). Table 10 shows Crooked Fork-Emory watershed sampling data along with mean ecoregion values for reference streams. Crooked Fork-Emory reference streams showed some variability between each other, but both reference streams have values less than the eight-month mean water sampling data for Crooked Fork-Emory watershed.

Pond Creek

Examination of Pond Creek land use showed most of Pond Creek watershed farms have cows grazing in pastures, with some pastures showing signs of heavy use and poor ground cover. Riparian zones are generally worn down, often with steep undercuts along the banks. Cattle are allowed uninhibited access to the streams in this watershed, which is likely the cause for the riparian damage. Studies in North Carolina have shown that decreased riparian zones can increase nutrient streams loading to streams (Stone et al., 1995). Cattle cross the streams at numerous locations along Pond Creek, without the benefit of hardened crossings. Hardened crossings are a type of BMP that provides a solid area, using geotextile fabric and gravel, for the animals to use when they cross the

stream. The crossing looks similar to a small gravel road that dips into the water as it spans the stream. These crossings are beneficial in the reduction of stream bank damage incurred when animals cross streams. Hardened crossings also help reduce sediment, nutrient, and organic inputs into the water.

Several dairy producers have feed lots and holding pens within close proximity to the streams, which can encourage the cows prolonged presence along the riparian zones. Pond Creek farms also have areas with poor vegetative cover, the exposed soil can lead to soil erosion and sediment and nutrient stream inputs. All of these factors have been cited in studies to increase nutrient and sediment stream inputs (Carpenter et al., 1998). BMPs such as nutrient management plans, runoff management, strategic fencing, protected heavy use areas, pasture management, buffer strips and alternative watering systems could help reduce sediment and nutrient concentrations entering the stream.

Nutrient management plans are a good starting place for reducing sediment and nutrient inputs in streams. Nutrient management plans provide the farmer an estimate of what nutrients are entering his land, what's being utilized on the land, and what is leaving the land, possibly entering the streams. Runoff management practices involve diverting rainwater so that it does not come in contact with manure and allowing this water to cross a vegetative buffer strip. This reduces the overall volume of contaminated liquid that has to be treated as waste. Strategic fencing, simply fencing the cows out of the stream, can also help in Pond Creek. Currently, there were no observable areas where cows were denied access to streams. Blocking access to the stream by fencing, could eliminate direct animal inputs to the stream, as well as reduce stream bank damage and sediment inputs that can occur when the cows are crossing through the streams. When the cows

are fenced out of the stream, an alternative watering system will be needed. Alternative watering systems benefits are cleaner, dependable water source for animals, reduced injury risk of animals that would have been climbing muddy banks to get to stream water, reduced stream bank damage which could allow buffer strips to grow. Reduction in soil erosion, sediment and organic matter into streams could also be accomplished using protected heavy use areas. Many areas surrounding both Pond Creek and its tributaries have areas denuded of vegetation surrounding the feed and watering troughs. These heavy use areas could be protected by constructed a compact surface, with geotextile and gravel, similar to hardened crossings. In Pond Creek watershed, overgrazed areas with poor vegetative cover from pasture management BMPs could be utilized.

The animal production in this watershed is primarily small family-owned farms. These farms can have a significant impact on the water quality in this watershed. The cows are grazed in pasture and generally not considered CAFOs. However, once an animal comes in direct contact with the waters of the state, the farm is considered a CAFO, despite the size of animal units per farm (Walker, 2002).

Pond Creek data showed positive correlations ($\alpha < 0.05$) for most of the tested parameters (Table 11). Suspended solids (SS) did not show a correlation with dissolved oxygen (DO). Expectations were contrary to this because suspended solids influence several water parameters such as turbidity, temperature, and nutrient loading. These factors affect the concentration of dissolved oxygen (Denton et al., 2000). Correlations of nitrogen and phosphorus are shown in table 11. This was expected due to agricultural land use throughout Pond Creek watershed, with multiple dairy farms within close proximity to the streams that were sampled. Agriculture, specifically animal operations,

has been cited in numerous studies as being a significant contributor to nonpoint source pollutants such nutrients and solids (Eghball and Gilley, 1999; Younos et al., 1998).

Comparison of water quality parameter values among the eight sites in Pond Creek showed some parameters were variable among the eight sampling sites while others were not (Table 12). This could be contributed to different transport methods for nitrogen and phosphorus.

Table 13 shows LSMeans from the GLM procedure for each parameter averaged over eight months of sampling data for each site. Figures 20-22 show mean concentrations per site for nutrient and solids data. Concentration levels for all Pond Creek sampling sites were greater than ecoregion 67 reference stream values for Pond Creek. Site 1 has the lowest mean concentrations for total phosphorus, total Kjedahl nitrogen, ammonia-N, and biochemical oxygen demand, 5 day (Tables 13 and 14). Low concentrations for nutrients here were expected because the land use immediately surrounding site 1 is primarily forest, which is atypical for this watershed (Table 5). This site has the least amount of agricultural land use across the watershed. Studies have shown that agricultural land use usually contributes more nutrients to surface waters compared with forested areas (McFarland and Hauck, 1999). The minimum biochemical oxygen demand value seen at site 1 was related to lower nutrient and sediment concentrations at this site compared to the other seven sites in Pond Creek watershed (Sharpley et al., 1994).

Site 6, along Pond Creek had the lowest mean concentrations for TDS and TS (Table 14 and 15). This site is in the middle of a dairy pasture with a few cows grazing throughout the year (Table 5). Generally, the ground cover in this pasture is good which

could explain why solids concentrations are not as high as other sampling sites that have more intensive grazing pressure (Line et al., 1998). It is interesting to note that the greatest concentration of total solids occurred upstream of site 6, at site 8 Mud Creek. Very low stream flow along segments of Mud Creek could have caused the some of the suspended solids to settle out before reaching site 6, which would result in a decrease in total solids.

The lowest mean concentrations for phosphate-P and nitrate-N were seen at site 7 (Tables 13 and 14). This site is located on the same farm as site 6, but site 7 is on one of the tributaries (Greasy Creek) that join Pond Creek (Figure 12). The reasons for low nutrient values here may be because of reduced cow access to this stream. This stream is on the back of the property, away from the shelter and feeding bins, with relatively steep banks and no visible stream-crossing path. During the sampling events, cows were seen near this site, but never in the stream. Also, this stream sampling site is adjacent to where the producer disposes of dead cows. Decomposing cattle carcasses may be a deterrent to other cows.

Site 8 showed the greatest concentrations for many of the water quality parameters (Tables 13 and 14), indicating that this stream is one of the more impaired streams sampled. Site 8 is located along Mud Creek, which is a tributary that joins Pond Creek just above site 6 (Figure 12). Like most other sites in Pond Creek, land use here is dairy agriculture with some steep bank undercuts. This site typically has low flows and the water visually appears cloudy. The subbasin associated with site 8 has the largest total area and the largest agricultural land use in the watershed (Table 5).

Mean concentrations of total solids, suspended solids, total phosphorus, phosphate-P, total Kjedahl nitrogen, ammonia-N, biochemical oxygen demand, 5-day were greatest at site 8 (Tables 13 and 14). The presence of high concentrations of total phosphorus, total and suspended solids follows previous studies stating that phosphorus can be transported with solids to surface waters (Uusitalo et al., 2000). Studies have also shown that areas of intensive agriculture can have high nitrogen concentrations (Heathwaite et al., 2000). High concentrations of nutrients and solids along this stream segment are likely the reason for the high biochemical oxygen demand. This is expected because studies have shown that high concentrations of nutrients in surface waters can enhance eutrophication. Eutrophication can cause a decline in available oxygen due to the high oxygen demand placed on the water system by decomposition (Sharpley et al., 1994). The high concentration of total Kjedahl nitrogen and ammonia-N but not nitrate-N could be related to low oxygen available to oxidize the nitrogen to nitrate (Urban, 2000). With low flow at this site and high biochemical demand, oxygen would not be plentiful.

High concentrations of nitrate-N were seen at site 2 (Tables 13 and 14). The land use is agriculture, with a dairy farm and a few single-family residences that have septic tanks. This part of Pond Creek is surrounded by rounded hills that are grazed by dairy cows. Cows were frequently seen standing in this segment of Pond Creek. The cause of high mean nitrate-N values in the stream here could result from heavy nitrate inputs from grazing cows that leached through the soils and entered the stream via subsurface flow (Heathwaite et al., 2000). Other possible sources of the high nitrate-N levels could be nitrate, ammonia, or organic nitrogen carried downstream to site 2. Site 2 is located

downstream of two of the largest dairy operations along Pond Creek, which often have cows in the stream (Figure 12).

Mean suspended solids concentrations were greatest at site 4, on Pond Creek. This site has the largest dairy operation and the most impaired riparian area. This sampling site is adjacent to the path cows use to cross the stream. The area is denuded of vegetation along the crossing area and cows are often seen in the stream. Severe riparian damage and heavy animal stocking rates have shown increases in nutrient and sediment loads to streams and this seems to be the case here (Stone et al., 1995; Carpenter et al., 1998).

Comparisons among all dates showed significant differences between sampling dates when considering the parameters described in table 12 which indicates seasonal variations among the eight months. Contrasting the storm event sampling date of January with non-storm sampling events (Table 12) showed significant differences regarding all parameters with the exception of suspended solids, which could be a dilution effect. Sampling during storm events is important because much of the nutrient and sediment loading occurs during the major storm events of the year (Tate et al., 1999).

Maximum and minimum concentrations of Pond Creek water quality parameters over the entire data set are reported in table 15. High concentrations of total phosphorus, phosphate-P, total Kjedahl nitrogen, and suspended solids occurred at site 4 in January for Pond Creek (Table 15). This sampling date was during a storm event, so values for both nutrients and solids were expected to be higher than nonstorm sampling events. These finding are in agreement with current literature in that storm events can significantly contribute to the pollutant loading across watersheds, often showing

pollutant loadings more than twice the non-storm event sampling loadings (McFarland and Hauck, 1999; Tate et al., 1999).

During this sampling event, constant heavy rains and flash flooding was occurring. Due to the high volume of water in the streams, regular sampling sites could not be reached. Sampling was performed as close to mid-channel as safety would allow. Many sampling site locations were flooded, with streams spilling out of their banks onto the pasture, creating a large pool of swift moving water. This flooding of the pasture land may account for the high concentrations of total phosphorus, phosphate-P, total Kjedahl nitrogen, and suspended solids that were seen at site 4. As mentioned before, site 4 is near one of the largest dairy operations in Pond Creek. Land surrounding this site had poor cover and heavy cattle use. With flooding of this land, manure and exposed soil could be carried in the water, resulting in high concentrations of the nutrients and solids. Water samples were not taken at site 7, on Greasy Creek because the access bridge to this site was under water.

In viewing the eight months of water sampling data, table 15 shows the maximum total solids, ammonia-N, and total Kjedahl nitrogen occurred at site 8, with peaks in different months. Due to the heavy dairy use, these high concentrations were not surprising. Examination of all of the months of data showed that many sites had zero concentration of total phosphorus and phosphate, most often occurring in the summer and winter months. Pond Creek watershed overall has many impacted stream segments, with dairy agriculture most likely contributing to the stream pollution.

Crooked Fork-Emory watershed

The Crooked Fork-Emory watershed does not have intensive agricultural use as seen in Pond Creek. However, agriculture is not absent from this watershed. Dairy cows are raised along Flat Fork stream at the Morgan county prison facility and along segments of Crooked Fork stream within the watershed. Pockets of residential housing and small commercial lots also exist throughout Crooked Fork-Emory watershed, which can contribute to pollutant loading. The majority of land in this watershed is forested with evergreen and deciduous trees.

Studies have shown that forested areas can contribute nutrients and solids to watersheds, although the concentrations are generally less than agricultural inputs (Carpenter et al., 1998). Gross comparisons with Pond Creek show Crooked Fork-Emory mean suspended solids were greater than Pond Creek values. Greater concentrations of suspended solids could be attributed to steeper topography, in conjunction with poor ground cover and the lack of vegetative buffers along streams in Crooked Fork-Emory watershed. Additional factors such as streambed disturbances could cause more sediment to be carried into streams during precipitation events. Higher mean annual precipitation rates across the Cumberland Plateau subecoregion (122-152 cm mean annual rainfall) could enhance this effect (Table 4). Stands of dense forest along parts of the watershed could also account for some of the suspended solids in the streams due to leaf drop and other organic matter released from the vegetation along the stream banks.

In Crooked Fork-Emory watershed, correlations ($\alpha < 0.05$) were seen for suspended solids, total solids, and total phosphorus, indicating transport of organic phosphorus by solids into streams (Table 16). No correlation was seen for phosphate-P and total, dissolved, or suspended solids, which was surprising because previous studies have shown correlations between phosphate-P and suspended solids (Uusitalo et al., 2000). Total Kjedahl nitrogen was correlated with total and suspended solids, suggesting some transport of organic nitrogen with the solids to streams.

Statistical comparison of water quality parameter values among the eight sites in Crooked Fork-Emory showed no differences among the eight sampling sites (Table 17). This may be due to relatively low concentration levels of these parameters, or due to similar land use throughout this watershed.

Comparisons of the Cumberland Plateau (ecoregion 68) and Cumberland Mountains (ecoregion 69) reference stream values with Crooked Fork-Emory watershed data showed all ecoregion water quality concentrations were less than LSMean values of Crooked Fork-Emory (Table 18). Mean concentrations of total solids, total dissolved solids, total phosphorus, phosphate-P, total Kjedahl nitrogen, and ammonium-N were lowest at site 8 (Table 18 and 19). This is expected since site 8, located on Flat Fork in Frozen Head State Park is usual considered a good base line stream for this watershed. Land at this site is densely populated with both evergreen and deciduous forests and does not appear to negatively impact the stream (Table 6). Values for this site on Flat Fork stream were considerable higher that the ecoregion reference streams, showing that great variations occur among the ecoregion. This could support the use of subecoregion reference stream values for water quality parameters (Arnwine et al., 2000). Possibly this

stream could be considered for one of the reference streams for Crooked Fork-Emory watershed, showing further variability in "good" water quality in this region.

Site 6 mean concentrations were lowest for nitrate-N and highest for total Kjedahl nitrogen, total solids, and suspended solids concentrations (Table 18 and 19). Figures 23-24 show differences among all sites. These high levels are not surprising due to the heavy presence of older homes with septic waste systems along the stream banks. Denton et al. (2000) reported that urban residential land use could contribute concentrations of nutrients and solids to streams (Denton et al., 2000). Possible sources of pollution from residences could be leaking septic lines, tanks or direct inputs of wastes. A Delaware study in 2000 reported estimates for each septic system could contribute 0.014 kg (0.03 lbs) total nitrogen per day and 0.0006 kg (0.0013 lbs) total phosphorus per day (Jones, 2002). These findings support the possibility of the residential land use contributing substantially to the pollutant inputs at this site. The lower nitrate-N values may be due to lower oxygen concentration, which would likely be caused by the excess solids in the surface waters. Higher values of nitrate were seen down stream at site 5. This could be caused by conversion of the organic nitrogen see at site 6 as the pollutants move down stream. Site 6 also had the second highest mean concentration of phosphate-P and total phosphorus (Table 18). High levels of phosphorus in Tennessee can sometimes be attributed to naturally high back ground levels, mostly found in phosphatic limestones (USGS, 2000). Areas with naturally high levels of phosphorus can have elevated concentrations of phosphorus in soils and waters. The geology of the Cumberland Mountain ecoregion, which site 6 is located in, consists

of shale, sandstone, and coal (Table 4), not limestones. This indicates that the source of phosphorus found in the stream segment is not likely due to geology.

Site 1 had the greatest concentrations of total phosphorus and phosphate-P. Site 1 was located approximately 3 km downstream from the local municipal waste- water treatment plant and is used as a swimming/recreation area for local citizens (Table 6). Waste from both humans and other animals can contain high concentrations of organic phosphorus, so high levels of total phosphorus and phosphate-P are not surprising. (Nash and Halliwell, 2000). The treatment plant has been cited by TDEC in the past for release of untreated or poorly treated waste water (Burr, 2001). Often strong odors were detected when sampling at this site. Investigation of the possibility of relocating this waste treatment plant output is currently being performed.

Mean BOD 5-day concentrations were greatest at site 4 (Table 19). This site is adjacent to a University of Tennessee forestry experiment station and usually shaded by trees. Leaf drop and other organic matter is likely to contribute to a high biochemical oxygen demand. As organic matter enters the water, decomposition can occur, which requires oxygen, resulting in less oxygen available for other aquatic life (Manahan, 1999). This process could be occurring along this stream segment.

Table 19 shows mean ammonium-N concentration to be greatest at site 3. Site 3 is in a more residential area than some of other sites in Crooked Fork-Emory watershed. Specifically, the sampling site is located next to a residential home with a beauty salon on the premises (Table 6). The land immediately surrounding the home and business slopes gently towards the stream. Inputs of waste from leaking septic systems, wash water, or chemicals from the beauty salon may increase pollutants in the stream segment here.

Land use was mixed at site 2, located towards the bottom Crooked Fork stream. One side of the stream consisted of residential houses while the other side was a small farm with a hay field. During the study, the hay field was cut and harvested, but no animal use was observed. Mean levels of total dissolved solids were greatest at this site, which could be related to cutting of the hay field (Table 19, Figure 23). Low values for biochemical oxygen demand and suspended solids also occurred here; showing that pollutant loading is not causing much stress on the stream for oxygen (Tate et al., 1999).

Differences were seen among sampling months for all parameters except nitrate-N (Table 17), indicating that seasonal variation influences pollutant loading and nutrient and solids concentrations. Temperature and precipitation greatly effect water quality parameters. Higher temperatures usually mean lower dissolved oxygen in streams, which can affect the speciation of nitrogen and phosphorus (Scheiber et al., 2001). Precipitation events, such as the one sampled in January of 2002, can show increases in many water quality parameters (McFarland and Hauck, 1999). When storm event sampling data was contrasted with other sampling dates, significant differences were seen for the nutrients total phosphorus, total Kjedahl nitrogen, phosphate-P, nitrate-N, and ammonia-N. However no significant differences were seen for biochemical oxygen demand, pH, total solids, total dissolved solids, and suspended solids. Sampling during this storm event varied from standard sampling protocol in that mid-channel samples could not be taken due to the fast current and high volume of water in the streams. At all sites, sampling was performed from the stream bank, dipping the sample bottle into the water at arms length. This was determined to be the safest method for sampling the streams during the storm.

Concentrations of total solids (2668 mg/L) and dissolved solids (2284 mg/L) taken at site 6 in January were considerably higher than any other sampling data at any site. Table 19 shows Phosphate-P levels, which on average are higher at site 6, were found in greatest concentration here during the storm event. Total Kjedahl nitrogen and biochemical oxygen demand concentrations were also highest at site 6 during January (Table 19). Site 1 had the greatest level of total phosphorus in January, which is consistent with the mean values. Examining all storm event sampling results, it appears that a combination of factors could be responsible for the high inputs. Both sites 1 and 6 have relatively steep topography and probable high input from human waste, site 6 from the septic systems along the stream and site 1 from being downstream of the municipal waste treatment plant.

For Crooked Fork-Emory, summer months appear to produce overall lower concentrations in pollutant loads, compared to other seasons. This type of seasonal variation has been seen in other studies and could be contributed to less precipitation during these months (Carpenter et al., 1998). Overall, Crooked Fork-Emory watershed does have water quality that is in impaired along both the primary stream and one of the tributaries, Flat Fork.

Conclusions

Water quality in both Pond Creek and Crooked Fork-Emory watersheds is impaired. Comparisons to ecoregion reference streams show that nutrient and solids concentrations for both streams are above the reference values. Pond Creek, the watershed with primarily dairy agriculture, showed much greater concentrations of nutrients and sediments when compared with Crooked Fork-Emory. Crooked Fork-Emory watershed's land use is mixed, consisting of residential areas, commercial areas, forest, and some agriculture. While both watersheds had impaired streams, land use did appear to have an effect on the amount of nutrient and sediment concentrations found in each stream.

The use of computer software such as BASINS and SWAT helped identify land use and water quality patterns. Additionally, BASINS and SWAT provided useful information regarding land use on record, soils, and river networks within each watershed. The ability to delineate the subbasins within each watershed allowed a closer look on land use effects to water quality. BASINS and SWAT are powerful tools that could be utilized in watershed assessment, land use planning, and TMDL development.

Concentrated agricultural practices along the streams in Pond Creek watershed contributed to the high concentrations of nutrients and solids seen in Pond Creek and its tributaries, Greasy Creek and Mud Creek. The land use here consisted of grazed pasture, with areas of bare soils possibly from overgrazing. Riparian damage was seen throughout the watershed, often with the degree of damage related to the intensity of

animal use. The degraded riparian zones and exposed soils allowed for runoff to occur, which can transport sediment and nutrients to near by streams. Allowing cows direct access to the streams further increases water impairment. As the cattle enter and exit the water, they not only make direct inputs of waste, stream banks are destabilized and stream beds are disturbed, which can contribute to water quality impairment. Throughout this study, no observable efforts were made to keep the cattle out of the streams. Implementation of other BMPs, such as hardened crossings, protected heavy use areas, alternative watering systems, or buffer strips were not evident.

Site 5 along Pond Creek might be a slight exception to this. This site did have a partial buffer strip that was naturally maintained and a concrete slab that provided cows with access into the stream without traveling down the banks. This concrete slab appeared to have been in place for a long time, due to the wear shown. This site generally had mid-range mean concentrations of total solids (400 mg/L), suspended solids (66 mg/L), total Kjedahl nitrogen (0.98 mg/L), nitrate-N (2.48 mg/L), ammonium (0.36 mg/L), total phosphorus (0.188 mg/L), and phosphate-P (0.058 mg/L) when compared to other Pond Creek sites. It was also noted previously that this site was in pasture, but cattle were not seen grazing in the area surrounding the stream often.

Improvements to water quality in this watershed could likely be affected by implementation of BMP on several farms (Heathwaite et al., 2000). Sharpely et al. (1999) reported that phosphorus control efforts should focus on near-stream areas instead of the entire watershed (Sharpely et al., 1999). This could indicate that perhaps pollution in Pond Creek could be best addressed by starting with the farms that have the most cows closest to the streams and implemented some BMPs here. Many studies agree that

nutrient management plans would be a good starting place to reduce nutrient inputs (Carpenter et al., 1998; Beegle et al., 2000).

Sites 3 and 4, along Pond Creek, and site 8 on Mud Creek, would be good places to initiate BMPs in this watershed to reduce the concentrations of sediment and nutrients due to the close proximity of the dairies to the streams, the size of the operations, and the cooperativeness of the land owners. These sites have large dairy operations with stream segments meandering through much of their pasture. The land owners have worked this land for many years and are knowledgeable of the historic appearance of these streams and watershed and could provide beneficial information for water quality improvement.

Site 8 is the most upstream of the Pond Creek study area, and showed the greatest mean concentration levels of total solids (533 mg/L), total phosphorus (0.536 mg/L), phosphate-P (0.096 mg/L), total Kjedahl nitrogen (2.357 mg/L), NH_3-N, and biochemical oxygen demand, 5 day (5.037 mg/L). In addition to nutrient management planning, strategic fencing could help at this site. Keeping the cows off the already undercut stream banks here could reduce sediment entering the stream. Installation of alternative watering systems would be needed to provide a fresh water source for the grazing cows.

Site 4 is located on Pond Creek, within the pastures one of the largest dairy producer on Pond Creek. Site 4 had high mean concentrations of nitrate-N (2.57 mg/L), NH_3-N (0.309 mg/L), and total Kjedahl nitrogen (0.83 mg/L). Cattle seem to migrate and remain in this area surrounding the stream. There are trees for shade with very little grass. During course of this study, numerous cows were seen near or in the stream on every sampling trip to this watershed. Strategic fencing on this farm would likely reduce the nutrient and sediment concentrations in the water. However, fencing may not be a

viable option for the land owner because this site provides access to a larger pasture. However, this site has an extremely muddy crossing area that could benefit greatly with the construction of a hardened crossing. This hardened crossing could provide a nonmuddy route to the rest of pasture and help prevent further stream bank damage.

Site 3 has many areas of poor riparian zones. The banks here are steep and undercut in some places, with less steep banks upstream on the property. Strategic fencing could help reduce the direct waste inputs and allow the growth of a vegetative buffer next to the stream. Both of these BMPs could reduce sediment and nutrient concentrations. This site has a holding and feedlot close to the stream. This farm might benefit from runoff management, routing the water through buffer strips to prevent additions of waste washing off into the streams.

Numerous studies have shown measures such as nutrient management planning, strategic fencing, alternative watering systems, and buffer strips could greatly reduce the nutrient and solids inputs that are impairing this watershed (NRCS, 2000). The actual reductions of pollutant inputs vary according to best management practice used, pollutant type and concentration you are trying to reduce, and location of the inputs. Vegetated filter strips have shown to reduce up to 90% of nutrient and sediments in a Vermont dairy study (Meals, 1996). Other studies, such as Line et al. (1998) showed only a 30% reduction with buffer strips at dairy operations (Line et al., 1998).

Land use also played an important role in Crooked Fork-Emory watershed. This watershed contains Frozen Head State Park, with mixed forests prevalent throughout this area. The area surrounding Frozen Head State Park is considered the least impacted in the watershed, with Flat Fork, the stream running through thought of as a near pristine.

The topography in this region is steep, with the much of the level land along the floodplain. Floodplain development is common throughout this watershed, with both residential and small commercial developments. Sites along Crooked Fork stream showed high levels of nutrients and solids.

Since much of the development is along the flood plains, future zoning of land surrounding this stream could reduce further impaction. Restrictions from developing on floodplain land could improve water quality in Crooked Fork-Emory watershed by allowing vegetative buffers along the stream grow which can reduce the sediment and nutrient concentrations. Also, by limiting the number of septic systems that will be located along the floodplain, the chance of inputs from septic system failure could be reduced. Site 6 is located just past a small community, Petros, TN. The land near this sampling site in wooded with mobile homes situated along Crooked Fork stream. Most of the houses in this area are not on public sewage systems and most have septic systems. Site 6 had the greatest mean values for highest for total Kjedahl nitrogen (0.976 mg/L), total solids (598 mg/L), and suspended solids (352 mg/L) concentrations. There is a possibility of leaking septic tanks or lines at this site or along other segments of this stream. Testing of the septic tanks is possible to determine if a failure is occurring, however, this was not part of the study.

If the higher concentrations are coming from septic tanks, repairs or replacements for the septic systems can be made. However, this requires the homeowner's cooperation, as well as funding would be needed. Previous studies have had success with this type of homeowner cooperation where the State agency provided testing and funding

for replacement of faulty septic systems. This study is predicting significant reductions in pollutant loading to the streams (Jones, 2002).

There were some small agricultural areas along this watershed, but not as intensive as seen in Pond Creek. The largest dairy farm in the area is at the Morgan County prison facility. Site 7 is located on Flat Fork, downstream of Frozen Head State Park, just under a bridge at the back of the prison property. This dairy facility raises mostly calves, selling them when they reach maturity. Due to this most of the cows here are confined to small fenced areas and do not have access to the stream that meanders through the grounds. Nutrient (total phosphorus and nitrate) concentrations are greater here than upstream at site 8 on Flat Fork. The land upstream of site 7 could likely benefit from BMPs. However, this land is on prison property and due to security measures, BMPs such as maintaining a vegetative buffer zone surrounding the stream that runs through their property cannot be implemented.

Both of these watersheds are slated for TMDL development due to water quality impairments. The data that was collected for this study will be shared with TDEC, to provide a starting point for the water assessment in Pond Creek and Crooked Fork-Emory watersheds. Further water quality monitoring (at least twelve additional months) is needed for TDEC to be able to assess these watersheds and determine more precisely the sources of impairment. Following their assessments and evaluations, TDEC will likely be prepared to determine methods best suited for pollutant load reductions in each watershed. Hopefully, with the cooperation of landowners, state and federal agencies, and community groups, the water quality in both of these watersheds can be restored.

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APPENDIX

APPENDIX A. TABLES

Table 1. Top five sources of nonpoint pollutants to waterways nationwide according to EPA 303(d) fact sheet from 1998.

Nonpoint Source Type	Percent Contributed
Agriculture	15
Channelization	11
Urban Runoff	11
Land Development	7
Contaminated Sediment	5

(EPA, 2002d).

Table 2. Prevalent models used for soil movement and water quality assessment since 1960 in the United States.

Date	Name	Description of use
1960	USLE (Universal Soil Loss Equation)	Assess soil movement across landscape
1978	GLEAMS (Groundwater Loading Effects of Agricultural Management)	Field scale water quality. Modification of CREAMS
1987	AGNPS (agricultural nonpoint source pollution)	Field scale chemical runoff
1983	WASP (Water Quality Analysis Simulation Program)	Stream water quality
1980	EPIC (Erosion-Productivity Impact Calculator	Field scale water quality.
1998	RUSLE (Revised Soil Loss Equation)	Soil movement across landscape
1994	SWAT (Soil and Water Assessment Tool)	Hydrological assessment across watersheds
1996	BASINS (Better Assessment Science Integrating point and Nonpoint Sources	Watershed water quality assessment

Table 3. Factors considered for grab water sample site selection in Pond Creek and Crooked Fork-Emory watersheds.

Accessibility	Walking distance from access road	Public right-of-way or land owner permission	Access year round and for the duration of the study
Location	Above and below possible pollutant inputs	Consideration of tributaries entering main stream	Consistent distant between sites if possible, or reasonable cause for not doing so
Representational	Select streams that are representative of area		

Table 4. Descriptions of subecoregions 67f, 68a, and 69d found in Tennessee that pertain to Pond Creek and Crooked Fork-Emory watersheds. Adapted from Ecoregions of Tennessee (Griffith et al., 1999b).

Level IV Ecoregion (Subecoregion)	Physiography	Elevation and Local Relief (m)	Geology	Soil Great Groups	Precipitation Annual mean (cm)
67(f) Southern Limestone/Dolomite Valleys and Low Rolling Hills	Gently rolling hills, some steep slopes found in north region, moderate to low stream gradient with bedrock, cobble, gravel, and sandy substrate	213-609 30-213	Quaternary cherty clay solution residuum; Ordovician dolomite and limestone, some chert	Paleudults	101-137
68(a) Cumberland Plateau	Rolling tableland with some low, open mountains	366-610 91-244	Quaternary sandy decomposition residuum; Pennsylvanian conglomerate, sandstone, siltstone, shale	Hapludults Dystrochrepts	122-152
69(d) Cumberland Mountains	Low mountains containing long, steep slopes, some narrow crests and winding valleys; highly dissected by moderate to high gradient clear water streams dominated by bedrock	366-1067 457-609	Quaternary sandstone and shale-clast loamy colluvium; Pennsylvanian shale, sandstone, siltstone, and coal	Dystrochrepts Hapludults	127-140

Table 5. Description of 8 Pond Creek water grab sampling sites with dominant land use per subbasin given in ha, followed by secondary land use within Pond Creek watershed.

Site	Creek Name	Latitude Longitude	Soil Description	Total Subbasin Drainage Area	Land Use per subbasin	Site Description
1	Pond Creek	N 35°43"53.42' W - 84°26"30.73'	Silt loam Ultisol	641 ha	Agriculture (326 ha), mixed forest (263 ha),	Moderately dense forest and shrubs with shaded banks, appears to be less impacted
2	Pond Creek	N 35°42"19.11' W - 84°27"32.18'	Silt loam Ultisol	467 ha	Agriculture (309 ha) - Dairy, mixed forest	Pasture, Gently rolling hills with moderate riparian damage from dairy grazing
3	Pond Creek	N 35°41"18.28' W - 84°27"59.80	Silt loam Ultisol	948 ha	Agriculture (822 ha)- Dairy and Emu	Pasture, Dairy and Emu farm in close proximity to stream, feedlots within 6-8 meters of bank, moderate to severe riparian damage
4	Pond Creek	N 35°39"57.57' W - 84°28"59.47'	Silt loam Ultisol, Loamy Inceptisol	1217 ha	Agriculture (947 ha- Dairy, mixed forest	Pasture, Heavy dairy use, poor ground cover, severe riparian damage, large stream crossing area
5	Pond Creek	N 35°38"46.15' W - 84°29"7.77'	Silt loam Ultisol, Loamy Inceptisol	774 ha	Agriculture (627 ha)- Dairy, mixed forest	Pasture, Good ground cover, good riparian zone, infrequent cattle use
6	Pond Creek	N 35°38"37.13' W - 84°29"40.55'	Silt loam Ultisol	1458 ha	Agriculture (1018 ha)- Dairy, evergreen forest	Pasture, Low cattle use, severe undercuts in riparian zone
7	Greasy Creek	N 35°38"20.38' W - 84°29"30.91'	Silt loam Ultisol, Loamy Inceptisol	1096 ha	Agriculture (866 ha)- Dairy, mixed forest	Pasture, Presence of dead and decaying cattle next to stream bank, some riparian damage
8	Mud Creek	N 35°36"41.58' W - 84°30"56.63'	Silt loam Ultisol Silt loam Inceptisol	1508 ha	Agriculture (1202 ha)- Dairy, mixed forest	Pasture, Moderate cattle use, severe undercuts in riparian zone, visually high turbidity

Table 6. Description of 8 Crooked Fork-Emory water grab sampling sites with dominant land use per subbasin given in ha, followed by secondary land use within Crooked Fork-Emory watershed.

Site	Creek Name	Latitude Longitude	Soil Type Description	Total Subbasin Drainage Area	Land Use per subbasin	Site Description
1	Crooked Fork	N 36°4"55.94' W - 84°34"34.59'	Gravely silt loam Ultisol, Loam Ultisol, Fine loamy Ultisol, Loam Inceptisol, Silt loam Alfisol	2737 ha	Mixed forest (1243 ha), agriculture, medium density residential	3 km downstream of sewer treatment facility, unofficial local recreation area
2	Crooked Fork	N 36°4"54.82' W - 84°32"23.21'	Gravely silt loam Ultisol, Loam Ultisol, Fine loamy Ultisol	535 ha	Deciduous forest (292 ha), low density residential	At highway bridge, stream between house and hayfield, good riparian zone
3	Crooked Fork	N 36°4"9.76' W - 84°31"30.81'	Gravely silt loam Ultisol, Loam Ultisol, Fine loamy Ultisol	2609 ha	Deciduous forest (1053 ha), agriculture, medium density residential	At highway bridge, next to residential area with beauty salon
4	Crooked Fork	N 36°3"20.16' W - 84°29"15.58'	Gravely silt loam Ultisol Loam Ultisol Fine loamy Ultisol	735 ha	Mixed forest (357 ha), agriculture, medium density residential	At highway bridge, adjacent to forestry experiment station, low to moderate riparian damage
5	Crooked Fork	N 36°4"2.65' W - 84°27"13.13'	Gravely silt loam Ultisol Fine loamy Ultisol	2045 ha	Deciduous forest (1733), agriculture, medium density residential	At highway bridge, forested and commercial area

Site	Creek Name	Latitude Longitude	Soil Type Description	Total Subbasin Drainage Area	Land Use per subbasin	Site Description
6	Crooked Fork	N 36°5"37.20' W - 84°25"24.85'	Gravely silt loam Ultisol Fine loamy Ultisol	943 ha	Deciduous forest (864 ha), low density residential	Upper reach of Crooked Fork, bedrock substrate, close proximity of low density residential area
7	Flat Fork	N 36°5"36.97' W - 84°32"44.12'	Gravely silt loam Ultisol Loam Ultisol Fine loamy Ultisol	2118 ha	Deciduous forest (1033 ha), agriculture, medium density residential	At highway bridge, adjacent to commercial properties, state prison and dairy farm, moderate riparian damage
8	Flat Fork	N 36°7"31.51' W - 84°30"22.91'	Loam Ultisol Fine loamy Ultisol	1244 ha	Deciduous forest (1161 ha), mixed forest	Frozen Head State Park, least impacted stream within watershed, good riparian zone

Table 7. Monthly flow data for 2001 in Pond Creek and Crooked Fork watersheds. No data was recorded for the entire month of November, 2001, other flow values are missing due to equipment failure.

Watershed	Site	June	July	August	September	October	Decemember
Pond Creek	1	0.25	0.30	0.59	0.41	0.21	
	2	0.35		1.66	0.45	1.41	
	3	1.08		1.09	0.89	0.53	
	4	3.77		0.35	0.14	0.00	
	5	0.69		0.14	0.10	0.03	
	6	0.60	0.25		0.25	0.14	
	7	0.60			0.03	0.00	
	8	0.54			0.00	0.00	
Crooked Fork	1						
	2	0.20			0.23	0.00	2.02
	3	0.17			0.23	0.01	
	4	0.14			0.27		
	5	0.11			0.17		2.08
	6	0.04			0.08		1.74
	7	0.41			0.08		1.79
	8	0.18					

Table 8. Data sets available for use with BASINS 3.0 and SWAT2000 computer models for watersheds throughout the United States.

Data Available within the HUC project set	
Reach file, version 1	National sediment inventory stations
Reach file, version 3	Toxic release inventory
STATSGO soil	Catalog boundary units
Ecoregion	County demographics
Permit compliance systems	USGS gauge stations
Water quality observation stations	WDM weather data stations
Industrial facilities discharge sites	Bacteria stations

Table 9. Simple statistics for Pond Creek watershed in Loudon County, Tennessee, combining results for 8 sampling sites that were collected during 8 monthly sampling events.

Parameter	N	Mean	Std Dev	Minimum	Maximum	Ecoregion 67
pH	71	7.78	0.59	6.90	10.75	7.94
TS	62	399	191	120	958	
SS	70	81	131	0.80	577	6
TDS	70	274	131	4.80	576	168
TP	71	0.241	0.328	0.00	1.890	0.047
PO4-P	71	0.050	0.110	0.00	0.542	
TKN	71	1.075	0.974	0.00	5.027	0.087
NO3-N	71	2.263	1.012	0.00	4.734	
NH3-N	71	0.41	0.46	0.00	2.31	0.01
BOD-5	55	3.28	2.02	1.13	8.81	

TS=Total Solids (mg/L), SS= Suspended Solids (mg/L), TDS= Total Dissolved Solids (mg/L),
TP= Total phosphorus (mg P/L), PO4-P= Phosphate-P (mg P/L),
TKN= Total Kjedahl Nitrogen (mg N/L), NO3-N= Nitrate-N (mg N/L),
NH3-N= ammonia-N (mg N/L), BOD-5= Biochemical oxygen demand, 5 day (mg/L)

Table 10. Simple statistics for Crooked Fork-Emory watershed in Morgan County, Tennessee, combining results for 8 sampling sites that were collected during 8 monthly sampling events.

Variable	N	Mean	Std Dev	Minimum	Maximum	Ecoregion 68	Ecoregion 69
pH	63	7.75	0.62	6.00	7.20	7.05	7.00
TS	55	350	442	14.8	2686		
SS	63	130	348	0.0	2205	5.6	5
TDS	63	203	142	4.8	619	60	59
TP	71	0.20	0.347	0.0	2.10	0.016	0.009
PO4-P	71	0.009	0.028	0.0	0.144		
TKN	71	0.762	0.924	0.021	4.66	0.055	0.051
NO3-N	71	0.299	0.341	0.0	2.57		
NH3-N	71	0.25	0.50	0.0	2.73	0.01	0.01
BOD-5	55	2.29	1.37	0.0	5.54		

TS=Total Solids (mg/L), SS= Suspended Solids (mg/L), TDS= Total Dissolved Solids (mg/L),
TP= Total phosphorus (mg P/L), PO4-P= Phosphate-P (mg P/L),
TKN= Total Kjedahl Nitrogen (mg N/L), NO3-N= Nitrate-N (mg N/L),
NH3-N= ammonia-N (mg N/L), BOD-5= Biochemical oxygen demand, 5 day (mg/L)

Table 11. Pond Creek watershed correlation data from statistical analysis with alpha < 0.05.

	TS	SS	TDS	TP	PO4-P	TKN	NO3-N	NH3-N	BOD	DO
TS	1.00	.45396	.38259	.32759	.2045	.3535	-.21879	.36149	.31405	.29813
		.0002	.0021	.0093	.1108	.0048	.0876	.0039	.0335	.0286
SS	.45396	1.0	-.13898	.67096	.54254	.70226	-.06542	.77352	.5081	-.03979
	.0002		.2512	<.0001	<.0001	<.0001	.5905	<.0001	<.0001	.7588
TDS	.38259	-.13898	1.0	-.1841	-.2767	-.0049	-.3427	-.0053	-.1311	.30233
	.0021	.2512		.1271	.0204	.9677	.0037	.9651	.3446	.0169
TP	.32759	.67096	-.1841	1.0	.88230	.77841	-.0918	.6381	.64588	-.1035
	.0093	<.0001	.1271		<.0001	<.0001	.4463	<.0001	<.0001	.4194
PO4-P	.2045	.54254	-.2767	.8823	1.0	.62145	.01972	.43567	.58142	-.1042
	.1108	<.0001	.0204	<.0001		<.0001	.8703	.0001	<.0001	.4164
TKN	.3535	.70226	-.0049	.77841	.62145	1.0	-.4694	.74469	.74230	.11765
	.0048	<.0001	.9677	<.0001	<.0001		<.0001	<.0001	<.0001	.3584
NH3-N	.36149	.77352	-.0053	.6381	.43567	.74468	-.1989	1.0	.6967	-.0189
	.0039	<.0001	.9651	<.0001	.0001	<.0001	.0963		<.0001	.8833
NO3-N	-.2188	-.0654	-.3427	-.0918	.01972	-.4694	1.0	-.1989	-.2597	-.2338
	.0876	.5905	.0037	.4463	.8703	<.0001		.0963	.0555	.0652
DO	.29813	-.0398	.30233	-.1035	-.1042	.11765	-.2338	-.0189	-.023	1.0
	.0286	.7588	.0169	.4194	.4164	.3584	.0652	.8833	.8781	
BOD	.31405	.5081	-.1311	.64588	.58142	.7423	-.2598	.6967	1.0	-.023
	.0335	<.0001	.3446	<.0001	<.0001	<.0001	.0555	<.0001		.8781

Table 12. Comparisons using the general linear model statistical procedure showing water quality sampling variability among: the eight sampling sites, among the eight sampling months, and contrasting the storm event sampling month with all other months for Pond Creek watershed water sampling data.

Parameter Evaluated	Parameters showing differences among sites over 8 month period	Parameters showing no differences among sites over 8 month period	Parameters showing differences when comparing 8 monthly sampling dates	Parameters showing differences when comparing storm event sampling and monthly sampling dates
Total solids		X	X	X
Total dissolved solids		X	X	X
Suspended solids	X		X	
Total Kjedahl nitrogen	X		X	X
Ammonia-N	X		X	X
Nitrate-N	X		X	X
Total phosphorus		X	X	X
Phosphate-P		X	X	X
pH		X	X	X
Biochemical oxygen demand, 5- day		X	X	X

Table 13. Eight-month mean of monthly water quality sampling events in Pond Creek watershed in Loudon county comparing water sampling data by site and with ecoregion 67 reference stream data.

Site	1	2	3	4	5	6	7	8	ECOREGION 67
pH	7.81	7.72	7.75	7.55	7.83	8.07	7.99	7.50	7.94
Total Solids (mg/L)	334	363	377	376	401	326	507	532	
Suspended Solids (mg/L)	33	41	40	97	66	60	33	291	6.116
Total Dissolved Solids (mg/L)	240	301	266	301	294	232	323	238	168.46
Total phosphorus (mg P/L)	0.149	0.172	0.153	0.326	0.188	0.242	0.156	0.536	0.047
Phosphate-P (mg P/L)	0.029	0.036	0.035	0.070	0.058	0.057	0.014	0.096	
Total Kjedahl Nitrogen (mg N/L)	0.490	0.819	0.831	1.159	0.984	0.828	1.139	2.357	0.087
Nitrate-N (mg N/L)	2.513	2.730	2.527	2.378	2.483	2.491	1.147	1.707	
Ammonia-N (mg N/L)	0.172	0.291	0.309	0.308	0.358	0.290	0.358	1.159	0.012
Biochemical oxygen demand, 5 day (mg/L)	2.52	3.11	2.57	3.18	3.05	2.73	4.21	5.04	

Table 14. Maximum and minimum concentration levels of mean water quality parameters and the site location where occurred in Pond Creek watershed as determined by GLM procedure.

Parameter examined measured in mg/L	Site where maximum value occurred	Concentration	Site where minimum value occurred	Concentration
Total solids	Site 8	533	Site 6	326
Suspended solids	Site 4	98	Site 7	34
Total dissolved solids	Site 7	323	Site 6	232
Total phosphorus	Site 8	0.536	Site 1	0.149
Phosphate-P	Site 8	0.096	Site 7	0.016
Total Kjedahl Nitrogen	Site 8	2.357	Site 1	0.490
NH_3-N	Site 8	1.159	Site 1	0.172
Nitrate-N	Site 2	2.730	Site 7	1.147
BOD 5-day	Site 8	5.037	Site 1	2.519

Table 15. Pond Creek maximum and minimum water quality parameter concentrations for the eight-month sampling period for the eight sampling sites.

Parameter examined	Site of maximum concentration	Date of maximum concentration	Concentration in mg/L	Site of minimum concentration	Date of minimum concentration	Concentration in mg/L
Total solids	8	September	958	8	July	120
Suspended solids	4	January	577	3	September	.8
Total dissolved solids	7	July	576	3	November	4.8
Total phosphorus	4	January	1.89	1, 2, 3, 5, 6	June, October, November, February	0
Phosphate-P	4	January	.542	1,2,3, 5, 6, 7	June, July, august, October, November, December, February	0
Total Kjedahl Nitrogen	4	January	5.026	1	June	0
NH_3-N	8	July	2.31	1,2, 6	February	0
Nitrate-N	8	February	4.734	7,8	October	0
BOD 5-day	7	November	8.813	6	August	1.128

Table 16. Crooked Fork-Emory watershed correlation data from statistical analysis with alpha < 0.05.

	TS	SS	TDS	TP	PO4-P	TKN	NO3-N	NH3-N	BOD	DO
TS	1.00	0.962	-0.088	.59397	-.0845	.809	.1305	.31127	.6979	.1088
		<.0001	.5214	<.0001	.5397	<.0001	.3422	.0207	<.0001	.4716
SS	.9626	1.0	-.2241	.63423	-.1053	.8337	.11032	.36515	.6304	.0270
	<.0001		.0798	<.0001	.4114	<.0001	.3894	.0033	<.0001	.8464
TDS	-.088	-.2241	1.00	-.2775	.1254	-.1999	.07277	-.2703	-.1133	.2372
	.5214	.0798		.0277	.3273	.1162	.5709	.0322	.4102	.0841
TP	.59397	.63423	-.2775	1.0	.2876	.5523	.1254	.2931	.3454	-.0628
	<.0001	<.0001	.0277		.015	<.0001	.2975	.0131	.0098	.6278
PO4-	-.0845	-.1053	.1254	.2876	1.0	-.1377	.58106	-.1282	-.2184	-.1302
P	.5397	.4114	.3273	.015		.2519	<.0001	.2864	.1091	.3131
TKN	.809	.8337	-.1999	.5523	-.1377	1.0	.1081	.4389	.7787	.1983
	<.0001	<.0001	.1162	<.0001	.2519		.3694	.0001	<.0001	.1224
NH3-	.31127	.36515	-.2703	.2931	-.1282	.4389	.05131	1.0	.4787	.0091
N	.0207	.0033	.0322	.0131	.2864	.0001	.6709		.0002	.9439
NO3-	.1305	.1103	.0728	.12538	.58106	.10814	1.0	.05131	.03727	-.0862
N	.3422	.3894	.5709	.2975	<.0001	.3694		.6709	.7871	.5064
DO	.1088	.027	.23727	-.0628	-.1302	.19829	-	.00913	.34823	1.0
	.4716	.8464	.0841	.6278	.3131	.1224	.08619	.9439	.0177	
							.5054			
BOD	.6979	.63043	-.1133	.3454	-.2185	.77867	.03727	.4787	1.0	.34823
	<.0001	<.0001	.4102	.0098	.1091	<.0001	.7871	.0002		.0177

Table 17. Comparisons using the general linear model statistical procedure for Crooked Fork-Emory watershed water sampling data.

Parameter Evaluated	Parameters showing differences among sites over 8 months	Parameters showing no differences among sites over 8 months	Parameters showing differences,comparing 8 monthly sampling dates	Parameters showing differences, comparing storm event and monthly sampling dates
Total solids		X	X	
Total dissolved solids		X	X	
Suspended solids		X	X	
Total Kjedahl nitrogen		X	X	X
Ammonia-N		X	X	X
Nitrate-N		X		X
Total phosphorus		X	X	X
Phosphate-P		X	X	X
pH		X	X	
Biochemical oxygen demand, 5- day		X	X	

Table 18. Crooked Fork-Emory watershed sampling data by site and ecoregions 68 and 69 reference stream, averaging over an eight month period of monthly sampling events.

Site	1	2	3	4	5	6	7	8	ECO 68	ECO 69
pH	7.75	7.67	7.74	7.54	7.89	7.89	8.10	7.98	7.05	7.00
Total Solids (mg/L)	356	286	327	343	508	599	197	164		
Suspended Solids (mg/L)	46	41	94	144	222	353	65	74	6	5.000
Total Dissolved Solids (mg/L)	224	274	154	224	236	187	198	118	60	59
Total phosphorus (mg P/L)	0.411	0.125	0.126	0.173	0.221	0.271	0.142	0.124	0.016	0.009
Phosphate-P (mg P/L)	0.037	0.004	0.004	0.003	0.012	0.011	0.000	0.000		
Total Kjedahl Nitrogen (mg N/L)	0.647	0.617	0.612	0.811	0.883	0.976	0.962	0.568	0.055	0.051
Nitrate-N (mg N/L)	0.493	0.218	0.215	0.256	0.569	0.200	0.202	0.228		
Ammonia-N (mg N/L)	0.307	0.262	0.459	0.369	0.278	0.072	0.207	0.063	0.011	0.010
Biochemical oxygen demand, 5 day (mg/L)	2.30	1.96	2.46	2.68	2.36	2.08	2.32	2.08		

Table 19. Maximum and minimum concentration levels of mean water quality parameters and the sites, which they occurred in Crooked Fork-Emory watershed.

Parameter examined measured in mg/L	Site where maximum value occurred	Concentration	Site where minimum value occurred	Concentration
Total solids	6	598	8	163
Suspended solids	68	352	2	40.6
Total dissolved solids	2	274	8	117
Total phosphorus	1	.4105	8	.124
Phosphate-P	1	.037	7,8	0
Total Kjedahl Nitrogen	6	.976	8	.567
NH_3-N	3	.459	8	.06
Nitrate-N	5	.568	6	.1997
BOD 5-day	4	2.68	2	1.96

Table 20. Crooked Fork-Emory watershed maximum and minimum concentration levels over the eight-month sampling period at all eight sites.

Parameter examined	Site maximum concentration	Date maximum concentration	Conc. mg/L	Site minimum concentration	Date minimum concentration	Conc. mg/L
Total solids	6	January	2668	8	June	14.8
Suspended solids	2	November	489	8	February	23
Total dissolved solids	6	January	2285	7	August	.08
Total phosphorus	1	February	2.1	All sites	June.	0
				Sites 2-8	October, November, February	0
Phosphate-P	6	September	.105	All sites	June-August, October, December, January.	0
				7,8	September	
				2-7		
				2-8	November	
					February	
Total Kjedahl Nitrogen	6	January	4.662	8	August	.02

NH_3-N	3	January	2.73	8	June	0
				7,8	July	
				3	August	
				6,8	September, October.	
				All sites	February	
Nitrate-N	6	November	2.57	June	7,8	
				August	4	
				October	2-6	
				November	2-4,7,8	
BOD 5-day	6	January	5.543	4	August	0

APPENDIX B. FIGURES

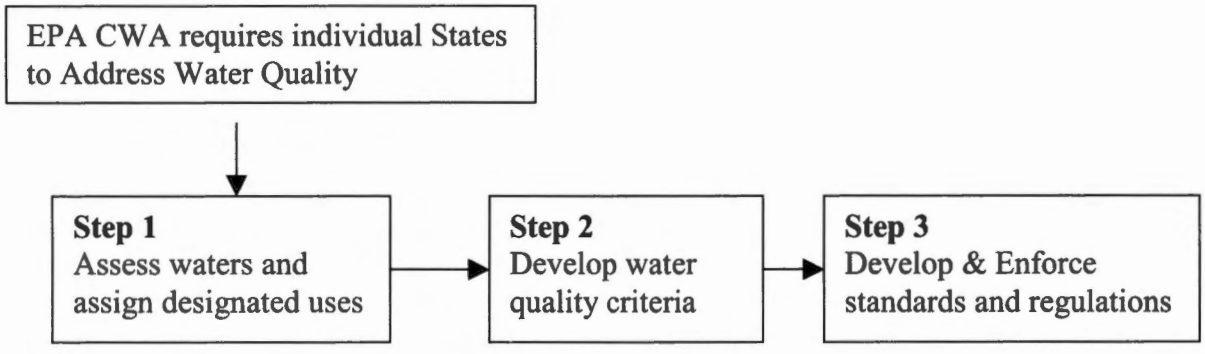


Figure 1. Summarization of the steps required of individual States to address water quality issues according to the Clean Water Act (CWA).

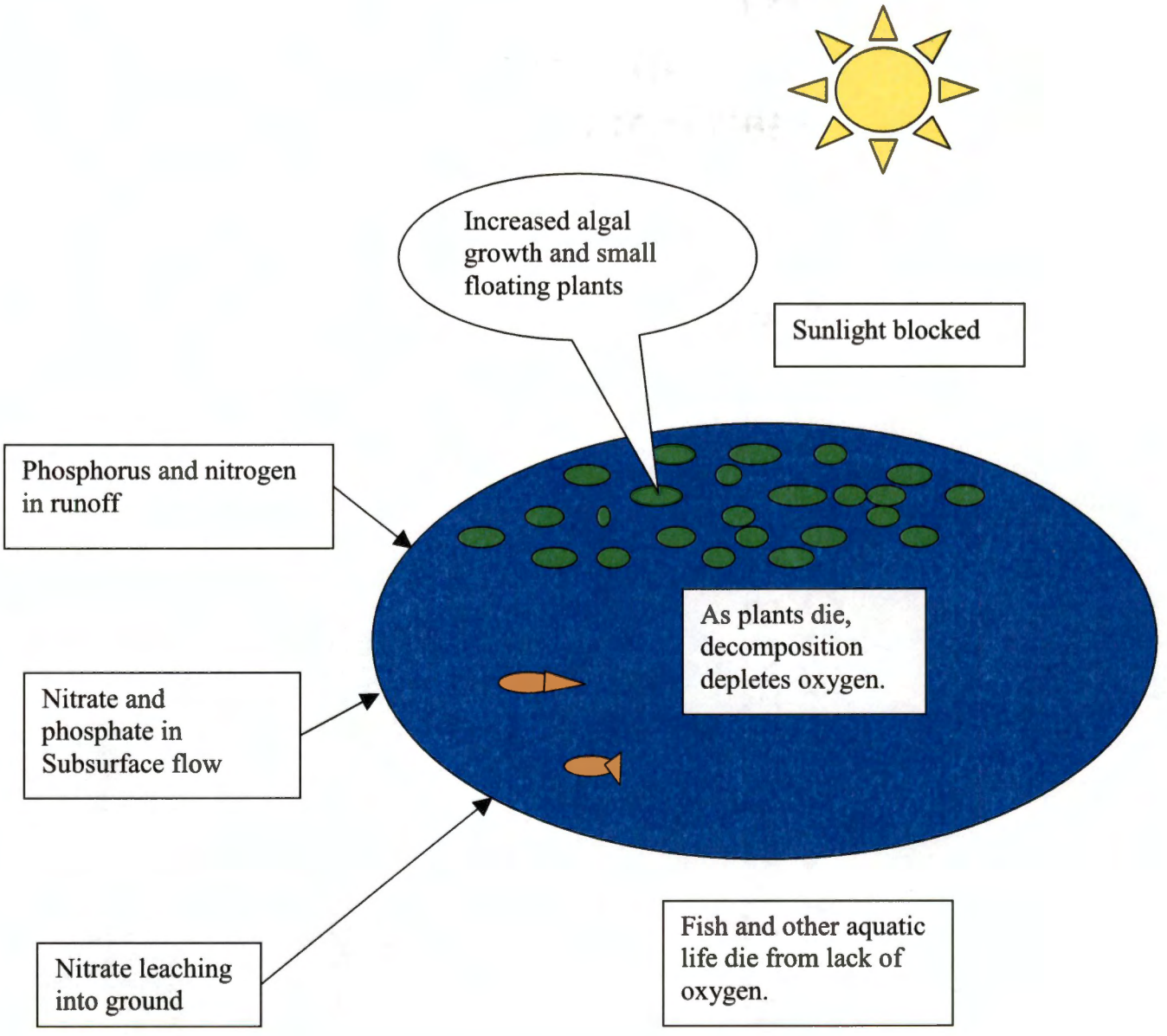
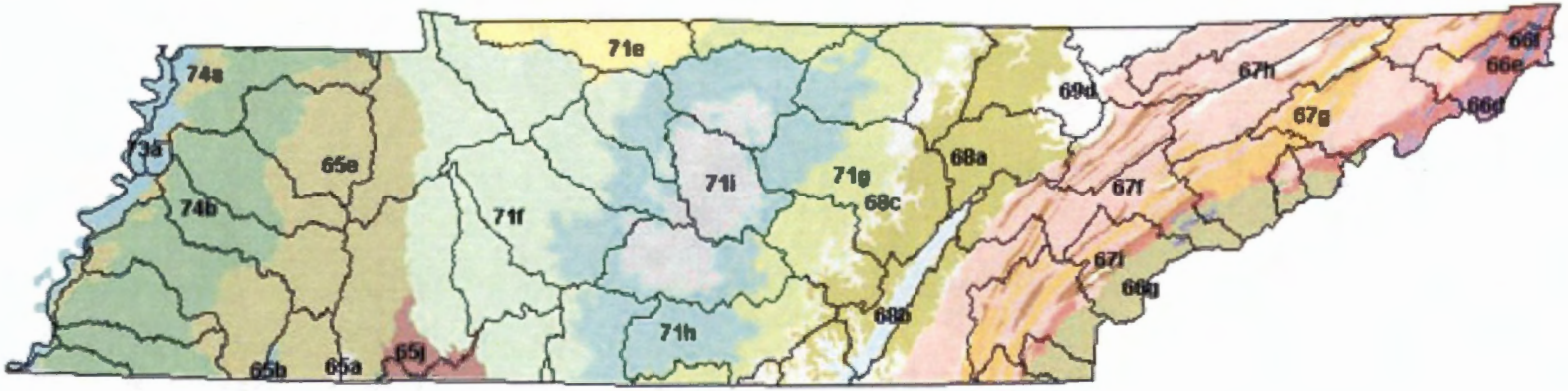


Figure 2. Eutrophication processes occurring in streams.

LEVEL IV ECOREGION AND HUC-8 WATERSHED BOUNDARIES IN TENNESSEE



www.state.tn.us/environment/riv/how.htm

Figure 3. Tennessee Level IV ecoregions.

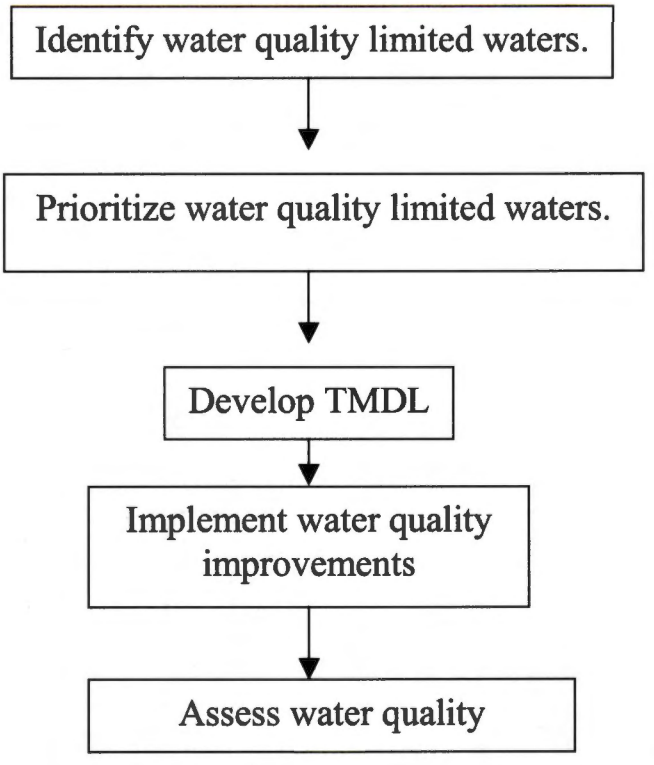


Figure 4. Simplified steps of TMDL development.

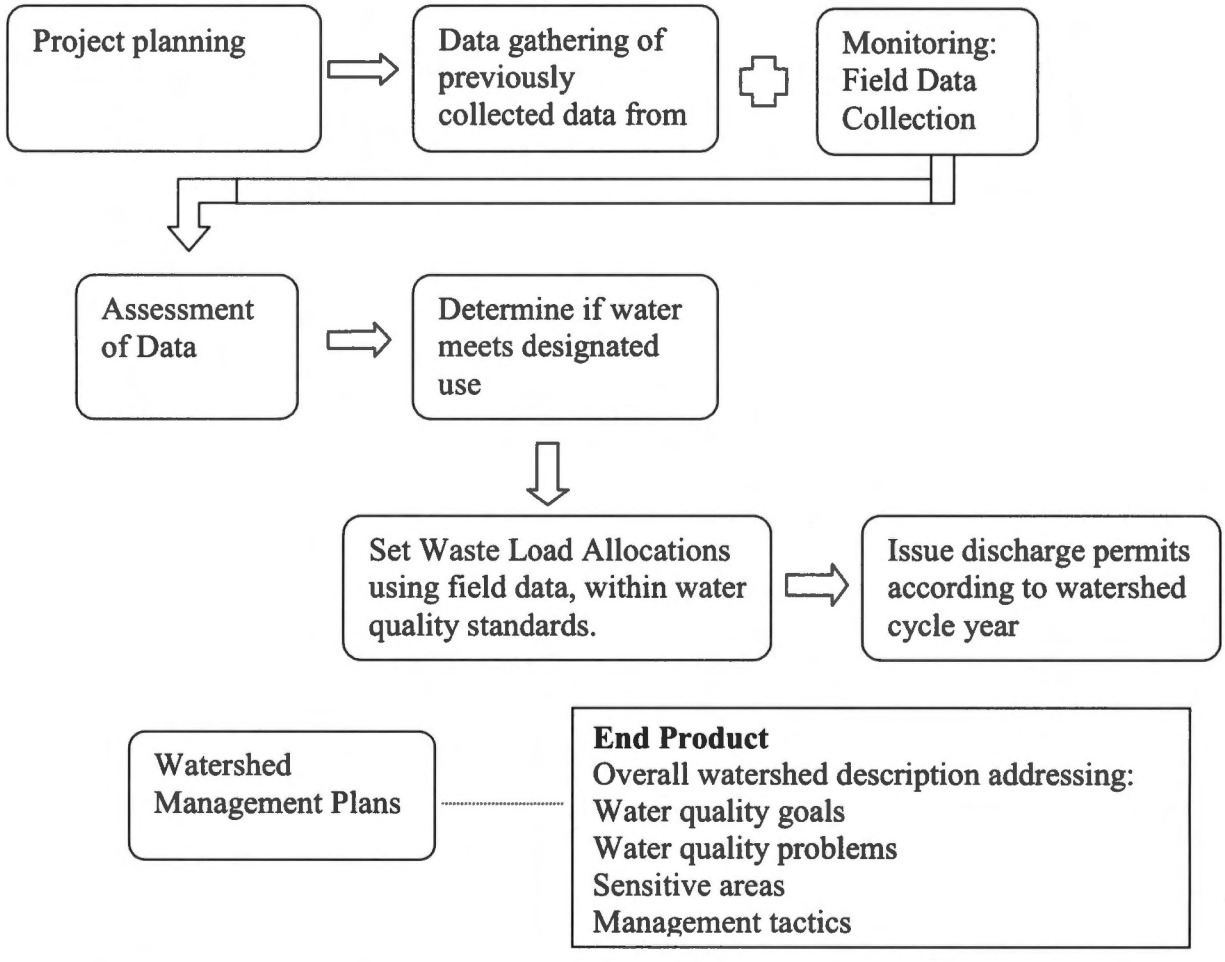


Figure 5. Basic elements of the watershed management approach cycle for developing TMDLs (TDEC, 2001a).

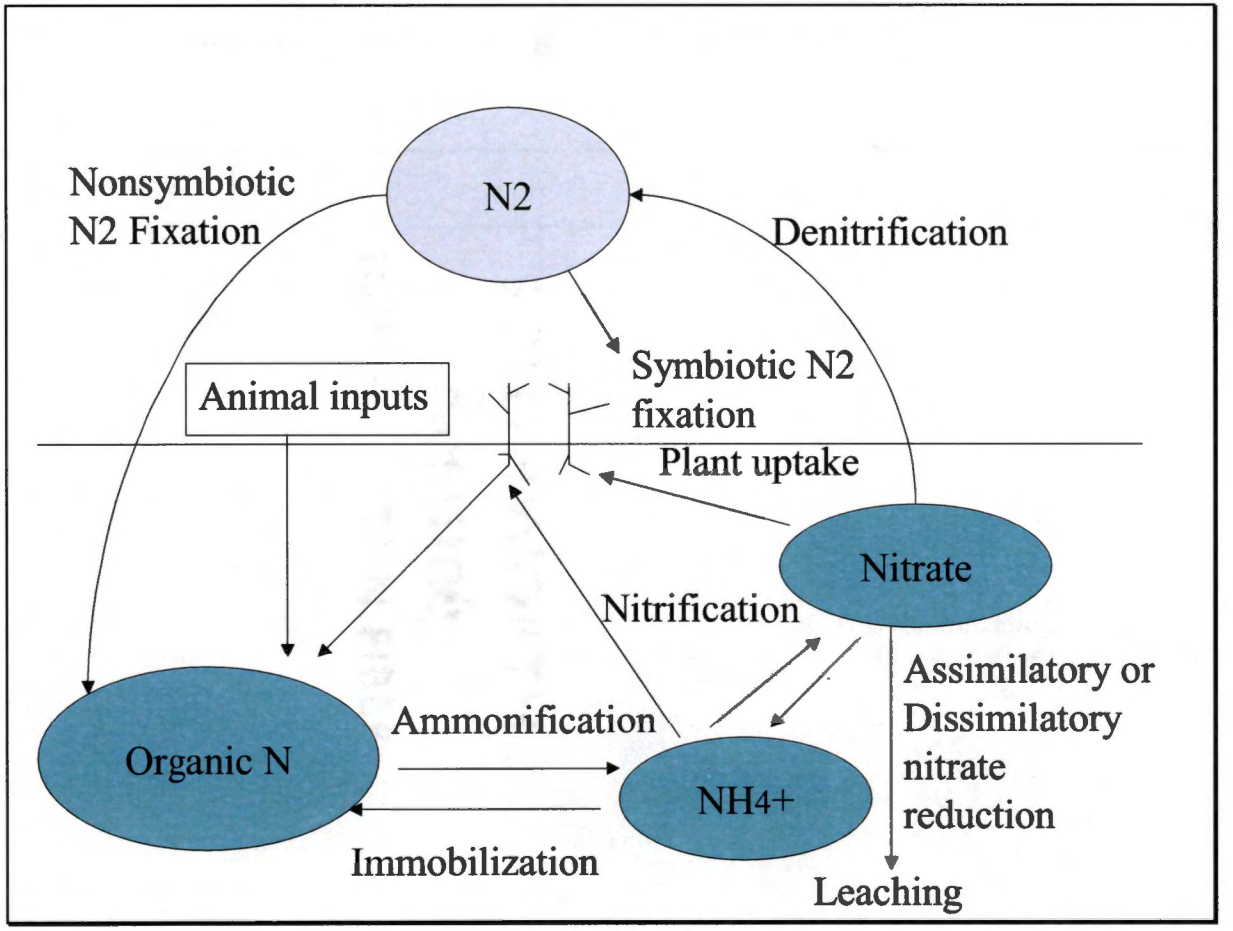


Figure 6. Simplified nitrogen cycle.

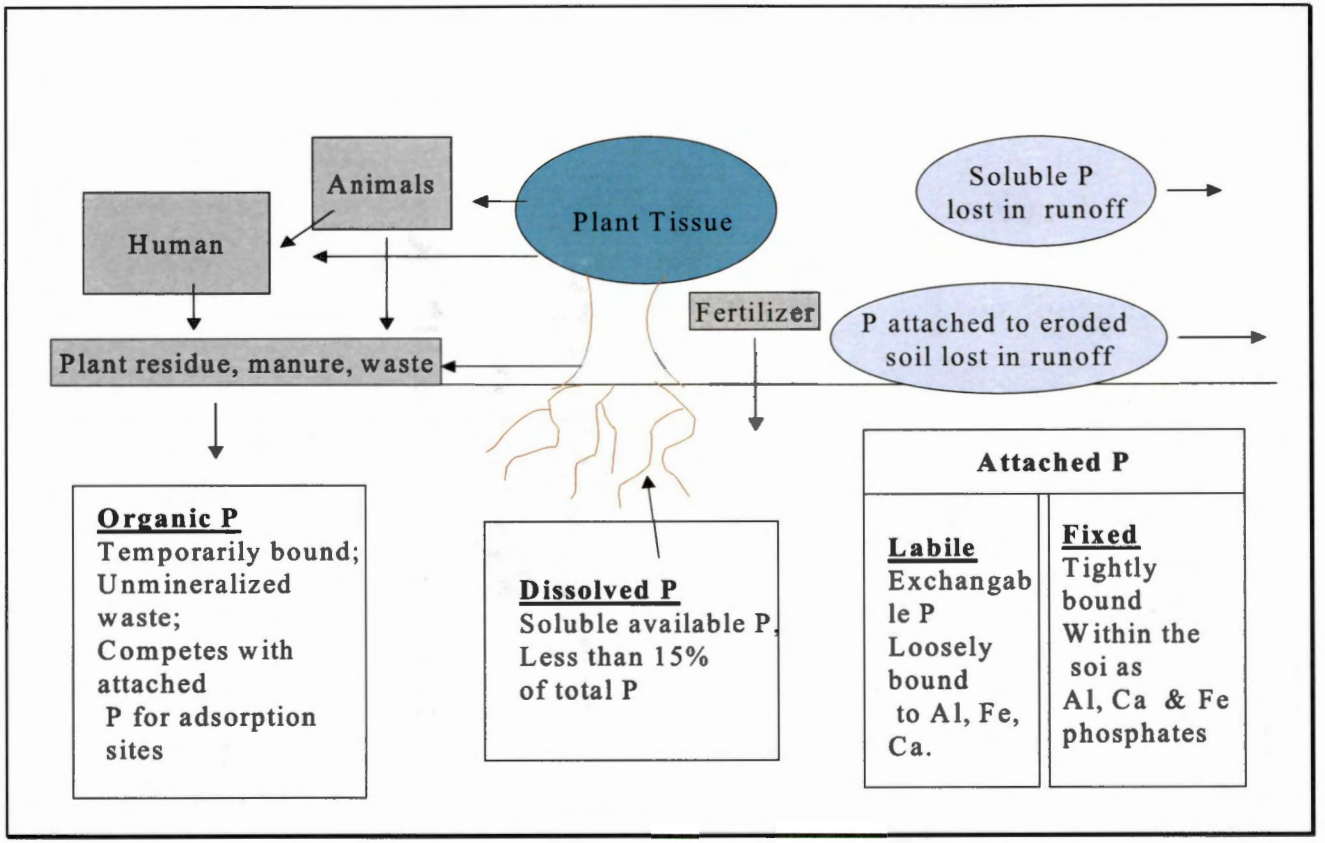
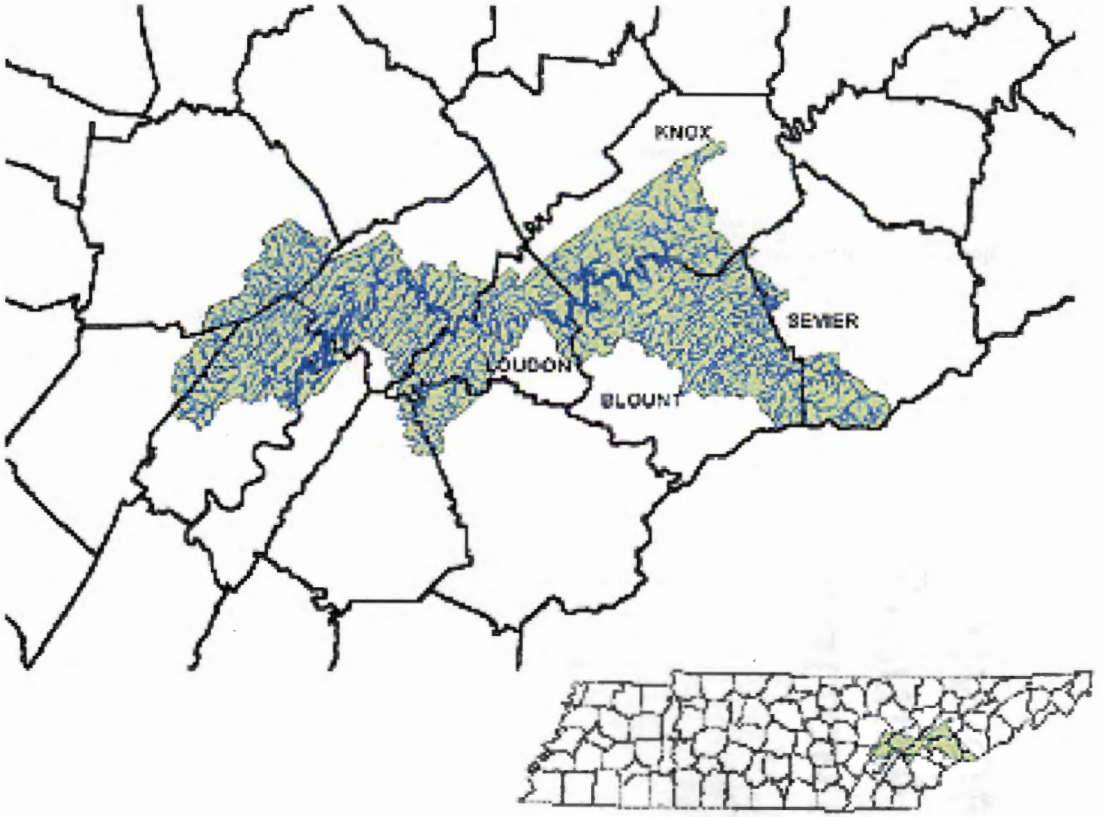


Figure 7. **Phosphorus cycle adapted from Brady and Weils, 1999.**



www.state.tn.us/environment/wpc/wshed1.htm

Figure 8. Watts Barr watershed containing Pond Creek watershed, HUC 06010201

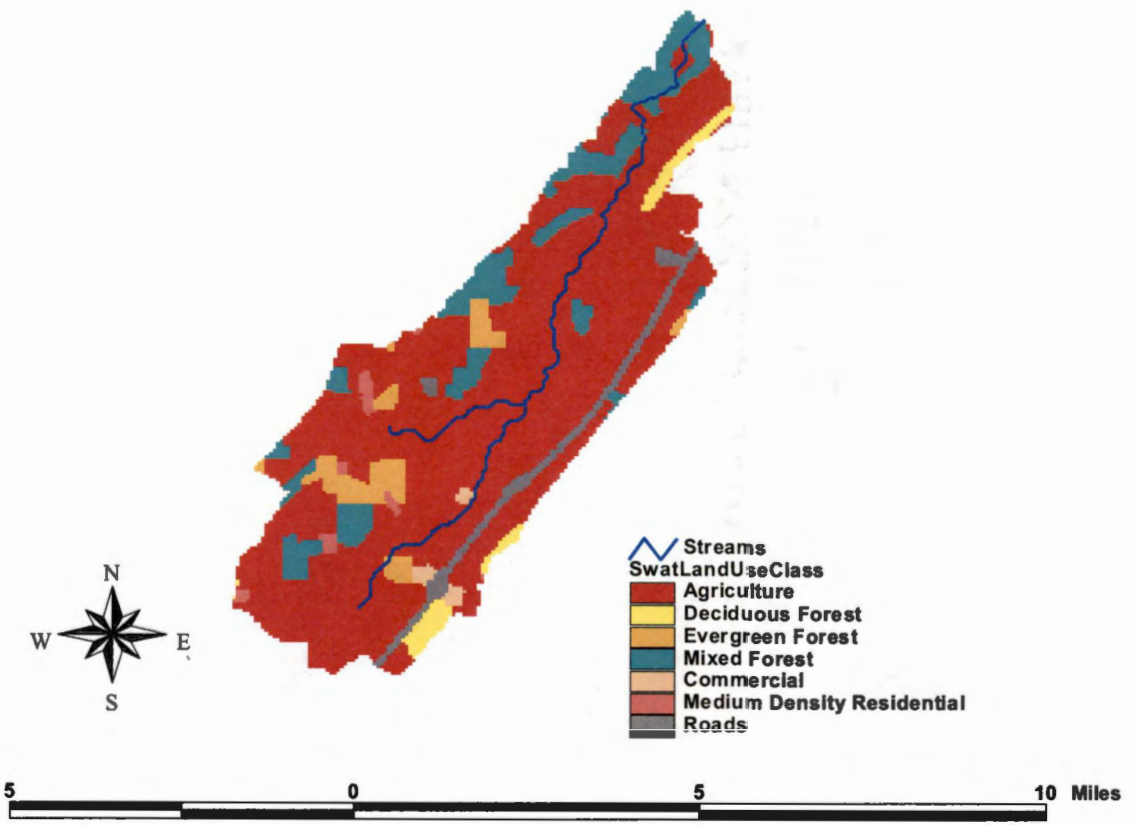


Figure 9. Land use classification in Pond Creek watershed study area.

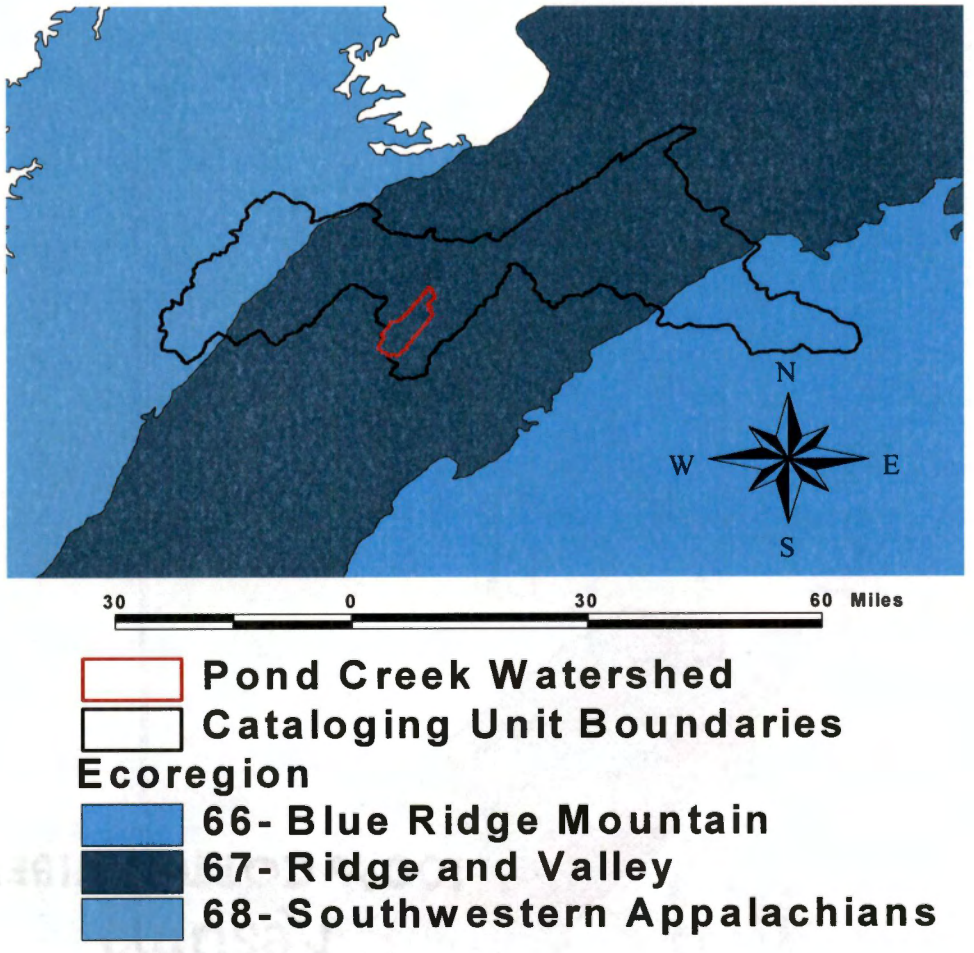


Figure 10. Ecoregion Level IV containing Pond Creek watershed study site.

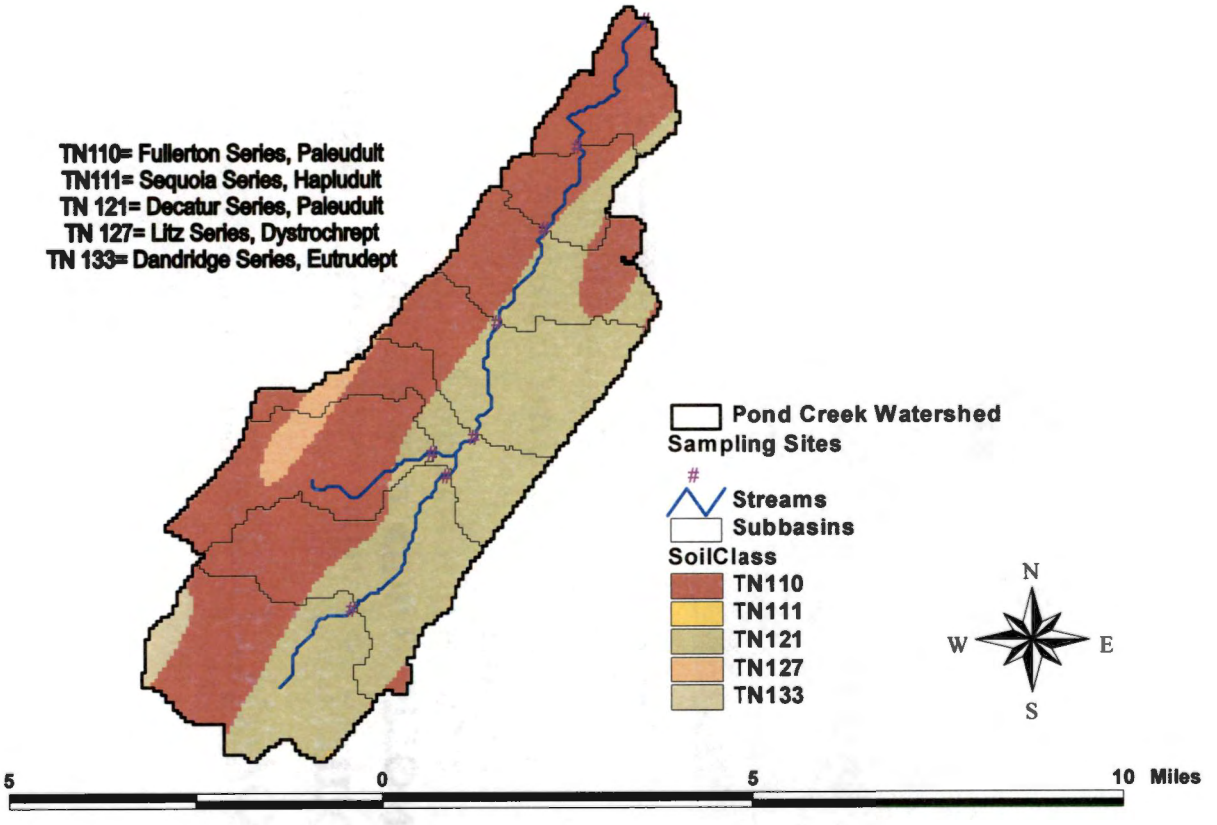


Figure 11. Soil classification using STATSGO soils data for Pond Creek watershed study area.

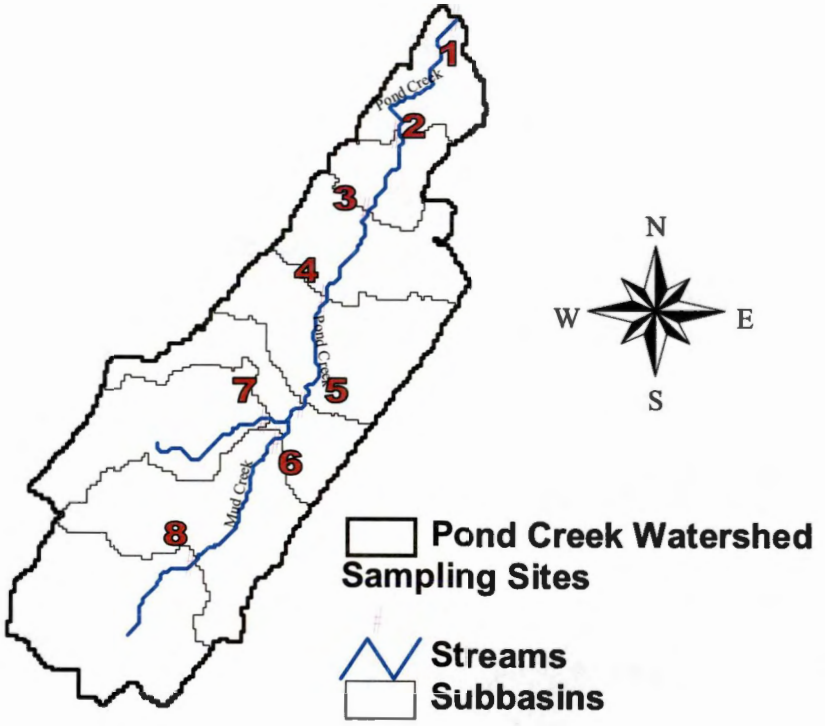


Figure 12. Pond Creek watershed study area showing 8 sampling sites and subbasins.

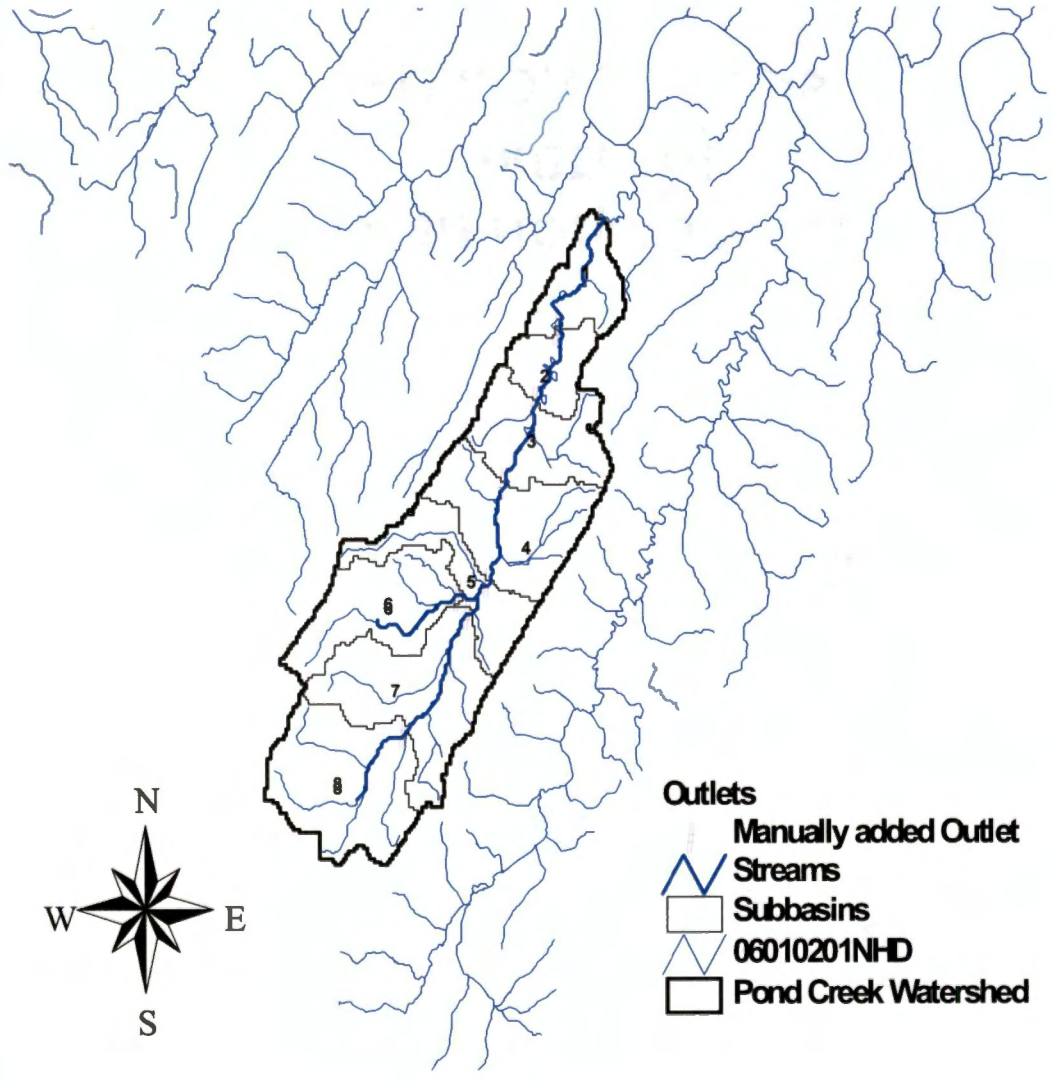


Figure 13. Pond Creek watershed stream network.

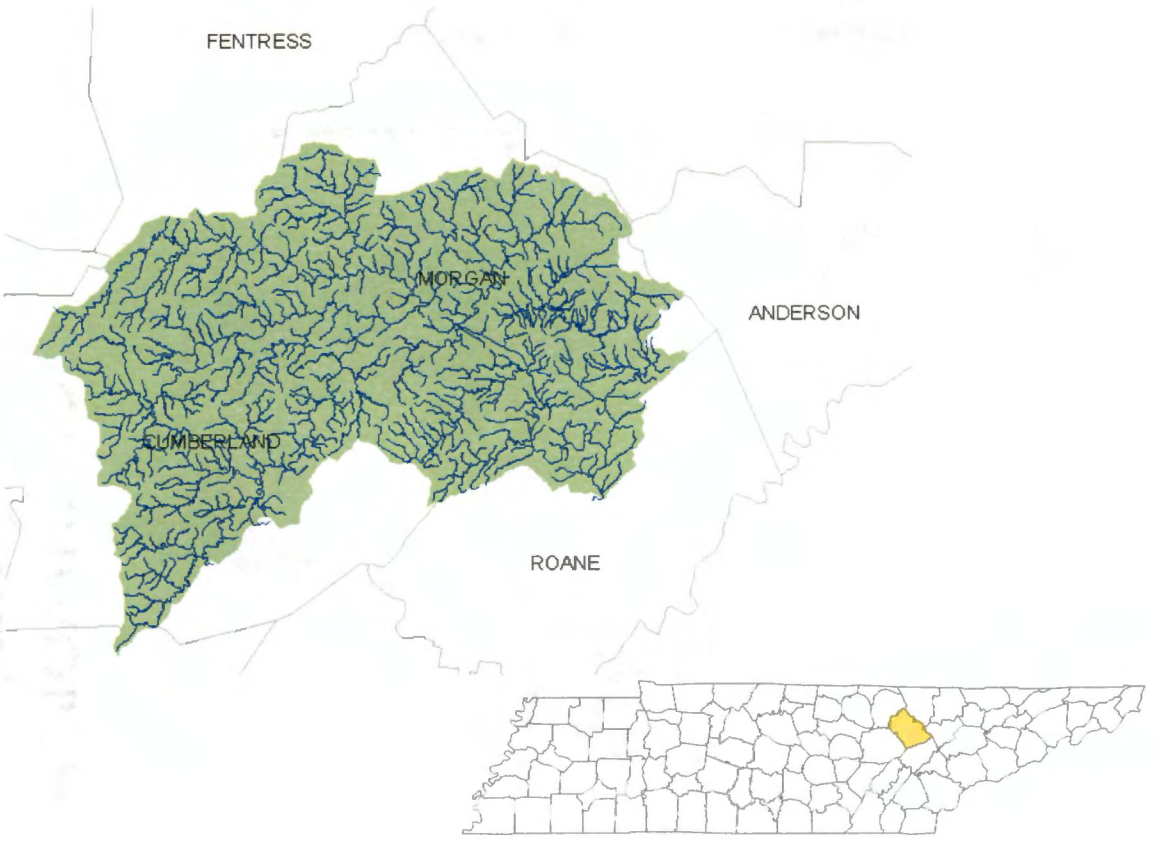


Figure 14. Emory watershed containing Crooked Fork-Emory watershed, HUC 06010208.

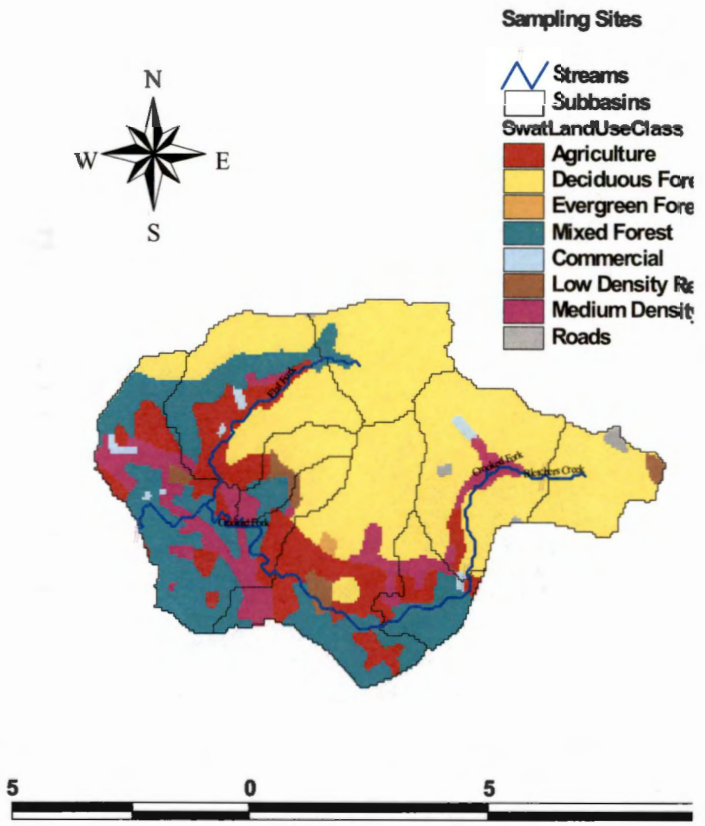


Figure 15. Land use classification in Crooked Fork-Emory watershed study area.

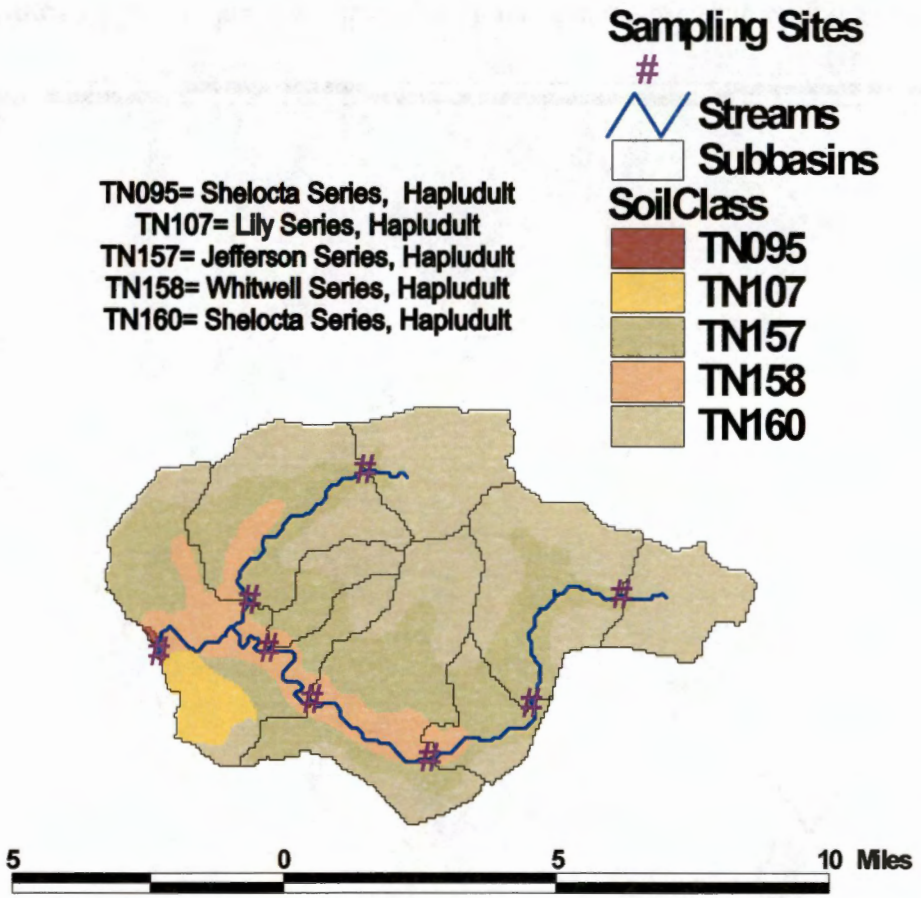


Figure 16. Soil classification using STATSGO soils data for Crooked Fork-Emory watershed.

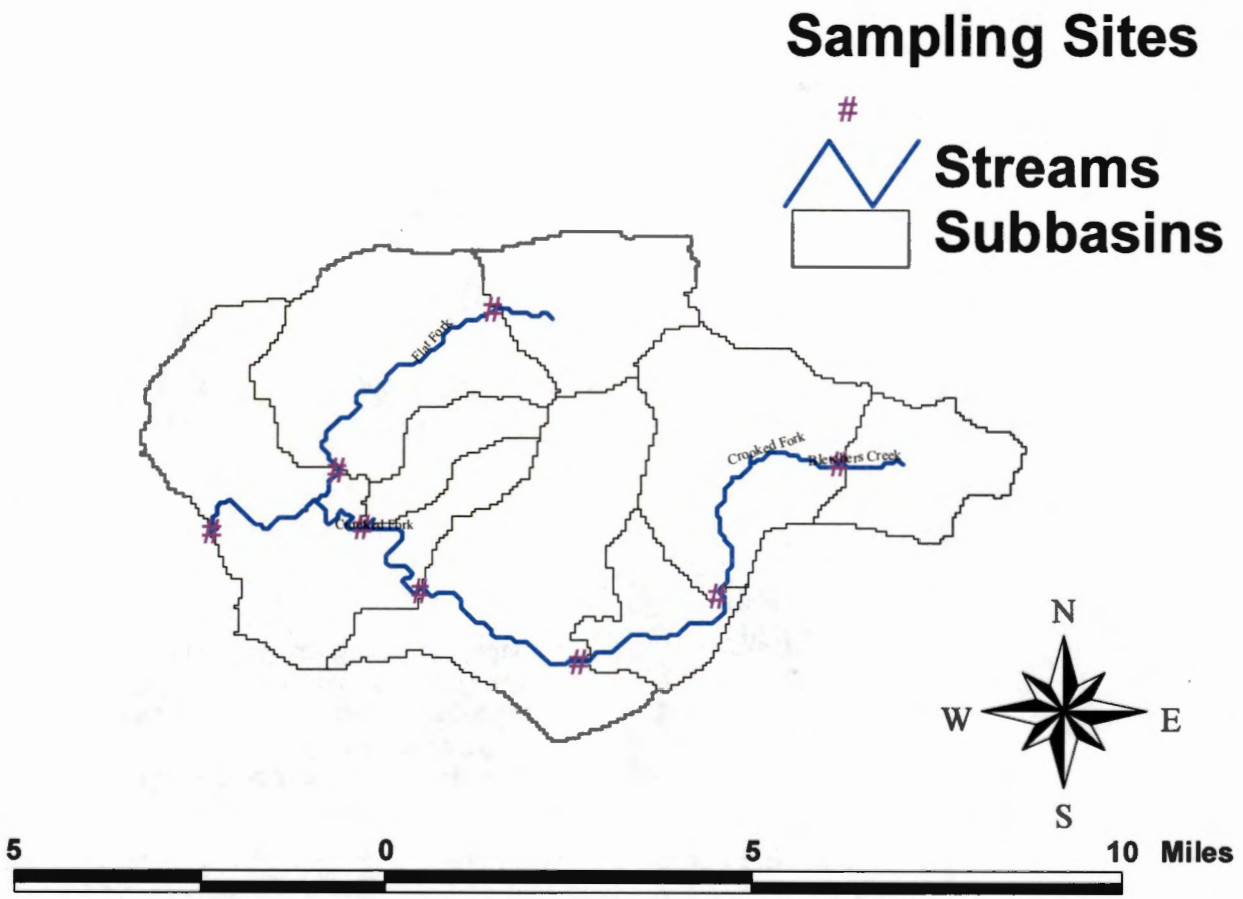


Figure 17. Crooked Fork-Emory watershed study area showing 8 sampling sites and subbasins.

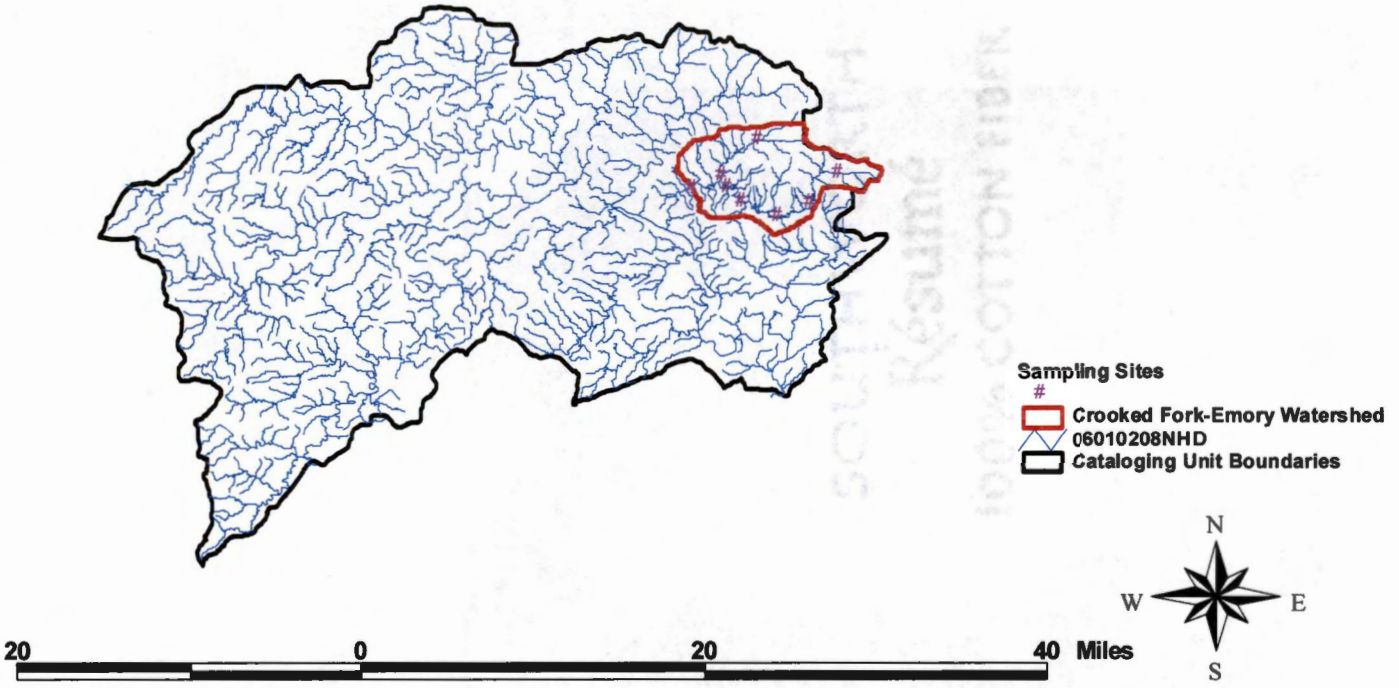


Figure 18. Emory watershed and study area stream network.

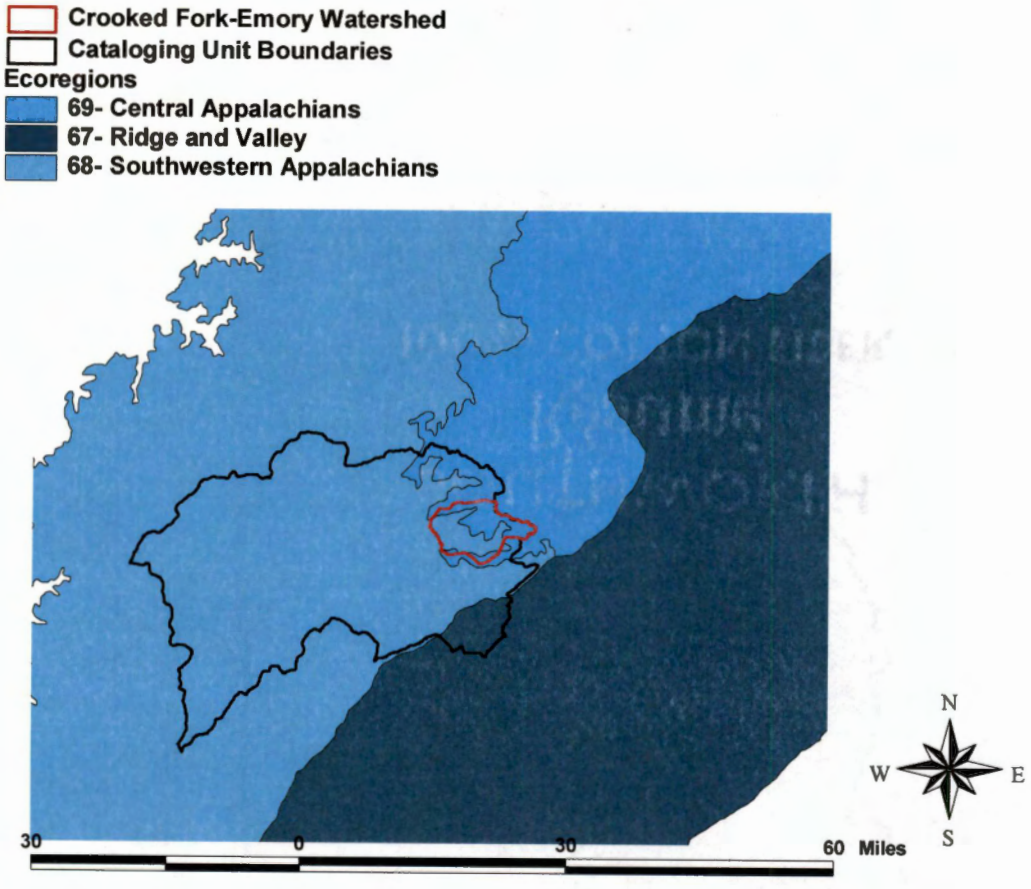


Figure 19. Crooked Fork-Emory Level IV Ecoregions.

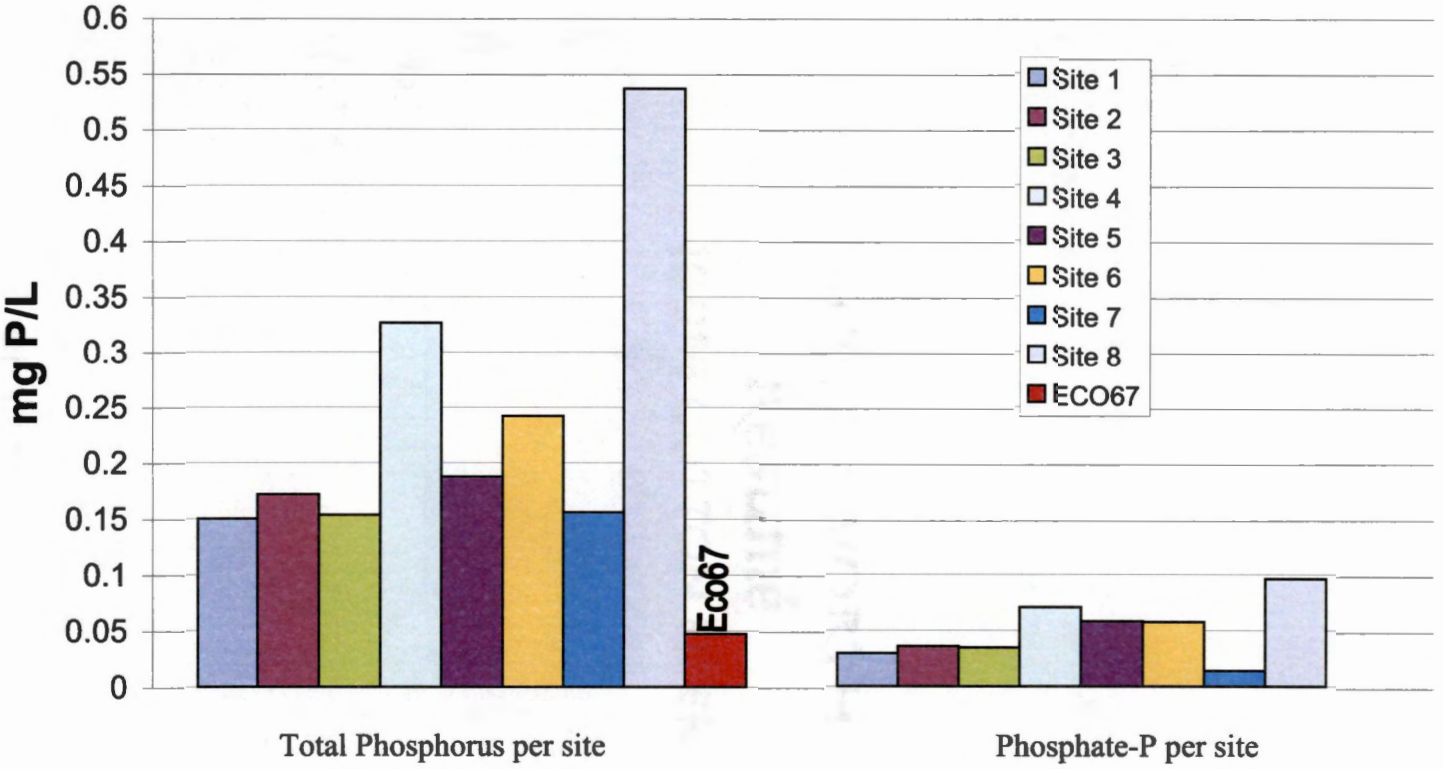


Figure 20. Pond Creek watershed mean phosphorus values per sampling site compared with ecoregion 67 reference stream values.

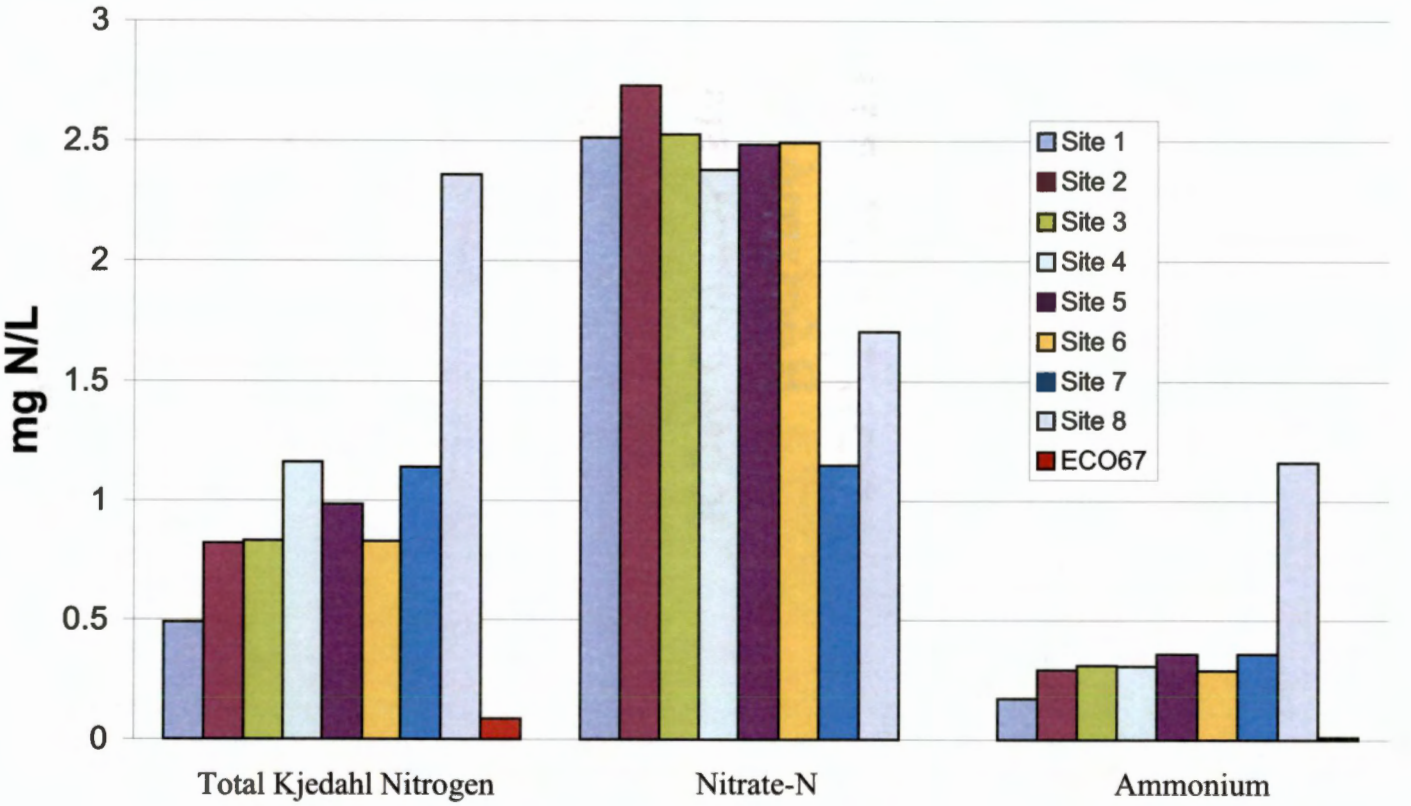


Figure 21. Pond Creek watershed mean nitrogen values per sampling site compared with ecoregion 67 reference stream.

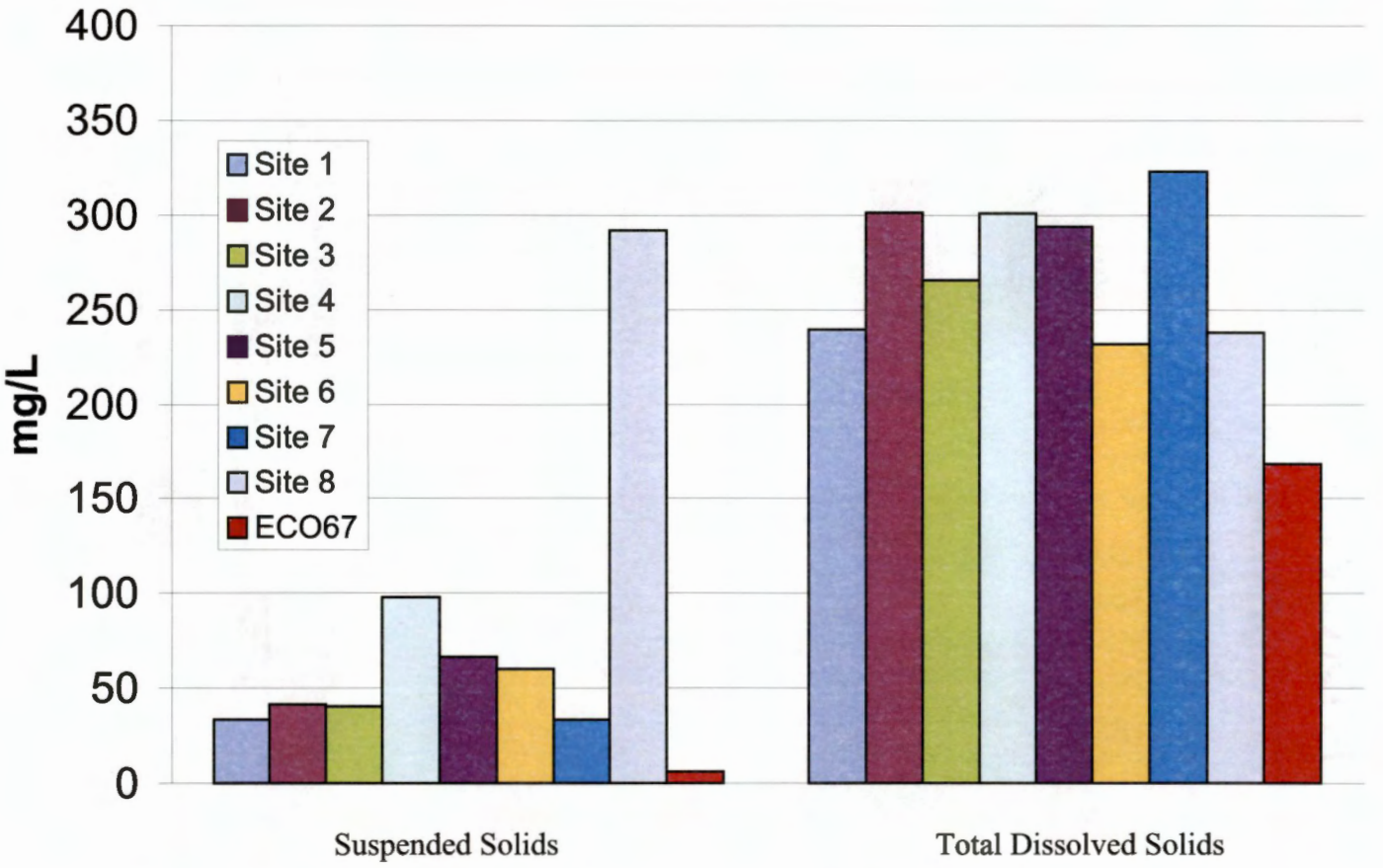


Figure 22. Pond Creek Watershed Mean suspended solids and total dissolved solids mean values per sampling site compared with Ecoregion 67 Reference Stream values.

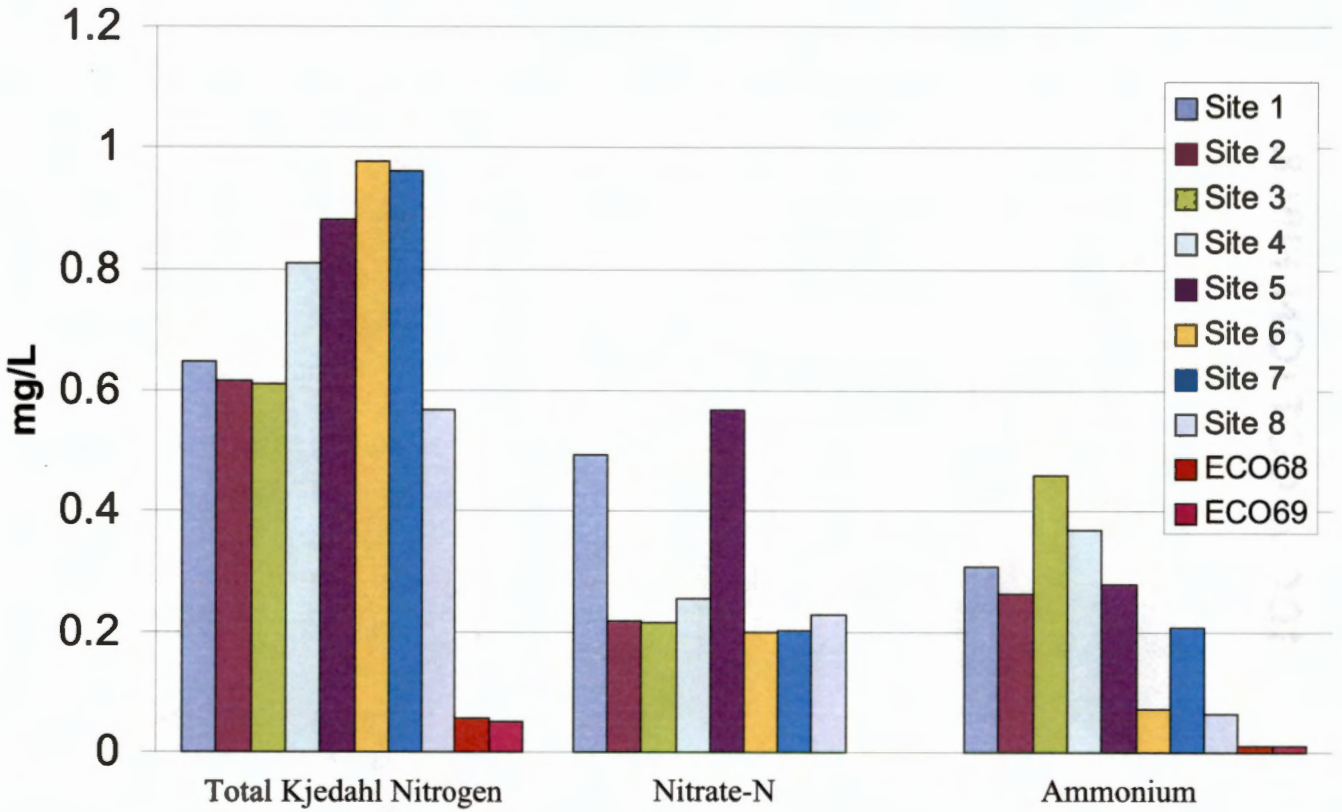


Figure 23. Crooked Fork-Emory mean nitrogen values per site compared with ecoregion 68 and 69 reference streams.

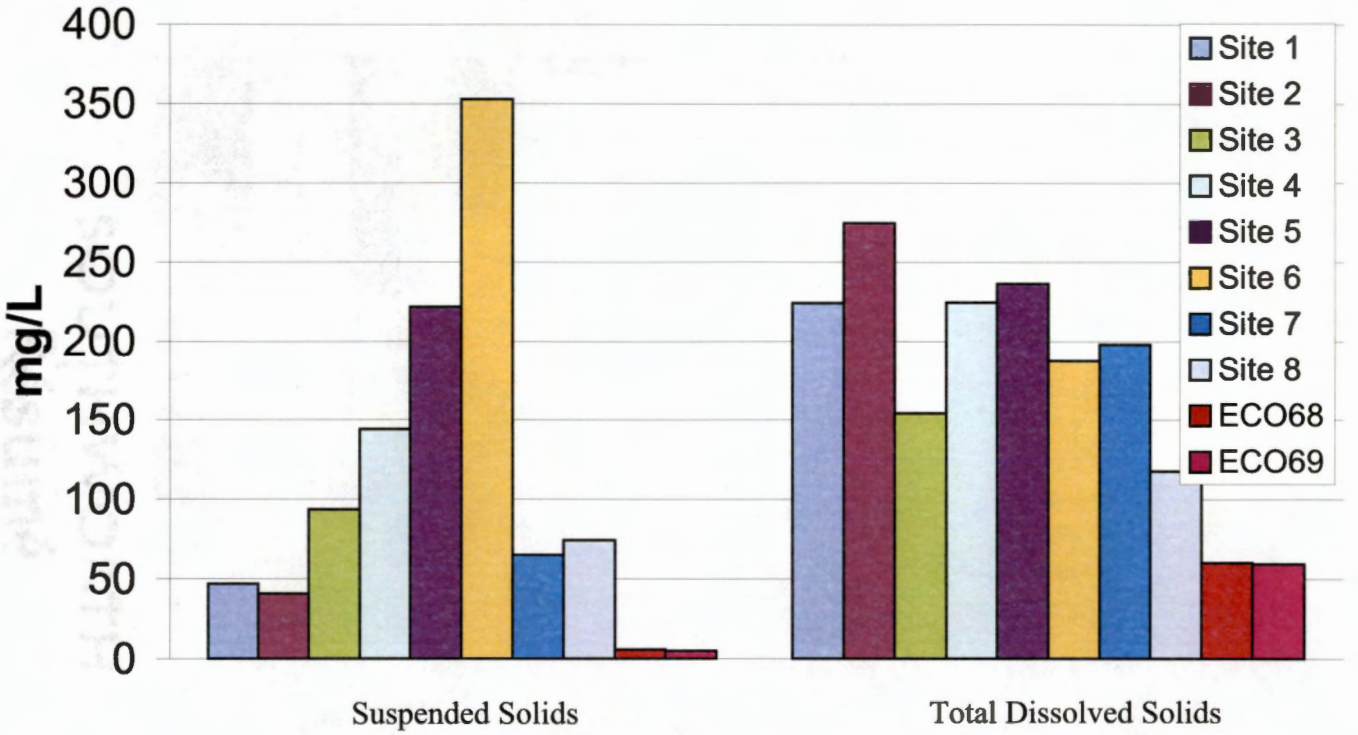


Figure 24. Crooked Fork-Emory suspended solids and total dissolved solids water sampling data compared with ecoregions 68 and 69 reference streams.

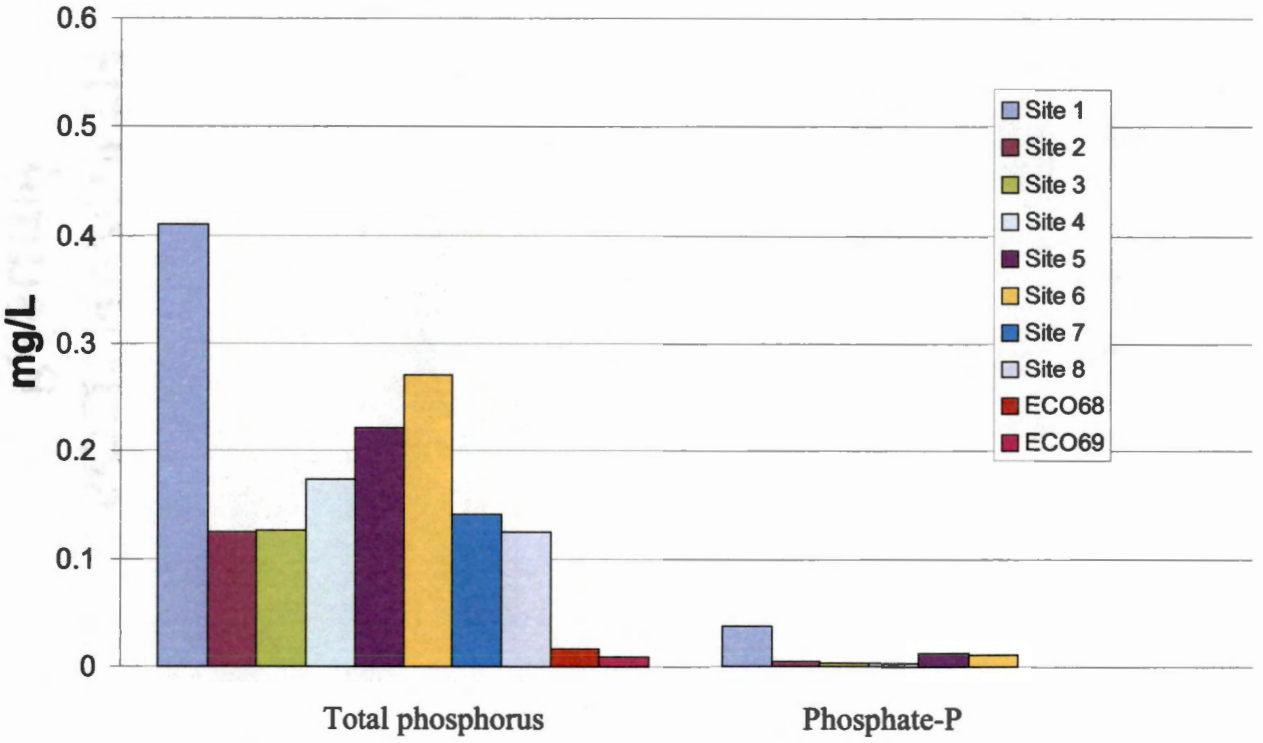
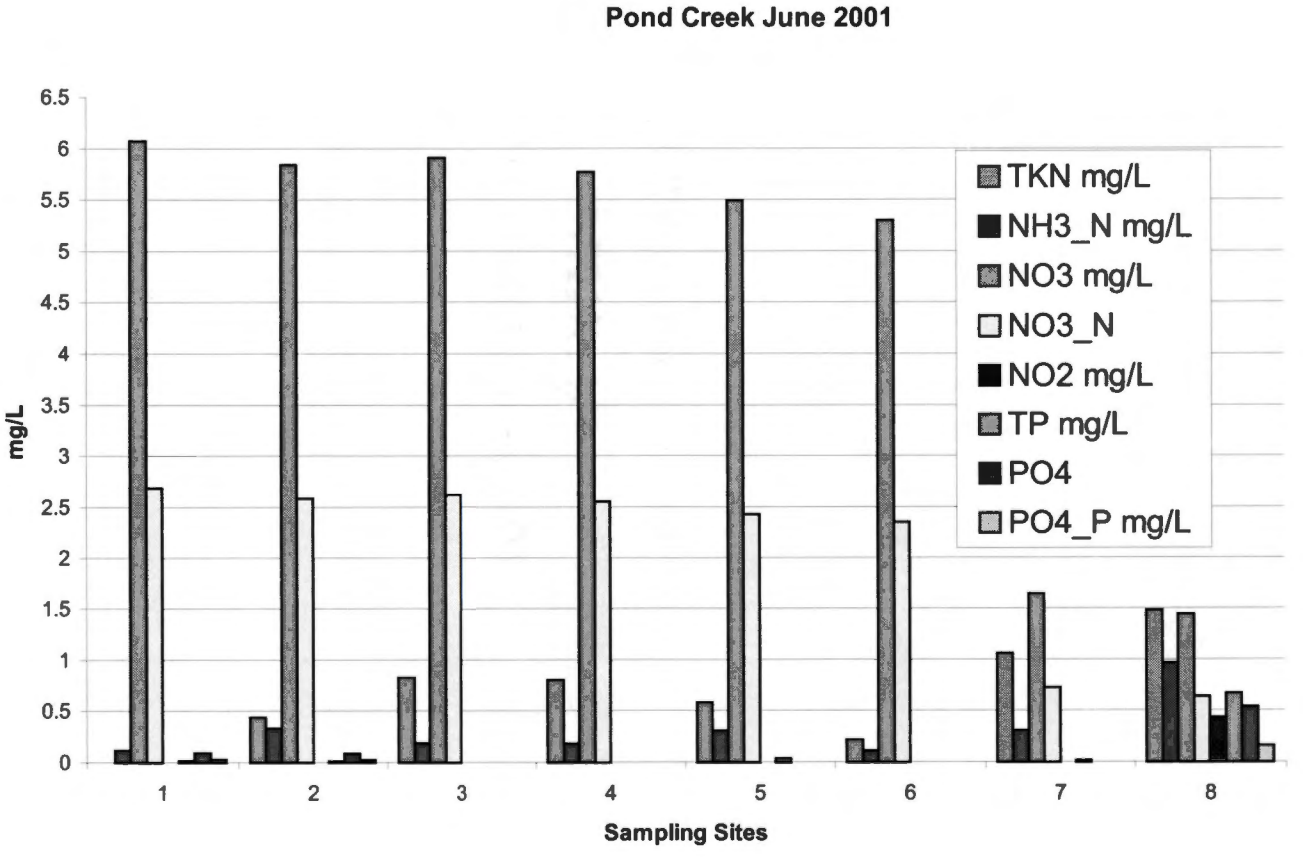
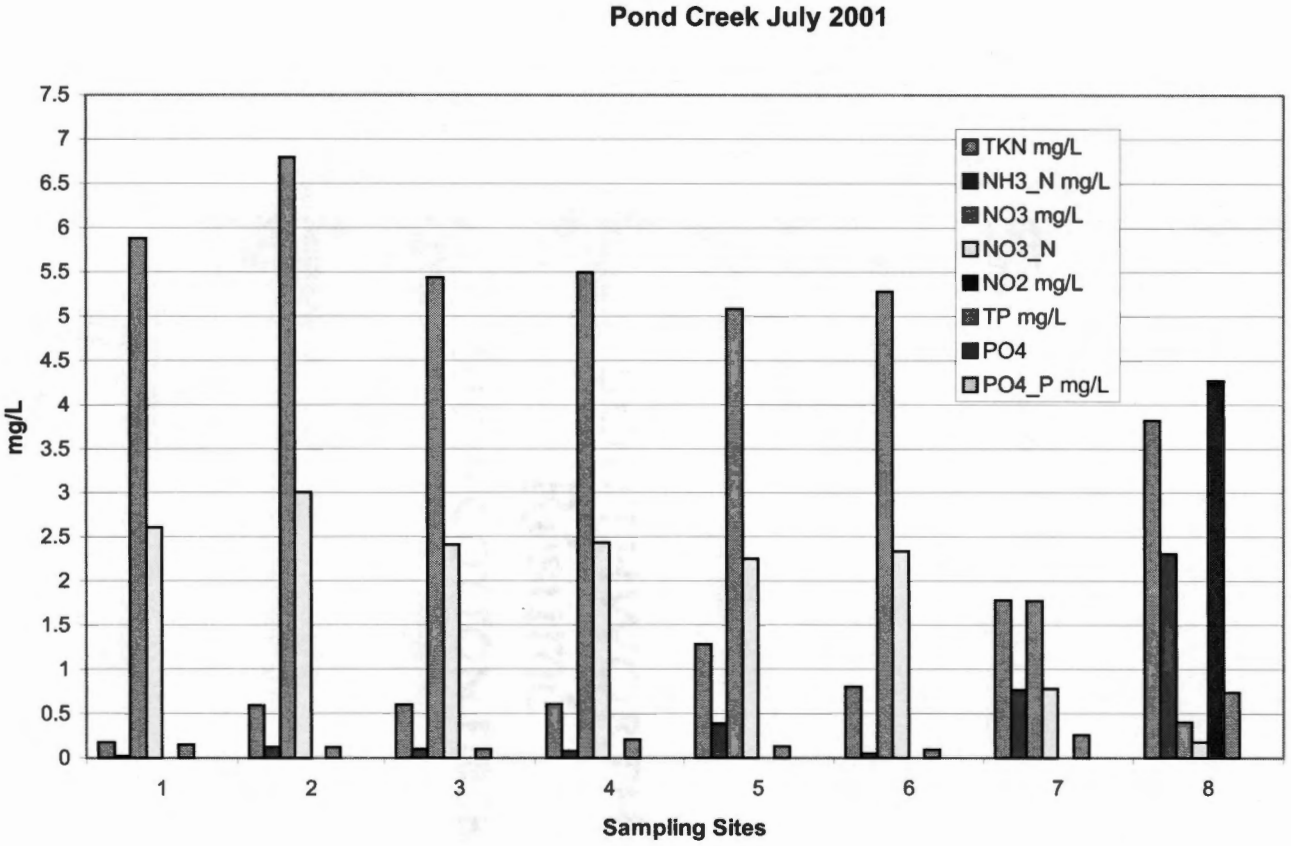
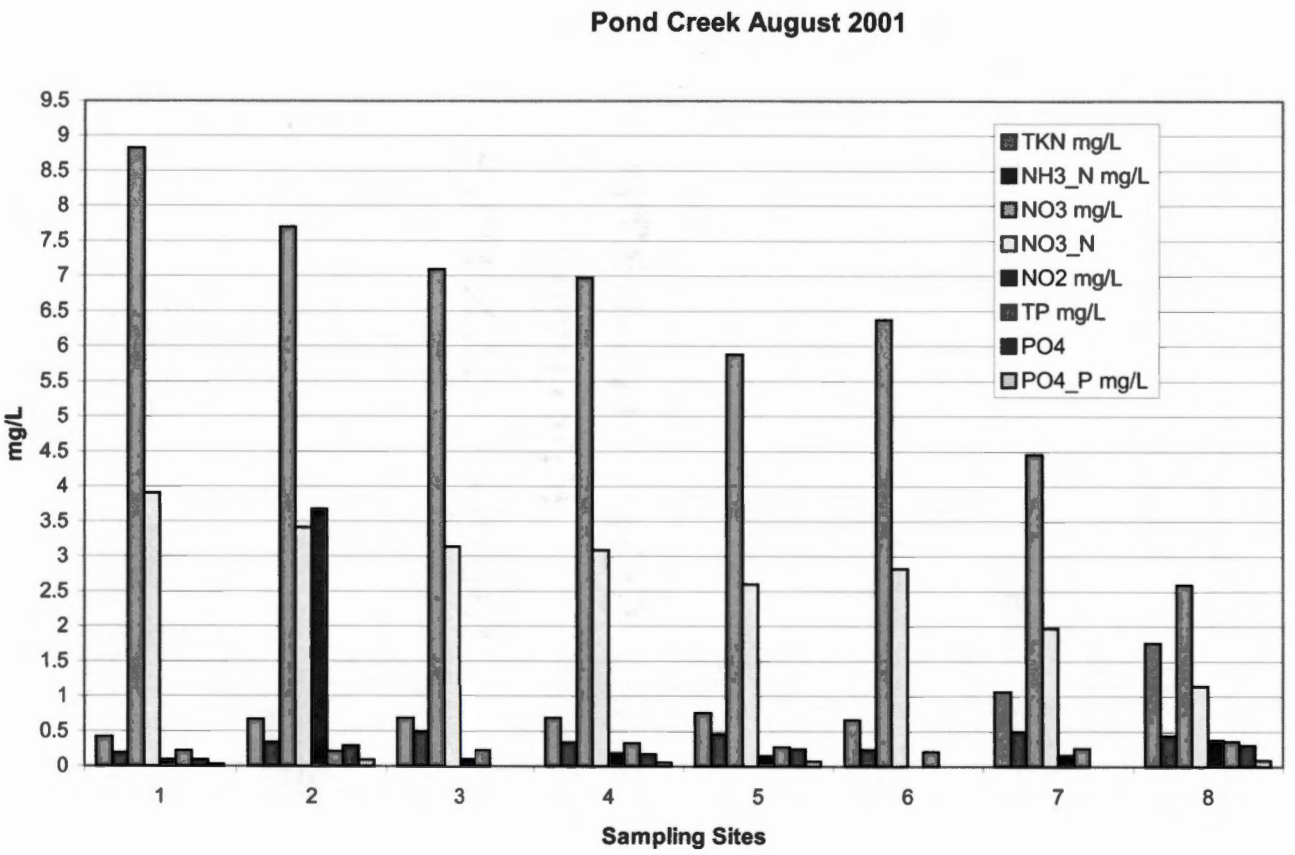


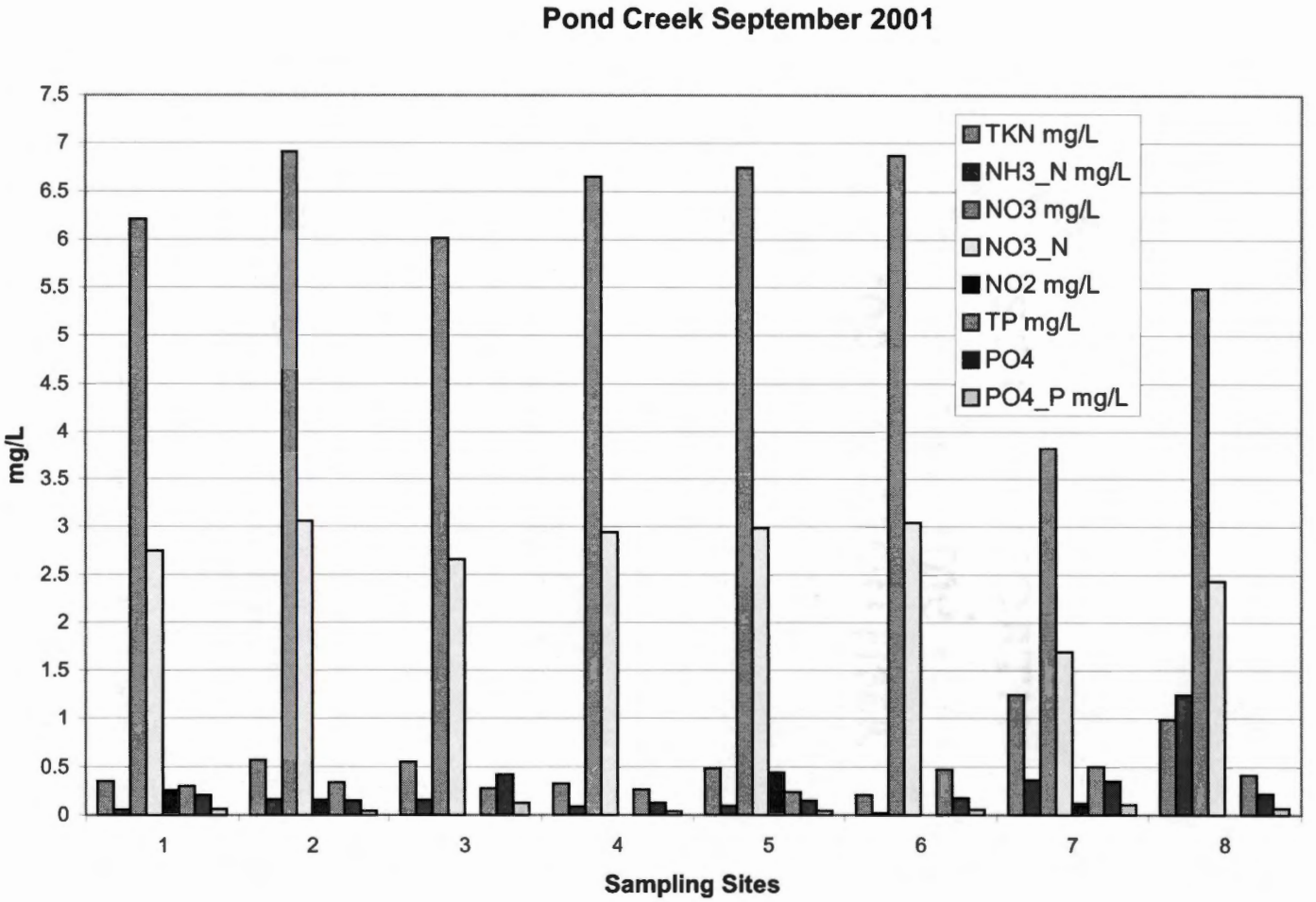
Figure 25. Crooked Fork-Emory mean phosphorus values per site compared with ecoregions 68 and 69 reference streams.

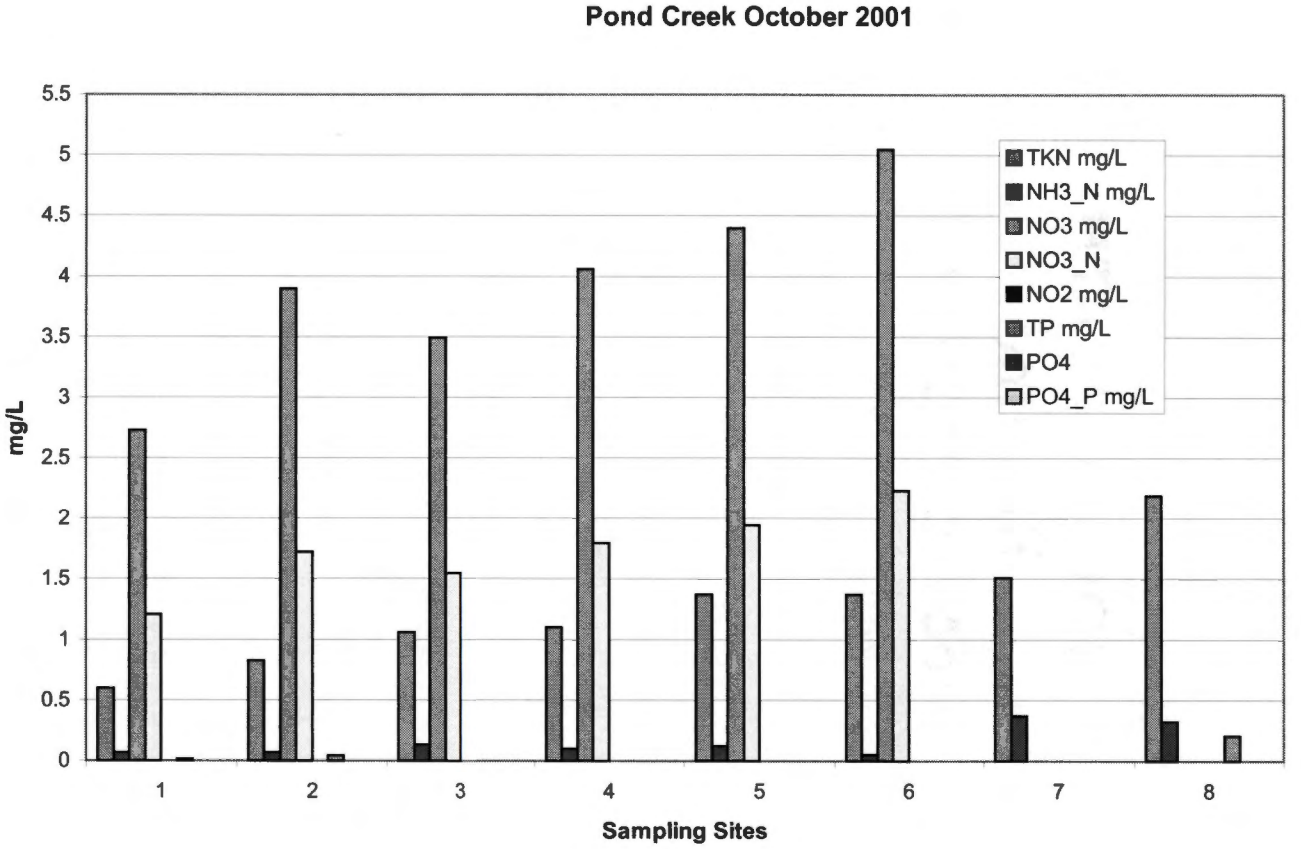
APPENDIX C: SUPPLEMENTAL DATA

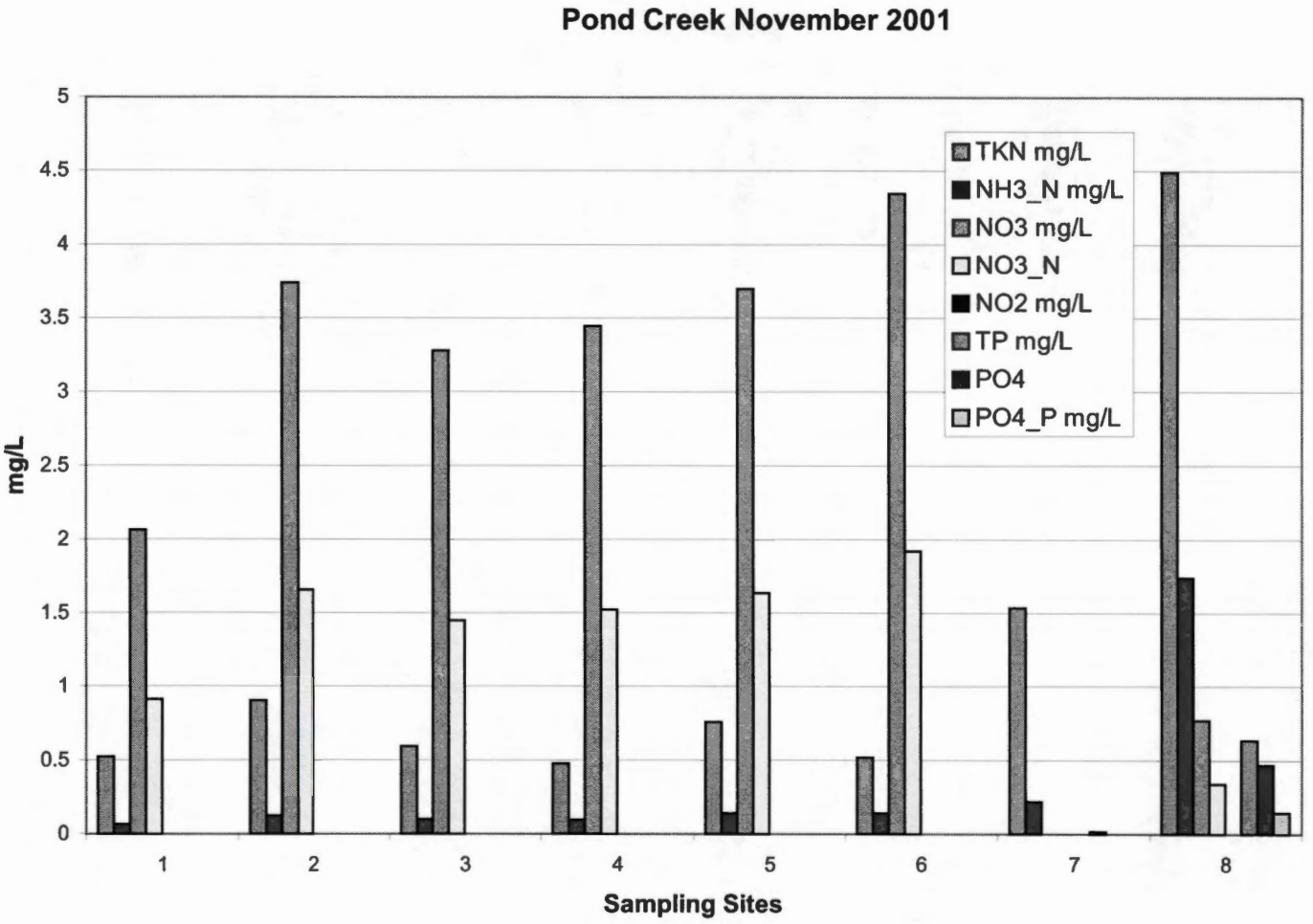

Pond Creek June 2001
6.5
6
5.5
5
4.5
4
3.5
3
2.5
2
1.5
1
0.5
0
mg/L
1
2
3
4
5
6
7
8
Sampling Sites
TKN mg/L
NH3_N mg/L
NO3 mg/L
NO3_N
NO2 mg/L
TP mg/L
PO4
PO4_P mg/L

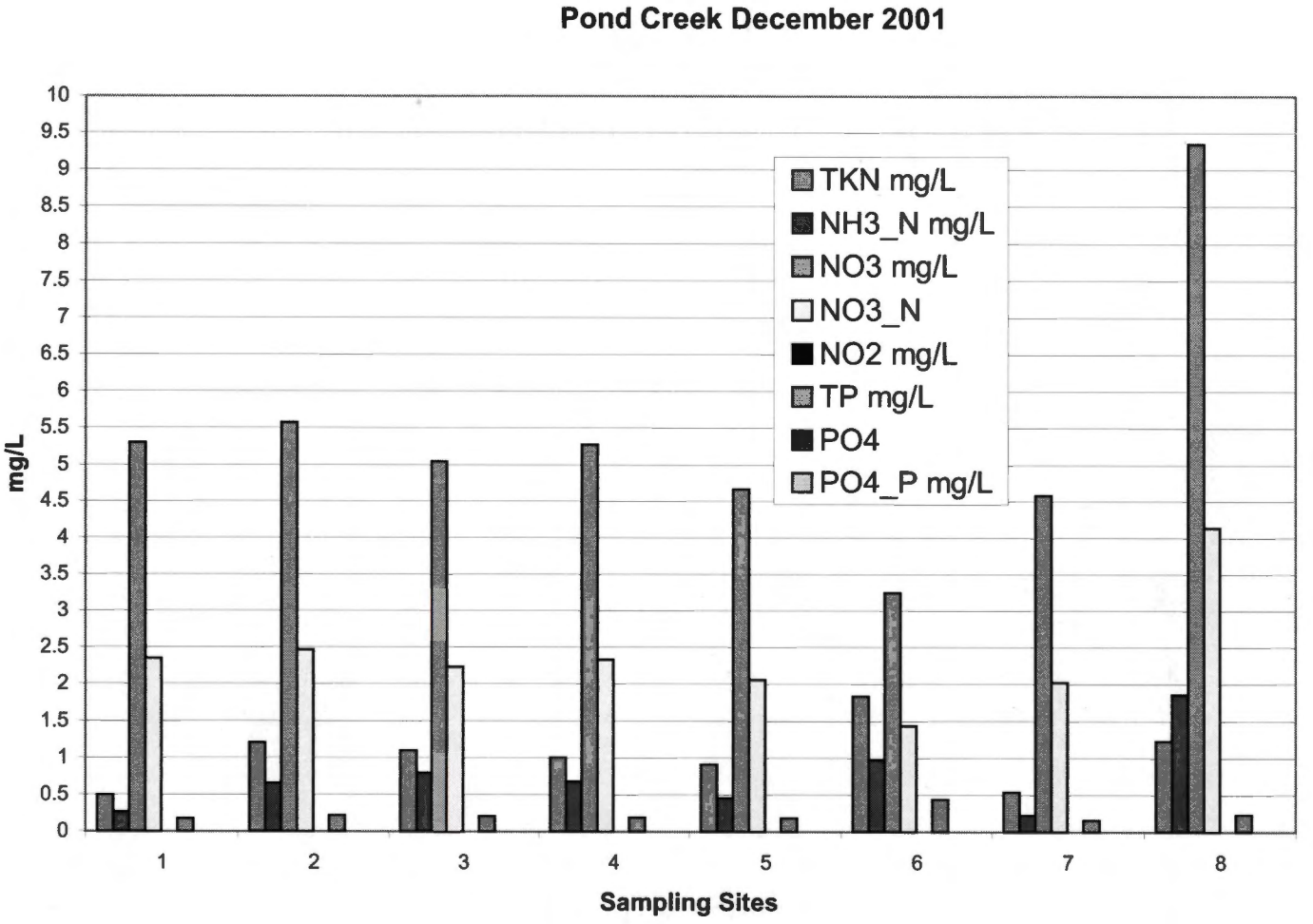

Pond Creek July 2001
7.5
7
6.5
6
5.5
5
4.5
4
3.5
3
2.5
2
1.5
1
0.5
0
mg/L
TKN mg/L
NH3_N mg/L
NO3 mg/L
NO3_N
NO2 mg/L
TP mg/L
PO4
PO4_P mg/L
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2
3
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6
7
8
Sampling Sites

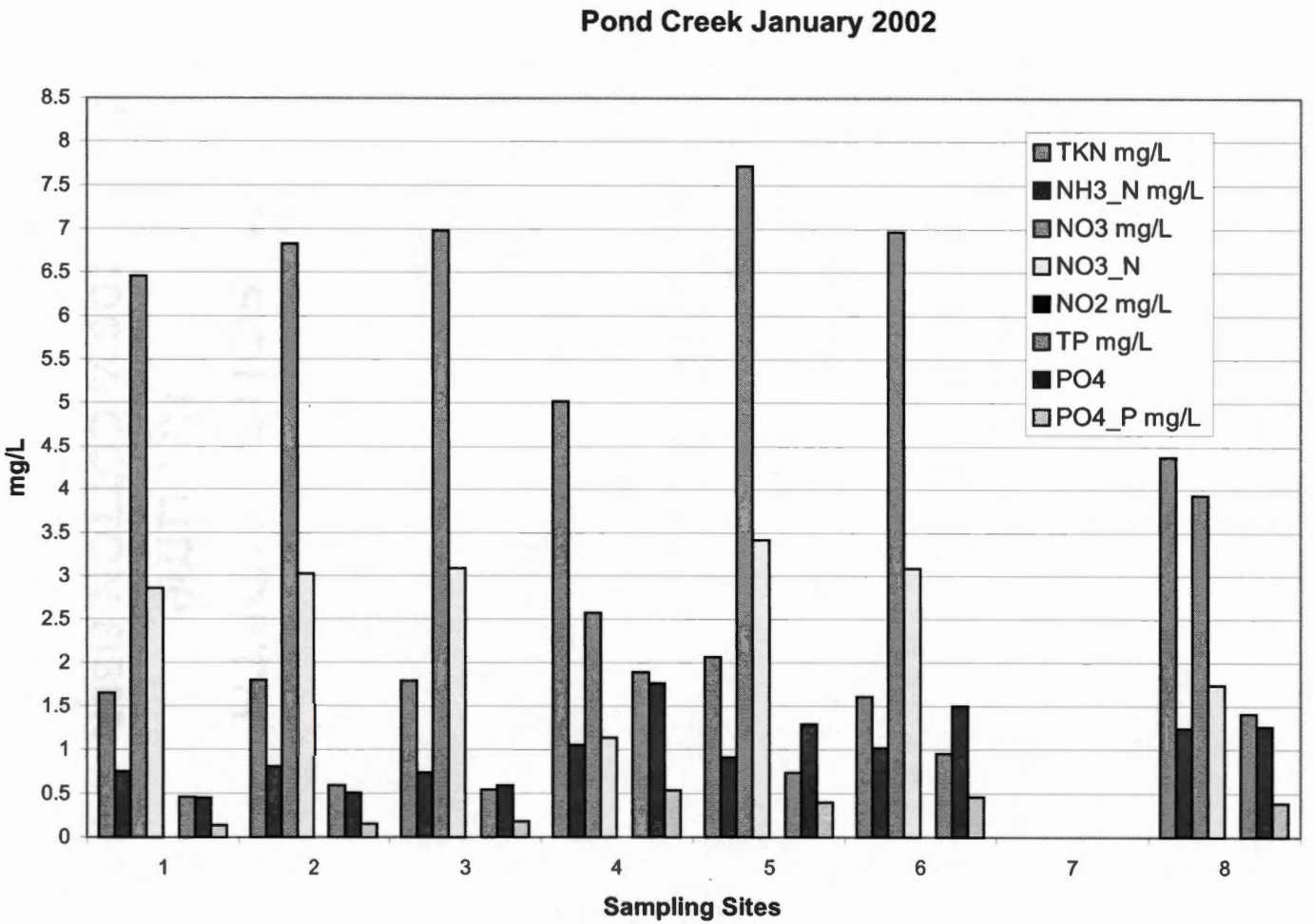

Pond Creek August 2001
9.5
9
8.5
8
7.5
7
6.5
6
5.5
5
4.5
4
3.5
3
2.5
2
1.5
1
0.5
0
mg/L
1
2
3
4
5
6
7
8
Sampling Sites
TKN mg/L
NH3_N mg/L
NO3 mg/L
NO3_N
NO2 mg/L
TP mg/L
PO4
PO4_P mg/L

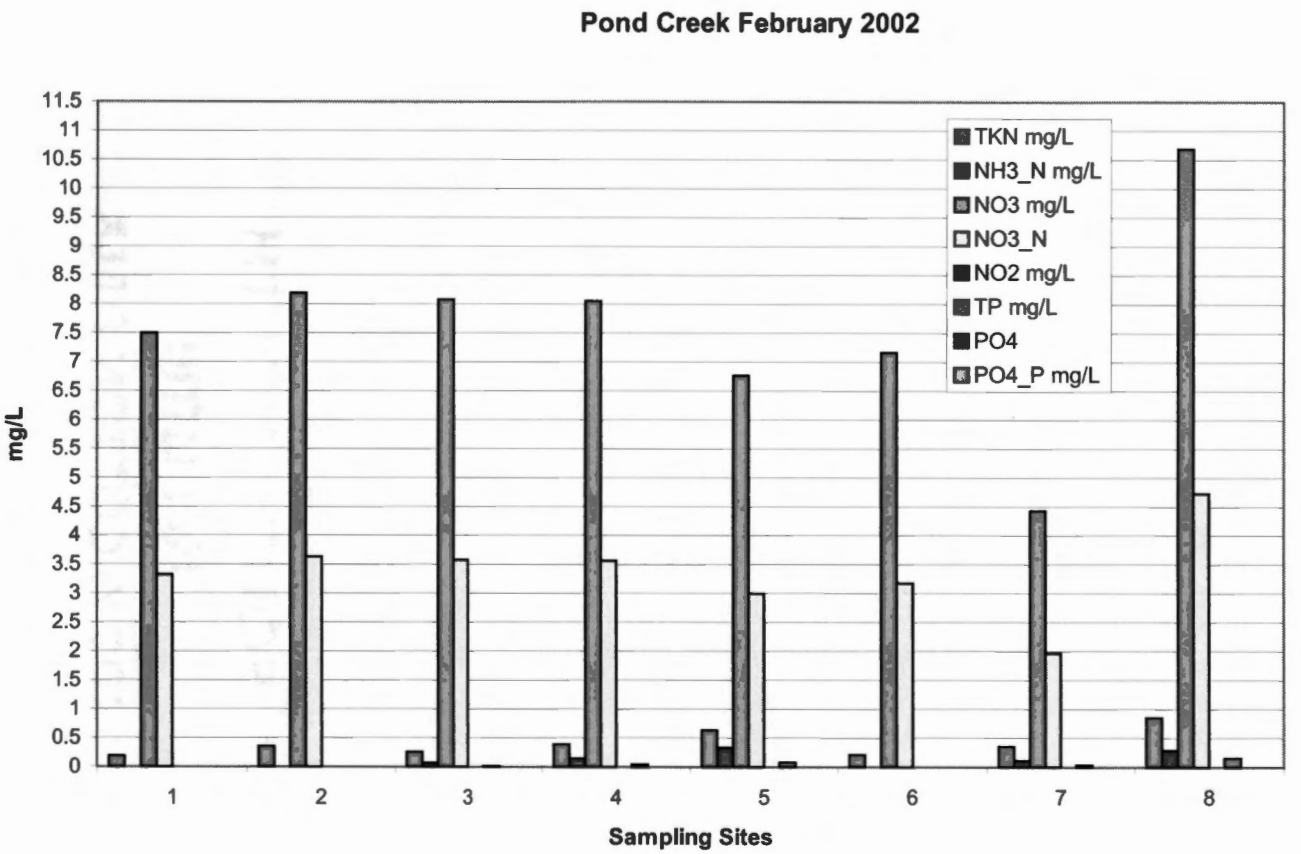

Pond Creek September 2001
7.5
7
6.5
6
5.5
5
4.5
4
3.5
3
2.5
2
1.5
1
0.5
0
mg/L
1
2
3
4
5
6
7
8
Sampling Sites
TKN mg/L
NH3_N mg/L
NO3 mg/L
NO3_N
NO2 mg/L
TP mg/L
PO4
PO4_P mg/L

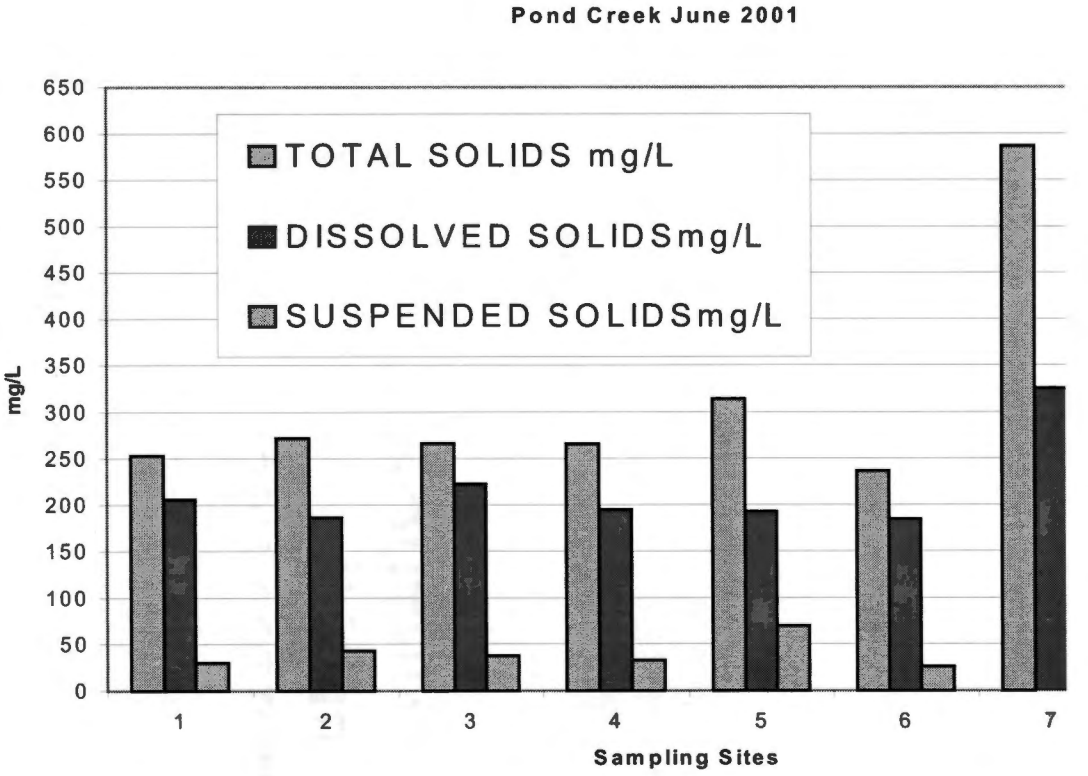

Pond Creek October 2001
5.5
5
4.5
4
3.5
3
2.5
2
1.5
1
0.5
0
mg/L
1
2
3
4
5
6
7
8
Sampling Sites
TKN mg/L
NH3_N mg/L
NO3 mg/L
NO3_N
NO2 mg/L
TP mg/L
PO4
PO4_P mg/L

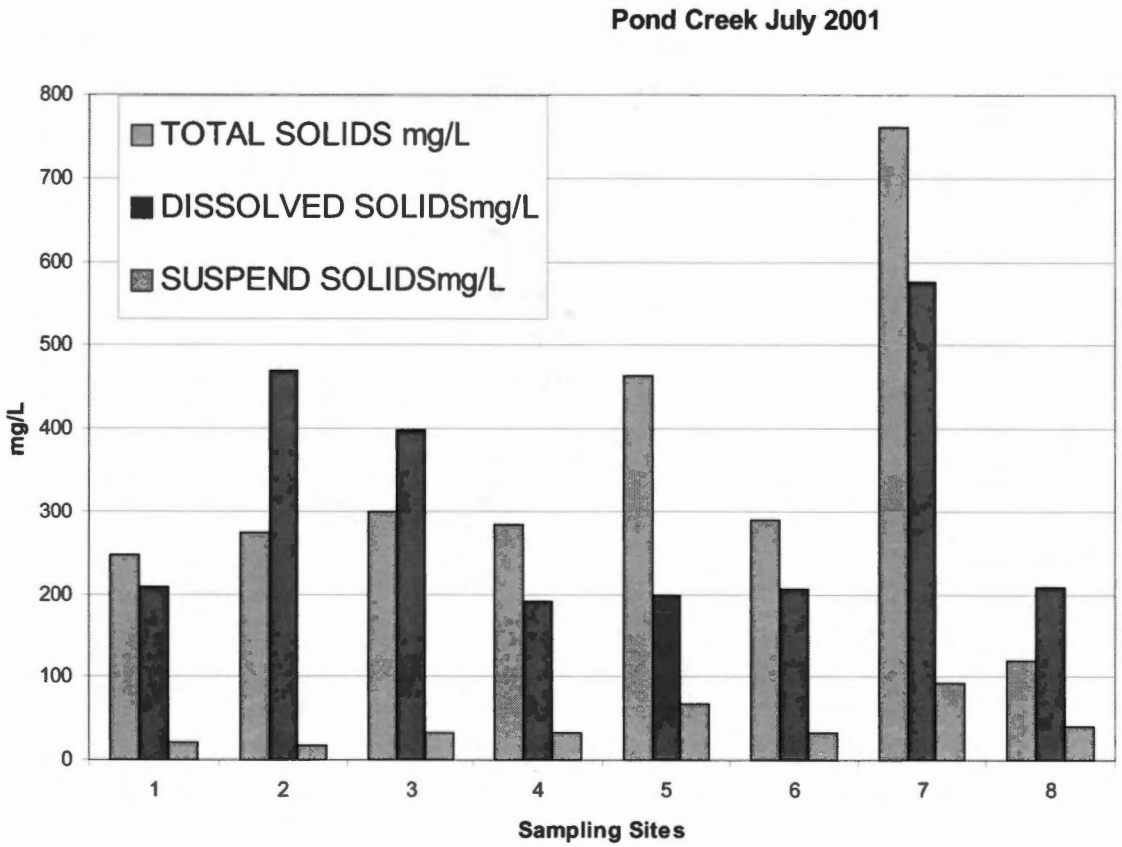

Pond Creek November 2001
mg/L
Sampling Sites
TKN mg/L
NH3_N mg/L
NO3 mg/L
NO3_N
NO2 mg/L
TP mg/L
PO4
PO4_P mg/L
0
0.5
1
1.5
2
2.5
3
3.5
4
4.5
5
1
2
3
4
5
6
7
8

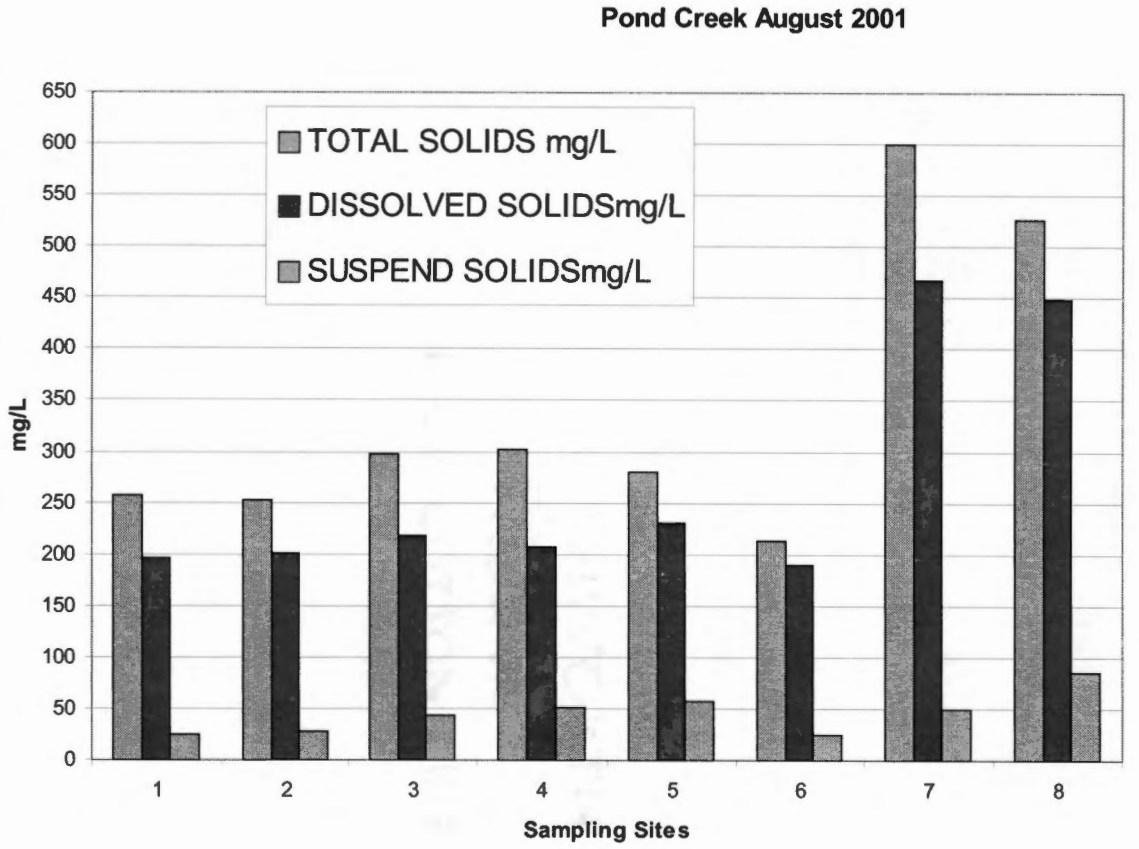

Pond Creek December 2001
mg/L
10
9.5
9
8.5
8
7.5
7
6.5
6
5.5
5
4.5
4
3.5
3
2.5
2
1.5
1
0.5
0
1
2
3
4
5
6
7
8
Sampling Sites
TKN mg/L
NH3_N mg/L
NO3 mg/L
NO3_N
NO2 mg/L
TP mg/L
PO4
PO4_P mg/L

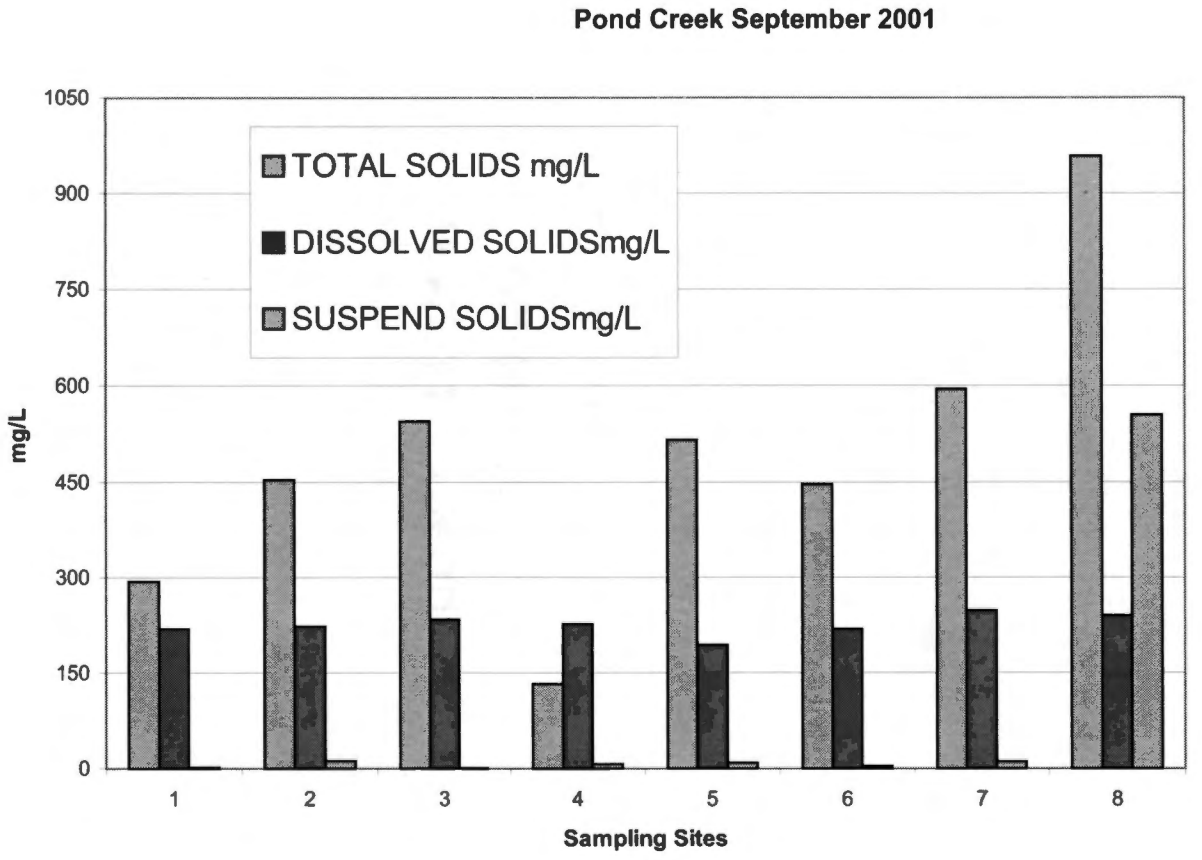

Pond Creek January 2002
8.5
8
7.5
7
6.5
6
5.5
5
4.5
4
3.5
3
2.5
2
1.5
1
0.5
0
mg/L
1
2
3
4
5
6
7
8
Sampling Sites
TKN mg/L
NH3_N mg/L
NO3 mg/L
NO3_N
NO2 mg/L
TP mg/L
PO4
PO4_P mg/L

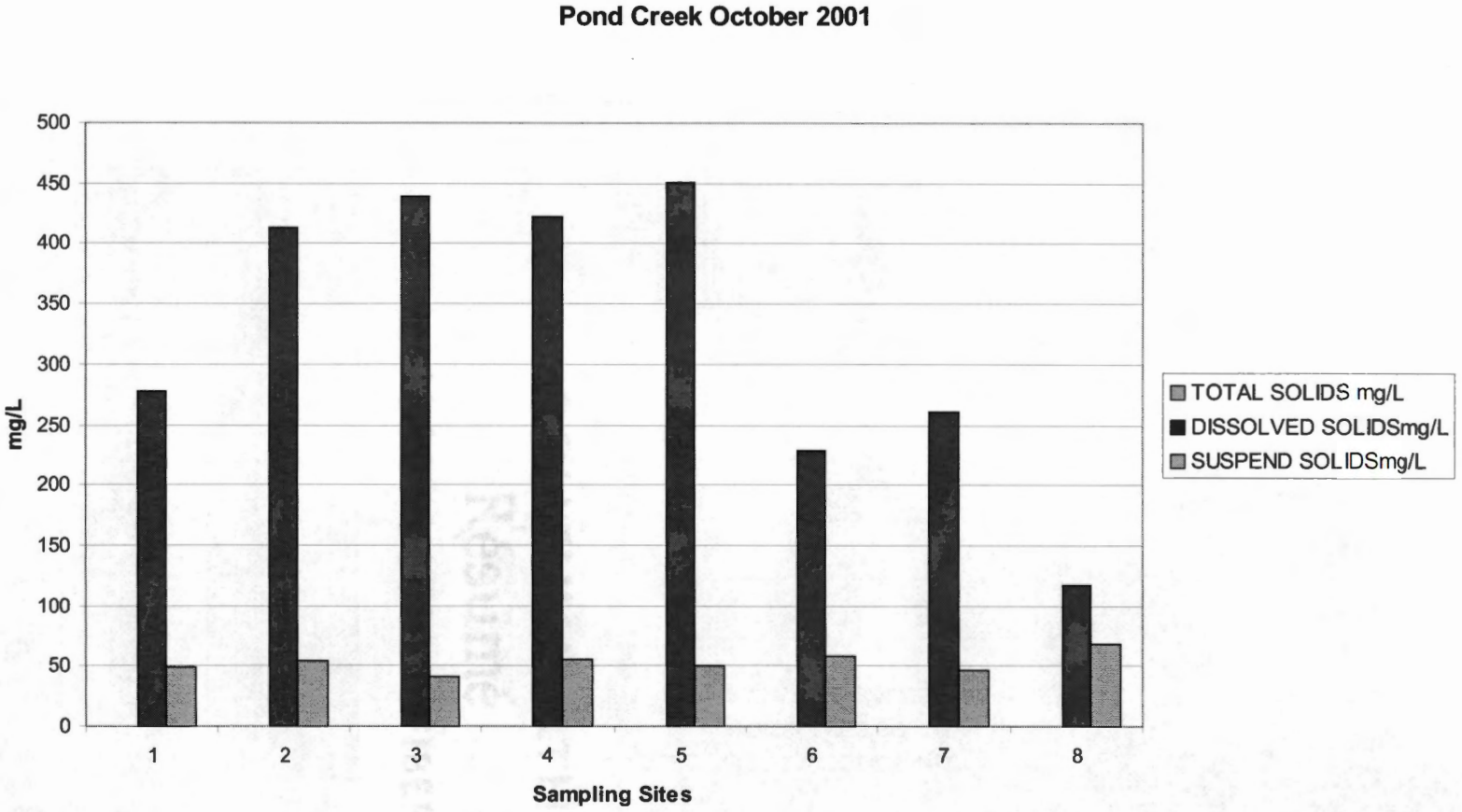

Pond Creek February 2002
mg/L
11.5
11
10.5
10
9.5
9
8.5
8
7.5
7
6.5
6
5.5
5
4.5
4
3.5
3
2.5
2
1.5
1
0.5
0
1
2
3
4
5
6
7
8
Sampling Sites
TKN mg/L
NH3_N mg/L
NO3 mg/L
NO3_N
NO2 mg/L
TP mg/L
PO4
PO4_P mg/L

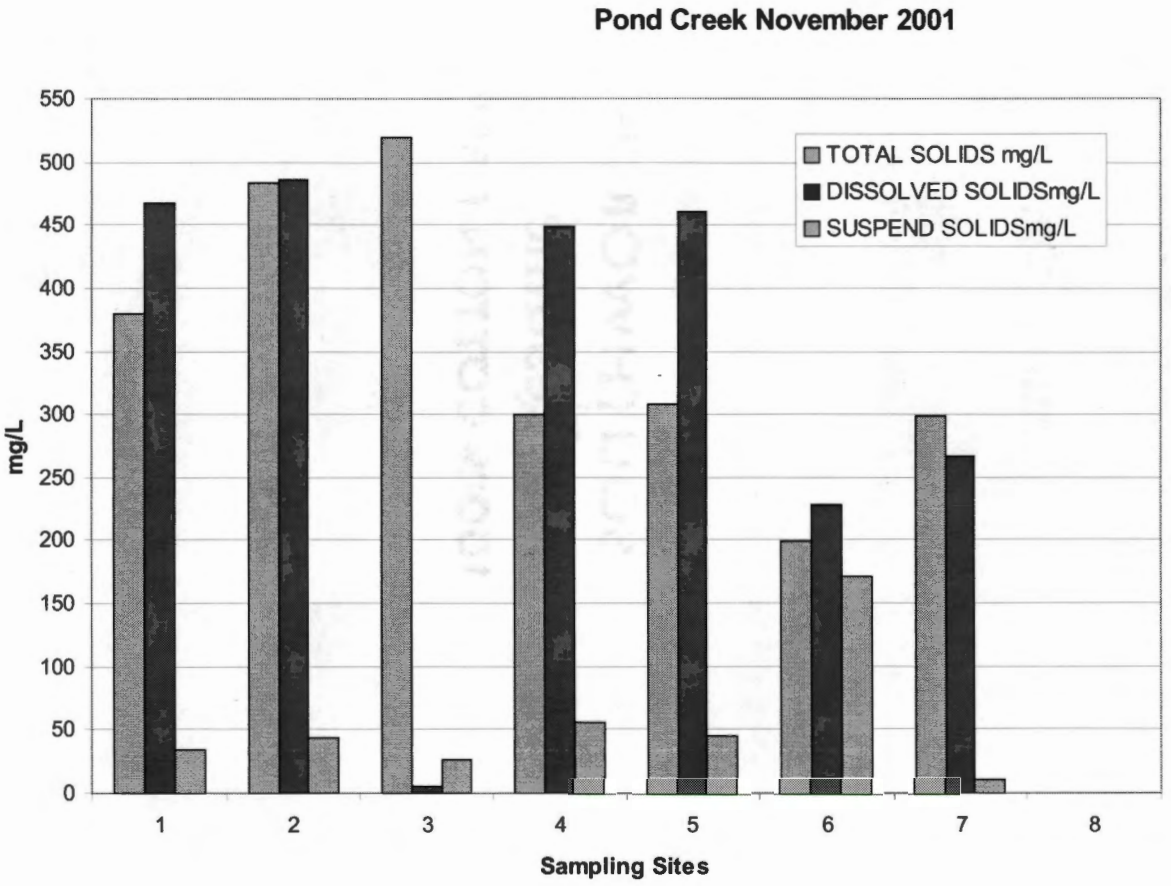

Pond Creek June 2001
650
600
550
500
450
400
350
300
250
200
150
100
50
0
mg/L
TOTAL SOLIDS mg/L
DISSOLVED SOLIDSmg/L
SUSPENDED SOLIDSmg/L
1
2
3
4
5
6
7
Sampling Sites

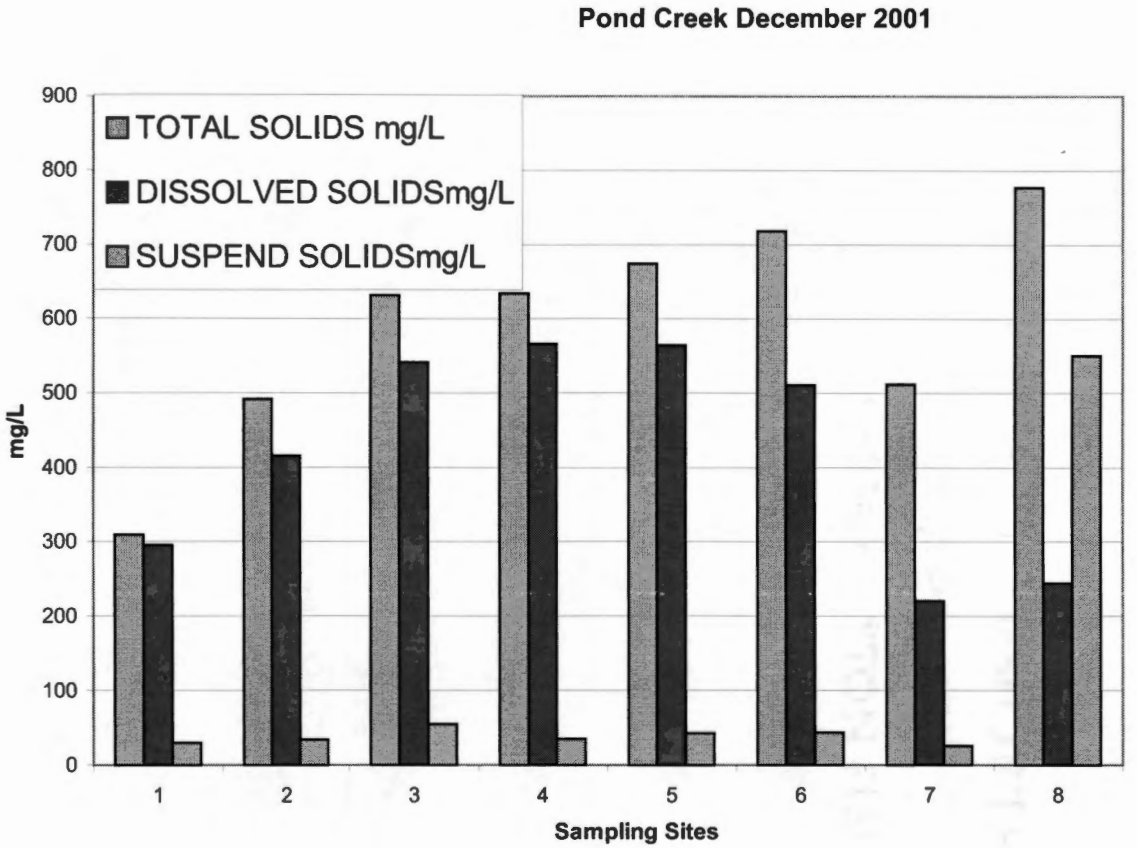

Pond Creek July 2001
TOTAL SOLIDS mg/L
DISSOLVED SOLIDSmg/L
SUSPEND SOLIDSmg/L
mg/L
800
700
600
500
400
300
200
100
0
1
2
3
4
5
6
7
8
Sampling Sites

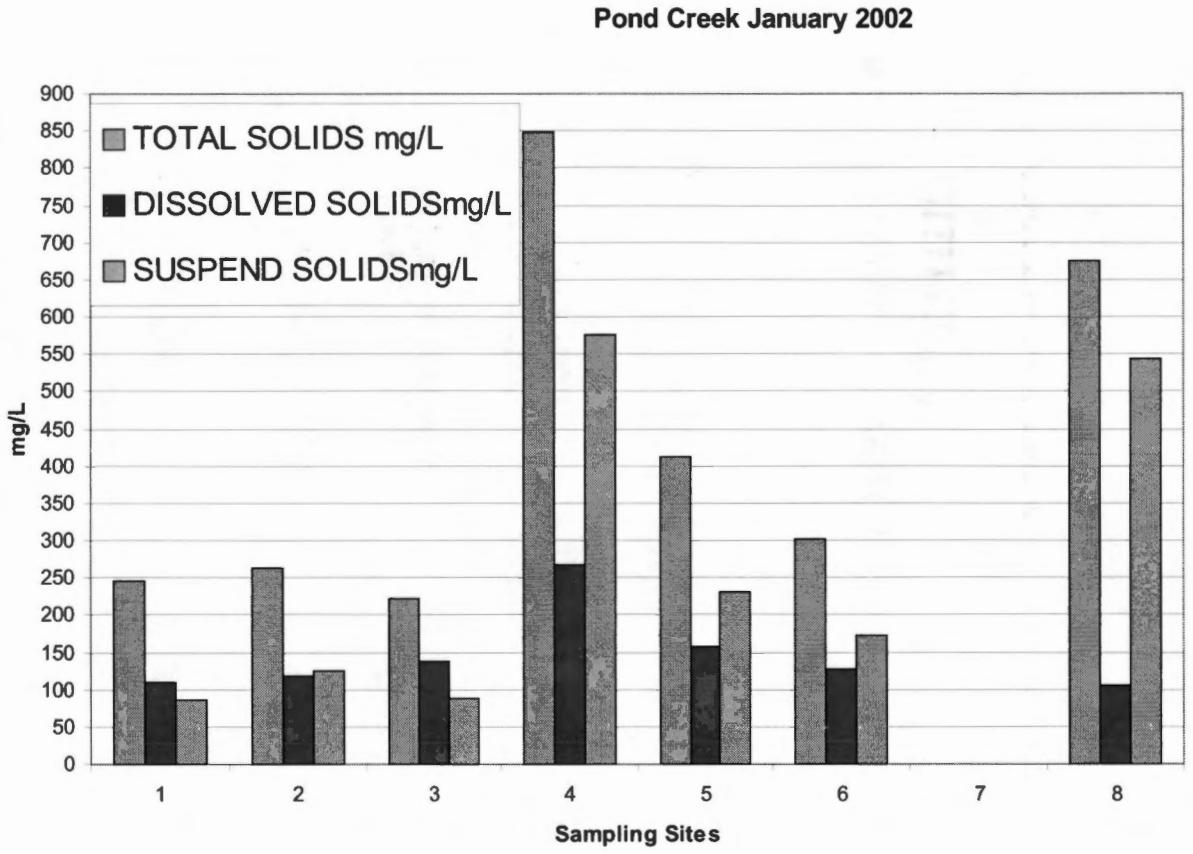

Pond Creek August 2001
TOTAL SOLIDS mg/L
DISSOLVED SOLIDSmg/L
SUSPEND SOLIDSmg/L
mg/L
650
600
550
500
450
400
350
300
250
200
150
100
50
0
1
2
3
4
5
6
7
8
Sampling Sites

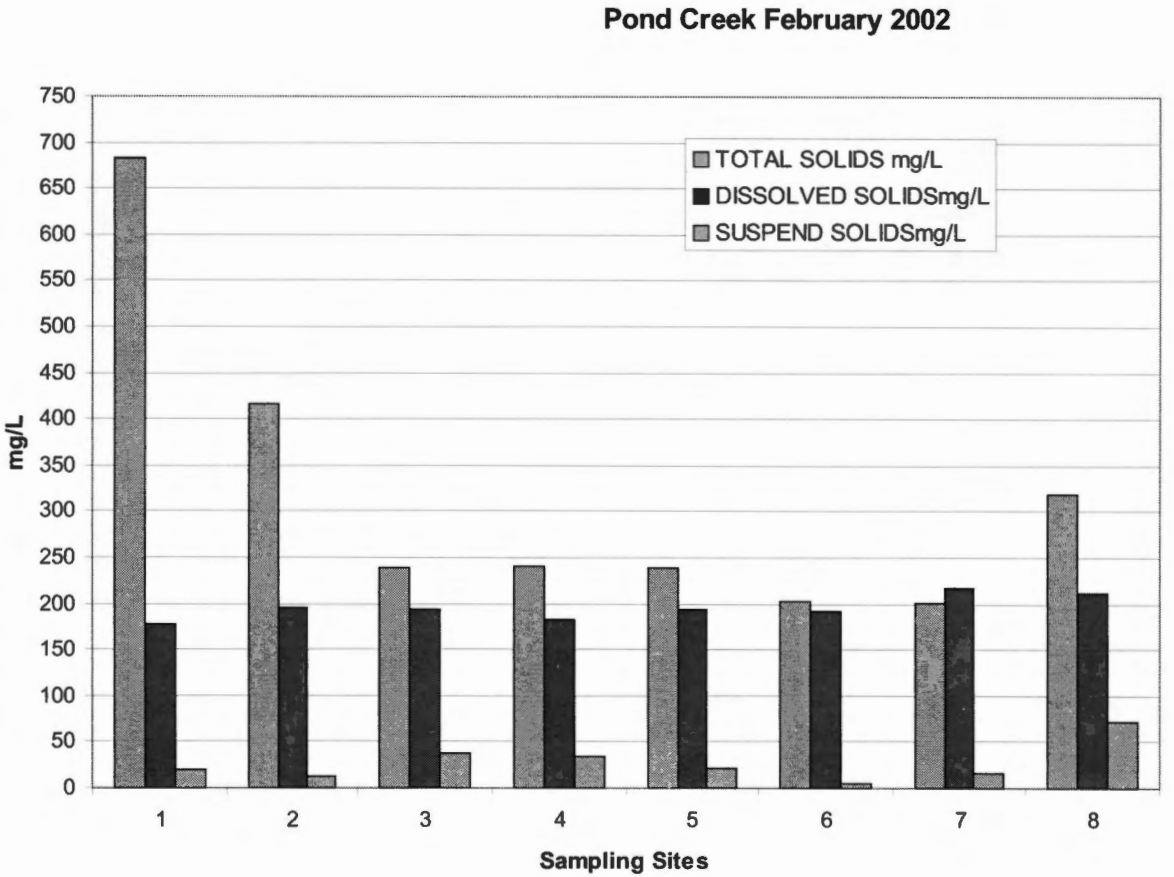

Pond Creek September 2001
TOTAL SOLIDS mg/L
DISSOLVED SOLIDSmg/L
SUSPEND SOLIDSmg/L
mg/L
1050
900
750
600
450
300
150
0
1
2
3
4
5
6
7
8
Sampling Sites

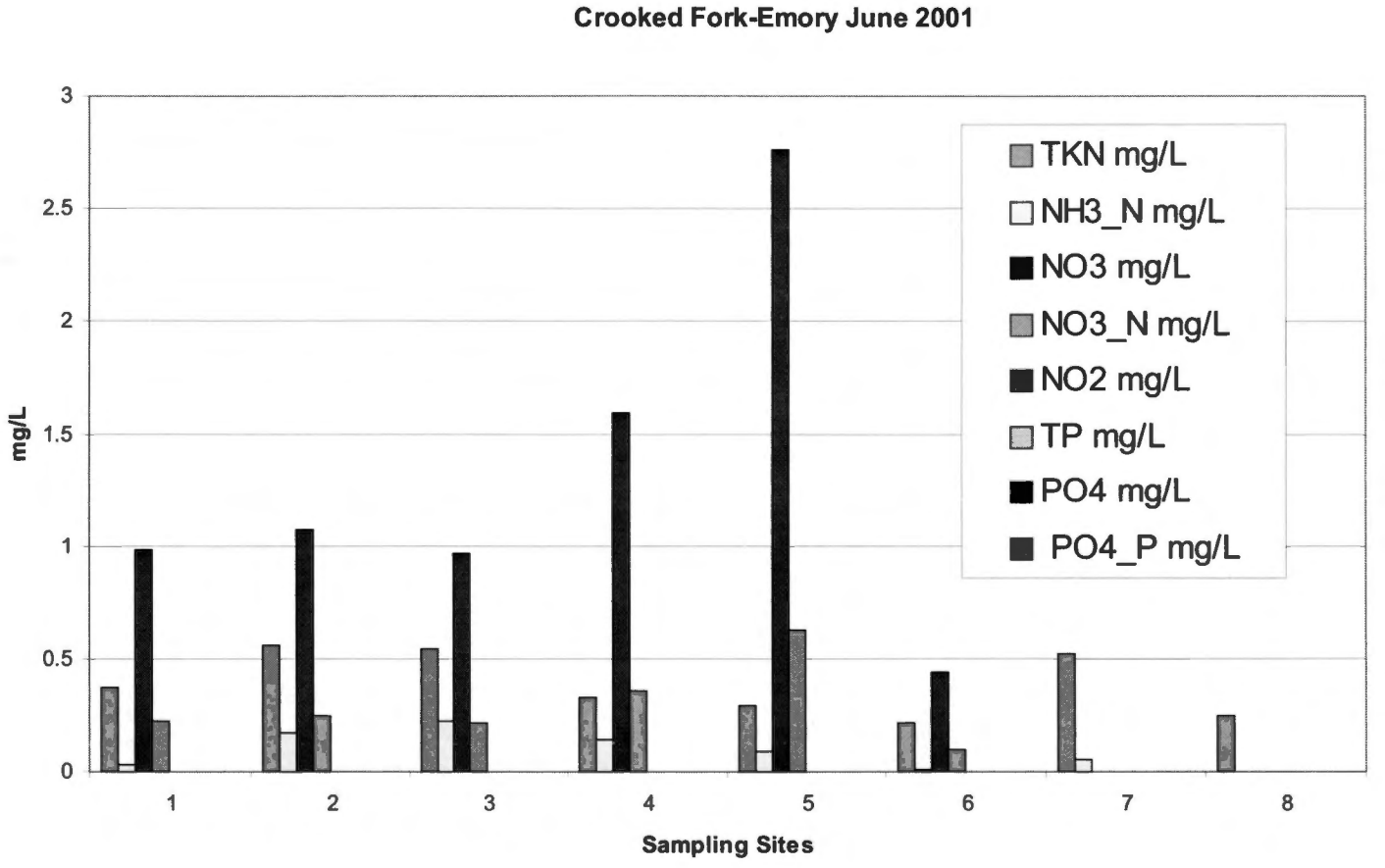

Pond Creek October 2001
500
450
400
350
300
250
200
150
100
50
0
mg/L
1
2
3
4
5
6
7
8
Sampling Sites
TOTAL SOLIDS mg/L
DISSOLVED SOLIDSmg/L
SUSPEND SOLIDSmg/L

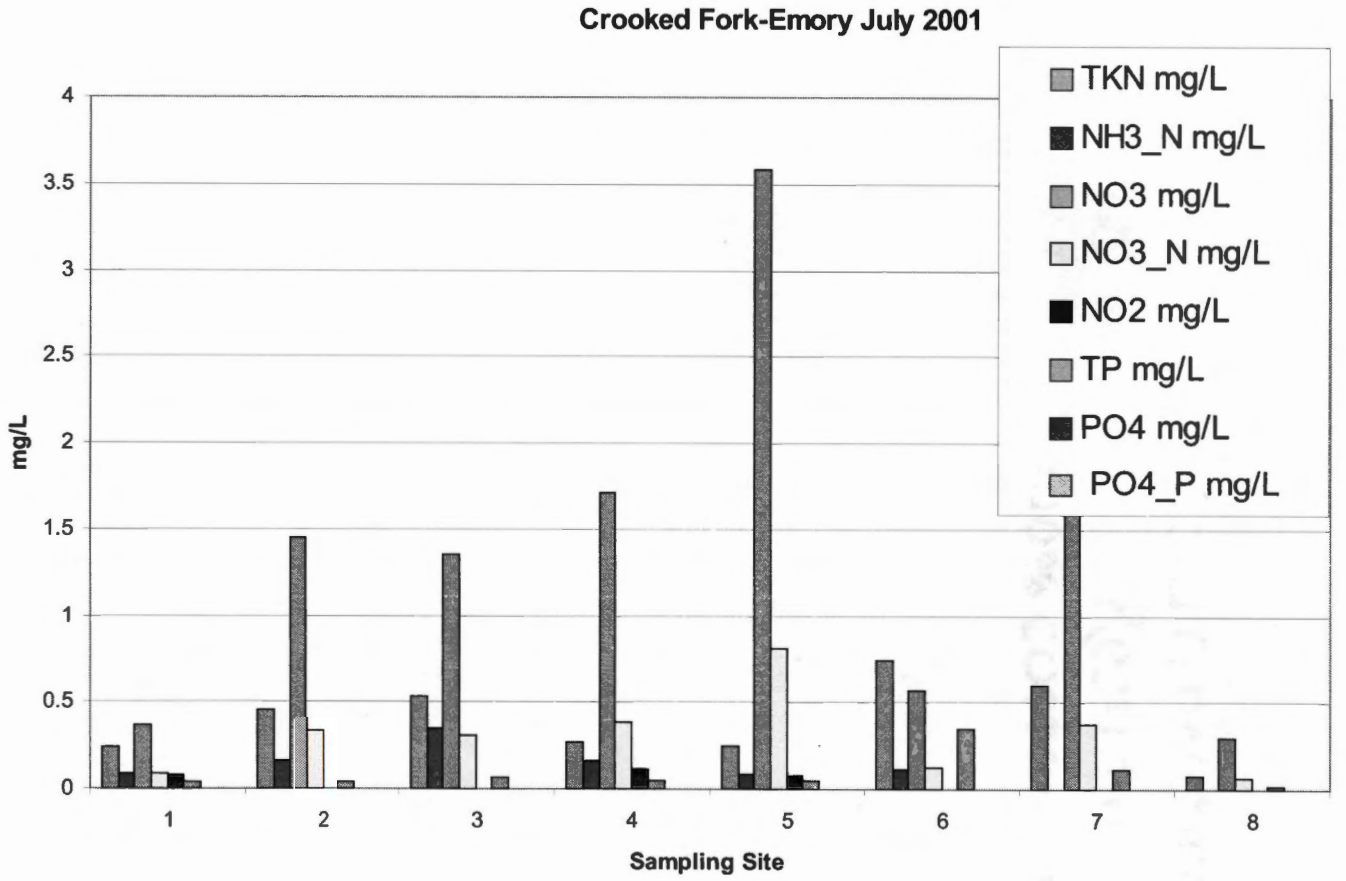

Pond Creek November 2001
550
500
450
400
350
300
250
200
150
100
50
0
mg/L
TOTAL SOLIDS mg/L
DISSOLVED SOLIDSmg/L
SUSPEND SOLIDSmg/L
1
2
3
4
5
6
7
8
Sampling Sites

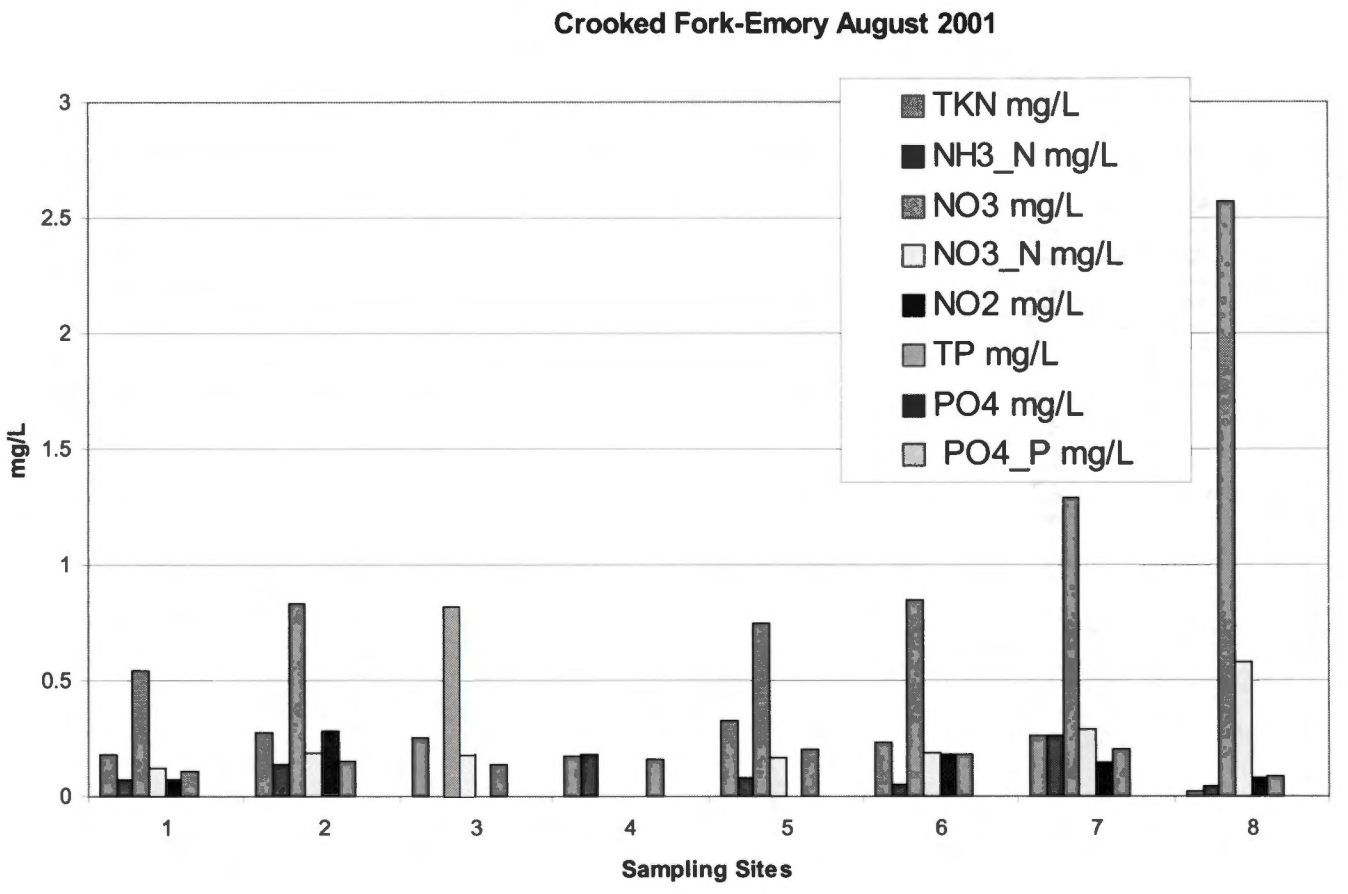

Pond Creek December 2001
TOTAL SOLIDS mg/L
DISSOLVED SOLIDSmg/L
SUSPEND SOLIDSmg/L
mg/L
900
800
700
600
500
400
300
200
100
0
1
2
3
4
5
6
7
8
Sampling Sites

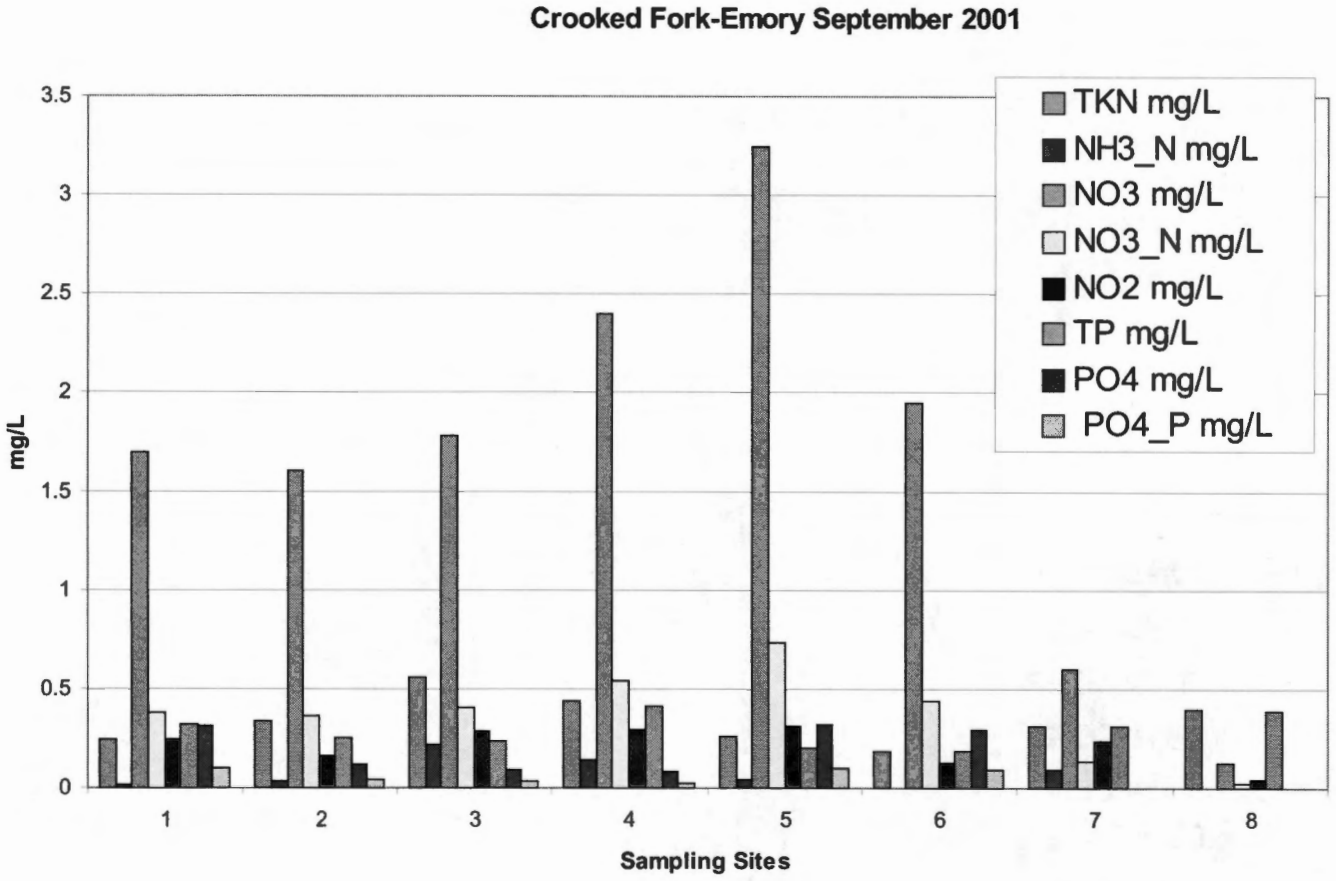

Pond Creek January 2002
TOTAL SOLIDS mg/L
DISSOLVED SOLIDSmg/L
SUSPEND SOLIDSmg/L
mg/L
900
850
800
750
700
650
600
550
500
450
400
350
300
250
200
150
100
50
0
1
2
3
4
5
6
7
8
Sampling Sites

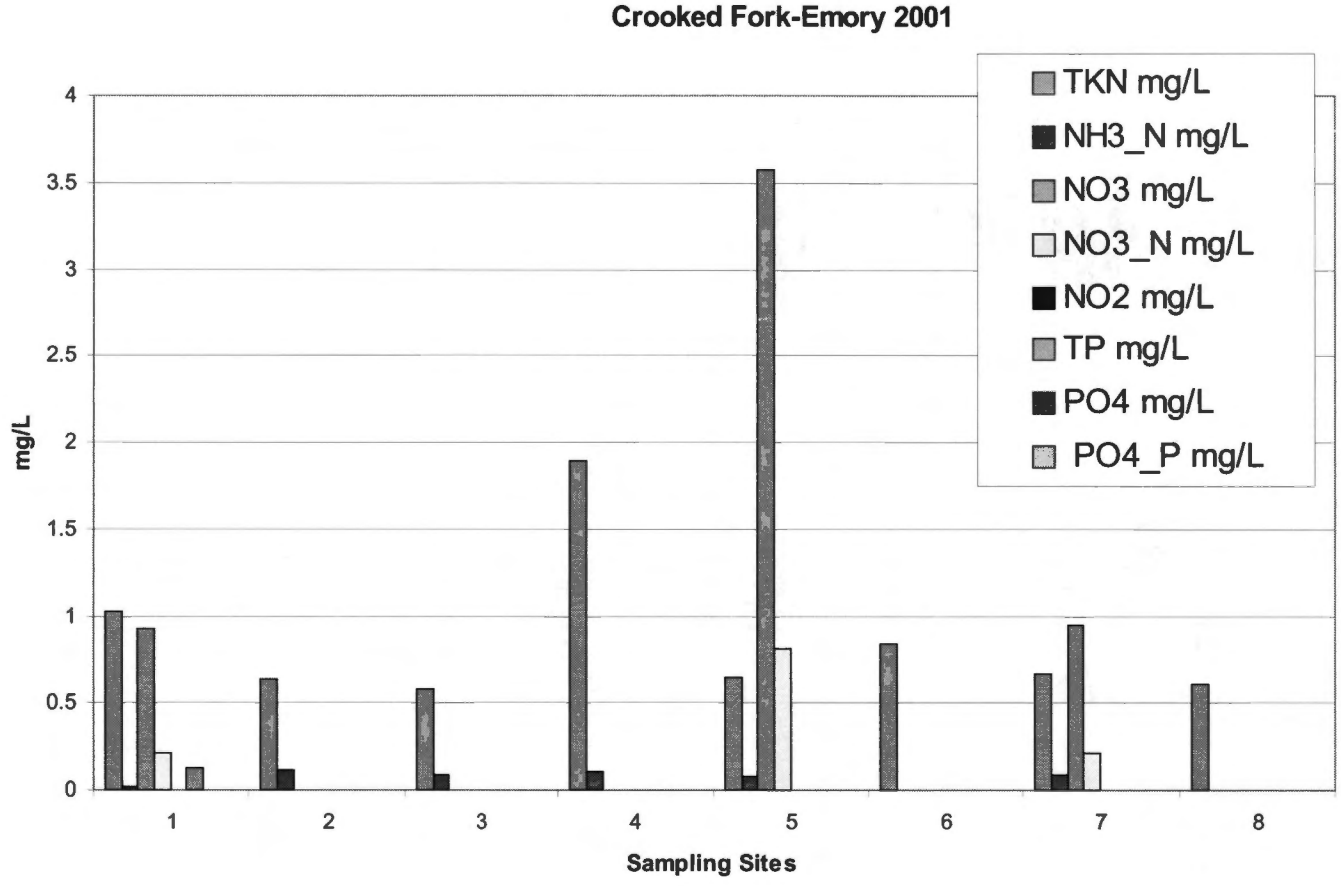

Pond Creek February 2002
TOTAL SOLIDS mg/L
DISSOLVED SOLIDSmg/L
SUSPEND SOLIDSmg/L
mg/L
750
700
650
600
550
500
450
400
350
300
250
200
150
100
50
0
1
2
3
4
5
6
7
8
Sampling Sites

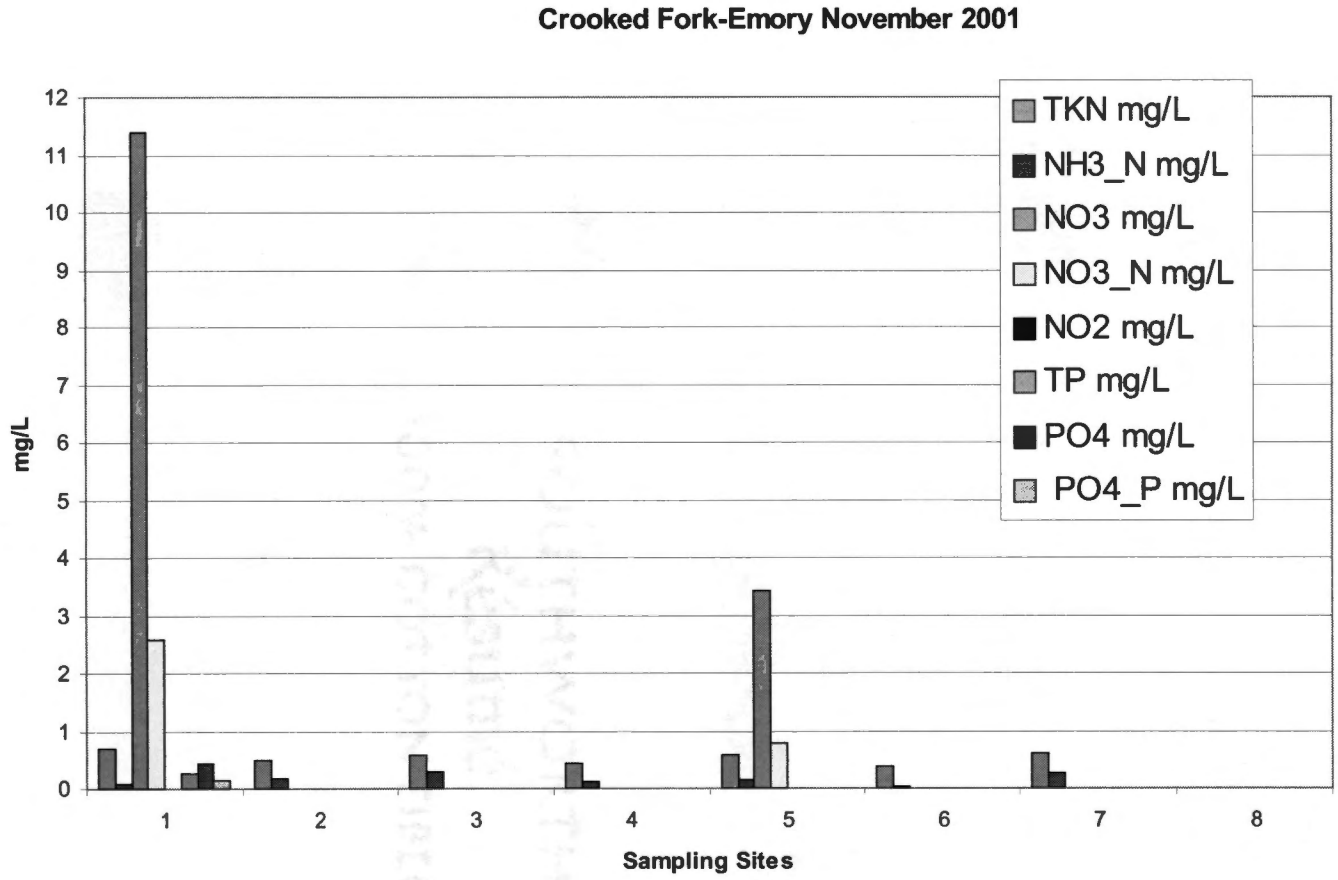

Crooked Fork-Emory June 2001
mg/L
3
2.5
2
1.5
1
0.5
0
1
2
3
4
5
6
7
8
Sampling Sites
TKN mg/L
NH3_N mg/L
NO3 mg/L
NO3_N mg/L
NO2 mg/L
TP mg/L
PO4 mg/L
PO4_P mg/L

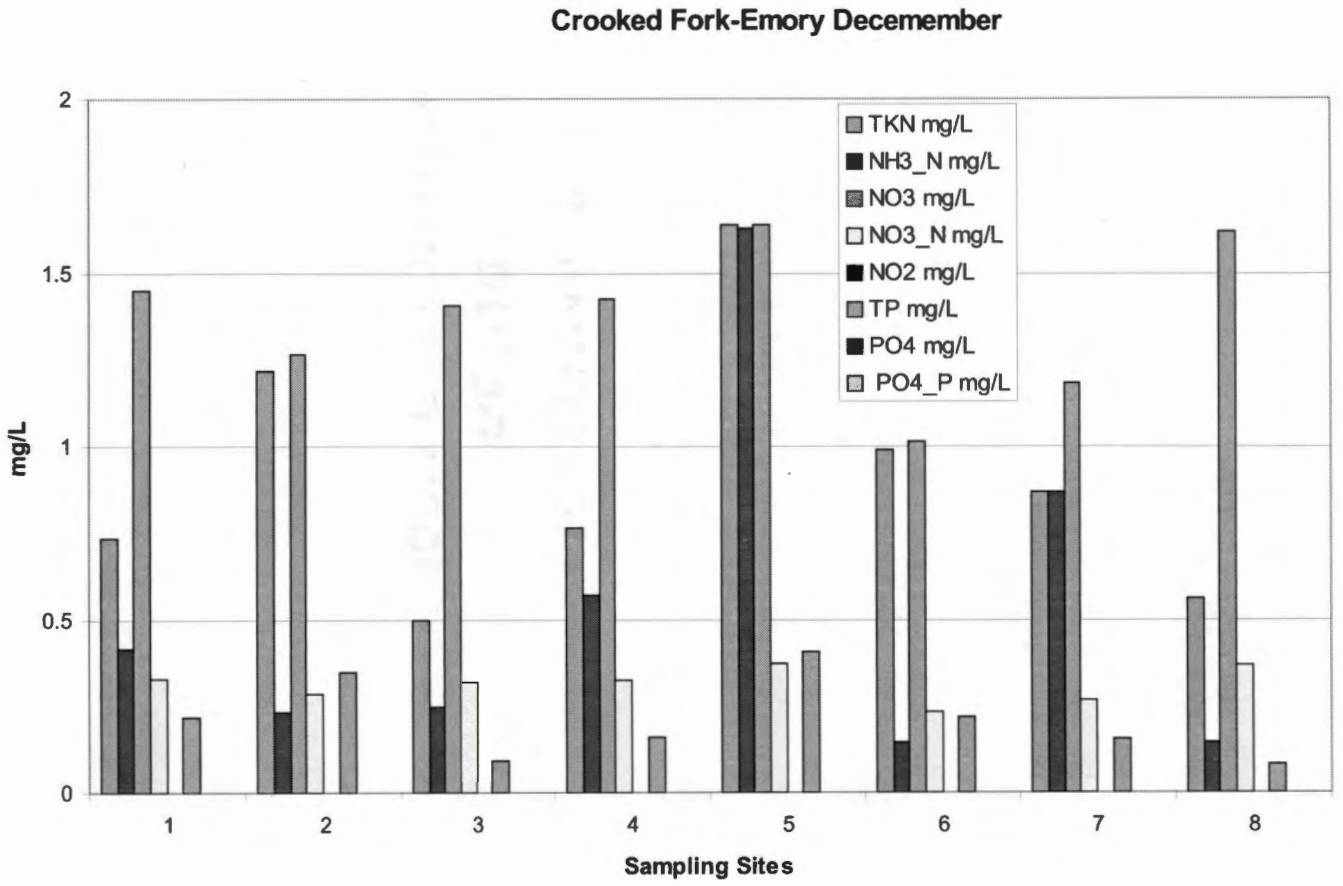

Crooked Fork-Emory July 2001
TKN mg/L
NH3_N mg/L
NO3 mg/L
NO3_N mg/L
NO2 mg/L
TP mg/L
PO4 mg/L
PO4_P mg/L
mg/L
4
3.5
3
2.5
2
1.5
1
0.5
0
1
2
3
4
5
6
7
8
Sampling Site

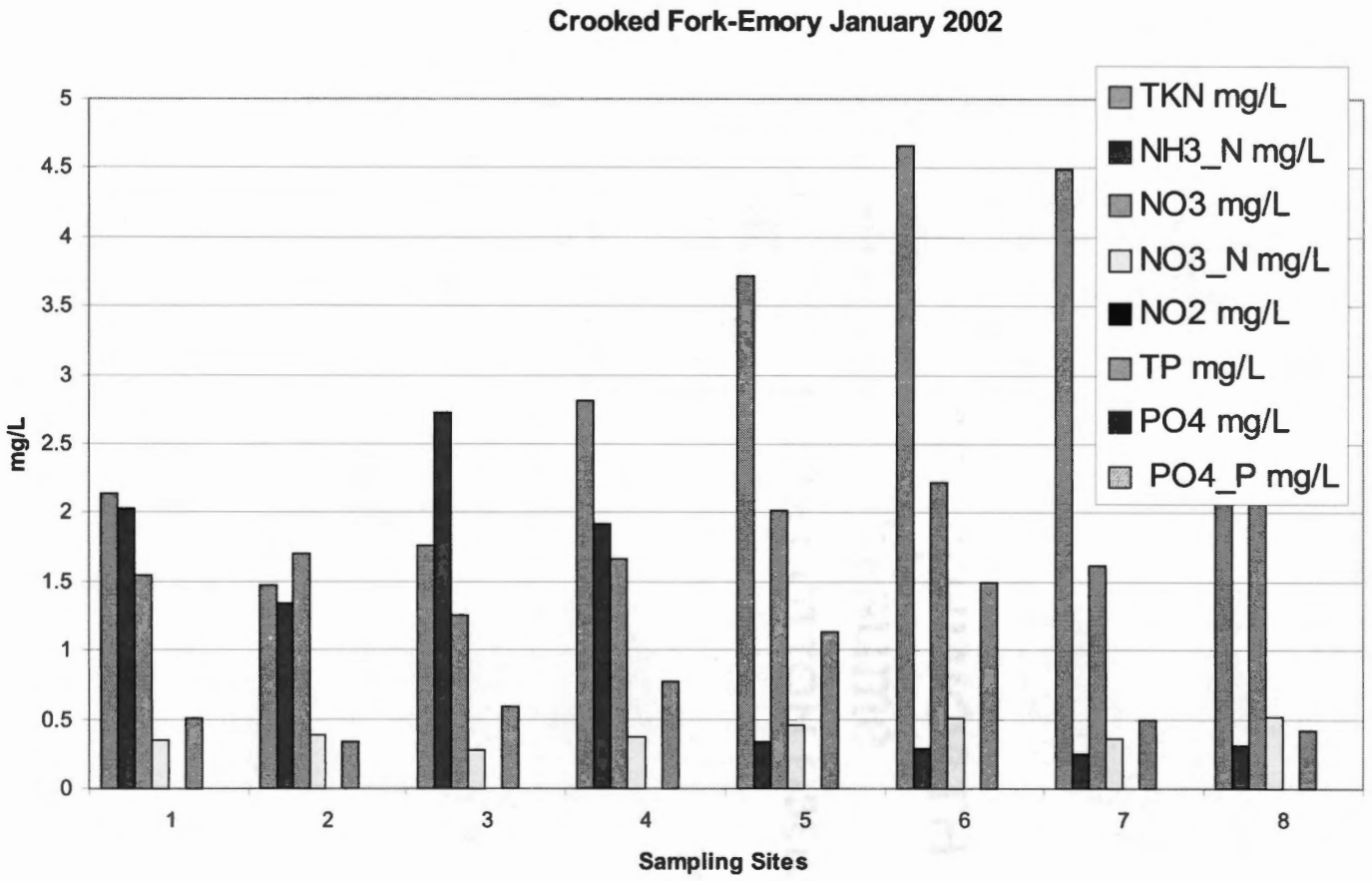

Crooked Fork-Emory August 2001
TKN mg/L
NH3_N mg/L
NO3 mg/L
NO3_N mg/L
NO2 mg/L
TP mg/L
PO4 mg/L
PO4_P mg/L
mg/L
3
2.5
2
1.5
1
0.5
0
1
2
3
4
5
6
7
8
Sampling Sites

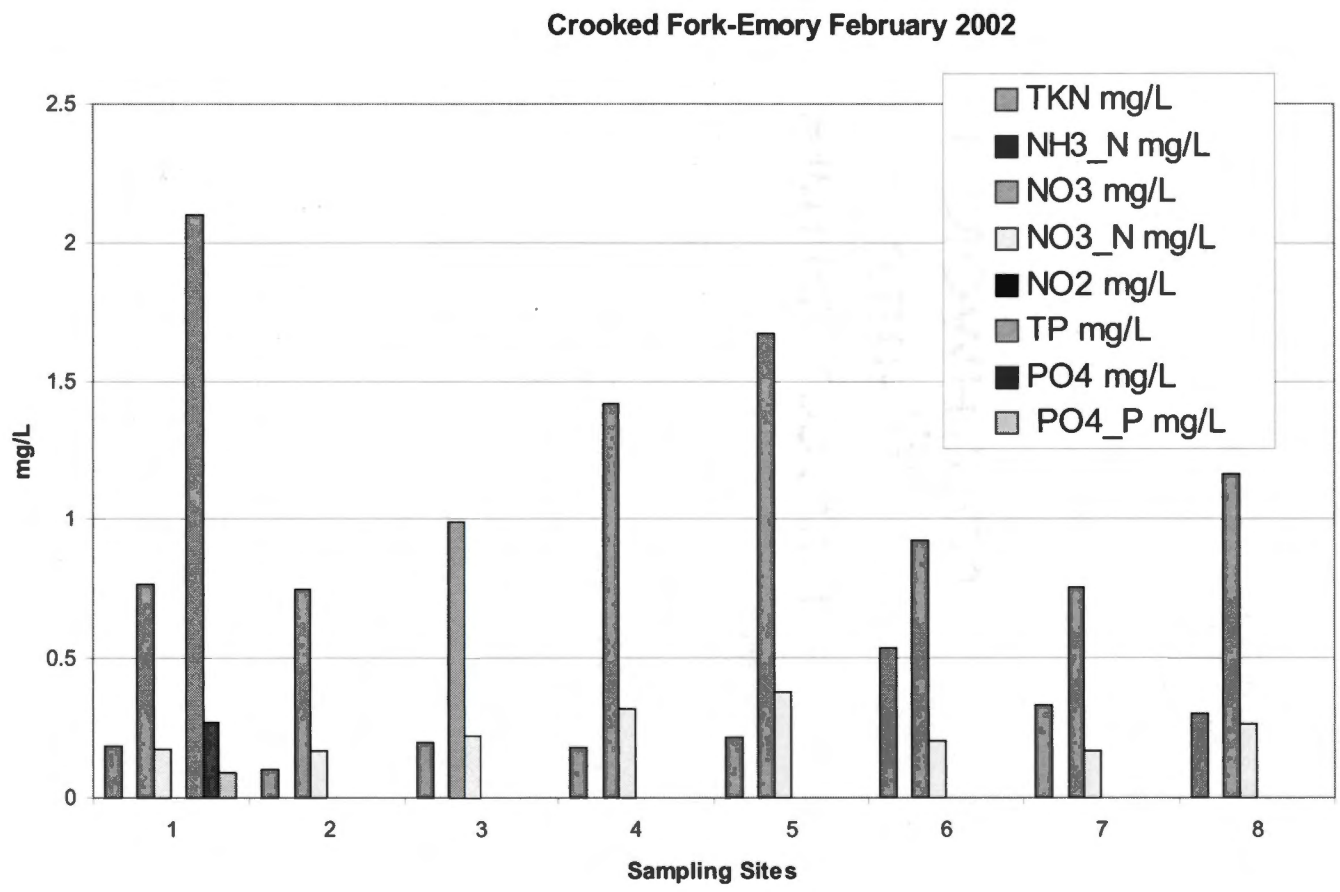

Crooked Fork-Emory September 2001
TKN mg/L
NH3_N mg/L
NO3 mg/L
NO3_N mg/L
NO2 mg/L
TP mg/L
PO4 mg/L
PO4_P mg/L
mg/L
3.5
3
2.5
2
1.5
1
0.5
0
1
2
3
4
5
6
7
8
Sampling Sites

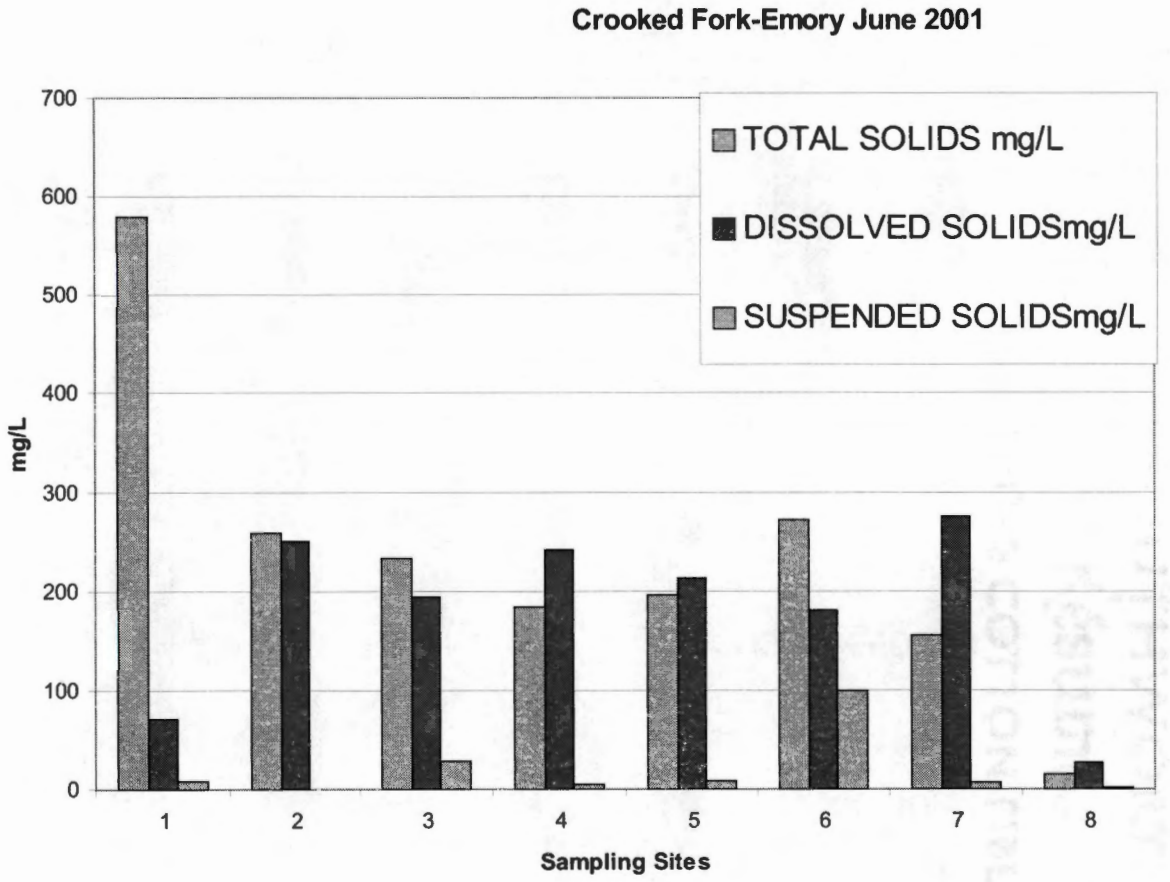

Crooked Fork-Emory 2001
TKN mg/L
NH3_N mg/L
NO3 mg/L
NO3_N mg/L
NO2 mg/L
TP mg/L
PO4 mg/L
PO4_P mg/L
mg/L
4
3.5
3
2.5
2
1.5
1
0.5
0
1
2
3
4
5
6
7
8
Sampling Sites

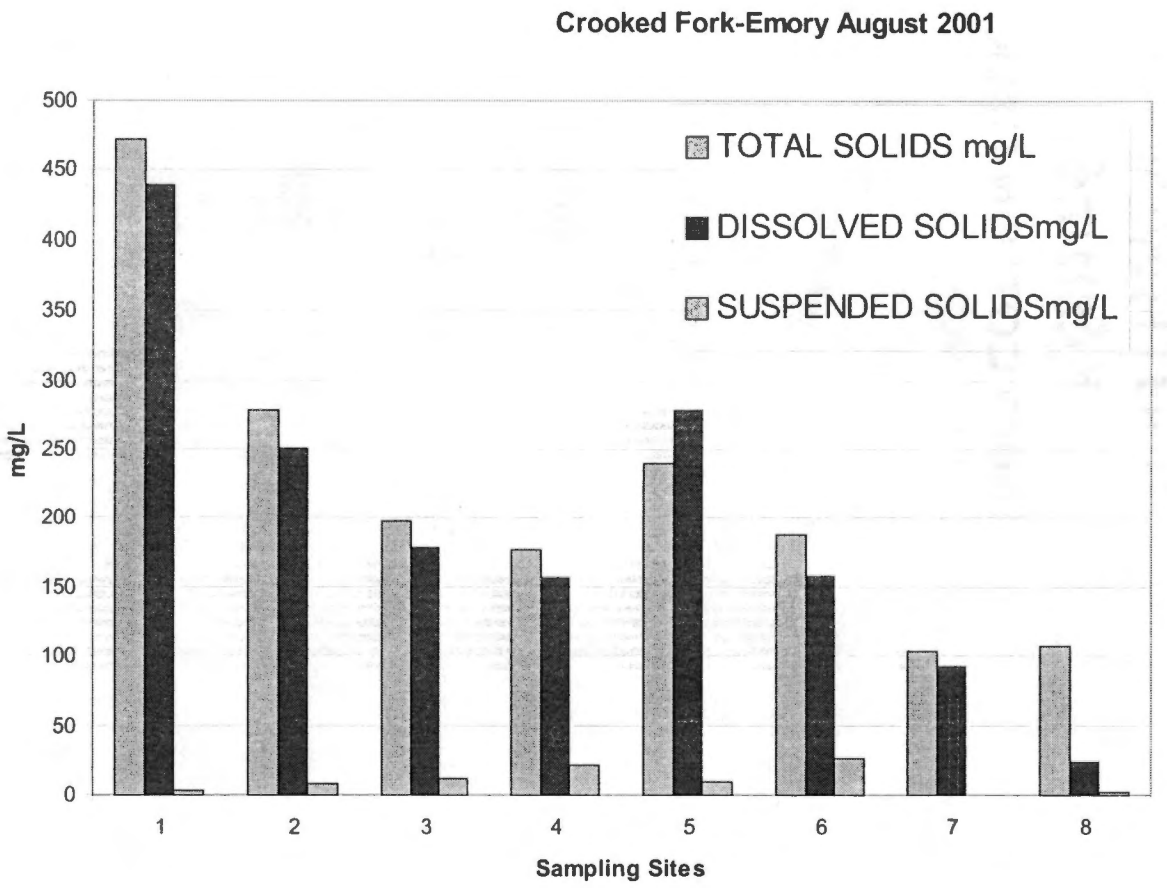

Crooked Fork-Emory November 2001
TKN mg/L
NH3_N mg/L
NO3 mg/L
NO3_N mg/L
NO2 mg/L
TP mg/L
PO4 mg/L
PO4_P mg/L
mg/L
0
1
2
3
4
5
6
7
8
9
10
11
12
1
2
3
4
5
6
7
8
Sampling Sites

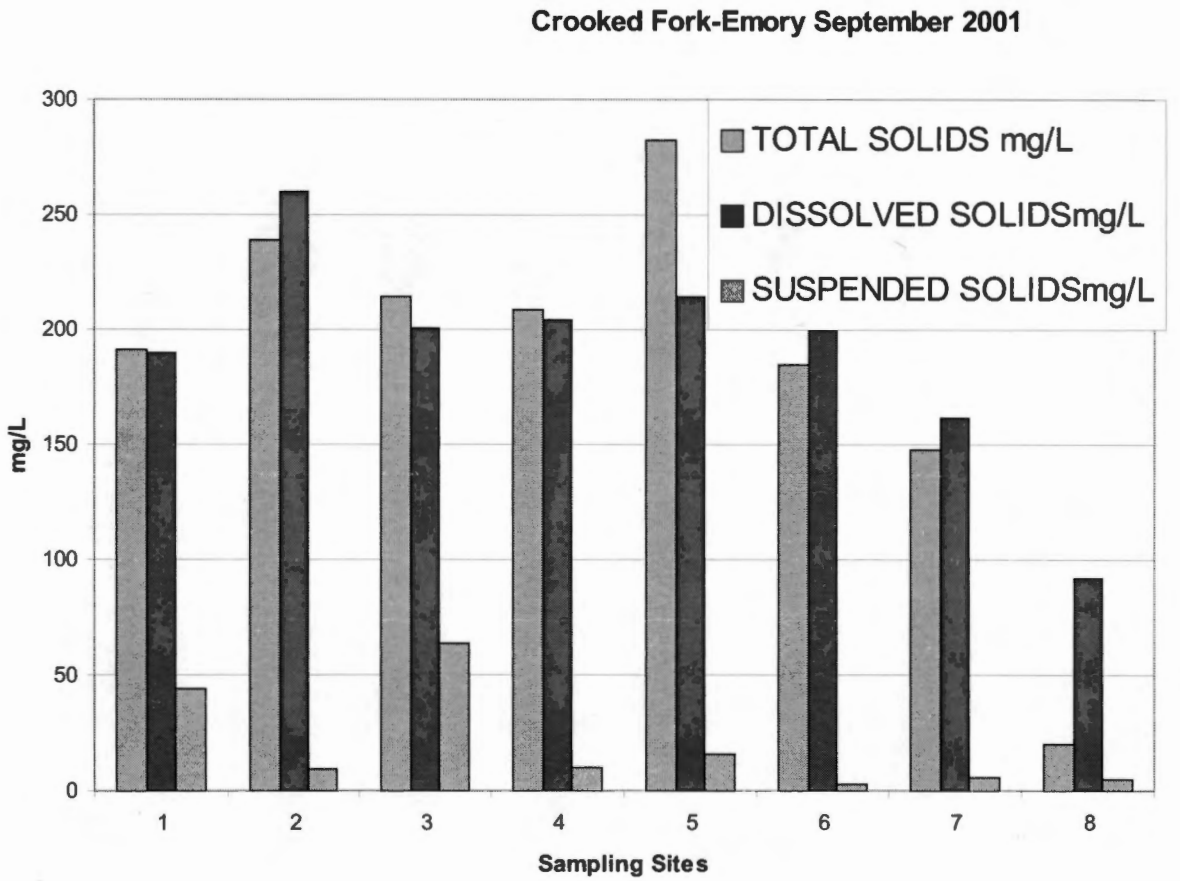

Crooked Fork-Emory Decemember
TKN mg/L
NH3_N mg/L
NO3 mg/L
NO3_N mg/L
NO2 mg/L
TP mg/L
PO4 mg/L
PO4_P mg/L
mg/L
2
1.5
1
0.5
0
1
2
3
4
5
6
7
8
Sampling Sites

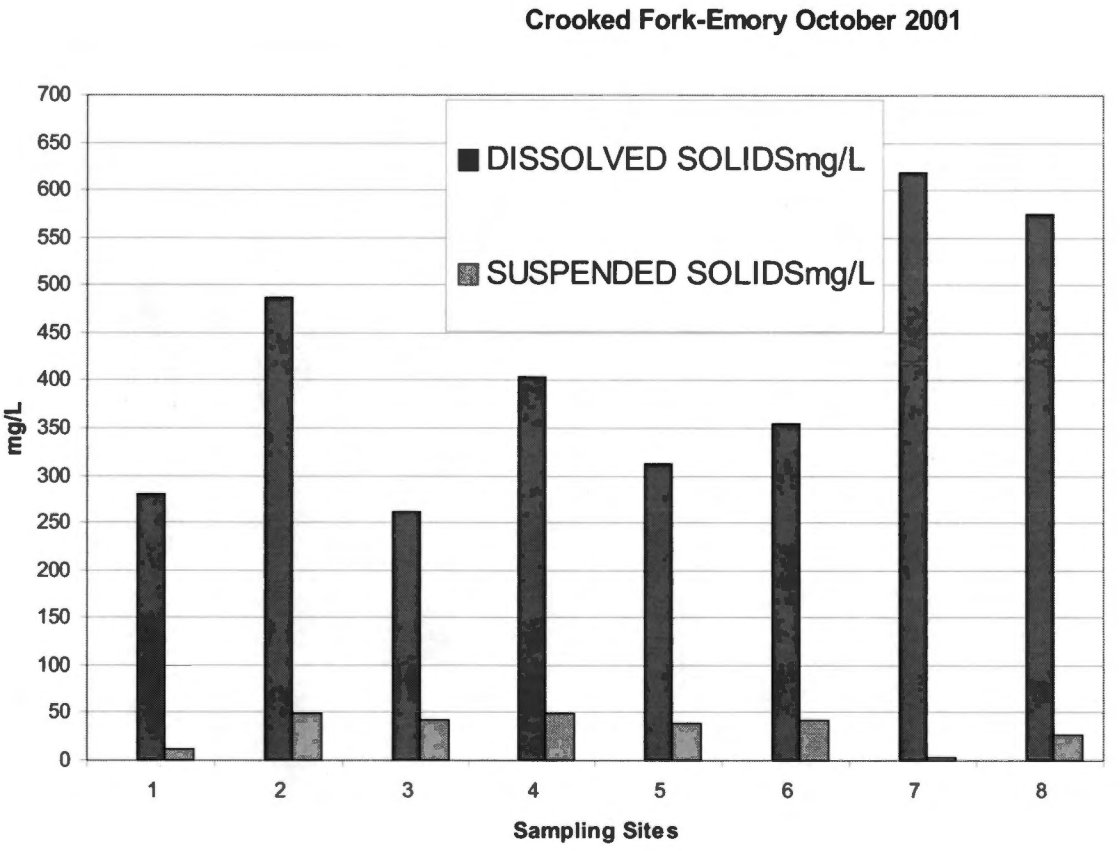

Crooked Fork-Emory January 2002
TKN mg/L
NH3_N mg/L
NO3 mg/L
NO3_N mg/L
NO2 mg/L
TP mg/L
PO4 mg/L
PO4_P mg/L
mg/L
0
0.5
1
1.5
2
2.5
3
3.5
4
4.5
5
1
2
3
4
5
6
7
8
Sampling Sites

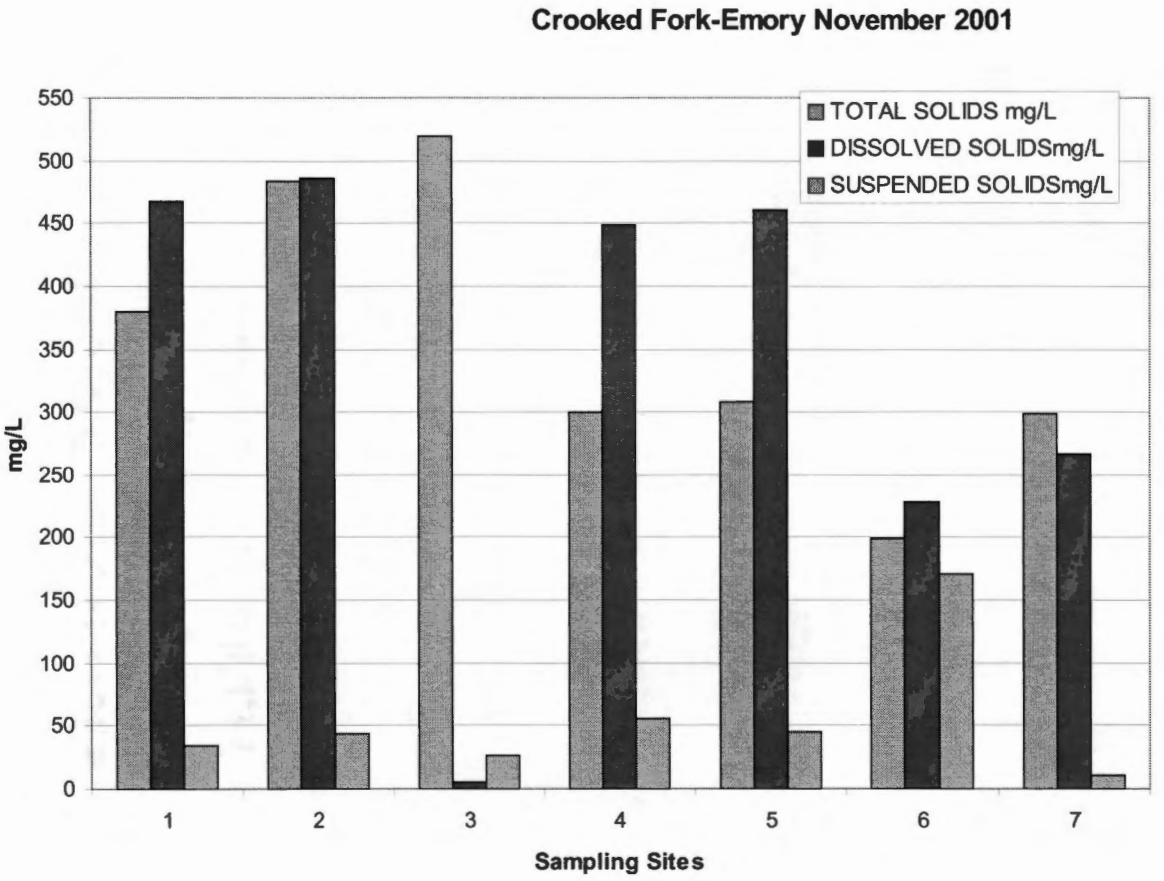

Crooked Fork-Emory February 2002
TKN mg/L
NH3_N mg/L
NO3 mg/L
NO3_N mg/L
NO2 mg/L
TP mg/L
PO4 mg/L
PO4_P mg/L
mg/L
2.5
2
1.5
1
0.5
0
1
2
3
4
5
6
7
8
Sampling Sites

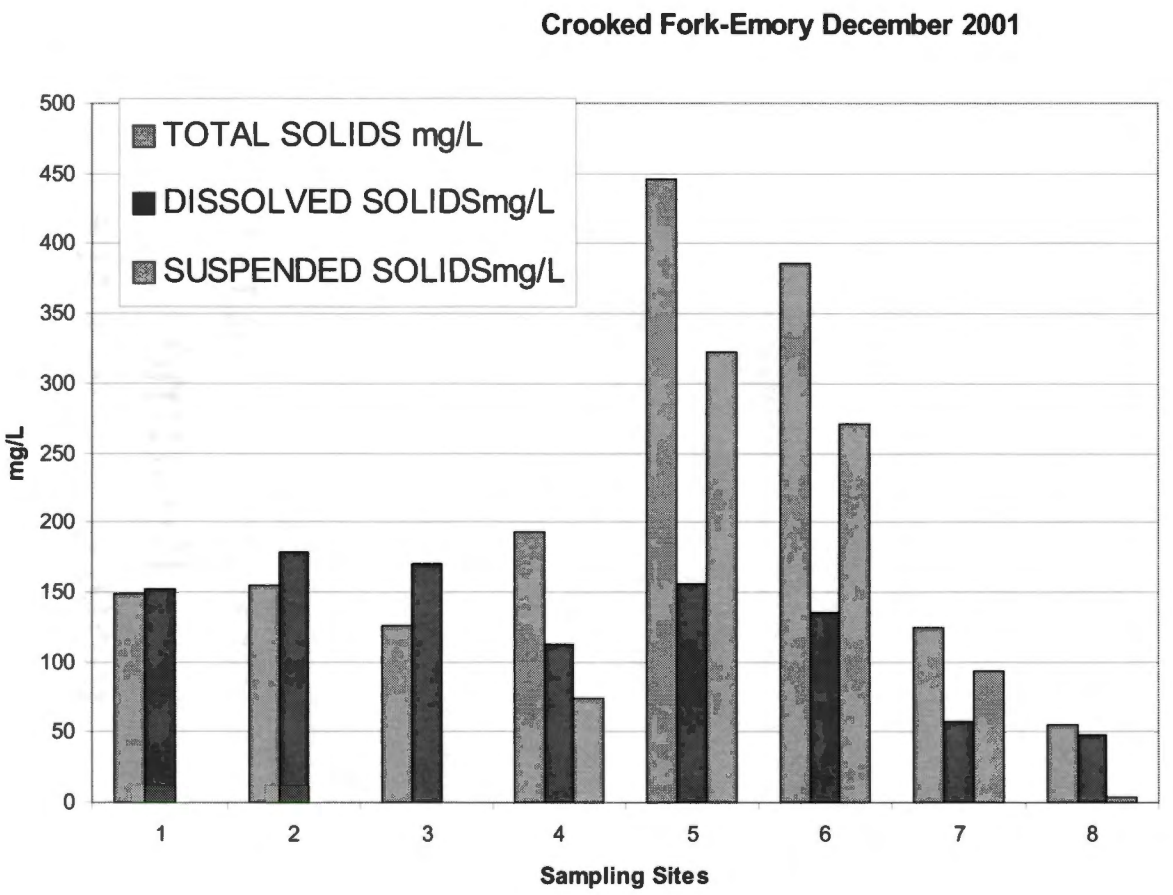

Crooked Fork-Emory June 2001
700
600
500
400
300
200
100
0
mg/L
TOTAL SOLIDS mg/L
DISSOLVED SOLIDSmg/L
SUSPENDED SOLIDSmg/L
1
2
3
4
5
6
7
8
Sampling Sites

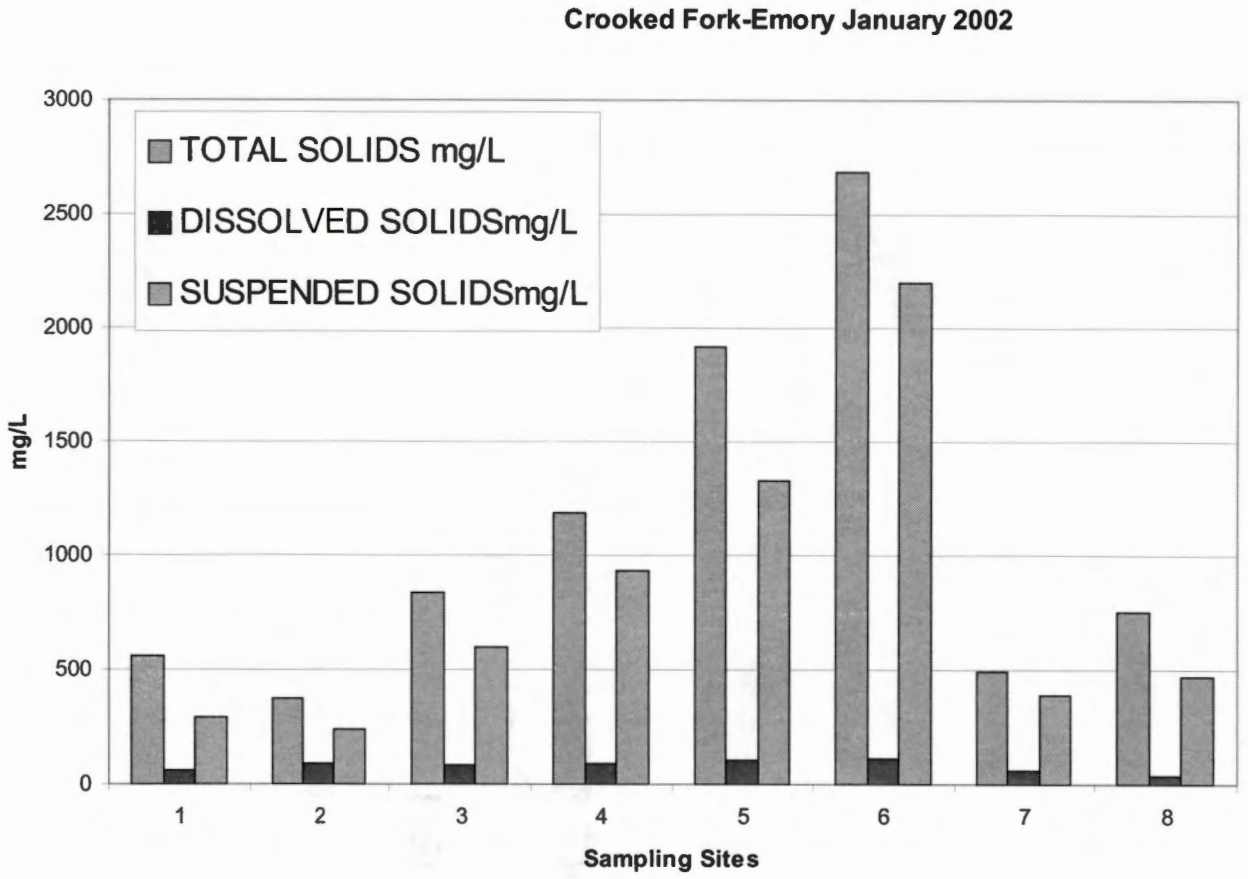

Crooked Fork-Emory August 2001
TOTAL SOLIDS mg/L
DISSOLVED SOLIDSmg/L
SUSPENDED SOLIDSmg/L
mg/L
500
450
400
350
300
250
200
150
100
50
0
1
2
3
4
5
6
7
8
Sampling Sites

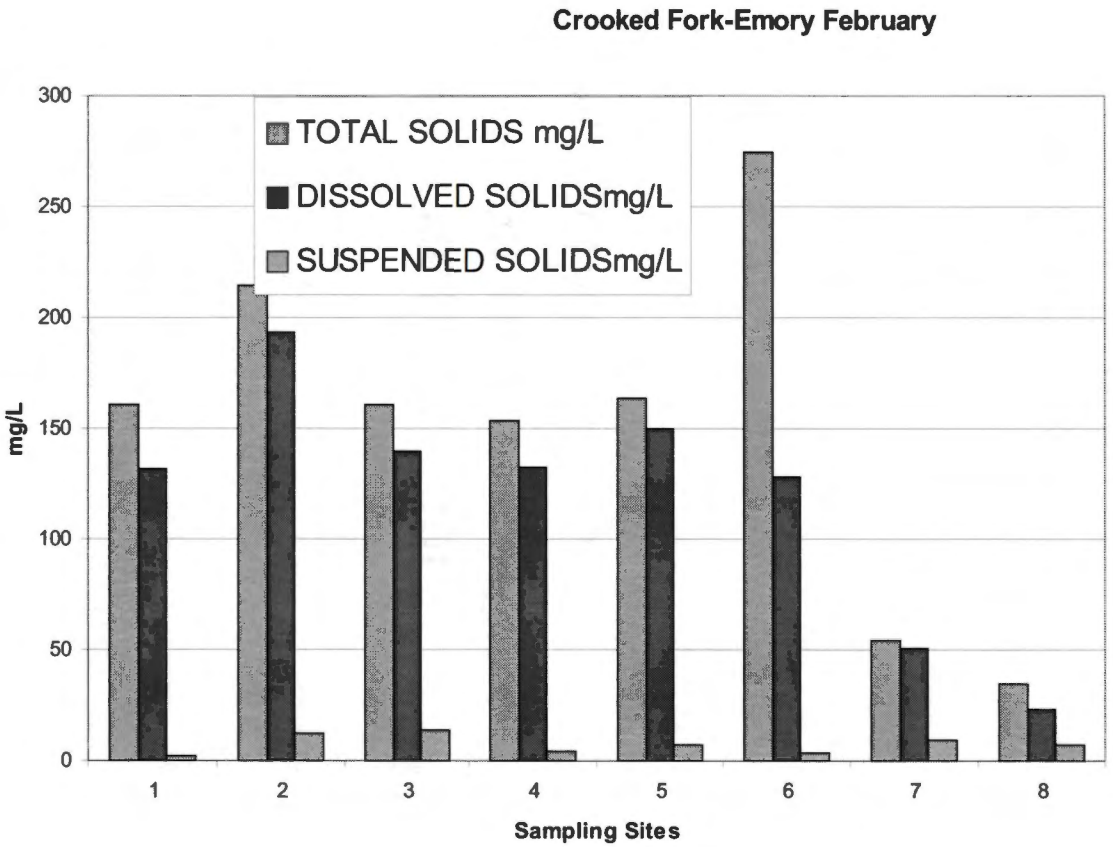

Crooked Fork-Emory September 2001
300
250
200
150
100
50
0
mg/L
TOTAL SOLIDS mg/L
DISSOLVED SOLIDSmg/L
SUSPENDED SOLIDSmg/L
1
2
3
4
5
6
7
8
Sampling Sites


Crooked Fork-Emory October 2001
DISSOLVED SOLIDSmg/L
SUSPENDED SOLIDSmg/L
mg/L
700
650
600
550
500
450
400
350
300
250
200
150
100
50
0
1
2
3
4
5
6
7
8
Sampling Sites

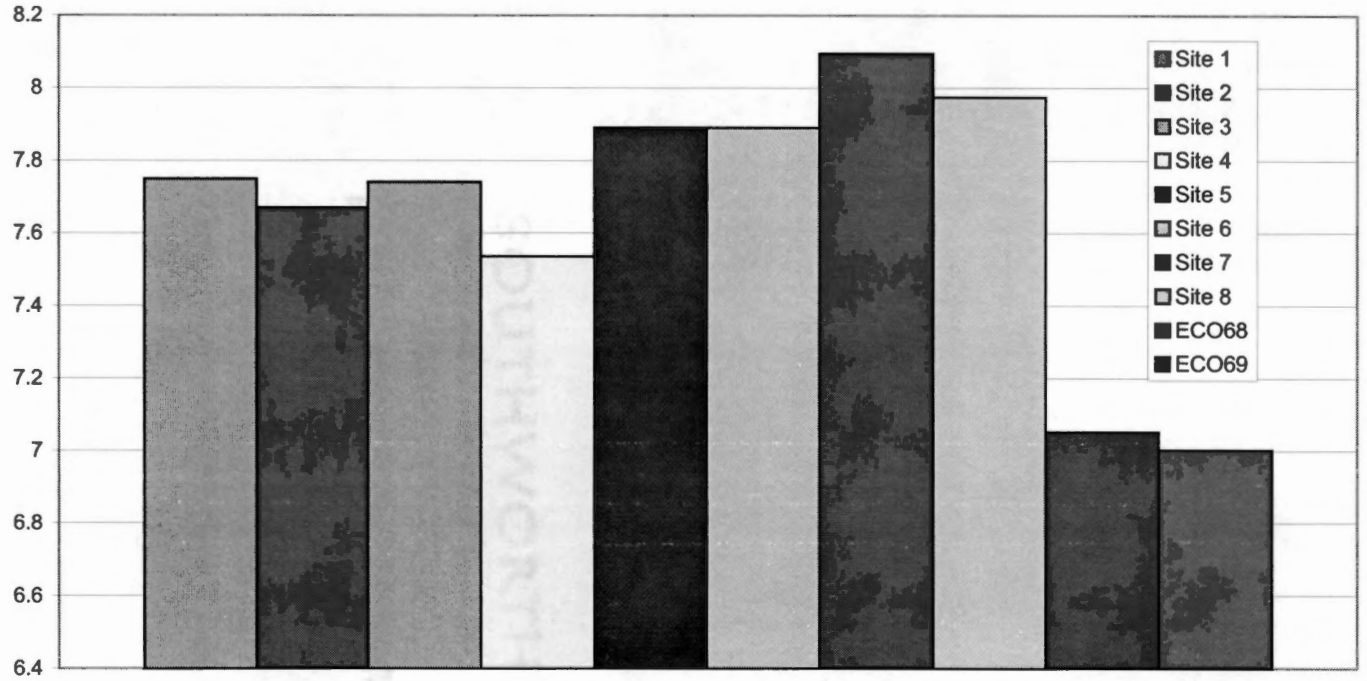

Crooked Fork-Emory November 2001
TOTAL SOLIDS mg/L
DISSOLVED SOLIDSmg/L
SUSPENDED SOLIDSmg/L
mg/L
550
500
450
400
350
300
250
200
150
100
50
0
1
2
3
4
5
6
7
Sampling Sites

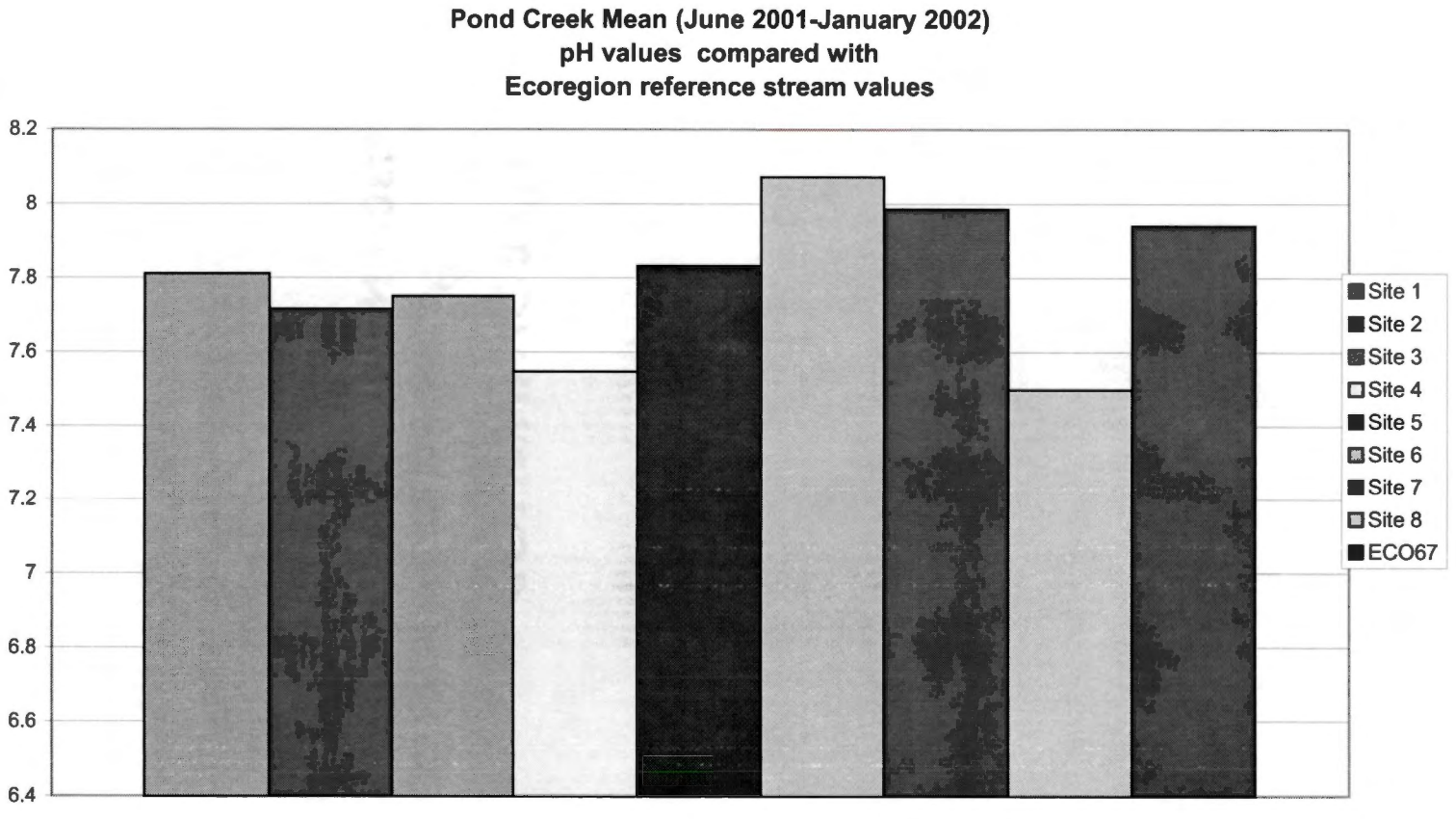

Crooked Fork-Emory December 2001
TOTAL SOLIDS mg/L
DISSOLVED SOLIDSmg/L
SUSPENDED SOLIDSmg/L
mg/L
500
450
400
350
300
250
200
150
100
50
0
1
2
3
4
5
6
7
8
Sampling Sites


Crooked Fork-Emory January 2002
TOTAL SOLIDS mg/L
DISSOLVED SOLIDSmg/L
SUSPENDED SOLIDSmg/L
mg/L
3000
2500
2000
1500
1000
500
0
1
2
3
4
5
6
7
8
Sampling Sites


Crooked Fork-Emory February
TOTAL SOLIDS mg/L
DISSOLVED SOLIDSmg/L
SUSPENDED SOLIDSmg/L
mg/L
300
250
200
150
100
50
0
1
2
3
4
5
6
7
8
Sampling Sites

Croked Fork-Emory Mean pH (June 2001- January 2002)
values compared with
Ecoregion 68 and 69 reference streams




Pond Creek Mean (June 2001-January 2002)
pH values compared with
Ecoregion reference stream values
8.2
8
7.8
7.6
7.4
7.2
7
6.8
6.6
6.4
Site 1
Site 2
Site 3
Site 4
Site 5
Site 6
Site 7
Site 8
ECO67

Pond Creek Watershed

Date	Site	pH	TKN mg/L	NH3_N mg/L	NO3 mg/L	NO2 mg/L	TP mg/L	PO4	BOD 5-day	TS mg/L	TDSmg/L	SSmg/L
June	1	**7.92**	**0.000**	0.120	**6.075**	0.000	0.020	0.093		254	206	30
June	2	7.79	0.439	0.330	5.838	0.000	0.010	0.091		272	187	44
June	3	7.69	0.826	0.190	5.913	0.000	**0.000**	**0.000**		267	222	38
June	4	**7.54**	0.801	0.180	5.770	0.000	**0.000**	**0.000**		266	195	33
June	5	7.62	0.581	0.310	5.493	0.000	0.040	**0.000**		314	193	**70**
June	6	7.75	0.221	**0.110**	5.303	0.000	**0.000**	**0.000**		**237**	**184**	26
June	7	7.71	1.060	0.310	1.648	0.000	0.020			**586**	326	**13**
June	8	7.65	**1.485**	**0.970**	**1.448**	**0.433**	**0.670**	**0.541**		355	**326**	56
July	1	8.45	0.179	**0.020**	5.885	0.000	0.155	0.000		248	208	21
July	2	8.6	**0.592**	0.120	**6.796**	0.000	0.125	0.000		274	469	**18**
July	3	8.9	0.602	0.100	5.443	0.000	0.100	0.000		300	398	34
July	4	7.5	0.612	0.080	5.499	0.000	0.210	0.000		283	**192**	33
July	5	9.9	1.280	0.390	5.085	0.000	0.130	0.000		463	199	67
July	6	**10.75**	0.806	0.050	5.283	0.000	**0.095**	0.000		291	206	33
July	7	9.2	1.784	0.770	1.774	0.000	0.260	0.000		**761**	**576**	**93**
July	8	**6.9**	**3.828**	**2.310**	**0.407**	**4.277**	**0.740**	0.000		**120**	208	40
August	1	**7.2**	**0.421**	**0.190**	**8.833**	0.096	0.220	0.092	1.18	258	196	25
August	2	7.4	0.674	0.340	7.700	**3.678**	**0.215**	0.297	1.53	253	201	29
August	3	7.4	0.688	**0.495**	7.098	0.114	0.230	**0.000**	1.78	298	218	43
August	4	7.8	0.687	0.340	6.977	0.184	0.330	0.173	2.38	302	207	51
August	5	7.5	0.758	0.460	5.880	0.144	0.275	0.245	2.53	280	230	58
August	6	**8.1**	0.665	0.240	6.384	**0.000**	**0.215**	**0.000**	**1.13**	**214**	**190**	**24**
August	7	7.9	1.064	**0.495**	4.457	0.155	0.260	**0.000**	2.03	**600**	**468**	50
August	8	7.6	**1.758**	0.440	**2.596**	0.373	**0.360**	**0.307**	**3.78**	526	448	**85**

Pond Creek

Date	Site	pH	TKN mg/L	NH3_N mg/L	NO3 mg/L	NO2 mg/L	TP mg/L	PO4	BOD 5-day	TS mg/L	TDSmg/L	SSmg/L
September	1	7.34	0.352	0.055	6.214	**0.260**	0.300	0.210	2.23	294	220	2
September	2	**7.01**	0.574	0.165	**6.915**	0.156	0.340	0.152	2.08	454	224	12
September	3	7.47	0.554	0.155	6.016	**0.000**	0.280	0.421	**1.43**	546	235	**1**
September	4	7.65	0.328	0.090	6.656	**0.000**	0.265	**0.127**	3.03	**133**	227	7
September	5	7.7	0.488	0.095	6.749	0.444	**0.240**	0.153	1.88	516	**194**	9
September	6	7.34	**0.209**	**0.020**	6.873	**0.000**	0.470	0.175	1.53	446	219	4
September	7	**7.84**	**1.249**	0.365	**3.829**	0.122	**0.505**	**0.356**	**5.93**	596	**249**	11
September	8	7.19	0.991	**1.250**	5.493	**0.000**	0.415	0.219	3.41	**958**	240	**555**
October	1	**7.98**	**0.598**	0.070	2.730	0.000	0.015	0.000	1.66		277	49
October	2	7.77	0.828	0.070	3.895	0.000	0.040	0.000	1.60		414	54
October	3	7.76	1.064	0.135	3.494	0.000	**0.000**	0.000	**1.27**		440	**41**
October	4	7.49	1.105	0.100	4.060	0.000	**0.000**	0.000	1.52		423	56
October	5	7.72	1.378	0.120	4.401	0.000	**0.000**	0.000	1.69		**450**	50
October	6	7.85	1.376	**0.055**	**5.048**	0.000	**0.000**	0.000	1.44		228	58
October	7	7.56	1.511	**0.370**	**0.000**	0.000	**0.000**	0.000	3.45		262	47
October	8	**7.39**	**2.195**	0.325	**0.000**	0.000	**0.205**	0.000	**5.00**		**118**	**68**
November	1	**8.13**	0.524	**0.065**	2.068	0.000	**0.000**	**0.000**	2.00	380	468	35
November	2	7.92	0.907	0.125	3.742	0.000	**0.000**	**0.000**	**1.61**	484	**487**	44
November	3	7.9	0.596	0.100	3.279	0.000	**0.000**	**0.000**	2.06	**519**	**5**	26
November	4	7.59	**0.477**	0.095	3.447	0.000	**0.000**	**0.000**	2.04	300	450	55
November	5	7.77	0.762	0.140	3.700	0.000	**0.000**	**0.000**	2.31	308	462	45
November	6	7.92	0.518	0.140	**4.347**	0.000	**0.000**	**0.000**	1.83	**200**	229	**172**
November	7	8.11	1.539	0.220	**0.000**	0.000	0.015	**0.000**	**8.81**	299	267	**11**
November	8	**7.51**	**4.493**	**1.740**	0.773	0.000	**0.635**	**0.469**	6.64			

Pond Creek

Date	Site	pH	TKN mg/L	NH3_N mg/L	NO3 mg/L	NO2 mg/L	TP mg/L	PO4	BOD 5-day	TS mg/L	TDSmg/L	SSmg/L
December	1	7.52	**0.499**	0.270	5.305	0.000	0.175	0.000	2.86	**310**	296	30
December	2	7.57	1.208	0.660	5.575	0.000	0.220	0.000	**7.38**	492	417	35
December	3	7.51	1.097	0.800	5.050	0.000	0.205	0.000	3.90	632	542	55
December	4	**7.35**	1.006	0.680	5.281	0.000	0.190	0.000	3.29	634	**567**	36
December	5	7.55	0.915	0.455	4.664	0.000	0.180	0.000	3.04	675	565	43
December	6	**7.7**	1.839	0.975	**3.248**	0.000	**0.440**	0.000	5.70	719	511	44
December	7	7.51	0.541	**0.225**	4.583	0.000	**0.155**	0.000	**2.58**	512	**220**	**26**
December	8	7.62	**1.230**	**1.860**	**9.355**	0.000	0.230	0.000	5.57	**777**	245	**551**
January	1	**7.46**	1.656	**0.760**	6.460	0.000	**0.460**	**0.458**	**5.29**	246	110	**86**
January	2	7.31	1.798	0.810	6.834	0.000	0.595	0.509	5.33	264	120	126
January	3	7.3	1.795	0.740	6.983	0.000	0.550	0.596	5.50	222	138	89
January	4	7.37	**5.027**	1.060	**2.581**	0.000	**1.890**	**1.767**	7.74	**848**	**267**	**577**
January	5	7.37	2.065	0.920	**7.725**	0.000	0.745	1.295	6.64	412	158	232
January	6	7.36	**1.613**	1.020	6.974	0.000	0.960	1.510	5.39	302	128	173
January	7											
January	8	**7.29**	4.382	**1.250**	3.936	0.000	1.415	1.270	**8.30**	675	**106**	544
February	1	8.31	**0.186**	**0.000**	7.506	0.000	**0.000**	0.000	2.42	**683**	**177**	20
February	2	8.09	0.354	**0.000**	8.194	0.000	**0.000**	0.000	2.27	416	195	12
February	3	7.84	0.260	0.070	8.074	0.000	0.015	0.000	**2.06**	240	194	**38**
February	4	7.65	0.389	0.150	8.052	0.000	0.050	0.000	2.23	241	183	34
February	5	**7.38**	0.632	**0.330**	6.769	0.000	0.080	0.000	**3.26**	239	193	22
February	6	7.89	0.209	**0.000**	7.167	0.000	**0.000**	0.000	2.10	204	192	**6**
February	7	8.06	0.361	0.110	**4.432**	0.000	0.030	0.000	2.46	**200**	**217**	17
February	8	**8.34**	**0.857**	0.285	**10.690**	0.000	**0.155**	0.000	2.57	319	212	72

Crooked Fork-Emory Watershed

Date	Site	pH	TKN mg/L	NH3_N mg/L	NO3 mg/L	NO2 mg/L	TP mg/L	PO4 mg/L	BOD 5-day	TS mg/L	TDSmg/L	SSmg/L
June	1	**7.92**	0.375	0.03	0.982	0.000	0.000	0.000		**580**	70	9
June	2	7.79	**0.558**	0.17	1.073	0.000	0.000	0.000		258	**251**	**0**
June	3	7.69	0.545	**0.22**	0.968	0.000	0.000	0.000		234	195	29
June	4	**7.54**	0.326	0.14	1.591	0.000	0.000	0.000		184	242	6
June	5	7.62	0.288	0.09	**2.764**	0.000	0.000	0.000		196	213	9
June	6	7.75	**0.213**	0.01	0.436	0.000	0.000	0.000		272	182	**100**
June	7	7.71	0.522	0.05	**0.000**	0.000	0.000	0.000		156	276	7
June	8	7.65	0.243	**0.00**	**0.000**	0.000	0.000	0.000		**15**	**27**	1
July	1	8.45	0.240	0.09	0.372	0.076	0.040	0.000				
July	2	8.6	0.453	0.16	1.447	**0.000**	0.040	0.000				
July	3	8.9	0.536	**0.35**	1.349	**0.000**	0.070	0.000				
July	4	7.5	0.266	0.16	1.714	**0.120**	0.050	0.000				
July	5	9.9	0.253	0.09	**3.587**	0.075	0.050	0.000				
July	6	**10.75**	**0.742**	0.12	0.570	**0.000**	**0.350**	0.000				
July	7	9.2	0.597	**0.00**	1.670	**0.000**	0.120	0.000				
July	8	**6.9**	**0.080**	**0.00**	**0.295**	**0.000**	**0.020**	0.000				

Crooked Fork-Emory

Date	Site	pH	TKN mg/L	NH3_N mg/L	NO3 mg/L	NO2 mg/L	TP mg/L	PO4 mg/L	BOD 5-day	TS mg/L	TDSmg/L	SSmg/L
August	1	**7.2**	0.184	0.07	0.541	0.072	0.110	0.000	0.93	**472**	**440**	3
August	2	7.4	0.275	0.14	0.832	**0.280**	0.150	0.000	0.03	279	251	8
August	3	7.4	0.256	**0.00**	0.817	**0.000**	0.140	0.000	0.53	198	179	12
August	4	7.8	0.175	0.18	**0.000**	**0.000**	0.160	0.000	**0.00**	178	157	22
August	5	7.5	**0.324**	0.08	0.749	**0.000**	**0.200**	0.000	1.03	240	279	10
August	6	**8.1**	0.229	0.05	0.845	0.178	0.180	0.000	0.23	188	159	**26**
August	7	7.9	0.263	**0.26**	1.291	0.147	**0.200**	0.000	0.63	**104**	93	**0**
August	8	7.6	**0.021**	0.04	**2.569**	0.079	**0.090**	0.000	**1.13**	108	**24**	2
September	1	7.34	0.249	0.02	1.697	**0.248**	0.325	0.310	1.03	191	190	44
September	2	**7.01**	0.336	0.03	1.603	0.159	0.250	0.122	1.38	239	**260**	9
September	3	7.47	**0.557**	**0.22**	1.782	0.287	0.240	0.097	1.03	214	201	**64**
September	4	7.65	0.441	0.14	2.401	0.295	**0.415**	0.082	1.33	209	204	10
September	5	7.7	0.263	0.05	**3.243**	0.315	0.205	**0.324**	1.38	**283**	214	16
September	6	7.34	**0.184**	**0.00**	1.951	0.131	**0.190**	0.295	**0.68**	185	200	**3**
September	7	**7.84**	0.312	0.10	**0.604**	0.236	0.310	**0.000**	**1.98**	148	162	6
September	8	7.19	0.399	**0.00**	0.128	**0.043**	0.385	**0.000**	1.23	**20**	**92**	5

Crooked Fork

Date	Site	pH	TKN mg/L	NH3_N mg/L	NO3 mg/L	NO2 mg/L	TP mg/L	PO4 mg/L	BOD 5-day	TS mg/L	TDSmg/L	SSmg/L
October	1	**7.98**	1.022	0.02	0.928	0.000	**0.130**	0.000	2.34		280	12
October	2	7.77	0.638	**0.12**	**0.000**	0.000	0.000	0.000	3.46		486	**49**
October	3	7.76	**0.581**	0.09	**0.000**	0.000	0.000	0.000	**5.03**		**263**	42
October	4	7.49	**1.895**	0.11	**0.000**	0.000	0.000	0.000	4.65		404	48
October	5	7.72	0.651	0.08	**3.576**	0.000	0.000	0.000	2.29		312	40
October	6	7.85	0.839	**0.00**	**0.000**	0.000	0.000	0.000	**1.94**		355	42
October	7	7.56	0.670	0.09	0.945	0.000	0.000	0.000	2.30		**620**	**4**
October	8	**7.39**	0.612	**0.00**		0.000	0.000	0.000	2.10		574	27
November	1	**8.13**	**0.688**	0.10	**11.383**	0.000	**0.265**	**0.441**	2.26	380	468	35
November	2	7.92	0.500	0.18	**0.000**	0.000	0.000	0.000	2.10	484	**487**	44
November	3	7.9	0.566	**0.28**	**0.000**	0.000	0.000	0.000	**2.98**	**519**	**5**	26
November	4	**7.59**	0.433	0.11	**0.000**	0.000	0.000	0.000	2.83	300	450	55
November	5	7.77	0.593	0.16	3.410	0.000	0.000	0.000	1.71	308	462	45
November	6	7.92	**0.388**	**0.03**	**0.000**	0.000	0.000	0.000	**1.33**	**200**	229	**172**
November	7	8.11	0.595	0.25	**0.000**	0.000	0.000	0.000	2.22	299	267	**11**
November	8											

Crooked Fork

Date	Site	pH	TKN mg/L	NH3_N mg/L	NO3 mg/L	NO2 mg/L	TP mg/L	PO4 mg/L	BOD 5-day	TS mg/L	TDSmg/L	SSmg/L
December	1	7.52	0.736	0.42	1.450	0.000	0.215	0.000	3.12	148	152	0
December	2	7.57	1.216	0.23	1.267	0.000	0.350	0.000	**1.55**	155	**179**	0
December	3	**7.51**	**0.499**	0.25	1.405	0.000	0.090	0.000	2.19	126	170	0
December	4	7.35	0.765	0.57	1.425	0.000	0.160	0.000	3.04	194	113	75
December	5	7.55	**1.637**	**1.63**	**1.638**	0.000	**0.405**	0.000	3.29	**446**	156	**322**
December	6	**7.7**	0.991	**0.14**	**1.017**	0.000	0.215	0.000	2.82	386	136	271
December	7	**7.51**	0.868	0.87	1.183	0.000	0.155	0.000	**3.32**	125	58	93
December	8	7.62	0.562	0.15	1.617	0.000	**0.080**	0.000	1.91	**55**	**48**	**4**
January	1	**7.46**	2.139	2.03	1.545	0.000	0.510	0.000	4.56	563	61	292
January	2	7.31	**1.470**	1.34	1.702	0.000	**0.335**	0.000	3.53	**372**	87	**241**
January	3	7.3	1.763	**2.73**	**1.252**	0.000	0.590	0.000	**3.51**	838	82	594
January	4	7.37	2.815	1.92	1.661	0.000	0.775	0.000	5.09	1185	92	934
January	5	7.37	3.720	0.34	2.020	0.000	**1.130**	0.000	4.97	1916	102	1325
January	6	7.36	**4.662**	0.29	2.221	0.000	1.500	0.000	**5.54**	**2686**	**111**	**2205**
January	7		4.499	**0.25**	1.614	0.000	0.490	0.000	4.30	494	57	389
January	8	**7.29**	2.321	0.32	**2.315**	0.000	0.420	0.000	4.72	750	**36**	473

Crooked Fork

Date	Site	pH	TKN mg/L	NH3_N mg/L	NO3 mg/L	NO2 mg/L	TP mg/L	PO4 mg/L	BOD 5-day	TS mg/L	TDSmg/L	SSmg/L
February	1	6.88	0.187	0.00	0.768	0.000	**2.100**	**0.272**	1.89	161	132	**2**
February	2	6.76	**0.106**	0.00	**0.747**	0.000	0.000	0.000	1.70	214	**193**	**12**
February	3	7.03	0.202	0.00	0.993	0.000	0.000	0.000	1.98	161	140	14
February	4	7.29	0.182	0.00	1.419	0.000	0.000	0.000	1.85	154	132	4
February	5	7.39	0.218	0.00	**1.675**	0.000	0.000	0.000	1.82	164	150	8
February	6	**7.87**	**0.539**	0.00	0.922	0.000	0.000	0.000	**2.06**	**275**	128	4
February	7	**6.56**	0.332	0.00	0.754	0.000	0.000	0.000	1.50	54	51	9
February	8	6.86	0.305	0.00	1.164	0.000	0.000	0.000	**1.42**	**35**	**23**	7

VITA

Tiffany Foster Day was born in Knoxville, Tennessee in 1966. She received her Bachelors of Science degree in Biology with a Chemistry minor at the University of North Carolina, Wilmington. Her work at the University of Tennessee was within the department of Plant and Soil Science where she served as a research and teaching assistant in soil science. She received her Masters of Science degree in May of 2002, with a concentration in Soil Science. She has plans to continue investigating soil and water quality. Her plans include working with local community groups to monitor impaired streams and raise public awareness regarding the quality of the streams in their area.

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