DETERMINING LIMITING NUTRIENTS IN LAKE EUCHA TRIBUTARIES

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Bachelor of Science

Texas A&M University

College Station, Texas

1997

Submitted to the Faculty of the
Graduate College of the
Oklahoma State University
in partial fulfillment of
the requirements for
the Degree of
MASTERS OF SCIENCE
December, 2000

DETERMINING LIMITING NUTRIENTS IN LAKE
EUCHA TRIBUTARIES

Thesis Approved:

Thesis Advisor

Dean of Graduate School

ACKNOWLEDGMENTS

Completion of my degree would not have been possible without the support and assistance from many people. I would like to thank my advisor, Dan Storm, for reviewing countless manuscripts, supporting me in pursuit of my engineering degree, and for encouraging me. I would also like to thank Mike Smolen and Bill Fisher for their insight and guidance. Brian Haggard went above and beyond the call of duty in helping me with numerous aspects of my research, including reviewing papers and helping with field work. I would like to thank my family for supporting me through my challenges and triumphs. My out of town friends, Robin, David, and Trey, gave me a place to get away from it all and relax. Finally, I would like to thank my colleagues for making my experience both in and out of school enjoyable.

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CHAPTER 1

INTRODUCTION

Background

Periphyton, or attached algae, production is limited by environmental factors including light, temperature, nutrients, and grazing. With regard to anthropogenic eutrophication of streams, limiting nutrients, i.e. any nutrient that limits plants growth, may control the trophic state of aquatic systems. For example, by controlling the limiting nutrient in stream ecosystems, excess algal growth can be controlled to prevent or reduce eutrophication.

Typically, nitrogen and phosphorus limit plant growth. However, a number of trace elements can also limit the algal growth including Si, K, Fe, Mg, and Mo (Allan, 1995; Hutchinson,1967). Nitrogen was found to limit algal growth in the Ozark Mountains at NO_3-N concentrations below 0.10mg/l (Lohman et al.,1991). Other studies have shown nitrogen to be limiting at NO_3-N concentrations below 0.05-0.06 mg/l and phosphorus limits algal growth with soluble reactive phosphorus (SRP) concentrations between 3 ug/l and 50 ug/l (Newbold,1992; Bothwell, 1989, 1985; Pringle, 1987). The addition of nitrogen and phosphorus can lead to increased algal growth and may lead to accelerated eutrophication (Deevey, 1972). Several watershed attributes such as land use, climate, geology, soils and cultural practices may influence the amount and forms of nutrients that enter the nutrient cycle in streams. The concentrations of nitrogen and phosphorus entering streams increases with percent agricultural and urban land use (Tufford et al.,1998; Jordan et al, 1997; Chessman et al., 1992; Smith et al. 1987; Beaulac and Reckhow,1982; Omernik, 1977;).

Nutrients do not enter streams at a constant rate. For example, an increased nutrient load can result from high runoff events or from increased discharge from point sources. Thus, stream nutrient concentrations are dependent on the watershed hydrology and seasonal precipitation patterns. These patterns, in conjunction with biological influences (Tate, 1990), produce seasonal variability in stream nutrient concentrations and may produce seasonal changes in the limiting nutrient.

In addition to surface runoff, subsurface contribuation may also influence the nutrient concentrations in streams. Ground water may contribute to streams and can affect the nutrient concentrations in the streams. For example, if the ground water contains high concentrations of nutrients and discharges into a stream, then the stream water will increase its nutrient concentrations. Increased levels of NO_3-N, Cl and PO_4-P were found in ground water with cropland compared to areas with forested land use (Petersen et al., 1999; Pionke and Urban, 1985).

Purpose of Study and Objectives

The City of Tulsa and other small communities receive their drinking water from two lakes, Lake Spavinaw and Lake Eucha. Lake Eucha is approximately four miles upstream of Lake Spavinaw and provides a continuous water supply to Lake Spavinaw (OCC, 1997). Eutrophication and its effects have become a concern for both lakes because of increased nutrient concentrations. Nitrate-nitrogen concentrations doubled and total phosphorus concentrations tripled in Lake Eucha from 1975 to 1995 (OCC, 1997). However, phosphorus is of particular concern in the Lake Eucha basin since the lake is phosphorus limited (OCC, 1997). Additionally, there have been increasing complaints about taste and odor problems, which are associated with blue-green algae (OCC, 1997; Horne and Goldman, 1994). Due to the problems associated with increased nutrients, the cost of treating the raw water has increased significantly (Marsha Slaughter, City of Tulsa, personal communication).

The limiting nutrient in Lake Eucha tributaries is needed to quantify nutrient-algal relationships. Once these relationships are understood, criteria for nutrient loading can be set to prevent excess algal growth in the tributaries. The nutrient loading criteria will help develop appropriate upland best management practice recommendations (EPA 2000). Furthermore, quantifying stream nutrient dynamics in Lake Eucha tributaries is needed to assess the form and availability of phosphorus and nitrogen as they enter the lake. Setting nutrient loading criteria will also help determine appropriate cost-effective lake management strategies. Since algal growth is affected by seasonal changes in the environment, the nutrient-algal relationship may also change with seasons. Understanding this relationship is needed to develop seasonal nutrient. The specific objectives of my research were to:

1. **Determine the limiting nutrient in seven streams in the Lake Eucha Basin**
   A) H_0: Columbia Hollow is nitrogen limited. H_A: Columbia Hollow is not nitrogen limited.
   B) H_0: Dry Creek, Cloud Creek, Cherokee Creek, Beaty Creek, Upper Spavinaw, and Lower Spavinaw are phosphorus limited. H_A: Dry Creek,

Cloud Creek, Cherokee Creek, Beaty Creek, Upper Spavinaw, and Lower Spavinaw are not phosphorus limited.

2. **Asses the Lotic Ecosystem Trophic Status Index (LETSI) in the seven streams.**

   A) H_0: LETSI is approaching 1.0 for Columbia Hollow. H_A: LETSI is less than 1.0 for Columbia Hollow.

   B) H_0: LETSI increases with increased percent agriculture land use. H_A: LETSI does not increase with increasing percent agricultural land use.

3. **Characterize seasonal effects on the limiting nutrients.**

   H_0: There are no seasonal effects on the limiting nutrients in seven streams in the Lake Eucha Basin. H_A: There are seasonal effects on the limiting nutrients in any of the seven streams in the Lake Eucha Basin.

CHAPTER 2

LITERATURE REVIEW

Background

Eutrophication is the natural aging of lakes due to increased nutrients (Rast and Thornton, 1996; National Academy of Sciences, 1969). More recently, eutrophication has become to mean highly nourished and can apply to both streams and lakes (Borchardt, 1969). Anthropogenic activities often accelerate eutrophication, and cultural eutrophication has become a worldwide problem (Dokulil et al., 2000; Rast and Thornton, 1996; Thomas, 1969; Rodhe, 1969; Edmondson, 1969). Excess algal growth caused by nutrient enrichment can lead to higher turbidity, taste and odor problems, and oxygen depletion (Borchardt, 1969; Thomas, 1969; Hasler, 1947). Thirty-six percent of lakes and reservoirs surveyed in the U.S. were eutrophic and 9% were hypereutrophic (US EPA, 1996). Furthermore, excess nutrients have been identified as the leading cause of impairment in lakes and the second leading cause of impairment in streams and rivers (US EPA, 1996). Nitrogen and phosphorus are the most common nutrients that contribute to accelerated eutrophication (Heathwaite et al., 1996; Horne and Goldman, 1994).

The 1972 Clean Water Act led to reductions in point source pollution and thus subsequent water quality concerns have focused on nonpoint source pollution (US EPA, 1990). The quantity of nutrients that enter stream ecosystems are dependent on the geology, soils, climate, land cover and management practices, which influence the form and bioavailability of nutrients entering aquatic systems (Beaulac and Reckhow, 1982). Forested watersheds have much lower nutrient concentrations and loading compared to agricultural land use (Chessman et al., 1992; Beaulac and Reckhow,1982). Several investigators have observed that stream water nitrogen concentrations increase with increasing agricultural land use in the watershed (Tufford et al.,1998; Jordan et al., 1997; Smith et al. 1987; Omernik, 1977).

Stream ecosystems exhibit a continuous gradient of physical and biological changes from the headwaters to the mouth. Headwater streams (orders 1-3) are strongly influenced by riparian vegetation, which shade the stream and provide allochthonous materials. Headwater streams have a gross primary production to community respiration ratio (P/R) less than 1. Medium sized rivers (orders 4-6) have a P/R >1. The effect of riparian vegetation in large rivers (orders >6) is not as significant as in smaller ordered streams. In addition, light may limit primary production from turbid waters and deep waters in large rivers (Vannote, 1980).

Trophic Classifications

The point at which a lake or stream becomes eutrophic is difficult to determine. Investigators have used turbidity, nutrient concentrations, and measures of primary production to quantify trophic status (Carlson, 1977; Rodhe, 1969). For example, Rodhe

(1969) defined the level of primary production for oligotrophic, natural eutrophic, and polluted eutrophic lakes. Furthermore, Carlson (1977) developed a trophic status index to quantify the degree of eutrophication using mathematical equations relating secchi transparency, chlorophyll *a* concentrations, and total phosphorus concentrations.

An open boundary trophic status classification system provides a range of values for parameters (Vollenweider, 1982). In this classification system, ranges are given for trophic categories. Two lakes that have similar values for a parameter may be classified in two different trophic categories. Therefore, probability becomes important in determining trophic classification. Table 1 gives the trophic state for the range of values for different parameters (Vollenweider, 1982).

Dodds (1998) introduced a statistical approach to characterize the trophic status of streams for total nitrogen, total phosphorus, and benthic chlorophyll *a*. To determine the boundaries for the trophic status, data were compiled from several previously published studies. Using frequency distributions, the lowest third of the streams were oligotrophic, the middle third were mesotrophic, and the upper third were eutrophic. The suggested boundaries for oligotrophic/mesotrophic and mesotrophic/eutrophic conditions for streams are given in table 2 (Dodds, 1998).

Another method to characterize the trophic status of streams is relating ambient algal growth on artificial substrate to growth on nutrient enriched substrate (Matlock et al., 1999). The Lotic Ecosystem Trophic Status Index (LETSI) is a ratio of baseline productivity to the maximum potential productivity in a stream. This index provides a way to compare ambient algal growth to the maximum algal growth. If this ratio is equal to one, then the stream is at its maximum potential productivity. If the ratio is less than 1, then the stream is not at its maximum nutrient assimilative capacity. For example, a stream at 50% of its nutrient assimilative capacity would have a LETSI value of 0.50.

Periphyton

Algae are a diverse group of organisms that produce oxygen and organic material from carbon dioxide, water, nutrients, and sunlight (Sze, 1998). Algae are divided into 10 major divisions and can indicate the condition of the water quality in streams (EPA, 1997; Lowe and Laliberte, 1996). Cyanobacteria, Chlorophyta, and Baceillariophyta are the three major divisions found in rivers and streams (Sze, 1998).

Cyanobacteria, blue-green algae, are prokaryotic and use chlorophyll *a* as their only source of photosynthetic pigment (Sze, 1998; Lowe and Laliberte,1996; Fogg et al., 1973). Some blue-green algae have the unique capability to fix nitrogen. Nitrogen fixation is the process of taking N_2 and converting it to a bioavailable form, NH_4 (Sze, 1998). Blue-green algae may occur in eutrophic waters and are able to tolerate a wide range of environmental conditions including temperature and salinity (Sze, 1998; Palmer, 1977).

Chlorophyta, green algae, are usually filamentous and contain both chlorophyll *a* and *b* (Sze, 1998; Lowe and Laliberte, 1996). Green algae are almost as widely distributed as blue-green algae and are also adapted to a wide range of environmental conditions. Eutrophic waters often contain green algae (Darley, 1982).

Baceillariophyta, diatoms, are the most widespread of all the benthic algae (Lowe and Laliberte, 1996). Diatoms are unicellular, eukaryotic and have both chlorophyll *a* and *c* (Lowe and Laliberte, 1996; Round et al., 1992). Silica is needed for the cell wall formation in diatoms (Round et al., 1992). Whereas blue-green algae and green algae have a wide range of tolerance for environmental conditions, diatoms have a narrow tolerance to environmental conditions. Diatoms also respond quickly to changes in the environment, therefore they can be indicators of changes in water quality (Dixit et al., 1992).

Physical Factors

Light

Light is essential to the process of photosynthesis and algal production. Photosynthesis is the conversion of carbon dioxide to oxygen and biomass (Bott, 1996). Without light algal growth can be inhibited (e.g. see Hill et al., 1995; McIntire, 1968; McIntire and Phinney, 1965).

The availability of this essential factor may vary seasonally influencing periphyton growth. During the summer months, the days are longer and light is able to reach the water surface for long periods of time. In contrast, the days are shorter during the winter and potentially less light reaches the water column surface (Hill et al., 1996). Canopy cover also changes with season. For example, during the summer or spring, riparian foliage reduces the amount of light available to the stream habitats (Hill et al., 1996, Hepinstall and Fuller, 1994). Riparian management may also impact light availability. Typically, light does not limit algal growth in a clearcut stream, but does limit algal growth in a forested stream with heavy canopy cover (Lowe et al., 1986; Keithan and Lowe, 1985).

Grazers

Grazers directly affect periphyton by consuming algal biomass and possibly limiting algal growth (Hill et al., 1995; Hill et al., 1992; Hill and Knight, 1987, Lamberti and Resh, 1983; Mulholland et al., 1983). While ungrazed algal communities have higher overall biomass, grazed communities have increased productivity on a per cell basis (Lamberti and Resh, 1983; Mullholland, 1983). Indirect affects of grazers on algae include fertilization from waste products and consuming the dead and senescent algal cells (Hill et al., 1992; Lamberti and Resh,1983). In addition, grazers may prevent light and nutrient limitations due to algal mass reduction (Lamberti and Resh, 1983). Depletion of biomass can also be caused by dislodging algal cells both actively and passively. Active dislodgement maximizes energy intake by selecting productive algal cells, whereas passive dislodgement loses algal cells due to limitations of their mouth parts (Scrimgeour et al., 1991). Therefore, grazers may cause a change in community structure by selecting certain species over other algal species (Rosemond, 1993; Power et al., 1988;).

Nutrients

If increased nutrient loading promotes accelerated eutrophication and excess algal growth, then accelerated eutrophication may be controlled by the limiting nutrient. The limiting nutrient regulates algal growth rates and therefore regulates the rate of eutrophication. The three most important nutrients for algal growth are carbon, nitrogen, and phosphorus (Redfield, 1958). Trace elements are also needed, i.e. silica, sulfur, iron, magnesium, sodium, calcium and potassium (Hutchinson, 1967).

Justus Liebig first introduced the concept of the Law of the Minimum working with plants (Liebig,1885). A limiting nutrient is a deficiency of any nutrient that a plant needs to grow. The growth rate and biomass will be limited by that nutrient. If the limiting nutrient is added or made available to the plant, then the plant will grow and accumulate biomass until that or another nutrient becomes limiting (Liebig,1885).

Nitrogen, phosphorus, and silica are typically the limiting nutrients of algae growth, but silica rarely limits algal growth in streams (Allan, 1995). Therefore, nutrient limitation investigations have focused on nitrogen and phosphorus in streams. The addition of these nutrients can lead to an increase in algal growth and possibly eutrophic conditions in aquatic systems (Deevey, 1972).

The Redfield ratio (Redfield, 1958), a ratio of carbon, nitrogen, and phosphorus, can indicate which nutrient limits algal growth. The ratio of atomic weights of carbon, nitrogen, and phosphorus in algal tissue under good growing conditions is 106:16:1, respectively. The nitrogen to phosphorus ratio in algal tissue can indicate if a stream is limited by nitrogen or phosphorus. This application has been further applied to the nutrient supply ratio in the water column of streams. Using the Redfield raito, the system is nitrogen limited if the N:P ratio is less than 16 and phosphorus limited if it is greater than 16 (Allan, 1995). However, in practice the change from phosphorus limitation to nitrogen limitation occurs over a range of values. In general, if the N:P ratio is less than 10, the stream tends to be nitrogen limited and greater than 20 indicates phosphorus limitation, the stream will tend to be phosphorus limited. Nitrogen and/or phosphorus can limit the algal growth if the ratio is between 10 and 20 (Schanz and Juon, 1983). However, the N:P supply ratio does not always correspond to the actual limiting nutrient

(Wold and Hershey, 1999; Allen and Hershey, 1996). Nitrogen and phosphorus occur in many different forms in streams and rivers, which makes it difficult to determine the limiting nutrient from an N:P ratio (Morris and Lewis, 1988). Phosphorus can be used by periphyton not only from dissolved inorganic phosphorus, but also from dissolved organic phosphorus (Morris and Lewis, 1988). Dissolved inorganic nitrogen is approximatly the sum of ammonia and nitrate, which are the two most bioavailable forms of nitrogen for algae (Morris and Lewis, 1988).

Major factors that influence nutrient concentrations in streams include hydrogeological characteristics, soil processes, land-use practices, terrestrial vegetation and coverage, as well as atmospheric loading (Meyer et al., 1988). Some of these characteristics will change seasonally, impacting the stream nutrient concentrations. A study of a watershed with mostly cropland showed seasonal cycles of nitrogen and phosphorus (Pionke et al., 1999). The dissolved phosphorus concentrations were highest during the summer months. In contrast, the nitrate-nitrogen concentrations were lowest in summer and highest in fall. The seasonal concentrations of nitrogen appeared to be controlled by two factors in this watershed. First, increased flow rate produced higher nitrogen concentrations in this stream. Second, seasonal increase of nitrogen during the fall may have been caused by the remobilization of the NO_3-N from the low soil moisture content in summer (Pionke et al., 1999). Similarly, the nitrogen concentration in prairie streams were highest in March and decreased from March to June (Dodds et al., 1996; Tate, 1990). The higher mean nitrate concentrations occurred when the vegetation was dormant and lower concentrations during the growing season. Thus, terrestrial and riparian systems regulated the supply of nitrogen to streams. Whereas nitrogen varied seasonally, there were no seasonal trends in phosphorus concentrations in these prairie streams (Tate, 1990).

Seasonal changes in water column nutrient concentrations affect the limiting nutrient in streams (Wold and Hershey, 1999; Allen and Hershey, 1996). Allen and Hershey (1996) found that the limiting nutrient changed seasonally from phosphorus in the spring, to nitrogen in the summer, and finally no limitation by nutrients in the fall. In three streams in eastern Oklahoma, the limiting nutrient also changed seasonally (Matlock et al., 1999a). During the spring two of the streams were primarily phosphorus limited and one was nitrogen limited. During the fall, the limiting nutrient in all of the streams changed to either co- limited or nitrogen limited (Matlock et al., 1999a). In another investigation of changes in nutrient limitations, two sub-alpine woodland streams were primarily nitrogen limited during the summer and one changed to phosphorus limited in the fall (Chessman, 1992). Forested streams did not show seasonal changes in the limiting nutrient and were phosphorus limited through the year (Chessman, 1992). Agricultural streams were mainly nitrogen limited (Chessman, 1992). However, one agricultural stream changed from nitrogen limited in the summer to phosphorus limited in the fall. Urban streams were primarily nitrogen limited throughout the year. (Chessman et al., 1992).

Nutrient Enrichment Methods

One of the first experiments examining the effects of nutrient enrichment involved placing a bag of fertilizer in the stream and recording visual changes in the benthic organisms. Downstream of the bag of fertilizer there was more algal growth and a higher invertebrate population (Huntsman, 1948). However, recent methods are more controlled and specific including flow through systems, nutrient diffusing substrata and whole stream enrichment. Despite different methodology, the goal is the same, to increase algal growth to identify the limiting variable.

One method to evaluate a stream's response to different nutrient enrichments is to build troughs in or alongside the stream. A nutrient solution is delivered to the trough providing continuous nutrient enrichment (see Rosemond, 1993; Hill et al., 1992; Lohman et al., 1991, Hart and Robinson, 1990; Grimm and Fisher, 1986). After a specified number of days, ranging from 12 days to 77 days, periphyton is collected and analyzed. Hart and Robinson (1990) allowed periphyton and macroinvertebrates to colonize their wooden troughs for eight months prior to phosphorus enrichment. Periphtyon was sampled 77 days after the enrichment began.

Another method used in Alaska to alleviate problems associated with flooding in their stream reaches involved a floating apparatus. This method placed clear plastic tubes made of Plexiglas on a wood frame with Styrofoam floats that allowed the apparatus to float on the water surface. Nutrients were siphoned through the tubes and either microscope slides or agar substrate were placed in tubes as the algal growth substrate (Pringle, 1987; Peterson et al., 1983).

The most common method used in nutrient limitation experiments is the nutrient diffusing substrate (see Lowe et al., 1986; Fairchild et al., 1985; Fairchild and Lowe, 1984). Typically, clay flowerpots are sealed with a Petri dish and then filled with 2% agar solution. Various treatments of nutrient solutions are incorporated into the agar in order to investigate specific nutrient addition affects on algal growth. The artificial substrates are placed in the stream and harvested between seven and 60 days later.

In order to determine nutrient limitation for a whole stream or stream reach, long-term or short-term solute injections may be used. Nutrients are delivered into the stream from either carboys or pumps from tanks (Peterson et al.,1993). Changes in numerous stream characteristics can be evaluated using this method. Algae from tiles and rocks were collected to measure chlorophyll content. Oxygen was measured to calculate the primary productivity, microbial activity was analyzed, insects were collected for estimation of density, growth, and production, and the growth rates of fish were calculated by following the changes in length and mass (Peterson et al., 1993).

Finally, recent investigations into stream limiting nutrients use another type of floating apparatus called the Matlock Periphytometer (Matlock et al., 1998). Polyethylene bottles on the apparatus are filled with different nutrient solutions and are suspended in the stream channel. A nylon membrane is placed on top of the bottle and a glass fiber filter is placed on the nylon membrane. The nylon membrane controls diffusion of the nutrient solution into the stream water and the glass fiber filter provides the substrate for algal growth. The lid of the bottle contains a 2.5 cm hole and holds the membrane and filter in place. After two weeks, the periphytometers are harvested and filters are analyzed for chlorophyll concentration (Matlock, 1996).

The Matlock Periphytometers have been used in Oklahoma and Texas, and are currently being used across the United States. In Texas, limiting nutrients were found to be either phosphorus, co-limited, or not limited by nutrients, with LETSI ranging from 0.18 to 0.90 (Matlock, 1999b). In Oklahoma, the limiting nutrient changed with seasons. During the fall, two streams were phosphorus limited and one stream was nitrogen limited. In the spring, the limiting nutrient changed in all three streams to either co-limited or nitrogen limited. The LETSI ranged from 0.30 to 0.64 (Matlock, 1999a; Matlocket al., 1998).

CHAPTER 3

MATERIALS AND METHODS

Study Site Selection

Lake Eucha is the first of two reservoirs on Spavinaw Creek in northeast Oklahoma and northwest Arkansas. Lake Eucha basin is approximately 93,100 hectares. The primary land use is forest and pasture. Agricultural production includes poultry, hog, cattle and dairy production. The most widespread agricultural practice is land application of animal waste, particularly poultry litter with some swine slurry. Ultisols and mollisols are the primary soil order in this basin containing kaolinite, illite, iron, and aluminum hydroxides. Karst features are also common in this area which are formed over limestone, dolomite, or gypsum (OCC, 1997; Fetter, 1994).

In 1952, Spavinaw Creek was impounded creating Lake Eucha. The purpose of the lake was to provide a constant water source to a downstream reservoir, Lake Spavinaw. The city of Tulsa and several smaller communities receive their drinking water from the Lake Eucha-Spavinaw complex. The reservoir complex is also used for sport fisheries, irrigation for agriculture, and recreation (OCC, 1997).

Wastewater treatment plants (WWTP) in Gravette, AR and Decatur, AR are two point sources in the Lake Eucha basin. Gravette's facility treats water from a residential community and has a design discharge of 0.56 million gallons per day (mgd). The stream receiving the point source discharge is an intermittent system which frequently has no surface flow entering Spavinaw Creek (personal communication, Brian Haggard). Decatur's facility treats wastewater from a residential community and a poultry processing plant. This facility discharges approximately 1.6 mgd (OCC,1997). The Decatur WWTP significantly impacts benthic sediments and nutrient retention in the receiving stream (Columbia Hollow) and Spavinaw Creek (Haggard, 2000; Popova, 2000). While point source pollution is a significant contributor to reservoir nutrient loading, nonpoint sources still contribute a greater proportion of the nutrients entering the reservoir complexes. A diagnostic study of Lake Eucha and Spavinaw indicate these lakes are eutrophic (OCC,1997).

Seven streams were chosen for this study (Figure 1). Beaty and Spavinaw Creek account for approximately 85% of the phosphorus flowing into Lake Eucha (OCC, 1997). Beaty Creek does not have a point source located in its watershed; therefore the nutrient concentrations are from nonpoint sources. Spavinaw Creek has both point and nonpoint sources located in its watershed. Two sampling sites are located on Spavinaw Creek, one is above the Decatur wastewater treatment plant and one is below it. Columbia Hollow was chosen since it is the receiving stream of the wastewater treatment plant located in Decatur, AR. Cloud, Cherokee, and Dry Creek were chosen because these locations have varying agriculture and forested land use. Cloud Creek and Cherokee Creek have high amounts agricultural land use and low amounts of forested land. On the other hand, Dry Creek has high amounts of forested land and low amounts of agricultural land. The land use for tributaries in the Lake Eucha basin is given in Table 3.

Methods

Matlock Periphytometers

Artificial growth substrates (Matlock Periphytometers) were used to determine the limiting nutrient in seven streams within the Lake Eucha-Spavinaw Basin (Matlock et al., 1998). The Matlock Periphytometers were constructed with three-gauge cattle panel (4" by 4" square) cut in a 3 ft by 5 ft rectangle. Three-inch diameter schedule 20 PVC pipe was attached with stainless steel hose clamps on the two sides and back of the cattle panel. On the front of the Matlock Periphytometer, the PVC pipe was in the shape of a 'V' (see Figure 2 for english units and Appendix H for metric units). This 'V' shape device diverts floating debris from shading the artificial growth substrates. The PVC pipe ends of the 'V' shaped device were attached with 90° schedule 40 elbows. The two front corners had 45° elbows and the bottom of the 'V' had 90° elbow (See Figure 2 for english units and Appendix H for metric units). This created one long continuous PVC pipe, which provided more strength and made the Matlock Periphytometer more durable.

Polyethylene bottles (8 oz high-density polyethylene bottles, Cole Parmer part no. P-06049-01) were attached to the cattle panel with a 2.75 inch maximum diameter stainless steel hose clamp. The bottles were filled with either nutrient solution or reverse osmosis water. Ten bottles were filled per treatment, for a total of forty bottles.

The nutrient limitation experiment used four treatments:

- 10 mg/L Phosphate - P (NaH_2PO_4- H_2O)
- 100 mg/L Nitrate - N ($NaNO_3$)
- 100 mg/L Nitrate and 10 mg/L Phosphate - P
- Control (Reverse Osmosis water)

A 47mm diameter nylon membrane (0.45µm pore size, Cole Parmer part no. CN 2916-44) was placed on top of the bottle, which controlled diffusion of the nutrient solution (Figure 3). A 37mm diameter glass fiber filter (Whatman 934-AH, pore size 1.5µm) was placed on top of the nylon membrane to serve as the growth substrate. The bottles were placed in the stream with growth substrate perpendicular to the flow. An aluminum screen (16x18 mesh) covered the top of the bottles and growth substrate to prevent macroinverterate or vertebrate grazing. The bottles were placed on the Matlock Periphytometer in a randomized block formation with 4 treatments per block and ten replicates.

The Matlock Periphytometers were deployed on 16 June 1999, 22 July 1999, 25 August 1999, 30 November 1999, and 25 February 2000. Natural stream periphyton was allowed to colonize the growth substrate for two weeks, and then the Matlock Periphytometers were harvested. The glass fiber filters were carefully removed and stored in glass vials with 5 mls of aqueous acetone saturated with magnesium carbonate, wrapped in aluminum foil and frozen for at least 48 hours (Matlock et al., 1998). Chlorophyll a, b, and c content were determined using the trichromatic method (APHA,1998).

Lotic Ecosystem Trophic Status (LETSI) was calculated for each sampling date. LETSI is a ratio of ambient conditions to maximum potential productivity, or control to the N+P treatment. N-LETSI is the ratio of the nitrogen treatment to the maximum potential productivity. P-LETSI is the ratio of the phosphorus treatment to the maximum potential productivity.

$$\text{LETSI} = \frac{control}{N+P}\text{; N-LETSI} = \frac{nitrogen}{N+P}\text{; P-LETSI} = \frac{phosphorus}{N+P}$$

Physicochemical and Biological Analysis

Temperature, pH, and conductivity measurements were taken during each deployment and harvest of the Matlock Periphytometers using an Oakton pHTestr2 for pH, and a HyDac meter (serial number 9403) for temperature, and a Hanna instruments multirange conductivity meter (HI 9033) for conductivity measurements. Flow rate was measured using a Flomate 2000 (Marsh-McBirney, Inc. MA).

Three filtered 20 ml grab samples (high density polyethylene scintillation vials, Fisher Part no 03-337-23A) were taken at the time of each deployment and retrieval of the Matlock Periphytometers. The water samples were filtered through a syringe filter (0.7μm, Fisher part no. 09-927-39B) using a Whatman glass fiber filter, and preserved with H_2SO_4 and kept on ice until return to the laboratory. The samples were then analyzed for soluble reactive phosphorus (SRP), NO_3-N, and NH_4 -N. Soluble reactive phosphorus was determined within 24-48 hours using the mixed reagent ascorbic acid method (APHA 1998). NO_3-N, and NH_4–N were determined on a Latchet QuikChem 9000(Milwaukee, WI) . NO_3-N was measured using the cadmium-copper reduction method (QuikChem Method 10-107-04-1-A), NH_4 -N was determined using the alkaline phenol, sodium hypochlorite and nitroprusside reaction (QuikChem Method 10-107-06-1-B).

Three unfiltered 8 oz grab samples (high-density polyethylene bottles, Cole Parmer part no. P-06049-01) were also taken for total Kjeldahl N and total phosphorus analysis. The samples were digested using H_2SO_4 with mercuric sulfate as a catalyst. Total Kjeldahl N was determined colorimetrically via the salicylate – nitroprusside method (APHA, 2000). Total phosphorus was measured using the ascorbic acid method (APHA, 2000).

Statistical Analysis

An Analysis of Variance procedure was performed using SAS Version 7.0. Least Significant Difference procedure was used to evaluate individual treatment differences. An $\alpha = 0.05$ was used to compare ambient nutrient concentrations between streams and between sampling dates. An $\alpha = 0.10$ was used to compare LETSI between streams and between sampling dates. To determine the limiting nutrient, an $\alpha = 0.10$ was used to compare the Matlock Periphytometer treatment differences. Percent land use was correlated with ambient nutrient concentrations and LETSI using Pearson's Correlation using a significant level of $\alpha = 0.05$.

CHAPTER 4

RESULTS

Ambient Nutrient Concentrations

Stream Variations

Ambient nutrient concentrations are in Appendix A. Significant spatial and temporal differences were observed for both inorganic nitrogen and phosphorus concentrations. The N:P ratios for each site are in Table 4. The water column NO_3-N and SRP concentrations in Columbia Hollow were several orders of magnitude greater than any other stream. Overall, NH_4-N ranged from below detection level (0.03 mg/l) to 0.25 mg/l whereas NO_3-N ranged from 0.57 to 7 mg/l. SRP ranged from 0.01 to 6.75 mg/l.

No significant differences in NH_4-N concentrations were found between streams for the sampling dates for July-Aug and Nov-Dec (Figure 4). During August - September sampling period, Dry Creek was significantly lower than both Beaty Creek and Lower Spavinaw. During the February-March sampling period, the ammonia concentrations for all six streams were significantly lower than Columbia Hollow. The p-values are in Appendix B.

Significant differences were observed in NO_3-N concentrations among streams (Figure 5). Lower and Upper Spavinaw Creeks were not significantly different during any of the sampling periods except July-August. Columbia Hollow was significantly higher from the other six sites during every sampling period. The p-values are available in Appendix B.

Columbia Hollow phosphorus concentration was significantly higher compared to the other six streams over all the sampling periods (Figure 6). Other than Columbia Hollow, the streams were not significantly different during any of the sampling dates. The p-values are available in Appendix B.

Seasonal Variation

Within stream nutrient concentrations were compared between sampling dates ($\alpha = 0.05$). NO_3-N concentrations were significantly higher in July-August compared to the other three sampling dates on Beaty Creek and Upper Spavinaw Creek. Cherokee, Cloud, and Columbia Hollow did not show any significant difference in NO_3-N concentrations over the four sampling dates. Figure 7 shows seasonal trends in NO_3-N for each stream. The p-values for the seasonal trends are available in Appendix C.

NH_4-N concentrations were significantly higher comparing August-September sampling and the other three sampling dates for Beaty Creek and Lower Spavinaw Creek. Columbia Hollow had significantly higher NH_4-N concentrations for the February-March sampling compared to the other three sampling dates. Cherokee, Cloud and Dry Creeks did not have any significant differences in NH_4-N concentrations over the sampling dates. Figure 8 shows seasonal trends for NH_4-N. The p-values for the seasonal comparisons are available in Appendix C.

Cloud Creek and Dry Creek were the only two streams that did not have any significant differences over the four sampling dates for soluble reactive phosphorus (SRP). Beaty Creek was significantly higher in July-August compared to the other three sampling dates. Columbia Hollow was significantly higher in February-March compared to the other three sampling dates. Figure 9 shows seasonal trends in SRP for each stream. The p-values are available in Appendix C.

LETSI

Table 5 shows the average LETSI, N-LETSI, and P-LETSI along with the seasonal and stream differences. No significant differences were found in the LETSIs between two winter sampling dates. The p-values results are available in Appendix D for comparisons between streams and Appendix E for seasonal comparisons.

No significant differences between LETSIs were observed between sampling date in any of the streams. When point source affected streams were included, no significant correlations were observed between the stream nutrients and LETSI (Figures 10-12). When the point source affected streams were excluded, the LETSI was negatively correlated with NO_3-N and NH_4-N ($\alpha= 0.10$) for the July-August sampling period and positively correlated with SRP in November-December. Table 6 and 7 shows the correlation factors for LETSI and NO_3-N, NH_4-N, and SRP.

Limiting Nutrients

Table 8 shows the limiting nutrient of each stream for each sampling. Figures 13-16 show the differences between treatments for each sampling site and date. Chlorophyll *a* data are available in Appendix F and treatment comparisons are shown in Appendix E.

Nitrogen and/or phosphorus did not limit algal growth except for a few streams. For example, Cherokee Creek was either limited by nitrogen and phosphorus or by phosphorus during the summer sampling dates. Beaty Creek was phosphorus limited during the summer. During the winter these systems were neither nitrogen, phosphorus nor co-limited. The other streams were consistently not limited by nitrogen and/or phosphorus throughout the sampling periods. Figures 17-18 show the correlation between mean control chlorophyll and ambient nutrient concentrations.

Land Use

Land use correlations are shown in Tables 6-7 and 9-10. LETSIs were not correlated with land use. However, significant trends were observed with ambient nutrient concentrations and percent land use. Mean NO_3-N was positively correlated with percent urban land use when the point source impacted streams (Columbia Hollow and Lower Spavinaw Creek) were included in the correlation. However, when the point source affected streams were excluded, the mean NO_3-N was not significantly correlated with percent urban land use. Instead, mean NO_3-N showed a significant positive correlation with percent agriculture and a negative correlation with forested landuse.

When the point sources were included, mean NH_4-N concentrations were positively correlated with percent urban land use during the winter sampling dates. When the point source impacted streams were excluded, the mean NH_4-N concentrations were not significantly correlated with percent urban, agriculture, or forested landuse.

SRP was positively correlated with urban land use for each sampling date when the point source impacted streams were included. However, when the point source impacted streams were excluded, SRP was positively correlated with percent urban land use during all of the sampling dates expect February-March. SRP showed significant positive correlation with percent agriculture and negative correlation with percent forested land use.

Flow Data

The flow measurements are available in Appendix H. Daily flow measurements for Beaty and Lower Spavinaw Creeks were obtained from the USGS gaging stations. The Beaty Creek gaging station was at the same location as the Matlock Periphytometers. However, the Lower Spavinaw Creek gaging station was located upstream of the Matlock Periphytometer sampling location. Figures 19 and 20 are the hydrographs from the data collected by USGS.

CHAPTER 5

DISCUSSION

Stream Nutrient Variations

The greatest NO_3-N concentrations in the water column were observed in conjunction with the greatest SRP concentrations in each stream. Columbia Hollow, which is impacted by a wastewater treatment plant discharge, had higher concentrations of dissolved inorganic nitrogen and phosphorus than the other six streams. The wastewater treatment plant probably dominates Columbia Hollow ambient nutrient concentrations (Haggard, 2000). Both nitrogen and phosphorus would be simultaneously high or low because of the impact of the point source. In contrast, streams that are predominantly affected by nonpoint source impacts may have increased nutrient loading during high flow events (EPA,2000). In addition to hydrologic characteristics, the terrestrial vegetation can also influence stream nutrient concentrations (Tate, 1990; Meyer et al., 1988). When there is vegetation growth, the stream nutrient concentrations are lower compared to dormant vegetation conditions (Tate, 1990). Determining the factor that primarily influences the nutrient concentrations in this study was difficult due to limited sampling dates and storm flows during some of the sampling dates.

NO_3-N concentrations were not significantly different in Cloud Creek, Columbia Hollow and Cherokee Creek among seasons. Dry Creek had higher NO_3-N during the winter, while Beaty Creek had higher concentrations during the summer. Dry Creek is predominantly forested and Beaty Creek is predominantly agricultural. Terrestrial vegetation and landuse practices can influence stream nutrient concentrations (Tate, 1990; Meyer et al., 1988). Dry Creek had the highest NO_3-N when the terrestrial vegetation growth was dormant. Beaty Creek, on the other hand, had higher NO_3-N and SRP concentrations during the summer, which could be due to increased surface runoff contributions (Figure 19). However, there are numerous other factors that may be influencing the seasonal changes in nutrient concentrations, including changes in fertilizer and animal waste applications, in-stream disturbances, and magnitude and frequency of storm events (Haggard et al., 2000; Meyer et al., 1988).

In comparison, three streams located in the Ouchita Mountains with more than 98% forested land use had median nitrate-nitrite concentrations of 0.1 mg/l, 0.1 mg/l, 0.05 mg/l (Mast and Turk, 1999). The maximum nitrate-nitrite concentrations for these streams were 0.12mg/l, 0.38mg/l, 0.48 mg/l (Mast and Turk, 1999). A tributary of Spring Creek, which is relatively unimpacted headwater stream located in northeast Oklahoma, had NO_3-N concentrations ranging from 0.31-0.35 mg/l (Haggard, 2000). The watershed in my study had over 50% agricultural land use in six of the seven sites and the nutrient concentrations were much greater than concentrations found in these unimpacted streams. The higher nutrients concentrations are probably associated with the increased agricultural land use.

NH_4-N concentrations were not significantly different between any of the seasons for Dry Creek, Cloud Creek, and Cherokee Creek. Columbia Hollow had significantly higher NH_4-N than the other six streams for the February- March sampling, which coincides with slightly higher NO_3-N concentrations. Columbia Hollow is impacted by a wastewater treatment plant, which dominates the ambient nutrient concentrations (Haggard, 2000). Lower Spavinaw Creek and Beaty Creek had significantly higher NH_4-N concentrations during the August-September sampling period. Other factors that may influence the concentrations include fertilizer and animal waste applications, and surface runoff events (Haggard et al., 2000; Meyer et al., 1988).

SRP concentrations were not significantly different among seasons for Dry Creek and Cloud Creek. Columbia Hollow had higher SRP concentrations in February-March, while Cherokee and Beaty Creeks had higher SRP concentrations in July-August. Columbia Hollow had its highest SRP, NH_4-N, NO_3-N concentrations during the February-March sampling period, and had its lowest NH_4-N and SRP concentrations during the July-August sampling date. The fluctuations in nutrient concentrations for Columbia Hollow is likely dominated by the discharge from the point source (Haggard, 2000).

Similar to seasonal variations, the magnitude of water column nutrient concentrations are also related to the terrestrial ecosystem, in particular land use practices. Several investigators have shown significant increases in concentrations of nitrogen and phosphorus with increasing proportions of agriculture in the upland areas. Numerous other investigations have found that nutrient concentrations were correlated with percent agriculture, forest and urban land use (Tufford et al.,1998; Jordan et al., 1997; Chessman et al., 1992; Smith et al. 1987; Beaulac and Reckhow,1982; Omernik, 1977). I observed similar results in my study. NO_3-N, NH_4-N, and SRP were all positively correlated with urban land use when the point source-impacted streams were included in the correlation. NO_3-N and SRP concentrations were positively correlated with agriculture and negatively correlated with forested land use, when the point source impacted streams were not included in the correlation (Tables 9-10). Variability in nutrient concentrations have also been shown to have different patterns depending on the land use and topography (Meyer et al., 1988).

High flow events may have increased the variability in the stream nutrient data (Figures 19-20). We collected our samples during baseflow conditions; however, thunderstorms occurred during the two-week period for the July-August, November-December, and February-March samplings. Nutrient concentrations have high variability with discharge depending on the magnitude of the storm, season, year, and time since last rainfall (Tate, 1990; Meyer et al., 1988). However, nutrient concentrations were not correlated with flow in this study. The lack of flow data during the increased surface runoff could have affected these results. Further research needs to be conducted in this watershed to understand how nutrient concentrations change with high flow events, which will help characterize how and when the nutrients are transported to Lake Eucha. In addition, understanding the factors influencing nutrient concentrations will help determine appropriate upland management practices needed to reduce the nutrients entering the streams.

Limiting Nutrients

Based on the Matlock Periphytometer data, neither nitrogen, nor phosphorus, nor the combination limited algal growth in all the streams expect in Dry Creek, Cherokee Creek, and Beaty Creek. Dry Creek was co-limited during the February-March. Cherokee and Beaty Creeks were either phosphorus or co-limited during the summer sampling periods. Columbia Hollow was expected to be either nitrogen limited, because its N:P ratio was less than 11, or not limited by nitrogen or phosphorus because of the high ambient nutrient concentrations. I observed that algal growth was not limited by either nitrogen and/or phosphorus. The algae may be saturated with stream nutrients since the algal growth was not limited by either nitrogen or phosphorus. An unforeseen problem in the highly enriched stream of Columbia Hollow was the algae not only grew on the artificial substrate, but also grew on the aluminum screens, shading the filters. This observation was unexpected since previous studies have found that aluminum screen was resistant to algae growth (Marty Matlock, personal communication). Therefore, caution is advised when interpreting Columbia Hollow data.

I expected the other six streams to be limited by phosphorus because the N:P ratios were typically greater than 70. Cherokee Creek was either phosphorus limited or co-limited by both nitrogen and phosphorus during summer, and Beaty Creek was phosphorus limited during summer. Interestingly, the SRP and NO_3-N concentrations in both streams were greater during the summer than winter/fall and were greater than 0.03 mg/l. Similarly, in Cherokee Creek the NO_3-N concentrations were similar throughout the sampling periods and SRP was higher during the summer. Thus, in both Beaty Creek and Cherokee Creek SRP concentrations were highest during the summer when the stream was phosphorus limited. The decrease in SRP during the fall and winter should indicate that the periphyton would continue to be limited by phosphorus; however, some other factor is controlling the algal growth. The decrease in temperature may inhibit a significant algal response during the winter and fall. Several other variables such as changes in light, changes in algal community structure, or high flow causing variability are possible explanations to the different limiting nutrients or the lack of observing similar nutrient limitations observed in Cherokee and Beaty Creeks.

In the Upper Illinois River Basin, an adjacent basin south of Lake Eucha, the primary limiting nutrient was phosphorus or nitrogen during the spring, and during the fall the streams were either co-limited or nitrogen limited (Matlock et al., 1999a). The N:P ratios also indicate phosphorus limitations in streams south of my watershed (Toetz et al., 1999).

Several reasons may explain why no nutrient limitation was observed in these systems, including light, temperature, or micro-nutrients (Hill, 1996; Hill et al., 1995; Hepinstall and Fuller, 1994; Lamberti and Resh, 1983; Hutchinson, 1967). Grazers do not significantly impact the algae on the Matlock Periphytometers because the aluminum screen protects the artificial growth substrate from most grazers, but the aluminum screen also decreases the amount of light reaching the filters. However, the reduction of light from the aluminum screens should be relatively similar for all samples. The periphytometers were placed in areas that not only received similar amounts of light, but also were well lit to reduce variability among sites and minimize light limitation.

Debris, such as leaves, floating on the Matlock Periphytometers may have also limited light and thus algal growth on some of the bottles. The bottles that were covered during harvesting are identified in Appendix H. We did not know how long the bottles were covered, or if other bottles had been covered and washed off during the two week sampling period. Covered samples that were more than two standard deviations from the mean, were considered to be outliers and were not used in identifying the limiting nutrients. The possibility of light limiting the stream periphyton on natural substrate was not examined in this study.

In addition to nitrogen and phosphorus, algae also needs silica, sulfur, iron, magnesium, sodium, calcium, potassium and several other micro-nutrients (Hutchinson, 1967). Micro-nutrients were not found to limit the algae growth in the Upper Illinois River Basin (Matlock et al., 1999a), however they were not tested in this study.

Perhaps most importantly, algae in these streams may be saturated with nutrients in the water column. Nitrate-nitrogen typically limits algal growth at concentrations less than 0.05 to 0.06 mg/l (Mosisch et al., 1999; Newbold, 1992; Grimm and Fisher, 1986), and streams in the Ozarks Plateau have expressed nitrogen limitation when concentrations were less than 0.1mg/L of NO_3-N (Lohman et al., 1991). The NO_3-N concentrations for my study streams were well above 0.1 mg/l and ranged from 0.49 to 8.69 mg/l, indicating that algal growth may be saturated with dissolved inorganic nitrogen. Additionally, the control chlorophyll a results did not increase with increased ambient nutrient concentrations, again indicating these streams may be saturated with nutrients (Figures 7-8).

SRP concentrations that limit algal growth range from 3 μg/l to 50 μg/l (Bothwell, 1985,1989; Pringle, 1986), but typically limit algal growth at concentrations less than 15 ug/l (Newbold,1992). In a watershed south of the Lake Eucha Basin, Toetz et al.(1999) observed that SRP concentrations below 10 ug/l could limit algal growth. The SRP concentrations for my study ranged from 0.002 mg/l to 9.2 mg/l, but were greater than 15 mg/l in all streams but Dry Creek. Thus, Dry Creek could be phosphorus limited but this was not supported by the Matlock Periphytometers results. All other streams are probably saturated with respect to SRP.

Since most of our streams would be considered saturated with nutrients, these streams may be limited by something other than nitrogen and phosphorus. The nutrient concentrations in the Upper Illinois River Basin were above the limiting levels and the Matlock Periphytometers were still able to observe nutrient limitations (Matlock et al., 1999a). Thus, changes in chlorophyll a from scouring or changes in flow (Figure 19-20) may have increased variability and reduced the possibility of detecting significant differences. High flow events occurred during the July-August, November-December, and February-March sampling periods.

A change in algal community structure likely occurred over the seasons, which could affect the limiting nutrients (Vis et al., 1998; Allan, 1995). Green algae usually dominate in spring and early summer, followed by blue-green algae in late summer (Sze, 1998; Horne and Goldman, 1994; Palmer, 1977). Diatoms typically dominate during the winter months.

LETSI

LETSIs for all streams ranged from 0.54 to greater than 1.0, with a mean of 0.97 and a median of 0.86. This suggests that all of the streams in this study are functioning at greater than half of their nutrient assimilative capacity on my sampling dates, with most at greater than three-quarters. All the streams except Dry Creek were approaching their nutrient assimilative capacity. LETSI did not increase with increased ambient nutrient concentrations, indicating that additional nitrogen and phosphorus enrichment to these streams probably will not result in an increase in periphyton growth (Figure 10-12).

The streams in my study are closer to 1.0 and are greater than the streams studied in the Upper Illinois River Basin, indicating that these systems are closer to reaching their nutrient assimilative capacity than those in the Upper Illinois River Basin. LETSIs for streams in the Upper Illinois River Basin ranged from 0.30 to 0.64 (Matlock et al., 1999a).

N-LETSI and the P-LETSI are ratios of chlorophyll *a* from the nitrogen treatment and phosphorus treatment, respectively, to the maximum potential productivity (nitrogen + phosphorus treatment). N-LETSI and P-LETSI give an indication of the streams response to nitrogen and phosphorus individually in comparison to the maximum potential productivity. If a stream is only nitrogen limited, then the N-LETSI should be equal to 1.0 because the addition of nitrogen will cause the same response as the addition of both nitrogen and phosphorus.

LESTI did not show a significant correlation with land use. LETSI was expected to increase with increased nutrient enrichment. Therefore, LETSI is expected to increase with agriculture or urban land use and decrease with forested land use, but we did not observe a significant relationship between these parameters.

Since algal growth is limited by something other that nitrogen and phosphorus and the streams are near their maximum nutrient assimilative capacity, I would classify these streams as eutrophic. My research suggests that further increases in nitrogen or phosphorus would probably not result in an increase in periphyton growth. The suggested benthic chlorophyll *a* concentration is greater than 40 mg/m^2 for eutrophic streams and less than 20 mg/m^2 for oligotrophic streams (Dodds et al., 1998). The chlorophyll *a* content for the Matlock Periphytometer control treatment ranged from 1.0 mg/m^2 to 96 mg/m^2. Therefore, most of the streams are oligo-mesotrophic, with some being eutrophic. However, as previously stated, the periphyton variability on the artificial growth substrates may have been affected by many different factors and may not represent the periphyton growth in the natural substrate. Aluminum screen and debris floating on top of the Matlock Periphytometer caused shading on the filters and may have reduced the chlorophyll *a* concentrations, and thus the chlorophyll *a* concentrations on the Matlock Periphytometers may not be directly related to the natural substrate chlorophyll *a* concentrations. Therefore, comparing chlorophyll *a* thresholds for natural substrate to Matlock Periphytometer chlorophyll *a* levels should be interpreted cautiously.

CHAPTER 6

SUMMARY AND CONCLUSIONS

Ambient Nutrients

Columbia Hollow had significantly higher nutrient concentrations than the other streams. Columbia Hollow is affected by a wastewater treatment plant, which appears to dominate the amount of nutrients in the stream (Haggard, 2000). The other streams have varying degrees of nonpoint source pollution. High flow events during the sampling periods may have increased ambient nutrient variability (Tate,1990; Meyer et al., 1988). The ambient nutrient concentrations for the nonpoint source dominated streams were positively correlated with percent agriculture and negatively correlated with percent forested land use. Other investigators have also found these correlations with land use (Tufford et al., 1998; Jordan et al., 1997; Chessman et al., 1992; Smith et al., 1987; Beaulac and Reckhow, 1982; Omernik, 1977). Total nitrogen and total phosphorus were not examined in this study, only bioavailable forms of nitrogen and phosphorus were examined.

Limiting Nutrients

The streams in my study were generally limited by something other than nitrogen or phosphorus. An increase in nutrient loading would probably not result in an increase in algal production. The algae are less likely to assimilate increased nutrient levels, since the streams appear to be saturated with nitrogen and phosphorus. Therefore, stream algal uptake will probably not provide additional phosphorus buffering for Lake Eucha. Other factor(s) that may be limiting algal growth are light, temperature, or micro-nutrients.

The increased streamflow from the storm events that occurred during the sampling periods may have caused increased stream nutrient variability (Tate,1990; Meyer et al., 1988), which may have affected the limiting nutrients. Furthermore, the high flow events increased the variability of the chlorophyll *a* data and may have caused scouring of the periphyton growth surface, which reduces algal biomass (Lohman, 1992; Jones et al., 1984). Therefore, additional deployment of the Matlock Periphytometers under base flow conditions should be conducted to confirm the results of this study.

LETSI

The average LETSI for these streams was 0.97, which indicates that the streams are reaching their nutrient assimilative capacity. As a stream becomes increasingly enriched by nutrients, the LETSI will approach 1.0. If more nutrients are added to the stream at this point, there probably will not be an increase in algal growth. In order to decrease the LETSI, the amount of nutrients flowing into the streams needs to decrease. By decreasing the LETSI, the algae will assimilate additional nutrients and, therefore, temporally buffer nutrient loading to Lake Eucha.

Overall, the streams in my study are saturated with nutrients and additional nutrient loading will probably not result in an increase in algal growth. Therefore, recommended management strategies for selection and implementation of upland best management practices should be based upon recommended management strategies for Lake Eucha.

Recommendations for Future Research

Further research should be conducted in order to examine what other factors limit the algal growth in these streams. These streams are saturated with nutrients and, therefore, are not limited by nutrients. Understanding the limiting factor may help determine its effects on periphyton growth. Once the limiting factor and its effects are understood, then possible steps can be taken to avoid excess algal growth in the streams.

Light is one factor that may limit the algal growth in these streams. Therefore, incoming solar radiation needs to be evaluated to determine if relationships exist between chlorophyll *a* and/or LETSI. Also, the collection of debris on the Matlock Periphytometers caused shading of the growth surface. In addition, in highly enriched streams such as Columbia Hollow, algae grew on the aluminum screens causing additional shading. A different Matlock Periphytometer design that prevents this collection of debris and excludes grazers without individual aluminum screens over the bottles should be examined.

In phosphorus and co-limited streams, studying the response of algal communities to different levels of nutrients should be examined to further explain the nutrient dynamics in the streams. For example, the nutrient concentrations that periphyton growth becomes co-limited by both nitrogen and phosphorus can be determined. If the algae are co-limited, then the addition of nitrogen or phosphorus will not result in an increase in growth because the other nutrient will become limiting. Additionally, studying the effects of different nutrient concentrations will allow nutrient thresholds to be determined. Nutrient thresholds will allow target concentration of nutrients to avoid excess algal growth. Currently, only nutrient enrichment can be examined; the effects of decreased nutrient loading on primary production are not known. A study that evaluates decreasing nutrient loading would be beneficial in evaluating the algal-nutrient relationship.

The algal composition in these streams should also be researched. Once the algal communities are known, then their nutrient requirements can be analyzed to determine if this caused a shift in limiting nutrients. Identifying the algal species would also help examine the response of algal communities to nutrient enrichment, which may provide an alternative method to determine nutrient-algal relationships.

Table 1. Vollenweider (1982) suggested ranges for trophic status for lakes.

Variable	Oligotrophic	Mesotrophic	Eutrophic
Total Phosphorus (mg/m^3)	3.0-17.7	10.9 - 95.6	16.2 - 386
Total Nitrogen (mg/m^3)	307 – 630	361 - 1387	393 - 6100
Chlorophyll a (mg/m^3)	0.3 - 4.5	3.0 - 11	2.7 - 78
Chlorophyll a Peak value (mg/m^3)	1.3 - 10.6	4.9 - 49.5	9.5 - 275
Secchi Depth (m)	5.4 - 28.3	1.5 - 8.1	0.8 - 7.0

Table 2. Suggested boundaries for oligotrophic and eutrophic conditions for streams (Dodds, 1998).

Variables	Oligotrophic/ Mesotrophic	Eutrophic/ Mesotrophic
Benthic chlorophyll a (mg/m^2)	20	40
Total Phosphorus (ug/l)	26	75
Total Nitrogen (ug/l)	700	1500

Table 3. Sub-basin landuse and distance downstream from the Decatur, Arkansas Municipal Waste Water Treatment Plant

	Land Use			
Site	Pasture (%)	Forest (%)	Urban (%)	WWTP# (km)
Lake Eucha	49	48	<1	28
Dry Creek	24	76	<1	*
Cloud Creek	63	36	1	*
Cherokee Creek	66	32	2	*
Columbia Hollow	73	23	4	2.5
Upper Spavinaw	60	40	<1	*
Beaty Creek	66	13	1	*
Lower Spavinaw	56	43	1	28

WWTP= waste water treatment plants

* Not affected by the Decature WWTP

Table 4. N:P ratios for each sampling site and sampling date for July 22 to August 6, 1999, August 22 to September 9, 1999, November 30 to December 12, 1999, and February 22 to March 6, 2000.

Stream Name	July-August	August-September	November – December	February-March
Dry Creek	111	103	192	337
Cloud Creek	107	141	91	129
Cherokee Creek	148	174	174	252
Columbia Hollow	11	6	88	3
Beaty Creek	106	130	120	154
Lower Spavinaw Creek	281	265	347	408
Upper Spavinaw Creek	148	191	175	162

Table 5 LETSI, N-LETSI, and P-LETSI for July 22 to August 6, 1999, August 22 to September 9, 1999, November 30 to December 12, 1999, and February 22 to March 6, 2000. DC= Dry Creek, CLC = Cloud Creek, CC= Cherokee Creek, CH = Columbia Hollow, BC= Beaty Creek, US= Upper Spavinaw Creek, LS= Lower Spavinaw Creek. Same letter across streams represent no significant differences α=0.05. Same numbers within each stream represent no significant seasonal effects α=0.05.

Sampling Date	Index	DC	CLC	CC	CH	BC	US	LS
July/Aug	LETSI	$0.80_{abc,1}$	$0.70_{abc,1}$	$0.60_{a,1}$	$0.89_{bc,1}$	$0.67_{ab,1}$		$0.98_{c,1}$
	N-LETSI	$1.04_{a,1}$	$1.02_{a,1}$	$0.77_{a,1}$	$0.92_{a,1}$	$0.77_{a,2}$		$0.88_{a,2}$
	P-LETSI	$0.81_{a,12}$	$0.80_{a,1}$	$0.82_{a,2}$	$0.86_{a,1}$	$1.12_{a,1}$		$0.83_{a,2}$
Aug/Sept	LETSI	$0.56_{de,1}$	$1.33_{a,1}$	$0.54_{e,1}$	$0.84_{cd,1}$	$0.89_{c,1}$	$1.20_{ab,1}$	$0.95_{bc,1}$
	N-LETSI	$0.60_{b,1}$	$1.06_{ab,1}$	$0.73_{ab,1}$	$1.08_{a,1}$	$0.90_{ab,2}$	$0.92_{ab,1}$	$1.05_{ab,12}$
	P-LETSI	$0.60_{b,2}$	$1.11_{a,1}$	$0.89_{ab,2}$	$0.74_{ab,1}$	$1.06_{a,1}$	$0.94_{ab,1}$	$0.99_{a,12}$
Nov/Dec	LETSI	$0.74_{a,1}$	$0.79_{a,1}$	$1.12_{a,1}$		$2.66_{a,1}$	$0.77_{a,12}$	$0.85_{a,1}$
	N-LETSI	$0.98_{b,1}$	$3.98_{a,1}$	$0.91_{b,1}$		$1.96_{ab,1}$	$1.20_{b,1}$	$0.10_{b,12}$
	P-LETSI	$1.10_{a,1}$	$1.66_{a,1}$	$2.78_{a,1}$		$3.10_{a,1}$	$1.12_{a,1}$	$0.94_{a,12}$
Feb/March	LETSI	$0.84_{a,1}$	$1.12_{a,1}$	$1.25_{a,1}$	$1.00_{a,1}$	$1.09_{a,1}$	$0.87_{a,2}$	$1.04_{a,1}$
	N-LETSI	$0.90_{a,1}$	$1.65_{a,1}$	$2.67_{a,1}$	$1.09_{a,1}$	$1.42_{a,12}$	$1.00_{a,1}$	$1.44_{a,1}$
	P-LETSI	$0.66_{a,12}$	$1.66_{a,1}$	$1.78_{a,12}$	$0.99_{a,1}$	$1.31_{a,1}$	$1.05_{a,1}$	$1.45_{a,1}$

Table 6. LETSI correlations with percent land use and ambient nutrients including point sources (Columbia Hollow and Lower Spavinaw Creek) at α=0.10 for July 22 to August 6, 1999, August 22 to September 9, 1999, November 30 to December 12, 1999, and February 22 to March 6, 2000

Parameter	July/Aug	Aug/Sept	Nov/Dec	Feb/March
Agriculture	-0.11	0.36	0.09	0.60
Forest	0.06	-0.27	-0.26	-0.59
Urban	0.44	-0.21	-0.36	0.39
NO_3-N	-0.11	0.03	-0.54	-0.02
NH_4-N	0.45	0.28	-0.54	-0.11
SRP	0.32	-0.09	-0.58	-0.09

* = significantly different at α=0.10

Table 7. LETSI correlations with percent land use and ambient nutrients excluding point sources (Columbia Hollow and Lower Spavinaw Creek) for July 22 to August 6, 1999, August 22 to September 9, 1999, November 30 to December 12, 1999, and February 22 to March 6, 2000

Parameter	July/Aug	Aug/Sept	Nov/Dec	Feb/March
Agriculture	-0.33	0.44	0.41	0.70
Forest	0.17	-0.32	-0.41	-0.66
Urban	0.33	-0.28	0.29	0.98
NO_3-N	-0.90*	0.24	0.14	0.60
NH_4-N	-0.92*	0.29	0.12	-0.11
SRP	-0.73	-0.08	0.83*	-0.06

* = significantly different at α=0.10

Table 8. Limiting Nutrient for Sampling Dates.
P = Phosphorus, C = Co –limited, both nitrogen and phosphorus, O = other, X = no data

Sites	July/Aug	Aug/Sept	Nov/Dec	Feb/March
Dry Creek	O	O	O	C
Cloud Creek	O	O	O	X
Cherokee Creek	P	C	O	O
Columbia Hollow	O	O	X	O
Upper Spavinaw	X	O	O	O
Beaty Creek	P	P	O	O
Lower Spavinaw	O	O	O	O

Table 9. Ambient nutrient correlation with percent land including point sources (Columbia Hollow and Lower Spavinaw Creek).

Parameter	Sampling Period	Agriculture	Forested	Urban
NO_3-N	July- Aug	0.69***	-0.71***	0.77***
	Aug-Sept	0.65***	-0.68***	0.83***
	Nov-Dec	0.23	-0.26	0.56***
	Feb-March	0.58***	-0.62***	0.82***
NH_4-N	July- Aug	0.199	-0.19	0.05
	Aug-Sept	0.30*	-0.29	0.07
	Nov-Dec	0.26	-0.29	0.66***
	Feb-March	0.36**	-0.40***	0.76***
SRP	July- Aug	0.40**	-0.44***	0.82***
	Aug-Sept	0.41***	-0.46***	0.87***
	Nov-Dec	0.32*	-0.36*	0.80*
	Feb-March	0.39**	-0.43***	0.83***

* = significantly different at $\alpha = 0.10$, ** = significantly different at $\alpha = 0.05$;
*** = significantly different $\alpha = 0.01$

Table 10. Ambient nutrient correlation with percent land use excluding point sources (Columbia Hollow and Lower Spavinaw Creek).

Parameter	Sampling Period	Agriculture	Forested	Urban
NO_3-N	July- Aug	0.72***	-0.71***	0.27
	Aug-Sept	0.76***	-0.75***	0.32*
	Nov-Dec	0.61***	-0.60***	0.11
	Feb-March	0.67***	-0.66***	0.14
NH_4-N	July- Aug	0.30	-0.31	0.39
	Aug-Sept	0.49	-0.49	0.32
	Nov-Dec	0.07	-0.07	0.07
	Feb-March	0.00	0.00	-0.08
SRP	July- Aug	0.77***	-0.77***	0.53***
	Aug-Sept	0.59***	-0.60***	0.54***
	Nov-Dec	0.62***	-0.62***	0.40**
	Feb-March	0.30	-0.11	0.19

* = significantly different at $\alpha = 0.10$, ** = significantly different at $\alpha = 0.05$;
*** = significantly different $\alpha = 0.01$

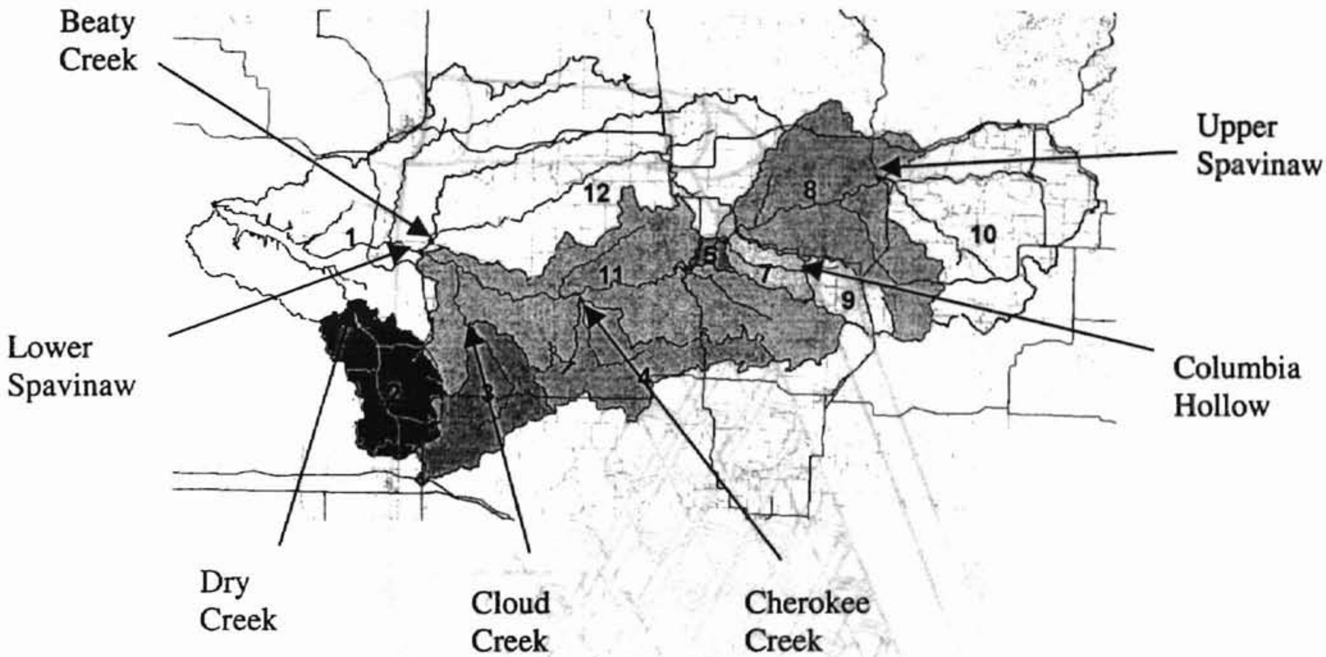

Figure 1. Map of Sub-basins with sampling locations in Lake Eucha Watershed.

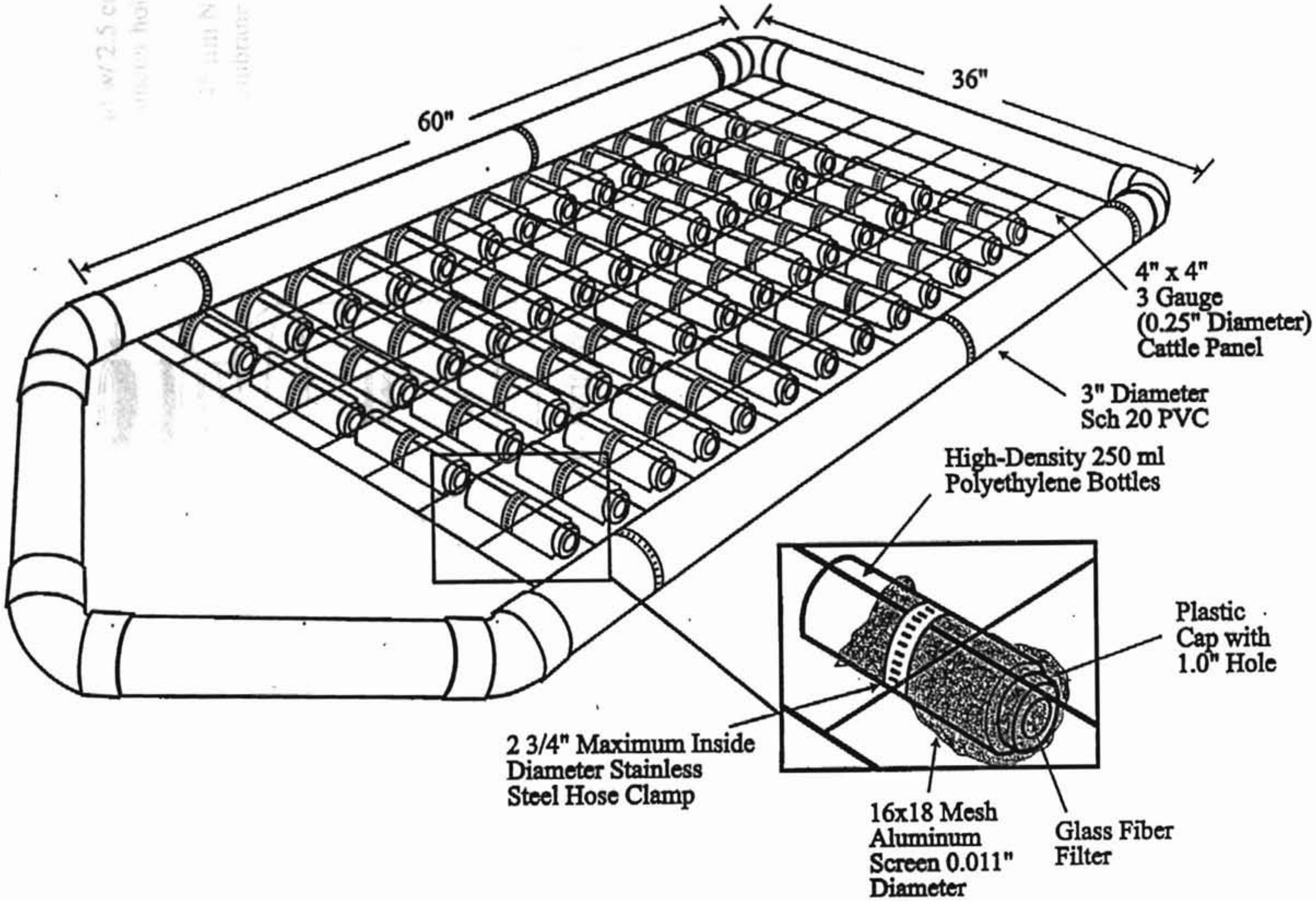

Figure 2: Schematic Matlock Periphytometer.

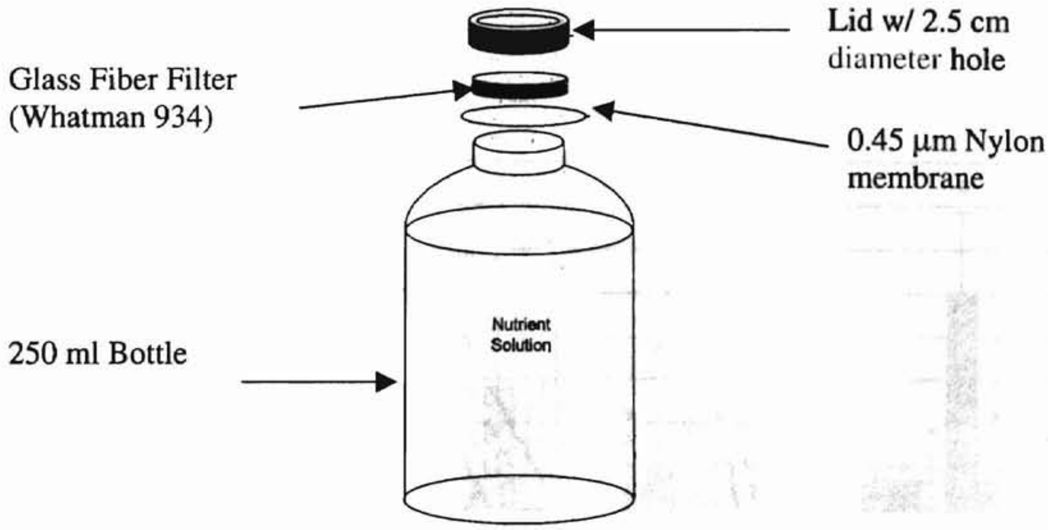

Figure 3. Structural Diagram of Matlock Periphytometer Bottles (Matlock et al., 1998)

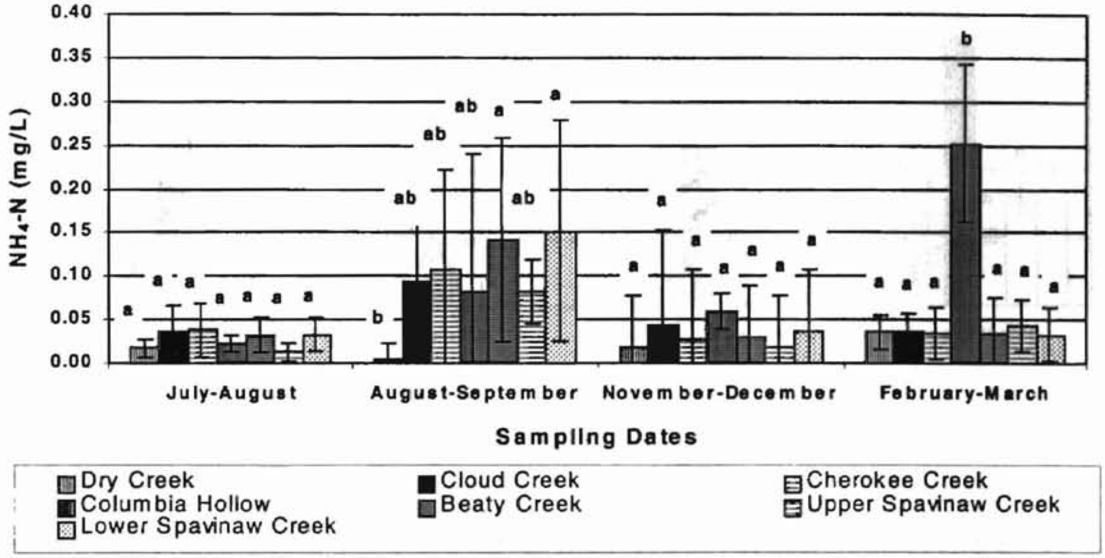

Figure 4. Mean and Standard Deviation (Error Bars) NH_4-N concentration comparison between streams. Similar letters within each sampling date represent sampling site means that are not significantly different at $\alpha = 0.05$.

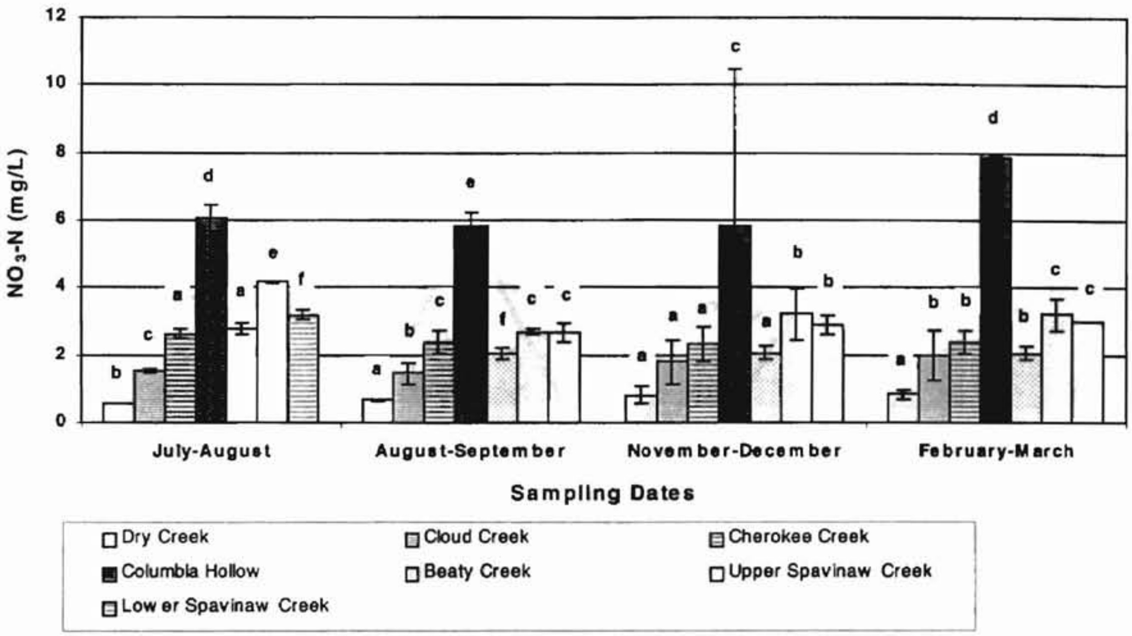

Figure 5. Mean and Standard Deviation (Error Bars) NO_3-N concentration comparison between streams. Similar letters within each sampling date represent sampling site means that are not significantly different at $\alpha= 0.05$.

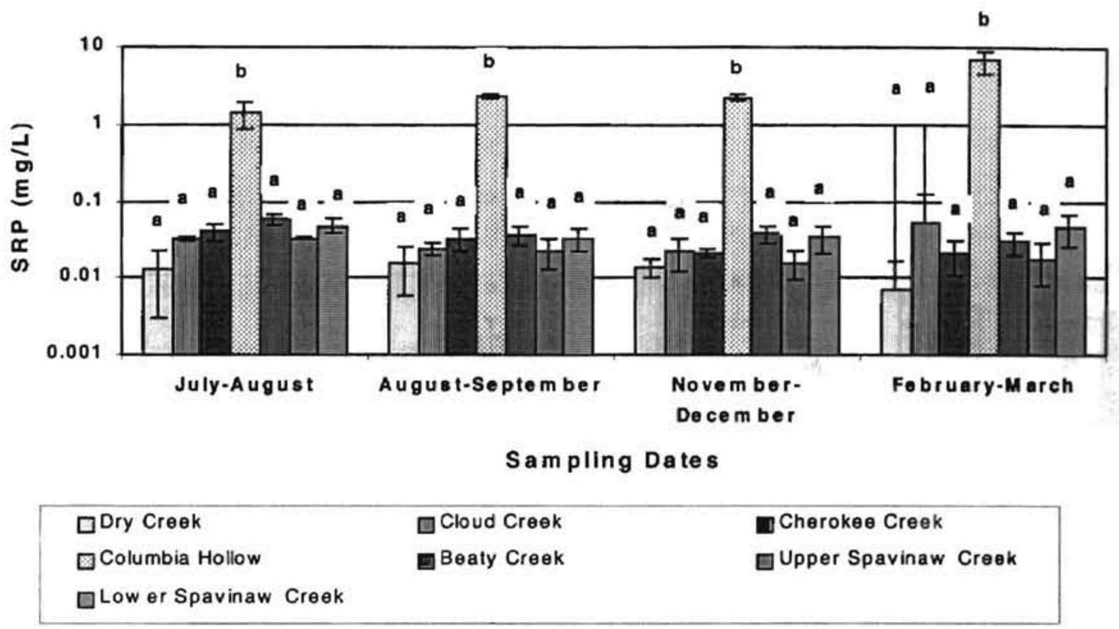

Figure 6. Mean and Standard Deviation (Error Bars) Soluble Reactive Phosphorus (SRP) concentration comparison between streams. Similar letters within each sampling date represent sampling site means that are not significantly different at $\alpha = 0.05$.

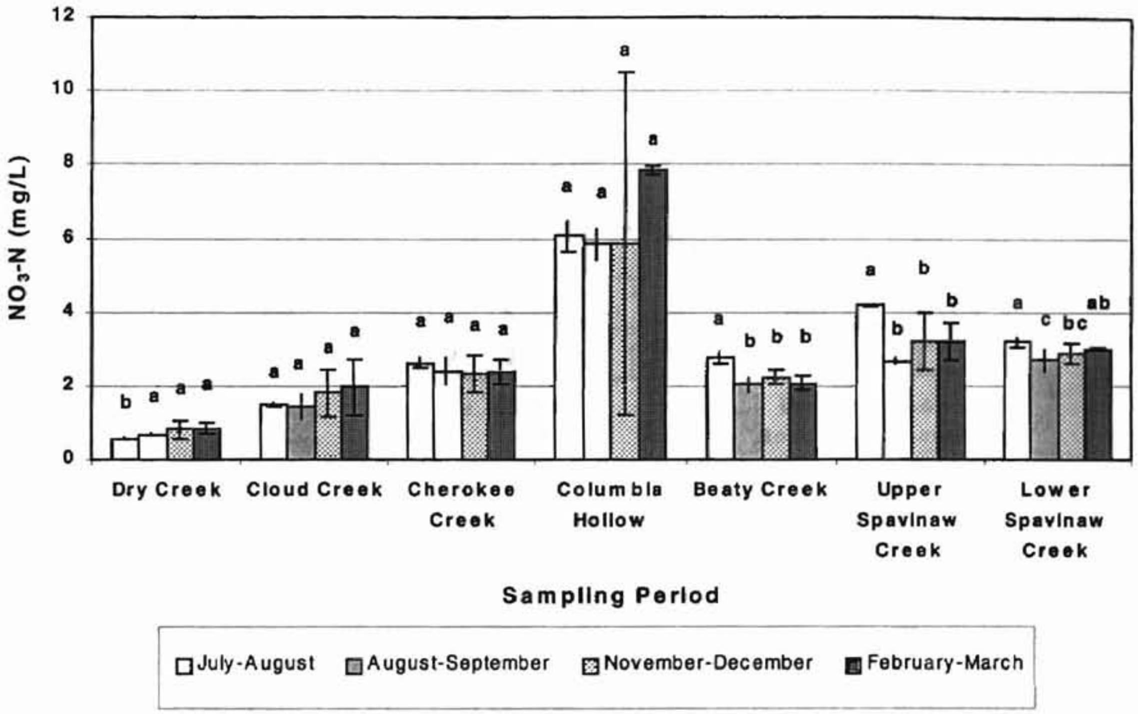

Figure 7. Seasonal Mean and Standard Deviation (Error Bars) NO_3-N concentration comparison. Similar letters within each sampling date represent sampling date means that are not significantly different at $\alpha = 0.05$.

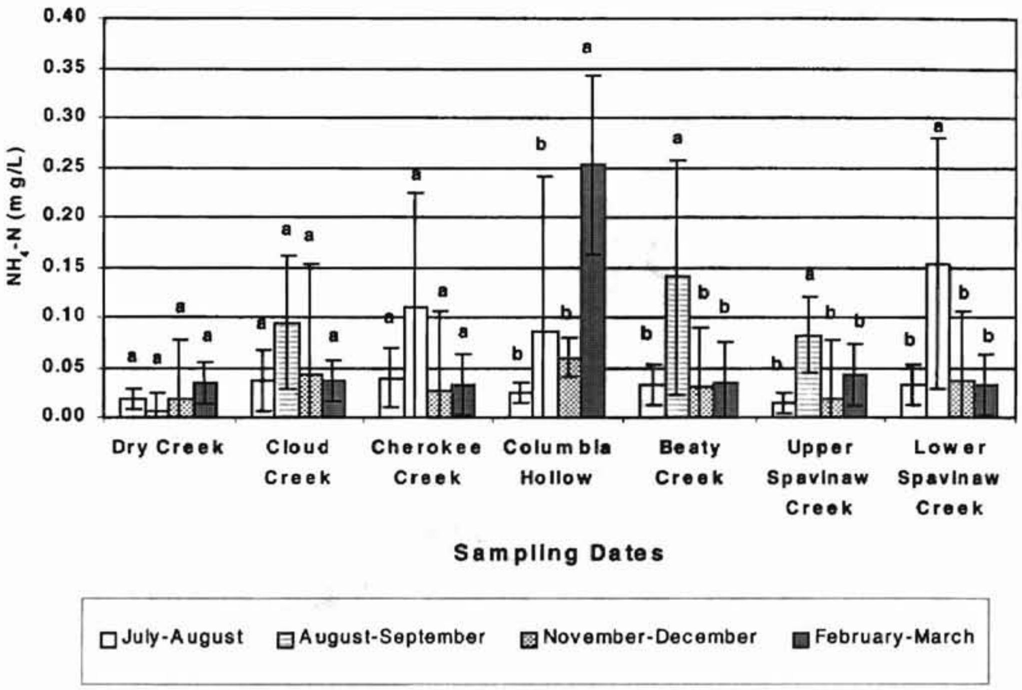

Figure 8. Seasonal Mean and Standard Deviation (Error Bars) NH_4-N concentration comparison. Similar letters within each sampling date represent sampling date means that are not significantly different at $\alpha = 0.05$.

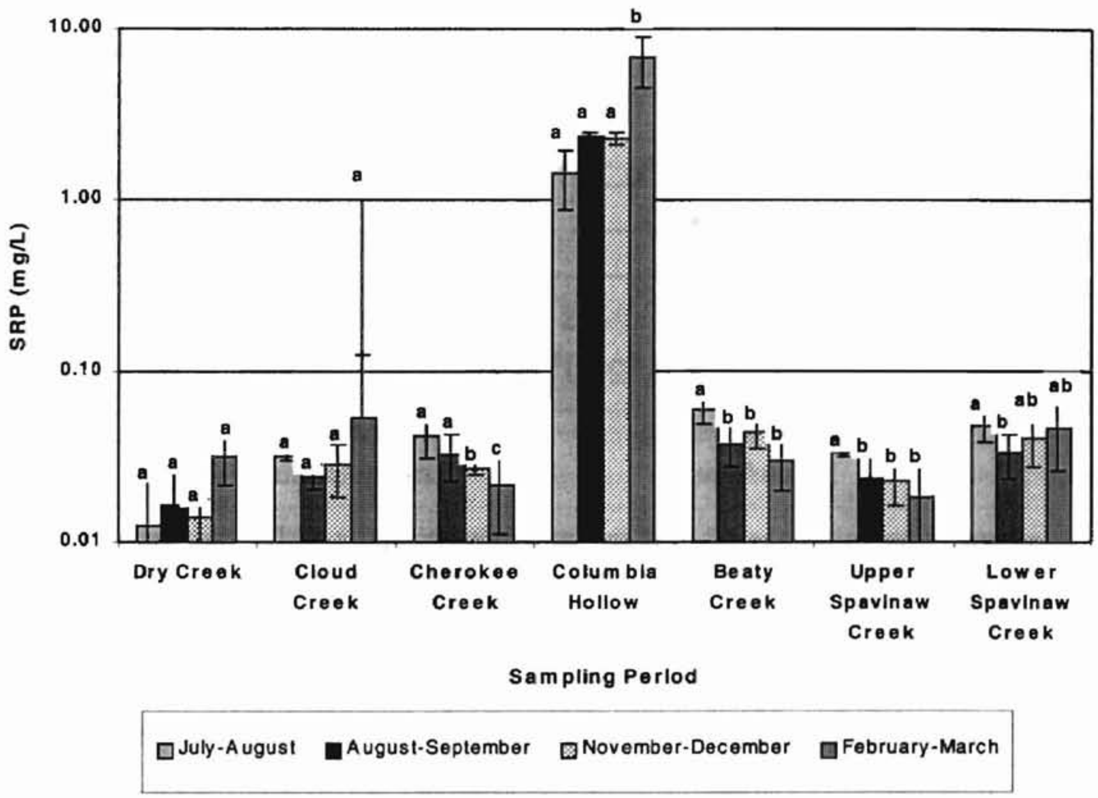

Figure 9. Seasonal Mean and Standard Deviation (Error Bars) Soluble Reactive Phosphorus (SRP) concentration comparison. Similar letters within each sampling date represent sampling date means that are not significantly different at $\alpha = 0.05$.

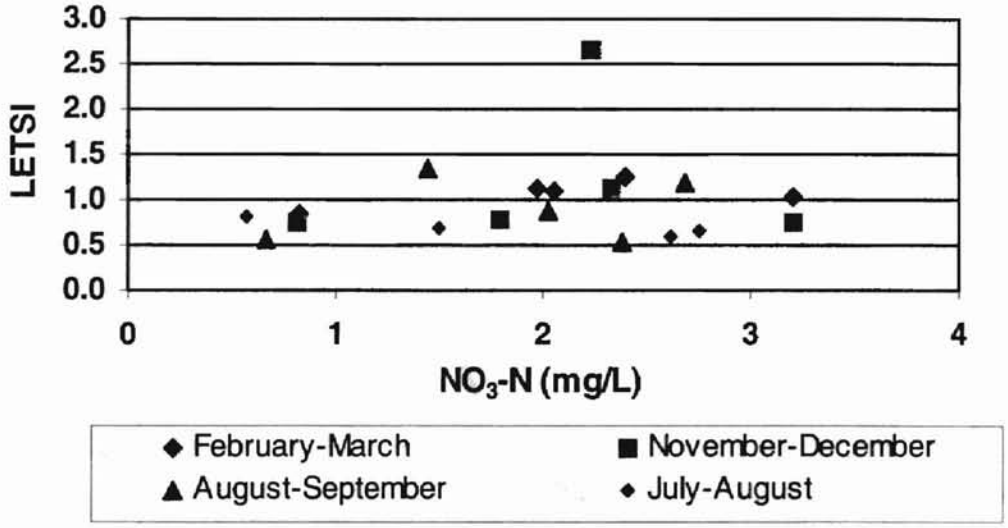

Figure 10. Average LETSI compared with average NO_3-N, excluding point source impacted streams (Columbia Hollow and Lower Spavinaw Creek).

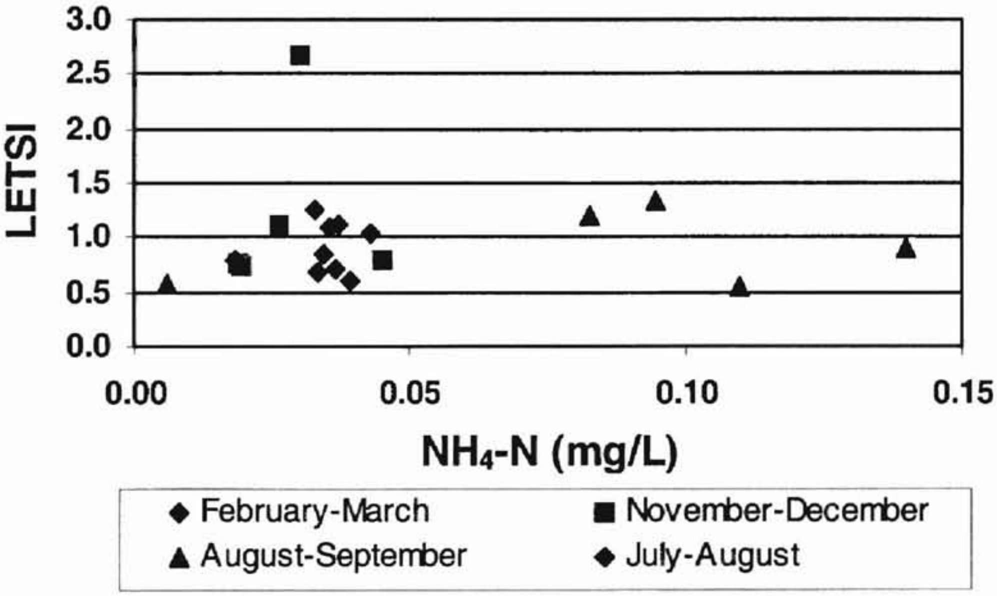

Figure 11. Average LETSI compared with average NH_4-N, excluding point source impacted streams (Columbia Hollow and Lower Spavinaw Creek).

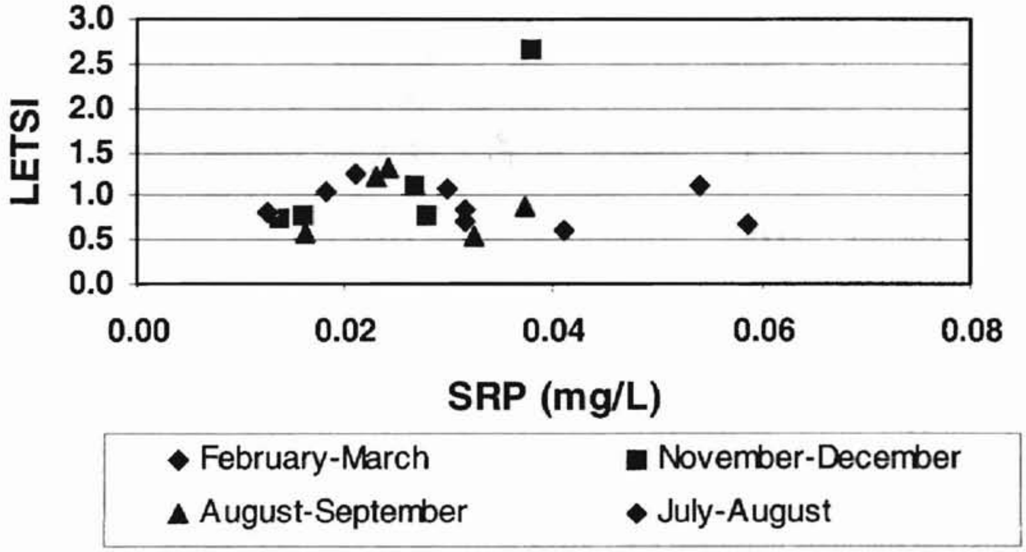

Figure 12. Average LETSI compared with average Soluble Reactive Phosphorus (SRP), excluding point source impacted streams (Columbia Hollow and Lower Spavinaw Creek).

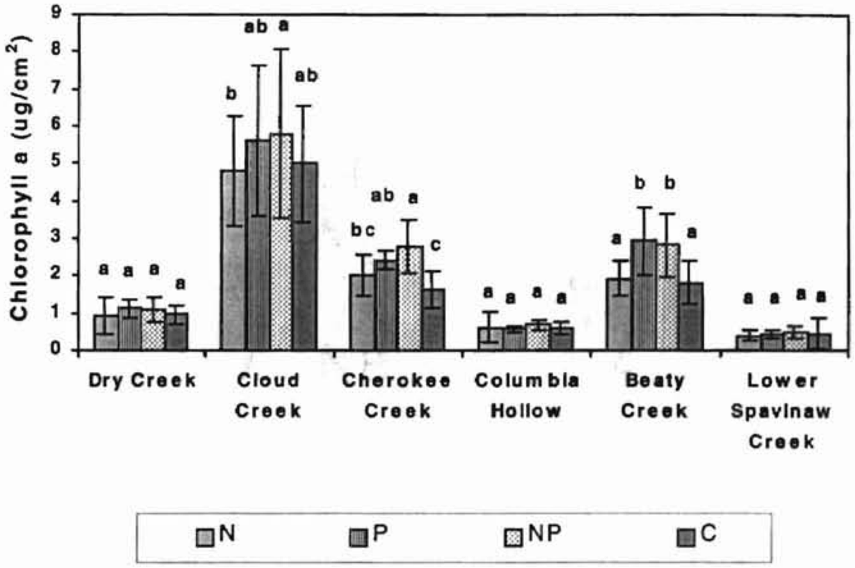

Figure 13. Treatment Comparisons by sampling site for July 22- August 5,1999. Same letters within each sampling site represent treatment means that are not significantly different at α= 0.10. Error bars represent standard deviation. Treatments: N= Nitrogen, P= Phosphorus, NP= Nitrogen + Phosphorus, C= Control .

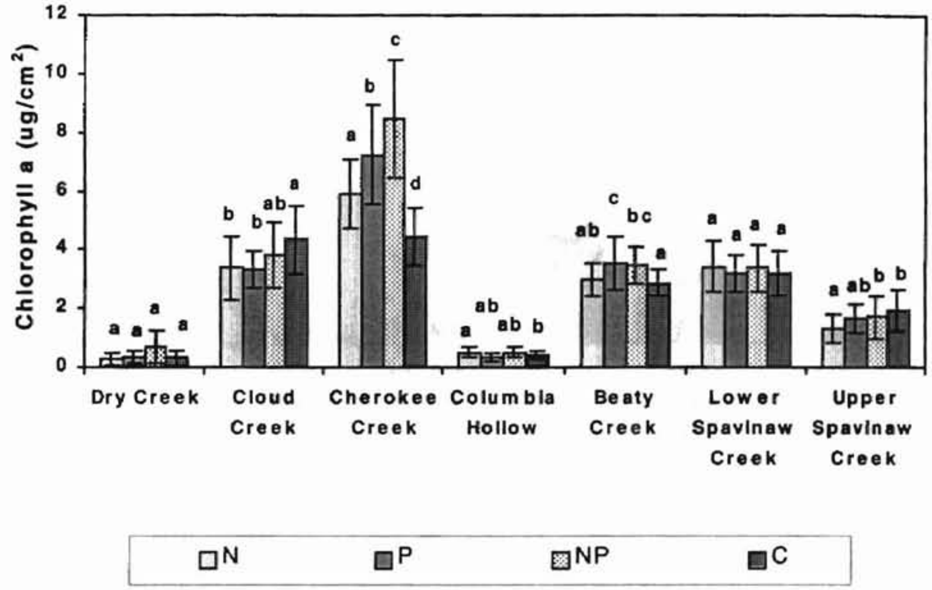

Figure 14. Treatment Comparisons by sampling site for August 26-September 9,1999. Same letters within each sampling site represent treatment means that are not significantly different at $\alpha = 0.10$. Error bars represent standard deviation. Treatments: N= Nitrogen, P= Phosphorus, NP= Nitrogen + Phosphorus, C= Control.

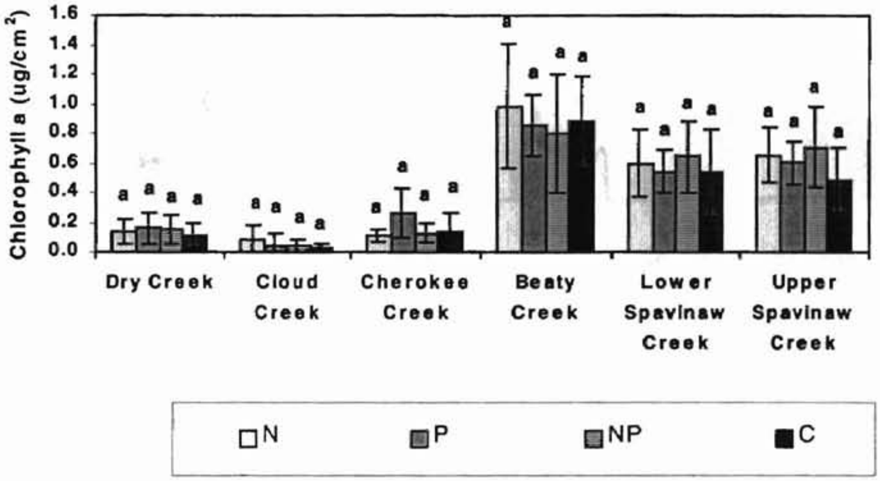

Figure 15. Treatment Comparisons by sampling site for November 30- December 12,1999. Same letters within each sampling site represent treatment means that are not significantly different at $\alpha = 0.10$. Error bars represent standard deviation. Treatments: N= Nitrogen, P= Phosphorus, NP= Nitrogen + Phosphorus, C= Control.

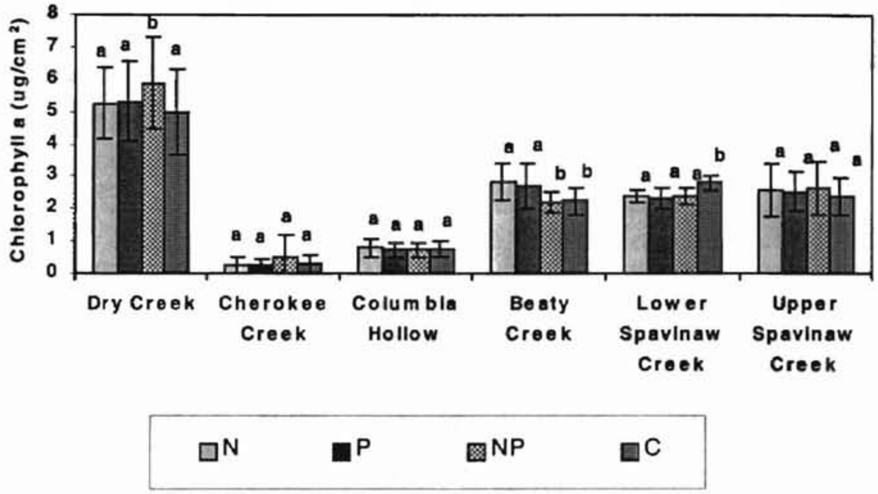

Figure 16. Treatment Comparisons by sampling site for February 23- March 9,2000. Same letters within each sampling site represent treatment means that are not significantly different at α= 0.10. Error bars represent standard deviation. Treatments: N= Nitrogen, P= Phosphorus, NP= Nitrogen + Phosphorus, C= Control.

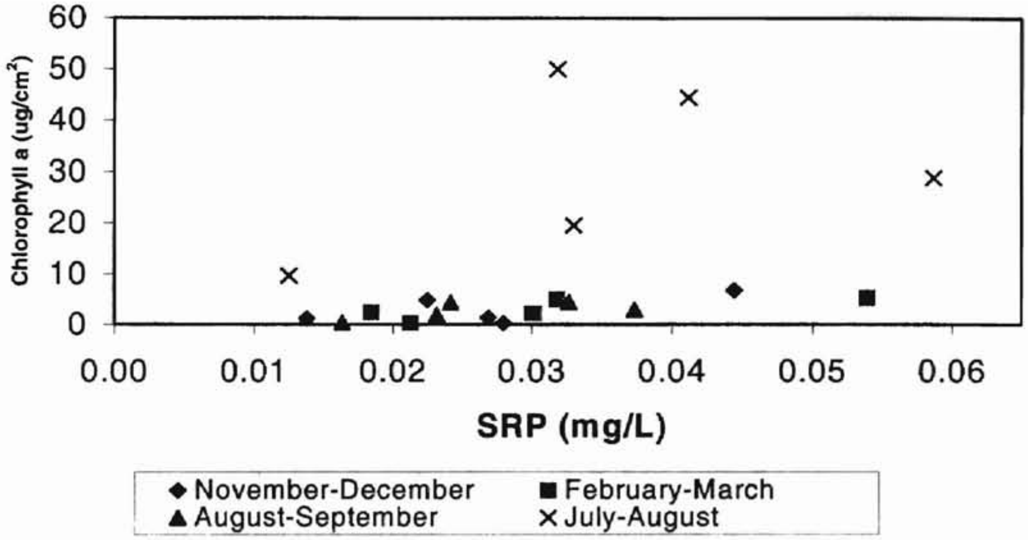

Figure 17. Mean control chlorophyll *a* compared with Soluble Reactive Phosphorus (SRP).

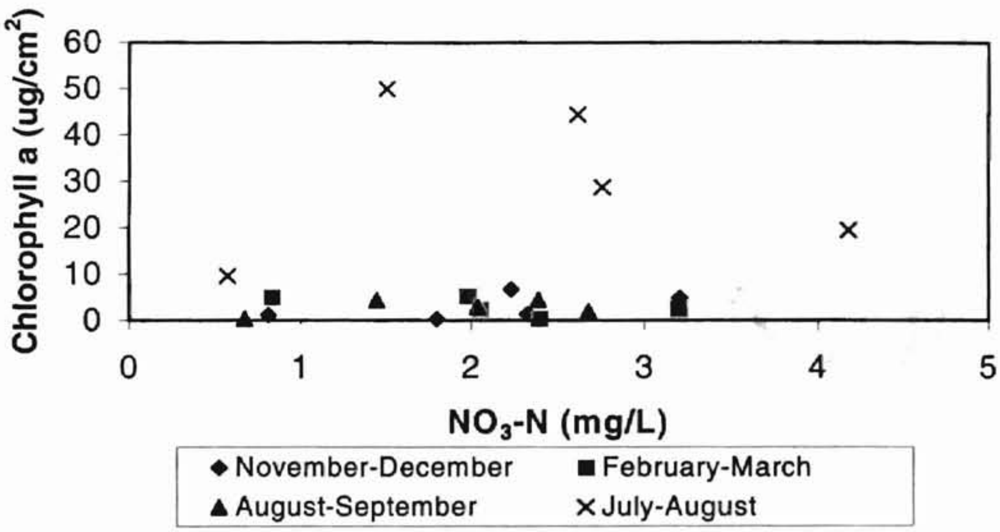

Figure 18. Mean control chlorophyll *a* compared with NO_3-N.

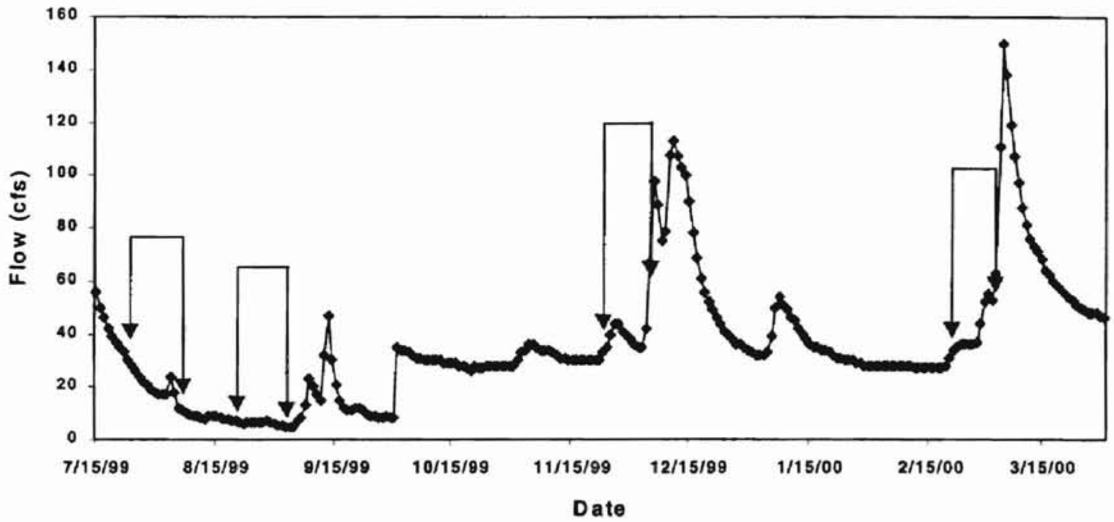

Figure 19. Daily Flow Rates for Lower Spavinaw Creek taken by USGS (station number 07191220) near Sycamore, OK for July 26- August 6, 1999,August 26 – September 9, 1999, November 30- December 12,1999, and February 23- March 9,2000. The arrows show when the Matlock Periphytometers were deployed and harvested. October 1, 1999 through March 15, 2000 are preliminary data from USGS.

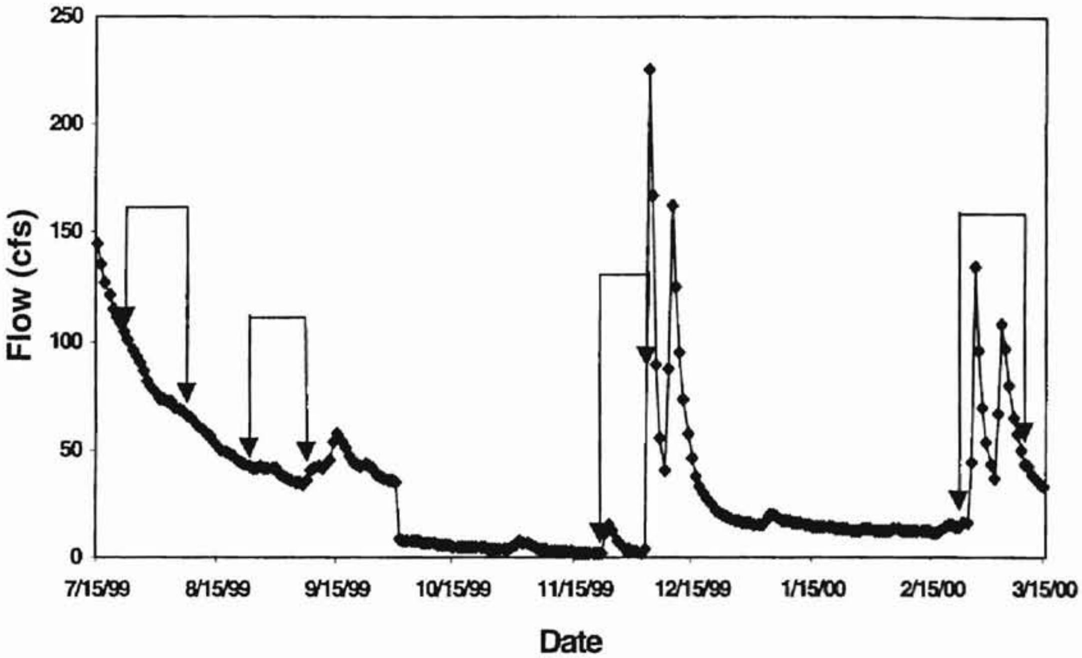

Figure 20. Daily Flow Rates for Beaty Creek taken by USGS (station number 07191222) near Jay, OK for July 26- August 6, 1999,August 26 –September 9, 1999, November 30- December 12,1999, and February 23- March 9,2000. The arrows show when the Matlock Periphytometers were deployed and harvested. October 1, 1999 through March 15, 2000 are preliminary data from USGS.

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APPENDIX A. STREAM NUTRIENT CONCENTRATIONS

Table A-1. Ambient Nutrient Concentrations and Standard Deviations Sampling for July 22 and August 6, 1999, with three replicates per date.

Stream Name	Mean NO_3-N (ppm)	SD**	Mean NH_4-N (ppm)	SD**	Mean Cl (ppm)	SD**	Mean SRP* (ppm)	SD**
Dry Creek	0.57	0.02	0.02	0.01	7.38	0.71	0.01	0.01
Cloud Creek	1.51	0.06	0.04	0.03	6.64	0.52	0.03	0.002
Cherokee Creek	2.62	0.13	0.04	0.03	7.23	0.23	0.04	0.01
Columbia Hollow	6.06	0.42	0.02	0.01	32.3	4.95	1.41	0.53
Beaty Creek	2.76	0.17	0.03	0.02	6.04	0.28	0.06	0.01
Upper Spavinaw	4.18	0.03	0.01	0.01	6.66	0.04	0.03	0.001
Lower Spavinaw	3.18	0.15	0.03	0.02	6.81	0.54	0.05	0.01

* Soluble Reactive Phosphorus ** Standard Deviation

Table A-2. Ambient Nutrient Concentrations and Standard Deviations Sampling for August 26 and September 9, with three replicates per date.

Stream Name	Mean NO_3-N (ppm)	SD**	Mean NH_3-N (ppm)	SD**	Mean Cl (ppm)	SD**	Mean SRP* (ppm)	SD**
Dry Creek	0.67	0.03	0.01	0.018	11.4	2.01	0.02	0.01
Cloud Creek	1.45	0.33	0.09	0.066	45.5	64.3	0.02	0.004
Cherokee Creek	2.39	0.35	0.11	0.114	21.3	30.0	0.03	0.01
Columbia Hollow	5.84	0.39	0.08	0.157	51.8	35.8	2.32	0.18
Beaty Creek	2.04	0.19	0.14	0.117	38.8	50.6	0.04	0.01
Upper Spavinaw	2.68	0.09	0.08	0.037	11.0	5.23	0.02	0.01
Lower Spavinaw	2.68	0.28	0.15	0.126	42.2	65.8	0.03	0.01

* Soluble Reactive Phosphorus ** Standard Deviation

Table A-3. Ambient Nutrient Concentrations and Standard Deviations Sampling for November 30 and December 12, 2000, with three replicates per date.

Stream Name	Mean NO_3-N (ppm)	SD**	Mean NH_3-N (ppm)	SD**	Mean Cl (ppm)	SD**	Mean SRP* (ppm)	SD**
Dry Creek	0.81	0.25	0.02	0.06	11.1	1.94	0.98	1.06
Cloud Creek	1.80	0.64	0.04	0.11	8.89	5.87	0.02	0.01
Cherokee Creek	2.33	0.52	0.03	0.08	10.2	0.67	0.02	0.01
Columbia Hollow	5.84	4.64	0.06	0.02	84.7	100	2.23	0.17
Beaty Creek	2.06	0.20	0.03	0.06	25.1	41.0	0.04	0.02
Upper Spavinaw	3.20	0.76	0.02	0.06	7.30	0.19	0.02	0.01
Lower Spavinaw	2.87	0.28	0.04	0.07	10.7	2.66	0.03	0.02

* Soluble Reactive Phosphorus ** Standard Deviation

Table A-4. Ambient Nutrient Concentrations and Standard Deviations Sampling between February 24 and March 8, 2000, with three replicates per date.

Stream Name	Mean NO_3-N (ppm)	SD**	Mean NH_3-N (ppm)	SD**	Mean Cl (ppm)	SD**	Mean SRP* (ppm)	SD**
Dry Creek	0.84	0.14	0.04	0.02	10.5	3.63	0.01	0.01
Cloud Creek	1.98	0.74	0.04	0.02	6.92	3.12	0.05	0.07
Cherokee Creek	2.39	0.34	0.03	0.03	10.3	1.61	0.02	0.01
Columbia Hollow	7.84	0.10	0.25	0.09	35.13	8.13	6.75	2.19
Beaty Creek	2.06	0.20	0.04	0.04	7.60	3.19	0.03	0.01
Upper Spavinaw	3.20	0.50	0.04	0.03	8.92	2.59	0.02	0.01
Lower Spavinaw	3.00	0.02	0.03	0.03	11.75	2.47	0.05	0.02

* Soluble Reactive Phosphorus ** Standard Deviation

APPENDIX B. STREAM NUTRIENT P-VALUES

Table B-1. P-Values from ANOVA for NH_4-N sampling July 22 and Aug 6, 1999, August 26 and September 6, 1999, November 30 and December 12, 1999, and February 22 and March 6, 2000. P-Values greater than α=0.05 were not significantly different. H_0: The NH_4-N concentrations are not significantly different between streams. H_A: The NH_4-N concentrations are significantly different between streams.

Stream Name	July-August	August-September	November-December	February-March
Dry Creek	0.0341	0.9046	0.5440	0.0524
Cloud Creek	0.0001	0.0306	0.1569	0.0465
Cherokee Creek	<0.0001	0.0131	0.3790	0.0674
Columbia Hollow	0.0082	0.0520	0.1655	<0.0001
Beaty Creek	0.0003	0.0016	0.3231	0.0612
Upper Spavinaw Creek	0.2634	0.0520	0.5440	0.0229
Lower Spavinaw Creek	0.0003	0.0008	0.2289	0.0741

Table B-2. Pair wise comparison P- Values for NH_4 sampling for July 22 and Aug 6, 1999, August 26 and September 6, 1999, November 30 and December 12, 1999, and February 22 and March 6, 2000. P-Values greater than α=0.05 were not significantly different.

Stream Name	July/ August	August/ September	November/ December	February/ March
Beaty Creek/ Cherokee Creek	0.6723	0.5729	0.9376	0.9740
Beaty Creek/ Cloud Creek	0.7778	0.4148	0.7545	0.9272
Beaty Creek/ Columbia Hollow	0.3995	0.3261	0.5664	<0.0001
Beaty Creek/ Dry Creek	0.2095	0.0255	0.7843	0.9584
Beaty Creek/ Lower Spavinaw Creek	1.000	0.8654	0.8757	0.9480
Beaty Creek/ Upper Spavinaw Creek	0.1728	0.3261	0.7843	0.7542
Cherokee Creek/ Cloud Creek	0.8877	0.7994	0.6960	0.9013
Cherokee Creek/ Columbia Hollow	0.2095	0.6721	0.5243	<0.0001
Cherokee Creek/ Dry Creek	0.0974	0.0864	0.8450	0.9324
Cherokee Creek/ Lower Spavinaw Creek	0.6723	0.4643	0.8145	0.9740
Cherokee Creek/ Upper Spavinaw Creek	0.0909	0.6721	0.8450	0.7296
Cloud Creek /Columbia Hollow	0.2634	0.8654	0.7496	<0.0001
Cloud Creek/ Dry Creek	0.1273	0.1405	0.5584	0.9688
Cloud Creek/ Lower Spavinaw Creek	0.7778	0.3261	0.8757	0.8755
Cloud Creek/ Upper Spavinaw Creek	0.1136	0.8654	0.5584	0.8244
Columbia Hollow/ Dry Creek	0.6723	0.1897	0.4269	<0.0001
Columbia Hollow/ Lower Spavinaw Creek	0.3995	0.2512	0.6553	<0.0001
Columbia Hollow/ Upper Spavinaw Creek	0.4907	1.000	0.4269	<0.0001
Dry Creek/ Lower Spavinaw Creek	0.2095	0.0171	0.6674	0.9065
Dry Creek/ Upper Spavinaw Creek	0.7297	0.1897	1.000	0.7941
Lower Spavinaw Creek/ Upper Spavinaw Creek	0.1728	0.2512	0.6674	0.7053

Table B-3. P-Values from ANOVA for NO_3-N sampling July 22 and Aug 6, 1999, August 26 and September 6, 1999, November 30 and December 12, 1999, and February 22 and March 6, 2000. P-Values greater than α=0.05 were not significantly different. H_0: The NO_3-N concentrations are not significantly different between streams. H_A: The NO_3-N concentrations are significantly different between streams.

Stream Name	July-August	August-September	November-December	February-March
Dry Creek	<0.0001	<0.0001	0.1328	0.0005
Cloud Creek	<0.0001	<0.0001	0.0017	<0.0001
Cherokee Creek	<0.0001	<0.0001	0.0001	<0.0001
Columbia Hollow	<0.0001	<0.0001	<0.0001	<0.0001
Beaty Creek	<0.0001	<0.0001	0.0002	<0.0001
Upper Spavinaw Creek	<0.0001	<0.0001	<0.0001	<0.0001
Lower Spavinaw Creek	<0.0001	<0.0001	<0.0001	<0.0001

Table B-4. Pair wise comparison P- Values for NO_3 sampling for July 22 and Aug 6, 1999, August 26 and September 6, 1999, November 30 and December 12, 1999, and February 22 and March 6, 2000. P-Values greater than α=0.05 were not significantly different.

Stream Name	July/ August	August/ September	November/ December	February/ March
Beaty Creek/ Cherokee Creek	0.2306	0.0288	0.8990	0.2756
Beaty Creek/ Cloud Creek	<0.0001	0.0006	0.5637	0.8075
Beaty Creek/ Columbia Hollow	<0.0001	<0.0001	0.0004	<0.0001
Beaty Creek/ Dry Creek	<0.0001	<0.0001	0.0643	0.0003
Beaty Creek/ Lower Spavinaw Creek	0.0008	0.0002	0.3977	0.0039
Beaty Creek/ Upper Spavinaw Creek	<0.0001	0.0002	0.2016	0.0007
Cherokee Creek/ Cloud Creek	<0.0001	<0.0001	0.4820	0.1847
Cherokee Creek/ Columbia Hollow	<0.0001	<0.0001	0.0005	<0.0001
Cherokee Creek/ Dry Creek	<0.0001	<0.0001	0.0492	<0.0001
Cherokee Creek/ Lower Spavinaw Creek	<0.0001	0.0666	0.4711	0.0556
Cherokee Creek/ Upper Spavinaw Creek	<0.0001	0.0681	0.2483	0.0126
Cloud Creek /Columbia Hollow	<0.0001	<0.0001	<0.0001	<0.0001
Cloud Creek/ Dry Creek	<0.0001	<0.0001	0.1919	0.0006
Cloud Creek/ Lower Spavinaw Creek	<0.0001	<0.0001	0.1594	0.0020
Cloud Creek/ Upper Spavinaw Creek	<0.0001	<0.0001	0.0682	0.0003
Columbia Hollow/ Dry Creek	<0.0001	<0.0001	<0.0001	<0.0001
Columbia Hollow/ Lower Spavinaw Creek	<0.0001	<0.0001	0.0026	<0.0001
Columbia Hollow/ Upper Spavinaw Creek	<0.0001	<0.0001	0.0067	<0.0001
Dry Creek/ Lower Spavinaw Creek	<0.0001	<0.0001	0.0092	<0.0001
Dry Creek/ Upper Spavinaw Creek	<0.0001	<0.0001	0.0029	<0.0001
Lower Spavinaw Creek/ Upper Spavinaw Creek	<0.0001	0.9915	0.6582	0.5204

Table B-5. P-Values from ANOVA for CL sampling July 22 and Aug 6, 1999, August 26 and September 6, 1999, November 30 and December 12, 1999, and February 22 and March 6, 2000. P-Values greater than α=0.05 were not significantly different. H_0: The CL concentrations are not significantly different between streams. H_A: The CL concentrations are significantly different between streams.

Stream Name	July-August	August-September	November-December	February-March
Dry Creek	<0.0001	0.5268	0.3708	<0.0001
Cloud Creek	<0.0001	0.0148	0.4722	0.0002
Cherokee Creek	<0.0001	0.2381	0.4091	<0.0001
Columbia Hollow	<0.0001	0.0060	<0.0001	<0.0001
Beaty Creek	<0.0001	0.0357	0.0481	<0.0001
Upper Spavinaw Creek	<0.0001	0.5411	0.5543	<0.0001
Lower Spavinaw Creek	<0.0001	0.0230	0.3857	<0.0001

Table B-6. Pair wise comparison P- Values for CL sampling for July 22 and Aug 6, 1999, August 26 and September 6, 1999, November 30 and December 12, 1999, and February 22 and March 6, 2000. P-Values greater than α=0.05 were not significantly different.

Stream Name	July/ August	August/ September	November/ December	February/ March
Beaty Creek/ Cherokee Creek	0.3142	0.4912	0.3951	0.2605
Beaty Creek/ Cloud Creek	0.6122	0.7892	0.3548	0.7727
Beaty Creek/ Columbia Hollow	<0.0001	0.6050	0.0083	<0.0001
Beaty Creek/ Dry Creek	0.2578	0.2821	0.4230	0.2306
Beaty Creek/ Lower Spavinaw Creek	0.5185	0.8920	0.4118	0.0842
Beaty Creek/ Upper Spavinaw Creek	0.6711	0.2754	0.3104	0.5761
Cherokee Creek/ Cloud Creek	0.6132	0.3411	0.9391	0.1602
Cherokee Creek/ Columbia Hollow	<0.0001	0.2315	0.0013	<0.0001
Cherokee Creek/ Dry Creek	0.8978	0.6939	0.9602	0.9396
Cherokee Creek/ Lower Spavinaw Creek	0.7141	0.4108	0.9759	0.5305
Cherokee Creek/ Upper Spavinaw Creek	0.6872	0.6826	0.8670	0.5661
Cloud Creek /Columbia Hollow	<0.0001	0.8020	0.0011	<0.0001
Cloud Creek/ Dry Creek	0.5267	0.1819	0.8995	0.1397
Cloud Creek/ Lower Spavinaw Creek	0.8888	0.8952	0.9152	0.0461
Cloud Creek/ Upper Spavinaw Creek	0.9916	0.1771	0.9274	0.3981
Columbia Hollow/ Dry Creek	<0.0001	0.1154	0.0015	<0.0001
Columbia Hollow/ Lower Spavinaw Creek	<0.0001	0.7024	0.0014	<0.0001
Columbia Hollow/ Upper Spavinaw Creek	<0.0001	0.1120	0.0009	<0.0001
Dry Creek/ Lower Spavinaw Creek	0.6211	0.2272	0.9842	0.5809
Dry Creek/ Upper Spavinaw Creek	0.6122	0.9876	0.8279	0.5163
Lower Spavinaw Creek/ Upper Spavinaw Creek	0.9174	0.2215	0.8434	0.2333

Table B-7. P-Values from ANOVA for SRP sampling July 22 and Aug 6, 1999, August 26 and September 6, 1999, November 30 and December 12, 1999, and February 22 and March 6, 2000. P-Values greater than $\alpha=0.05$ were not significantly different. H_0: The SRP concentrations are not significantly different between streams. H_A: The SRP concentrations are significantly different between streams.

Stream Name	July-August	August-September	November-December	February-March
Dry Creek	0.8856	0.5613	<0.0001	0.9832
Cloud Creek	0.7143	0.3914	0.9003	0.8740
Cherokee Creek	0.6362	0.2487	0.9056	0.9500
Columbia Hollow	<0.0001	<0.0001	<0.0001	<0.0001
Beaty Creek	0.5010	0.1887	0.8261	0.9298
Upper Spavinaw Creek	0.7883	0.4111	0.9263	0.9571
Lower Spavinaw Creek	0.5789	0.2394	0.8457	0.8918

Table B-8. Pair wise comparison P- Values for SRP sampling for July 22 and Aug 6, 1999, August 26 and September 6, 1999, November 30 and December 12, 1999, and February 22 and March 6, 2000. P-Values greater than $\alpha=0.05$ were not significantly different.

Stream Name	July/ August	August/ September	November/ December	February/ March
Beaty Creek/ Cherokee Creek	0.8867	0.9064	0.9429	0.9856
Beaty Creek/ Cloud Creek	0.8272	0.7401	0.9467	0.9602
Beaty Creek/ Columbia Hollow	<0.0001	<0.0001	<0.0001	<0.0001
Beaty Creek/ Dry Creek	0.7074	0.5972	0.0005	0.9622
Beaty Creek/ Lower Spavinaw Creek	0.9330	0.9197	0.9859	0.9729
Beaty Creek/ Upper Spavinaw Creek	0.8646	0.7212	0.9283	0.9807
Cherokee Creek/ Cloud Creek	0.9394	0.8304	0.9962	0.9459
Cherokee Creek/ Columbia Hollow	<0.0001	<0.0001	<0.0001	<0.0001
Cherokee Creek/ Dry Creek	0.8156	0.6809	0.0004	0.9765
Cherokee Creek/ Lower Spavinaw Creek	0.9535	0.9866	0.9571	0.9586
Cherokee Creek/ Upper Spavinaw Creek	0.9567	0.8108	0.9853	0.9950
Cloud Creek /Columbia Hollow	<0.0001	<0.0001	<0.0001	<0.0001
Cloud Creek/ Dry Creek	0.8750	0.8435	0.0004	0.9225
Cloud Creek/ Lower Spavinaw Creek	0.8932	0.8173	0.9609	0.9873
Cloud Creek/ Upper Spavinaw Creek	0.9938	0.9799	0.9815	0.9409
Columbia Hollow/ Dry Creek	<0.0001	<0.0001	0.0002	<0.0001
Columbia Hollow/ Lower Spavinaw Creek	<0.0001	<0.0001	<0.0001	<0.0001
Columbia Hollow/ Upper Spavinaw Creek	<0.0001	<0.0001	<0.0001	<0.0001
Dry Creek/ Lower Spavinaw Creek	0.7707	0.6686	0.0005	0.9352
Dry Creek/ Upper Spavinaw Creek	0.8916	0.8633	0.0004	0.9815
Lower Spavinaw Creek/ Upper Spavinaw Creek	0.9188	0.7978	0.9424	0.9536

APPENDIX C. SEASONAL NUTRIENT P-VALUES

Table C-1. Seasonal comparison P-Values from ANOVA for NH_4-N for each sampling site. P-Values greater than α=0.05 were not significantly different.

Stream Name	Dry Creek	Cloud Creek	Cherokee Creek	Columbia Hollow	Beaty Creek	Upper Spavinaw Creek	Lower Spavinaw Creek
July-August	0.2064	0.1881	0.2048	0.5717	0.2583	0.5996	0.2666
August-September	0.7254	0.0024	0.0014	0.0551	<0.0001	0.0002	<0.0001
November-December	0.2064	0.1230	0.3727	0.3091	0.3075	0.3128	0.2231
February-March	0.0185	0.1843	0.2610	<0.0001	0.2404	0.0270	0.2712

Table C-2. Pair-Wise comparisons P-Values for NH_4-N Concentrations between Seasons for each Stream. Letters in rows show groups that are not significantly different at α=0.05.

Stream Name	July-August/ August-September	July-August/ November-December	July-August/ February-March	November-December/ August-September	November-December/ February-March	February-March/ August-September
Dry Creek	0.5095	1.000	0.3841	0.5095	0.3841	0.1341
Cloud Creek	0.1520	0.8627	0.9931	0.2037	0.8695	0.1543
Cherokee Creek	0.1061	0.7808	0.9144	0.0623	0.8642	0.0868
Columbia Hollow	0.3091	0.6076	0.0009	0.7433	0.0136	0.0087
Beaty Creek	0.0146	0.9352	0.9741	0.0122	0.9095	0.0157
Upper Spavinaw Creek	0.0349	0.8718	0.3500	0.0184	0.3426	0.1211
Lower Spavinaw Creek	0.0095	0.9364	0.9936	0.0113	0.9300	0.0093

Table C-3. Seasonal comparison P-Values from ANOVA for NO_3-N for each sampling site. P-Values greater than α=0.05 were not significantly different.

Stream Name	Dry Creek	Cloud Creek	Cherokee Creek	Columbia Hollow	Beaty Creek	Upper Spavinaw Creek	Lower Spavinaw Creek
July-August	<0.0001	<0.0001	<0.0001	<0.0001	<0.0001	<0.0001	<0.0001
August-September	<0.0001	<0.0001	<0.0001	<0.0001	<0.0001	<0.0001	<0.0001
November-December	<0.0001	<0.0001	<0.0001	<0.0001	<0.0001	<0.0001	<0.0001
February-March	<0.0001	<0.0001	<0.0001	<0.0001	<0.0001	<0.0001	<0.0001

Table C-4. Pair wise comparison P-Values for NO_3-N Concentrations between Seasons for each Stream. Letters in rows show groups that are not significantly different at α=0.05.

Stream Name	July-August/ August-September	July-August/ November-December	July-August/ February -March	November-December/ August-September	November-December/ February-March	February-March/ August-September
Dry Creek	0.2559	0.0102	0.0052	0.1114	0.7692	0.0637
Cloud Creek	0.8464	0.3329	0.1257	0.2485	0.5516	0.0879
Cherokee Creek	0.2908	0.1852	0.3013	0.7769	0.7589	0.9811
Columbia Hollow	0.8210	0.8555	0.0889	0.9978	0.1156	0.0578
Beaty Creek	0.0075	0.0437	0.0091	0.4226	0.4702	0.9350
Upper Spavinaw Creek	0.0005	0.0123	0.0120	0.0842	0.9862	0.0869
Lower Spavinaw Creek	0.0006	0.0207	0.1565	0.1426	0.3107	0.0184

Table C-5. Seasonal comparison P-Values from ANOVA for CL for each sampling site. P-Values greater than α=0.05 were not significantly different.

Stream Name	Dry Creek	Cloud Creek	Cherokee Creek	Columbia Hollow	Beaty Creek	Upper Spavinaw Creek	Lower Spavinaw Creek
July-August	<0.0001	0.6201	0.2525	0.0632	0.6543	0.0020	0.6183
August-September	<0.0001	0.0025	0.0024	0.0053	0.0086	<0.0001	0.0052
November-December	<0.0001	0.5082	0.1116	0.0018	0.0737	<0.0001	0.4336
February-March	<0.0001	0.6057	0.1099	0.0451	0.5743	<0.0001	0.3925

Table C-6. Pair-Wise comparison P-Values in CL Concentrations between Seasons for each Stream. Letters in rows show groups that are not significantly different at α=0.05.

Stream Name	July-August/ August-September	July-August/ November-December	July-August/ February-March	November-December/ August-September	November-December/ February-March	February-March/ August-September
Dry Creek	0.0077	0.0118	0.0330	0.8488	0.6376	0.5096
Cloud Creek	0.0501	0.9053	0.9883	0.0636	0.9170	0.0516
Cherokee Creek	0.1207	0.7346	0.7302	0.2162	0.9953	0.2182
Columbia Hollow	0.4054	0.0799	0.9027	0.2598	0.0962	0.4759
Beaty Creek	0.0974	0.3231	0.9352	0.4762	0.3631	0.1132
Upper Spavinaw Creek	0.0718	0.7767	0.3269	0.0619	0.3893	0.2803
Lower Spavinaw Creek	0.0774	0.8380	0.7975	0.1136	0.9583	0.1249

Table C-7. Seasonal comparison P-Values from ANOVA for SRP for each sampling site. P-Values greater than α=0.05 were not significantly different.

Stream Name	Dry Creek	Cloud Creek	Cherokee Creek	Columbia Hollow	Beaty Creek	Upper Spavinaw Creek	Lower Spavinaw Creek
July-August	0.9544	0.0322	<0.0001	0.0119	<0.0001	<0.0001	<0.0001
August-September	0.9404	0.0958	<0.0001	0.0002	<0.0001	<0.0001	<0.0001
November-December	0.0002	0.1328	<0.0001	0.0059	<0.0001	0.0001	<0.0001
February-March	0.9738	0.0009	<0.0001	<0.0001	<0.0001	<0.0001	<0.0001

Table C-8. Pair-Wise comparison P-Values for SRP Concentrations between Seasons for each Stream. Letters in rows show groups that are not significantly different at α=0.05.

Stream Name	July-August/ August-September	July-August/ November-December	July-August/ February-March	November-December/ August-September	November-December/ February-March	February-March/ August-September
Dry Creek	0.9901	0.0048	0.9862	0.0049	0.0046	0.9763
Cloud Creek	0.6991	0.6088	0.2703	0.8995	0.1138	0.1427
Cherokee Creek	0.0875	0.0003	0.0004	0.0182	0.8620	0.0265
Columbia Hollow	0.2160	0.3580	<0.0001	0.9180	<0.0001	<0.0001
Beaty Creek	0.0007	0.0009	<0.0001	0.9016	0.1486	0.1836
Upper Spavinaw Creek	0.1031	0.0084	0.0199	0.1426	0.6231	0.3143
Lower Spavinaw Creek	0.0621	0.0676	0.7949	0.9654	0.1108	0.1023

APPENDIX D. LETSI P-VALUES

Table D-1. P-Values from ANOVA for LETSI sampling July 22 and Aug 6, 1999, August 26 and September 6, 1999, November 30 and December 12, 1999, and February 22 and March 6, 2000. P-Values greater than α=0.05 were not significantly different.

Stream Name	July-August	August-September	November-December	February-March
Dry Creek	<0.0001	<0.0001	0.3675	0.0006
Cloud Creek	<0.0001	<0.0001	0.3316	<0.0001
Cherokee Creek	<0.0001	<0.0001	0.1718	<0.0001
Columbia Hollow	<0.0001	<0.0001	X	<0.0001
Beaty Creek	<0.0001	<0.0001	0.0029	<0.0001
Upper Spavinaw Creek	X	<0.0001	0.3480	0.0002
Lower Spavinaw Creek	<0.0001	<0.0001	0.2963	<0.0001

Table D-2. Pair-Wise Comparison for LETSI P-Values for July 22 and Aug 6, 1999, August 26 and September 6, 1999, November 30 and December 12, 1999, and February 22 and March 6, 2000.

Stream Name	July/Aug	Aug/Sept	Nov/Dec	Feb/March
Beaty/Cherokee	0.6149	0.0183	0.1950	0.5872
Beaty/Cloud	0.8470	0.0030	0.1175	0.9048
Beaty/Columbia	0.0774	0.7683	X	0.7947
Beaty/Dry	0.2939	0.0268	0.1069	0.4455
Beaty/Lower Spavinaw	0.0165	0.5925	0.1296	0.8891
Beaty/Upper Spavinaw	X	0.0307	0.1124	0.4838
Cherokee/Cloud	0.5300	<0.0001	0.7755	0.6719
Cherokee/Columbia	0.0251	0.0433	X	0.4311
Cherokee/Dry	0.1234	0.8776	0.7376	0.1988
Cherokee/Lower Spavinaw	0.0044	0.0043	0.8162	0.4955
Cherokee/Upper Spavinaw	X	<0.0001	0.7578	0.2160
Cloud/Columbia	0.1775	0.0016	X	0.7066
Cloud/Dry	0.4720	<0.0001	0.9602	0.3797
Cloud/Lower Spavinaw	0.0562	0.0133	0.9579	0.7956
Cloud/Upper Spavinaw	X	0.3852	0.9815	0.4128
Columbia/Dry	0.4612	0.0604	X	0.6232
Columbia/Lower Spavinaw	0.5012	0.4156	X	0.9009
Columbia/Upper Spavinaw	X	0.0172	X	0.6728
Dry/Lower Spavinaw	0.1618	0.0067	0.9182	0.5300
Dry/Upper Spavinaw	X	<0.0001	0.9787	0.9347
Lower Spavinaw/ Upper Spavinaw	X	0.0992	0.9394	0.5746

Table D-3. P-Values from ANOVA for N-LETSI sampling July 22 and Aug 6, 1999, August 26 and September 6, 1999, November 30 and December 12, 1999, and February 22 and March 6, 2000. P-Values greater than $\alpha=0.05$ were not significantly different.

Stream Name	July-August	August-September	November-December	February-March
Dry Creek	<0.0001	0.0007	0.2751	0.2526
Cloud Creek	<0.0001	<0.0001	<0.0001	0.0298
Cherokee Creek	<0.0001	<0.0001	0.3116	0.0007
Columbia Hollow	<0.0001	<0.0001	X	0.1701
Beaty Creek	<0.0001	<0.0001	0.0411	0.0604
Upper Spavinaw Creek	X	<0.0001	0.1842	0.1816
Lower Spavinaw Creek	<0.0001	<0.0001	0.2662	0.0578

Table D-4. Pair-Wise Comparison for N-LETSI P-Values for July 22 and Aug 6, 1999, August 26 and September 6, 1999, November 30 and December 12, 1999, and February 22 and March 6, 2000.

Stream Name	July/Aug	Aug/Sept	Nov/Dec	Feb/March
Beaty/Cherokee	0.9923	0.4638	0.4184	0.2401
Beaty/Cloud	0.2442	0.5178	0.1233	0.8262
Beaty/Columbia	0.4367	0.4622	X	0.7580
Beaty/Dry	0.1580	0.1995	0.4508	0.6339
Beaty/Lower Spavinaw	0.5687	0.5382	0.4594	0.9884
Beaty/Upper Spavinaw	X	0.9561	0.5559	0.6925
Cherokee/Cloud	0.2409	0.1702	0.0178	0.3379
Cherokee/Columbia	0.4311	0.1501	X	0.1482
Cherokee/Dry	0.1552	0.5778	0.9544	0.1075
Cherokee/Lower Spavinaw	0.5622	0.1799	0.9427	0.2458
Cherokee/Upper Spavinaw	X	0.4311	0.8198	0.1184
Cloud/Columbia	0.6196	0.9154	X	0.6021
Cloud/Dry	0.9501	0.0560	0.0205	0.4908
Cloud/Lower Spavinaw	0.4986	0.9750	0.0212	0.8375
Cloud/Upper Spavinaw	X	0.5539	0.0309	0.5390
Columbia/Dry	0.5191	0.0497	X	0.8696
Columbia/Lower Spavinaw	0.8343	0.8912	X	0.7473
Columbia/Upper Spavinaw	X	0.4953	X	0.9387
Dry/Lower Spavinaw	0.3940	0.0600	0.9882	0.6239
Dry/Upper Spavinaw	X	0.1813	0.8644	0.9270
Lower Spavinaw/ Upper Spavinaw	X	0.5749	0.8760	0.6819

Table D-5. P-Values from ANOVA for P- LETSI sampling July 22 and Aug 6, 1999, August 26 and September 6, 1999, November 30 and December 12, 1999, and February 22 and March 6, 2000. P-Values greater than α=0.05 were not significantly different.

Stream Name	July-August	August-September	November-December	February-March
Dry Creek	<0.0001	<0.0001	0.2513	0.1196
Cloud Creek	<0.0001	<0.0001	0.0845	<0.0001
Cherokee Creek	<0.0001	<0.0001	0.0049	<0.0001
Columbia Hollow	<0.0001	<0.0001	X	0.0208
Beaty Creek	<0.0001	<0.0001	0.0030	0.0016
Upper Spavinaw Creek	<0.0001	<0.0001	0.2408	0.0104
Lower Spavinaw Creek	<0.0001	<0.0001	0.3251	0.0005

Table D-6. Pair-Wise Comparison for P-LETSI P-Values for July 22 and Aug 6, 1999, August 26 and September 6, 1999, November 30 and December 12, 1999, and February 22 and March 6, 2000.

Stream Name	July/Aug	Aug/Sept	Nov/Dec	Feb/March
Beaty/Cherokee	0.1036	0.3744	0.8143	0.4014
Beaty/Cloud	0.1250	0.7850	0.3000	0.5311
Beaty/Columbia	0.1564	0.1134	X	0.5851
Beaty/Dry	0.0939	0.0180	0.1506	0.2648
Beaty/Lower Spavinaw	0.1118	0.7363	0.1217	0.7977
Beaty/Upper Spavinaw	X	0.5530	0.1557	0.6445
Cherokee/Cloud	0.9013	0.2470	0.4087	0.8304
Cherokee/Columbia	0.8276	0.4651	X	0.1753
Cherokee/Dry	0.9607	0.1298	0.2147	0.0560
Cherokee/Lower Spavinaw	0.9690	0.5799	0.1754	0.5590
Cherokee/Upper Spavinaw	X	0.7665	0.2215	0.1956
Cloud/Columbia	0.7546	0.0659	X	0.2498
Cloud/Dry	0.9352	0.0088	0.6740	0.0872
Cloud/Lower Spavinaw	0.8748	0.5426	0.5909	0.7109
Cloud/Upper Spavinaw	X	0.3874	0.6876	0.2785
Columbia/Dry	0.7894	0.4504	X	0.5762
Columbia/Lower Spavinaw	0.8579	0.2065	X	0.4271
Columbia/Upper Spavinaw	X	0.3092	X	0.9226
Dry/Lower Spavinaw	0.9298	0.0406	0.9067	0.1738
Dry/Upper Spavinaw	X	0.0715	0.9851	0.5027
Lower Spavinaw/ Upper Spavinaw	X	0.7971	0.8920	0.4736

APPENDIX E. LETSI SEASONAL COMPARISONS

Table E-1. P-Values from ANOVA for LETSI for each sampling site comparing sampling dates (July 22 and Aug 6, 1999, August 26 and September 6, 1999, November 30 and December 12, 1999, and February 22 and March 6, 2000). P-Values greater than α=0.05 were not significantly different.

Stream Name	Dry Creek	Cloud Creek	Cherokee Creek	Columbia Hollow	Beaty Creek	Upper Spavinaw Creek	Lower Spavinaw Creek
July-August	<0.0001	0.1550	0.0247	<0.0001	0.4769	X	<0.0001
August-September	<0.0001	0.0011	0.0426	<0.0001	0.3449	<0.0001	<0.0001
November-December	<0.0001	0.0398	0.0001	X	0.0101	<0.0001	<0.0001
February-March	<0.0001	0.0047	<0.0001	<0.0001	0.2498	<0.0001	<0.0001

Table E-2. Pair-Wise Comparison for LETSI P-Values for each sampling site comparing sampling dates (July 22 and Aug 6, 1999, August 26 and September 6, 1999, November 30 and December 12, 1999, and February 22 and March 6, 2000). P-Values greater than α=0.05 were not significantly different.

Stream Name	July-Aug/ Feb-March	July- Aug/ Nov-Dec	July- Aug/ Aug-Sept	Feb-March/ Nov-Dec	Feb- March/ Aug-Sept	Nov-Dec/ Aug- Sept
Beaty	0.7515	0.1479	0.8671	0.2503	0.8812	0.1968
Cherokee	0.0823	0.1655	0.8652	0.7123	0.0580	0.1213
Cloud	0.4831	0.8730	0.3009	0.5311	0.6956	0.3116
Columbia	0.3281	X	0.6774	X	0.1790	X
Dry	0.8176	0.7144	0.1851	0.5580	0.1306	0.3325
Lower Spavinaw	0.7323	0.5271	0.9560	0.3320	0.6913	0.5635
Upper Spavinaw	X	X	X	0.5510	0.0546	0.0145

Table E-3. P-Values from ANOVA for N-LETSI for each sampling site comparing sampling dates (July 22 and Aug 6, 1999, August 26 and September 6, 1999, November 30 and December 12, 1999, and February 22 and March 6, 2000). P-Values greater than α=0.05 were not significantly different.

Stream Name	Dry Creek	Cloud Creek	Cherokee Creek	Columbia Hollow	Beaty Creek	Upper Spavinaw Creek	Lower Spavinaw Creek
July-August	<0.0001	0.4895	0.3997	<0.0001	0.0276	X	<0.0001
August-September	0.0009	0.3587	0.4248	<0.0001	0.0109	0.0001	<0.0001
November-December	<0.0001	0.0013	0.3214	X	<0.0001	<0.0001	<0.0001
February-March	<0.0001	0.1546	0.0055	<0.0001	0.0002	<0.0001	<0.0001

Table E- 4. Pair-Wise Comparison for N-LETSI P-Values for each sampling site comparing sampling dates (July 22 and Aug 6, 1999, August 26 and September 6, 1999, November 30 and December 12, 1999, and February 22 and March 6, 2000). P-Values greater than α=0.05 were not significantly different.

Stream Name	July-Aug/ Feb-March	July- Aug/ Nov-Dec	July- Aug/ Aug-Sept	Feb-March/ Nov-Dec	Feb- March/ Aug-Sept	Nov-Dec/ Aug- Sept
Beaty Creek	0.1799	0.0199	0.7840	0.2757	0.2821	0.0368
Cherokee Creek	0.1460	0.9144	0.9748	0.1768	0.1378	0.8894
Cloud Creek	0.7361	0.1197	0.9862	0.1558	0.7120	0.0772
Columbia Hollow	0.4589	X	0.4735	X	0.9811	X
Dry Creek	0.5818	0.8083	0.0661	0.7524	0.2054	0.1074
Lower Spavinaw Creek	0.0240	0.6128	0.4766	0.0732	0.1104	0.8357
Upper Spavinaw Creek	X	X	X	0.5077	0.7603	0.3359

Table E-5. P-Values from ANOVA for P-LETSI for each sampling site comparing sampling dates (July 22 and Aug 6, 1999, August 26 and September 6, 1999, November 30 and December 12, 1999, and February 22 and March 6, 2000). P-Values greater than α=0.05 were not significantly different.

Stream Name	Dry Creek	Cloud Creek	Cherokee Creek	Columbia Hollow	Beaty Creek	Upper Spavinaw Creek	Lower Spavinaw Creek
July-August	<0.0001	0.2659	0.1907	<0.0001	0.2522	X	<0.0001
August-September	0.0004	0.0499	0.1584	<0.0001	0.2790	0.0001	<0.0001
November-December	<0.0001	0.0045	<0.0001	X	0.0042	<0.0001	<0.0001
February-March	0.0007	0.0046	0.0065	<0.0001	0.1831	<0.0001	<0.0001

Table E-6. Pair-Wise Comparison for P-LETSI P-Values for each sampling site comparing sampling dates (July 22 and Aug 6, 1999, August 26 and September 6, 1999, November 30 and December 12, 1999, and February 22 and March 6, 2000). P-Values greater than α=0.05 were not significantly different.

Stream Name	July-Aug/ Feb-March	July- Aug/ Nov-Dec	July- Aug/ Aug-Sept	Feb-March/ Nov-Dec	Feb- March/ Aug-Sept	Nov-Dec/ Aug- Sept
Beaty	0.8916	0.1646	0.9638	0.2069	0.8559	0.1521
Cherokee	0.2792	0.0310	0.9403	0.2591	0.3130	0.0367
Cloud	0.3391	0.3364	0.7268	0.9949	0.4807	0.4768
Columbia	0.3207	X	0.3684	X	0.0718	X
Dry	0.5148	0.2199	0.3479	0.0693	0.7902	0.0345
Lower Spavinaw	0.0199	0.6655	0.5236	0.0531	0.0816	0.8363
Upper Spavinaw	X	X	X	0.7967	0.7289	0.5467

APPENDIX F. CHLOROPHYLL A DATA

Table F-1. Chlorophyll *a* content for seven sites sampled between July 22 and Aug 5, 1999.

Stream Name	Statistic Variables	Nitrogen	Phosphorus	N&P	Control
Dry Creek	Mean Chlorophyll *a*	0.937	1.123	1.109	0.9600
	Standard Deviations	0.4907	0.2423	0.3350	0.2602
	Coefficient of Variation	0.5237	0.2158	0.3021	0.2710
	Count	9	10	10	10
Cloud Creek	Mean Chlorophyll *a*	4.811	5.632	5.808	4.992
	Standard Deviations	1.464	2.029	2.284	1.538
	Coefficient of Variation	0.3043	0.3603	0.3933	0.3081
	Count	7	6	6	5
Cherokee Creek	Mean Chlorophyll *a*	2.002	2.4211	2.791	1.648
	Standard Deviations	0.5555	0.2576	0.7241	0.4960
	Coefficient of Variation	0.2775	0.1064	0.2594	0.3010
	Count	10	9	10	10
Columbia Hollow	Mean Chlorophyll *a*	0.6200	0.5810	0.694	0.602
	Standard Deviations	0.3920	0.0968	0.1290	0.1393
	Coefficient of Variation	0.6323	0.1666	0.1859	0.2314
	Count	10	10	10	10
Beaty Creek	Mean Chlorophyll *a*	1.92	2.92	2.82	1.82
	Standard Deviations	0.461	0.890	0.852	0.558
	Coefficient of Variation	0.2401	0.3048	0.3021	0.3066
	Count	10	10	10	10
Lower Spavinaw	Mean Chlorophyll *a*	0.4060	0.4389	0.4910	0.4560
	Standard Deviations	0.1252	0.1033	0.1750	0.1778
	Coefficient of Variation	0.3084	0.2354	0.3564	0.3899
	Count	10	9	10	10

Table F-2. Chlorophyll *a* content for seven sites sampled between Aug 25 and Sept 9, 1999.

Stream Name	Statistic Variables	Nitrogen	Phosphorus	N&P	Control
Dry Creek	Mean Chlorophyll *a*	0.2620	0.3290	0.7010	0.3380
	Standard Deviations	0.2104	0.2246	0.5311	0.2470
	Coefficient of Variation	0.8031	0.6827	0.7576	0.7308
	Count	10	10	10	10
Cloud Creek	Mean Chlorophyll *a*	3.382	3.345	3.828	4.344
	Standard Deviations	1.073	0.6398	1.124	1.289
	Coefficient of Variation	0.3173	0.1913	0.2936	0.2967
	Count	9	8	8	8
Cherokee Creek	Mean Chlorophyll *a*	5.899	7.242	8.480	4.442
	Standard Deviations	1.159	1.686	2.022	0.9412
	Coefficient of Variation	0.1965	0.2328	0.2384	0.2119
	Count	10	10	10	10
Columbia Hollow	Mean Chlorophyll *a*	0.5100	0.3670	0.5033	0.4200
	Standard Deviations	0.1516	0.1517	0.1810	0.1686
	Coefficient of Variation	0.2973	0.4134	0.3596	0.4014
	Count	10	10	9	10
Beaty Creek	Mean Chlorophyll *a*	2.982	3.536	3.441	2.874
	Standard Deviations	0.5724	0.9120	0.6195	0.4500
	Coefficient of Variation	0.1920	0.2579	0.1800	0.1566
	Count	10	10	8	10
Lower Spavinaw	Mean Chlorophyll *a*	3.425	3.206	3.393	3.174
	Standard Deviations	0.8831	0.6378	0.8034	0.7672
	Coefficient of Variation	0.2578	0.1989	0.2368	0.2417
	Count	10	10	10	10
Upper Spavinaw	Mean Chlorophyll *a*	1.306	1.633	1.712	1.947
	Standard Deviations	0.4829	0.4845	0.7121	0.7086
	Coefficient of Variation	0.3698	0.2967	0.4159	0.3639
	Count	10	9	10	10

Table F-3. Chlorophyll *a* content for seven sites sampled between Nov 30 and Dec12, 1999.

Stream Name	Statistic Variables	Nitrogen	Phosphorus	N&P	Control
Dry Creek	Mean Chlorophyll *a*	0.1370	0.1610	0.1520	0.1130
	Standard Deviations	0.0790	0.1003	0.0930	0.0846
	Coefficient of Variation	0.5766	0.6230	0.6118	0.7487
	Count	10	10	10	10
Cloud Creek	Mean Chlorophyll *a*	0.0760	0.0450	0.0390	0.0230
	Standard Deviations	0.1000	0.0746	0.0412	0.0343
	Coefficient of Variation	1.316	1.658	1.056	1.491
	Count	10	10	10	10
Cherokee Creek	Mean Chlorophyll *a*	0.1070	0.2660	0.1290	0.1340
	Standard Deviations	0.0432	0.1628	0.0631	0.1234
	Coefficient of Variation	0.4037	0.6120	0.4891	0.9209
	Count	10	10	10	10
Beaty Creek	Mean Chlorophyll *a*	0.9856	0.8544	0.8000	0.8767
	Standard Deviations	0.4259	0.2014	0.3972	0.3110
	Coefficient of Variation	0.2282	0.2357	0.4965	0.3547
	Count	9	9	8	6
Lower Spavinaw	Mean Chlorophyll *a*	0.5980	0.5400	0.6440	0.5330
	Standard Deviations	0.2249	0.1428	0.2434	0.2960
	Coefficient of Variation	0.3761	0.2644	0.3780	0.5553
	Count	10	10	10	10
Upper Spavinaw	Mean Chlorophyll *a*	0.6540	0.6030	0.7080	0.4800
	Standard Deviations	0.1854	0.1464	0.2662	0.2204
	Coefficient of Variation	0.2835	0.2428	0.3760	0.4592
	Count	10	10	10	10

Table F-4. Chlorophyll *a* values for sampling between Feb 24 and March 9, 2000.

Stream Name	Statistic Variables	Nitrogen	Phosphorus	N&P	Control
Dry Creek	Mean Chlorophyll *a*	5.253	5.309	5.880	4.973
	Standard Deviations	1.100	1.224	1.400	1.339
	Coefficient of Variation	0.2094	0.2306	0.2381	0.2693
	Count	9	7	9	10
Cloud Creek	Mean Chlorophyll *a*	6.717	4.217	4.560	5.220
	Standard Deviations	1.753	1.415	3.599	x
	Coefficient of Variation	0.2610	0.3355	0.7893	x
	Count	3	3	3	1
Cherokee Creek	Mean Chlorophyll *a*	0.2680	0.2370	0.5110	0.2850
	Standard Deviations	0.2407	0.1748	0.6546	0.3054
	Coefficient of Variation	0.8981	0.7376	1.281	1.072
	Count	10	10	10	10
Columbia Hollow	Mean Chlorophyll *a*	0.8111	0.7330	0.7330	0.7656
	Standard Deviations	0.2806	0.2112	0.2113	0.2557
	Coefficient of Variation	0.3459	0.2881	0.2883	0.3340
	Count	9	10	10	9
Beaty Creek	Mean Chlorophyll *a*	2.839	2.686	2.199	2.239
	Standard Deviations	0.5433	1.880	0.6981	0.8650
	Coefficient of Variation	0.1914	0.6999	0.3175	0.3863
	Count	10	10	10	10
Lower Spavinaw	Mean Chlorophyll *a*	2.391	2.354	2.411	2.810
	Standard Deviations	0.5029	0.7305	0.5845	0.6144
	Coefficient of Variation	0.2103	0.3103	0.2424	0.2186
	Count	10	10	8	7
Upper Spavinaw	Mean Chlorophyll *a*	2.563	2.545	2.655	2.409
	Standard Deviations	0.8117	0.5904	0.8239	0.5557
	Coefficient of Variation	0.3167	0.2320	0.3103	0.2307
	Count	10	10	10	9

APPENDIX G TREATMENT COMPARISONS

Table G-1. Seasonal comparison p-Values from ANOVA for treatments for each sampling site for July 22 and August 5,1999. P-Values greater than α=0.10 were not significantly different.

Stream Name	Dry Creek	Cloud Creek	Cherokee Creek	Columbia Hollow	Beaty Creek	Upper Spavinaw Creek	Lower Spavinaw Creek
Control	<0.0001	<0.0001	<0.0001	<0.0001	<0.0001	<0.0001	0.0059
Nitrogen	<0.0001	<0.0001	<0.0001	<0.0001	<0.0001	<0.0001	0.0139
Phosphorus	<0.0001	<0.0001	<0.0001	<0.0001	<0.0001	<0.0001	0.0135
Nitrogen and Phosphorus	<0.0001	<0.0001	<0.0001	<0.0001	<0.0001	<0.0001	0.0031

Table G-2. P-Values of treatment comparisons for sampling between July 22 and August 5, 1999.

Stream Name	C/N	C/NP	C/P	N/NP	N/P	NP/P
Dry Creek	0.938	0.620	0.587	0.556	0.524	0.962
Cloud Creek	0.912	0.156	0.311	0.097	0.223	0.668
Cherokee Creek	0.291	0.001	0.031	0.020	0.250	0.258
Columbia Hollow	0.833	0.283	0.806	0.387	0.648	0.188
Beaty Creek	0.719	<0.001	<0.001	0.001	<0.001	0.722
Lower Spavinaw	0.810	0.866	0.897	0.682	0.917	0.770

C = Control, N = Nitrogen, NP = Nitrogen + Phosphorus, P = Phosphorus

Table G-3. Seasonal comparison p-Values from ANOVA for treatments for each sampling site for August 26 and September 9,1999. P-Values greater than α=0.10 were not significantly different.

Stream Name	Dry Creek	Cloud Creek	Cherokee Creek	Columbia Hollow	Beaty Creek	Upper Spavinaw Creek	Lower Spavinaw Creek
Control	0.1051	<0.0001	<0.0001	<0.0001	<0.0001	<0.0001	<0.0001
Nitrogen	0.2078	<0.0001	<0.0001	<0.0001	<0.0001	<0.0001	<0.0001
Phosphorus	0.1145	<0.0001	<0.0001	<0.0001	<0.0001	<0.0001	<0.0001
Nitrogen and Phosphorus	0.0010	<0.0001	<0.0001	<0.0001	<0.0001	<0.0001	<0.0001

Table G-4. P-Values of treatment comparisons for sampling between August 26 and September 9,1999.

Stream Name	C/N	C/NP	C/P	N/NP	N/P	NP/P
Dry Creek	0.794	0.215	0.975	0.134	0.818	0.204
Cloud Creek	0.080	0.332	0.063	0.437	0.881	0.364
Cherokee Creek	<0.0001	<0.0001	<0.0001	<0.0001	<0.0001	<0.0001
Columbia Hollow	0.294	0.320	0.535	0.980	0.097	0.113
Beaty Creek	0.686	0.062	0.015	0.135	0.040	0.658
Upper Spavinaw	0.004	0.273	0.141	0.060	0.156	0.678
Lower Spavinaw	0.228	0.293	0.878	0.878	0.293	0.369

C = Control, N = Nitrogen, NP = Nitrogen + Phosphorus, P = Phosphorus

Table G-5. Seasonal comparison P-Values from ANOVA for treatments for each sampling site for November 30 and December 12,1999. P-Values greater than α=0.10 were not significantly different.

Stream Name	Dry Creek	Cloud Creek	Cherokee Creek	Columbia Hollow	Beaty Creek	Upper Spavinaw Creek	Lower Spavinaw Creek
Control	0.5858	0.9532	0.6108	X	0.0010	0.0074	0.0014
Nitrogen	0.5089	0.8463	0.6844	X	<0.0001	0.0003	0.0004
Phosphorus	0.4378	0.9086	0.3133	X	0.0001	0.0009	0.0012
Nitrogen and Phosphorus	0.4638	0.9207	0.6242	X	0.0006	0.0001	0.0001

Table G-6. P-Values of treatment comparisons for sampling between November 30 and December 12, 1999.

Stream Name	C/N	C/NP	C/P	N/NP	N/P	NP/P
Dry Creek	0.9344	0.8936	0.8692	0.959	0.9344	0.9754
Cloud Creek	0.9109	0.9731	0.963	0.9378	0.9478	0.9899
Cherokee Creek	0.9356	0.9881	0.6931	0.9475	0.6346	0.6821
Beaty Creek	0.7751	0.8089	0.9449	0.5584	0.6878	0.8436
Upper Spavinaw	0.4163	0.2875	0.5651	0.8005	0.8113	0.6233
Lower Spavinaw	0.7542	0.5931	0.9731	0.8246	0.7800	0.6165

C = Control, N = Nitrogen, NP = Nitrogen + Phosphorus, P = Phosphorus

Table G-7. Seasonal comparison p-Values from ANOVA for treatments for each sampling site for February 23 and March 6,2000. P-Values greater than α=0.10 were not significantly different.

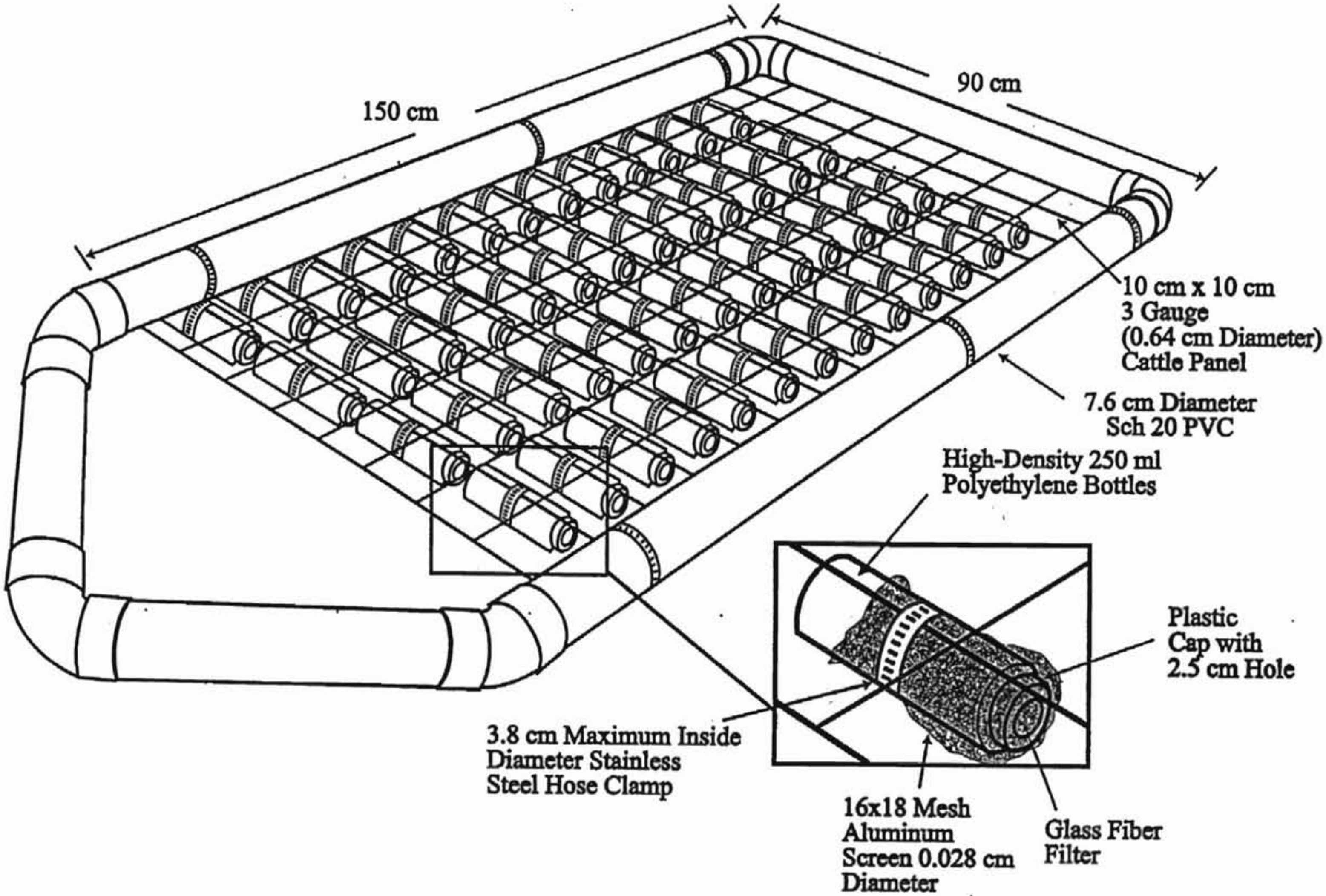
Stream Name	Dry Creek	Cloud Creek	Cherokee Creek	Columbia Hollow	Beaty Creek	Upper Spavinaw Creek	Lower Spavinaw Creek
Control	<0.0001	<0.0001	0.2801	<0.0001	<0.0001	<0.0001	<0.0001
Nitrogen	<0.0001	<0.0001	0.3097	<0.0001	<0.0001	<0.0001	<0.0001
Phosphorus	<0.0001	<0.0001	0.3687	<0.0001	<0.0001	<0.0001	<0.0001
Nitrogen and Phosphorus	<0.0001	<0.0001	0.0542	<0.0001	<0.0001	<0.0001	<0.0001

Table G-8. P-Values of treatment comparisons for sampling between February 23 and March 6,2000

Stream Name	C/N	C/NP	C/P	N/NP	N/P	NP/P
Dry Creek	0.3499	0.003	0.2888	0.0428	0.8518	0.0865
Cloud Creek	0.3394	0.4652	0.3187	0.0148	0.005	0.6916
Cherokee Creek	0.9595	0.4996	0.8859	0.4679	0.9261	0.4133
Beaty Creek	0.0264	0.8809	0.0963	0.0181	0.5668	0.0704
Upper Spavinaw	0.4178	0.2212	0.4660	0.6669	0.9328	0.6069
Lower Spavinaw	0.0671	0.0716	0.047	0.9621	0.8585	0.9052

C = Control, N = Nitrogen, NP = Nitrogen + Phosphorus, P = Phosphorus

APPENDIX H. DRAWING OF MATLOCK PERIPHYTOMETER


150 cm
90 cm
10 cm x 10 cm
3 Gauge
(0.64 cm Diameter)
Cattle Panel
7.6 cm Diameter
Sch 20 PVC
High-Density 250 ml
Polyethylene Bottles
Plastic
Cap with
2.5 cm Hole
3.8 cm Maximum Inside
Diameter Stainless
Steel Hose Clamp
16x18 Mesh
Aluminum
Screen 0.028 cm
Diameter
Glass Fiber
Filter

APPENDIX I. TEMPERATURE, CONDUCITIVY AND PH

Temperature, pH, and Conductivity for each sampling date.

Date	Stream Name	Temperature (°F)	pH	Conductivity µS/cm
July 22, 1999	Dry Creek	71.6	6.63	183
	Cloud Creek	73.5	6.79	139
	Cherokee Creek	71.0	6.61	172
	Columbia Hollow	78.6	6.86	258
	Beaty Creek	78.0	6.42	179
	Upper Spavinaw Creek	70.6	6.74	236
	Lower Spavinaw Creek	77.5	6.96	205
August 5, 1999	Dry Creek	66.4	6.11	188
	Cloud Creek	73.7	6.14	149
	Cherokee Creek	66.5	6.46	223
	Columbia Hollow	76.4	6.90	325
	Beaty Creek	77.9	6.47	223
	Upper Spavinaw Creek	N/A	N/A	N/A
	Lower Spavinaw Creek	79.6	6.97	243
August 25,1999	Dry Creek	73.5	N/A	185
	Cloud Creek	77.6	N/A	155
	Cherokee Creek	71.2	N/A	252
	Columbia Hollow	78.4	N/A	333
	Beaty Creek	78.0	N/A	232
	Upper Spavinaw Creek	76.4	N/A	205
	Lower Spavinaw Creek	78.7	N/A	223
September 9,1999	Dry Creek	68.0	7.5	225
	Cloud Creek	71.5	7.2	153
	Cherokee Creek	68.4	7.3	209
	Columbia Hollow	77.0	7.6	353
	Beaty Creek	76.5	7.7	231
	Upper Spavinaw Creek	75.7	8.0	240
	Lower Spavinaw Creek	75.6	7.7	247
November 30,1999	Dry Creek	53.0	6.4	267
	Cloud Creek	45.0	6.9	200
	Cherokee Creek	49.7	6.5	323
	Columbia Hollow	54.8	6.9	417
	Beaty Creek	N/A	6.9	234
	Upper Spavinaw Creek	56.7	6.8	239
	Lower Spavinaw Creek	N/A	7.0	238

N/A The measurement was not available due to equipment mailfunctions, or conditions were not suitable to take measurements.

Table Continued for Temperature, pH, and Conductivity for each sampling date.

Date	Stream Name	Temperature (°F)	pH	Conductivity µS/cm
December 13,1999	Dry Creek	51.5	8.2	117
	Cloud Creek	52.0	7.9	150
	Cherokee Creek	55.2	7.7	314
	Columbia Hollow	N/A	N/A	N/A
	Beaty Creek	58.0	6.8	234
	Upper Spavinaw Creek	53.7	7.2	247
	Lower Spavinaw Creek	59.2	6.9	266
February 24,2000	Dry Creek	N/A	8.1	195
	Cloud Creek	N/A	7.0	153
	Cherokee Creek	N/A	7.1	258
	Columbia Hollow	N/A	7.1	283
	Beaty Creek	N/A	7.1	223
	Upper Spavinaw Creek	N/A	7.1	205
	Lower Spavinaw Creek	N/A	7.2	190
March 9,2000	Dry Creek	N/A	7.0	100
	Cloud Creek	N/A	7.1	121
	Cherokee Creek	N/A	7.6	250
	Columbia Hollow	N/A	6.8	350
	Beaty Creek	N/A	6.9	146
	Upper Spavinaw Creek	N/A	6.9	252
	Lower Spavinaw Creek	N/A	6.9	221

N/A The measurement was not available due to equipment mailfunctions, or conditions were not suitable to take measurements.

APPENDIX J. CHLOROPHYLL A VALUES

Dry Creek - Sampling between July 22 and August 5,1999

Chlorophyll a values for each treatment (ug/cm^2)

	Mean	Median	Stand.Dev	Min.	Max.	Count	Coeff.Var.
Nitrogen	0.94	0.87	0.49	0.47	2.08	10	0.53
Phosphorus	1.12	1.12	0.24	0.61	1.44	10	0.22
N&P	1.11	1.10	0.33	0.60	1.69	10	0.30
Control	0.96	0.98	0.26	0.57	1.39	10	0.27

Chlorophyll a values and Standard Deviations for each glass vial.

Vial	Nitrogen	Vial	Phosphorus	Vial	N&P	Vial	Control
B-12	0.47	B-4	0.61	D-8	0.60	D-11	0.57
D-10	0.49	C-5	0.94	D-12	0.79	B-2	0.70
D-5	0.55	D-9	1.03	A-1	0.87	B-8	0.78
C-4	0.59	C-11	1.06	C-12	0.93	A-8	0.83
A-4	0.87	A-2	1.11	C-6	1.05	C-10	0.98
C-9	0.88	D-7	1.13	B-5	1.15	B-11	1.11
C-8	1.04	A-6	1.23	A-5	1.17	A-3	1.13
A-7	1.11	C-2	1.26	B-3	1.32	D-6	1.15
B-1	1.29	B-9	1.42	C-3	1.52	C-7	1.39
B-7	2.08	B-6	1.44	B-10	1.69		

One Standard Deviation

Two Standard Deviations

Cloud Creek- Sampling between July 22 and August 5,1999

Chlorophyll a values for each treatment (ug/cm^2)

	Mean	Median	Stand.Dev.	Min.	Max.	Count	Coeff.Var
Nitrogen	4.81	4.55	1.46	3.70	7.99	7	0.30
Phosphorus	5.63	5.47	2.03	3.20	9.01	6	0.36
N&P	5.81	5.65	2.29	3.18	9.13	6	0.39
Control	4.99	4.81	1.54	3.36	6.88	5	0.31

Chlorophyll a values and Standard Deviations for each glass vial.

Vial	Nitrogen
C-8	3.70
C-4	3.90
D-5	4.04
D-10	4.55
B-7	4.65
B-1	4.85
C-9	7.99

Vial	Phosphorus
C-2	3.20
D-9	4.11
D-7	5.26
B-6	5.68
C-11	6.53
C-5	9.01

Vial	N&P
B-3	3.18
D-12	4.07
D-8	4.38
C-6	6.93
C-12	7.16
C-3	9.13

Vial	Control
D-11	3.36
D-6	3.69
C-7	4.81
C-1	6.22
C-10	6.88

One Standard Deviation ------------

Two Standard Deviations _ - _ - _ -

Cherokee Creek- Sampling between July 22 and August 5, 1999

Chlorophyll a values for each treatment (ug/cm^2)

	Mean	Median	Stand.Dev	Min.	Max.	Count	Coeff.Var
Nitrogen	2.00	2.15	0.55	0.74	2.63	10	0.28
Phosphorus	2.42	2.46	0.26	1.96	2.74	9	0.11
N&P	2.79	2.63	0.72	1.66	4.13	10	0.26
Control	1.65	1.62	0.50	1.11	2.82	10	0.30

Chlorophyll a values and Standard Deviations for each glass vial.

Vial	Nitrogen
A-5	0.74
C-9	1.46
B-4	1.85
B-11	1.98
C-6	2.08
D-9	2.22
D-8	2.23
B-6	2.30
C-3	2.53
A-10	2.63

Vial	Phosphorus
D-11	1.96
B-7	2.22
C-1	2.23
B-2	2.35
D-7	2.46
A-8	2.48
A-11	2.66
B-10	2.69
C-8	2.74

Vial	N&P
B-9	1.66
C-11	2.25
B-1	2.35
D-6	2.49
A-12	2.49
C-4	2.77
B-5	2.82
D-12	3.33
A-6	3.62
C-7	4.13

Vial	Control
C-2	1.11
D-5	1.15
B-12	1.35
C-12	1.35
D-10	1.60
B-8	1.63
B-3	1.72
A-9	1.79
C-5	1.96
A-7	2.82

One Standard Deviation ----------

Two Standard Deviations -.-.-.-.-

Columbia Hollow - Sampling between July 22 and August 5, 1999

Chlorophyll a values for each treatment (ug/cm^2)

	Mean	Median	Stand.Dev	Min.	Max.	Count	Coeff.Var
Nitrogen	0.62	0.58	0.39	0.25	1.64	10	0.63
Phosphorus	0.58	0.56	0.10	0.49	0.79	10	0.17
N&P	0.69	0.70	0.13	0.53	0.93	10	0.18
Control	0.60	0.60	0.14	0.42	0.82	10	0.23

Chlorophyll a values and Standard Deviations for each glass vial.

Vial	Nitrogen
B-4	0.25
C-4	0.27
D-10	0.41
B-9	0.47
B-7	0.53
A-5	0.62
C-10	0.65
D-5	0.67
C-5	0.69
A-3	1.64

Vial	Phosphorus
A-1	0.49
A-8	0.54
B-2	0.51
B-6	0.51
B-12	0.59
C-2	0.58
C-7	0.71
C-12	0.57
D-8	0.79
D-9	0.52

Vial	N&P
A-2	0.70
A-7	0.93
B-1	0.72
B-5	0.53
B-11	0.59
C-3	0.64
C-8	0.69
C-11	0.53
D-7	0.80
D-12	0.81

Vial	Control
A-6	0.42
B-3	0.44
B-12	0.50
D-8	0.51
C-2	0.53
C-7	0.66
D-9	0.67
C-12	0.72
B-8	0.75
A-4	0.82

One Standard Deviation ----------

Two Standard Deviations -- — - — --

Beaty Creek- Sampling between July 22 and August 5, 1999

Chlorophyll a values for each treatment (ug/cm^2)

	Mean	Median	Stand.Dev.	Min.	Max.	Count	Coeff.Var
Nitrogen	1.91	1.78	0.46	1.34	2.60	10	0.24
Phosphorus	2.92	2.74	0.89	1.35	4.55	10	0.31
N&P	2.82	2.78	0.85	1.42	4.23	10	0.30
Control	1.82	1.66	0.56	1.29	2.80	10	0.31

Chlorophyll a values and Standard Deviations for each glass vial.

Vial	Nitrogen
C-11	1.34
B-12	1.36
B-7	1.54
C-3	1.73
A-4	1.75
A-6	1.82
D-11	2.18
D-6	2.31
B-1	2.52
C-6	2.60

Vial	Phosphorus
D-12	1.35
C-4	2.14
C-9	2.47
C-7	2.66
B-5	2.72
B-4	2.77
B-9	3.33
D-7	3.58
A-7	3.60
A-3	4.55

Vial	N&P
C-8	1.42
B-3	2.11
B-10	2.26
A-5	2.27
B-8	2.56
D-9	3.00
C-10	3.15
C-1	3.56
D-8	3.66
A-1	4.23

Vial	Control
C-5	1.29
D-10	1.35
B-11	1.39
C-12	1.49
A-8	1.53
D-5	1.79
B-2	1.81
B-6	1.95
A-2	2.79
C-2	2.80

One Standard Deviation ________

Two Standard Deviations - - - - - -

Lower Spavinaw -Sampling between July 22 and August 5,1999

Chlorophyll a values for each treatment (ug/cm^2)

	Mean	Median	Stand.Dev.	Min.	Max.	Count	Coeff. Var
Nitrogen	0.41	0.45	0.13	0.13	0.52	10	0.31
Phosphorus	0.44	0.42	0.10	0.29	0.64	9	0.24
N&P	0.49	0.44	0.17	0.24	0.81	10	0.35
Control	0.45	0.50	0.18	0.14	0.68	10	0.39

Chlorophyll a values and Standard Deviations for each glass vial.

Vial	Nitrogen
D-6	0.13
B-3	0.27
D-10	0.34
A-6	0.42
C-2	0.42
B-9	0.48
C-6	0.48
A-3	0.49
B-7	0.51
C-10	0.52

Vial	Phosphorus
D-9	0.29
A-7	0.36
D-7	0.38
C-3	0.39
B-5	0.42
B-12	0.45
C-7	0.50
C-11	0.52
A-2	0.64

Vial	N&P
B-1	0.24
D-8	0.35
C-12	0.41
A-1	0.41
B-11	0.42
C-4	0.46
D-12	0.47
B-8	0.61
A-8	0.73
C-8	0.81

Vial	Control
B-2	0.14
D-11	0.24
A-5	0.34
D-5	0.39
C-5	0.47
B-10	0.53
C-9	0.53
A-4	0.57
B-6	0.67
C-1	0.68

One Standard Deviation ----------

Two Standard Deviations -- — - — -.

Dry Creek- Sampling between August 26 and September 9,1999

Chlorophyll a values for each treatment (ug/cm^2)

	Mean	Median	Stand. Dev	Min.	Max.	Count	Coeff.Var
Nitrogen	0.26	0.25	0.21	-0.02	0.54	10	0.83
Phosphorus	0.33	0.26	0.22	0.03	0.72	10	0.68
N&P	0.70	0.64	0.53	0.23	2.01	10	0.76
Control	0.34	0.32	0.25	0.01	0.79	10	0.73

Chlorophyll a values and Standard Deviations for each glass vial.

Vial	Nitrogen
B-4	-0.02
D-10	0.03
C-3	0.06
A-7	0.13
D-5	0.24
B-6	0.27
B-12	0.30
C-10	0.52
A-4	0.53
C-5	0.54

Vial	Phosphorus
B-10	0.03
D-9	0.08
D-8	0.18
C-1	0.22
B-1	0.24
C-7	0.28
C-12	0.48
A-2	0.50
A-5	0.56
B-8	0.72

Vial	N&P
D-11	0.23
D-7	0.24
C-11	0.26
C-6	0.43
B-9	0.62
C-2	0.66
A-1	0.73
B-3	0.81
B-7	1.02
A-6	2.01

Vial	Control
D-12	0.01
D-6	0.08
B-11	0.08
A-8	0.30
B-5	0.32
C-9	0.32
C-8	0.36
A-3	0.52
C-4	0.60
B-2	0.79

One Standard Deviation ------------

Two Standard Deviations - - — - — - .

Cloud Creek - Sampling between August 25 and September 9, 1999

Chlorophyll a values for each treatment (ug/cm^2)

	Mean	Median	Stand. Dev	Min.	Max.	Count	Co. Var.
Nitrogen	3.38	3.39	1.07	2.04	5.69	9	0.32
Phosphorus	3.34	3.37	0.64	2.38	4.46	8	0.19
N&P	3.83	3.84	1.13	2.29	5.54	8	0.29
Control	4.34	4.23	1.29	2.53	6.29	8	0.30

Chlorophyll a values and Standard Deviations for each glass vial.

Vial	Nitrogen
C-7	2.04
B-9	2.17
A-1	2.79
C-10	3.38
B-1	3.39
B-5	3.57
D-6	3.61
D-11	3.80
C-4	5.69

Vial	Phosphorus
A-3	2.38
C-6	2.69
D-7	3.18
B-3	3.29
C-9	3.44
B-6	3.55
C-2	3.77
D-12	4.46

Vial	N&P
A-4	2.29
B-4	2.72
C-12	3.06
B-7	3.48
C-8	4.20
D-8	4.47
C-1	4.86
D-9	5.54

Vial	Control
B-8	2.53
B-2	3.33
A-2	3.41
C-11	3.87
D-10	4.59
C-5	4.99
C-3	5.74
D-5	6.29

One Standard Deviation ________

Two Standard Deviations - - —- - — - -

Cherokee Creek- Sampling between August 26 and September 9, 1999

Chlorophyll a values for each treatment (ug/cm^2)

	Mean	Median	Stand. Dev	Min.	Max.	Count	Co.Var
Nitrogen	5.90	5.82	1.16	4.01	7.63	10	0.20
Phosphorus	7.24	7.25	1.68	5.16	10.32	10	0.23
N&P	8.48	8.60	2.02	5.76	12.18	10	0.24
Control	4.44	4.28	0.94	3.07	6.13	10	0.21

Chlorophyll a values and Standard Deviations for each glass vial.

Vial	Nitrogen
A-3	4.01
A-7	4.40
B-3	5.11
B-7	5.77
C-3	5.82
D-11	5.83
B-11	6.53
C-7	6.80
C-10	7.09
D-7	7.63

Vial	Phosphorus
B-1	5.16
A-5	5.53
B-9	5.60
C-2	6.26
C-5	6.89
B-5	7.61
C-12	7.73
D-5	8.09
A-1	9.23
D-9	10.32

Vial	N&P
C-4	5.76
C-9	6.21
B-4	6.37
C-8	7.96
A-2	8.42
D-12	8.79
A-8	8.80
B-8	10.09
B-12	10.22
D-8	12.18

Vial	Control
B-2	3.07
A-4	3.74
C-11	3.77
B-6	3.80
A-6	4.02
D-10	4.54
C-1	4.69
D-6	5.16
C-6	5.50
B-10	6.13

One Standard Deviation ________

Two Standard Deviations _ - — - — -

Columbia Hollow- Sampling between August 26 and September 9, 1999

Chlorophyll a values for each treatment (ug/cm^2)

	Mean	Median	Stand. Dev.	Min.	Max.	Count	Coeff.Var.
Nitrogen	0.51	0.52	0.15	0.22	0.77	10	0.30
Phosphorus	0.37	0.31	0.15	0.21	0.68	10	0.42
N&P	0.50	0.45	0.18	0.28	0.82	9	0.36
Control	0.42	0.38	0.17	0.23	0.81	10	0.40

Chlorophyll a values and Standard Deviations for each glass vial.

	Vial	Nitrogen
	B-1	0.22
out of water	D-7	0.35
	A-3	0.46
	C-4	0.47
	B-7	0.50
	C-10	0.54
	B-11	0.57
	C-7	0.59
	A-5	0.63
out of water	D-10	0.77

	Vial	Phosphorus
	B-2	0.21
	C-1	0.22
	B-10	0.27
	C-9	0.28
	C-8	0.30
	B-8	0.32
out of water	D-8	0.39
out of water	D-9	0.46
	A-6	0.54
	A-2	0.68

	Vial	N&P
	C-6	0.28
	B-6	0.33
	B-9	0.45
	B-4	0.45
	D-6	0.45
	C-2	0.46
	A-1	0.52
out of water	D-11	0.77
	C-11	0.82

	Vial	Control
	C-5	0.23
	B-5	0.27
	D-5	0.32
out of water	B-12	0.33
	A-4	0.36
	A-7	0.41
	B-3	0.43
out of water	D-12	0.48
	C-3	0.56
out of water	C-12	0.81

One Standard Deviation ------------

Two Standard Deviations -.-- - -- - -

Beaty Creek- Sampling between August 26 and September 9, 1999

Chlorophyll a values for each treatment (ug/cm^2)

	Mean	Median	Stand. Dev.	Min.	Max.	Count	Co.Var
Nitrogen	2.98	2.91	0.57	1.97	4.26	10	0.19
Phosphorus	3.42	3.27	0.86	2.39	5.37	10	0.25
N&P	3.41	3.59	0.76	2.19	4.41	10	0.22
Control	2.87	2.81	0.45	2.29	3.85	10	0.16

Chlorophyll a values and Standard Deviations for each glass vial.

Vial	Nitrogen	Vial	Phosphorus	Vial	N&P	Vial	Control
D-6	1.97	D-8	2.39	D-7	2.19	D-5	2.29
D-9	2.72	B-8	2.56	C-7	2.44	B-6	2.30
B-5	2.79	B-4	2.90	B-10	2.68	A-6	2.70
A-8	2.81	A-7	2.95	C-11	3.22	B-2	2.78
C-5	2.86	D-12	3.26	B-3	3.54	D-10	2.78
B-12	2.96	A-1	3.28	A-2	3.63	C-6	2.83
B-1	2.97	C-8	3.75	C-2	3.84	A-3	2.92
C-9	3.18	C-1	3.83	B-7	4.02	C-4	3.13
C-3	3.30	B-9	3.92	A-5	4.16	C-10	3.16
A-4	4.26	C-12	5.37	D-11	4.41	B-11	3.85

One Standard Deviation ________

Two Standard Deviations _ . _ . _ .

Upper Spavinaw Creek - Sampling between August 26 and September 9, 1999

Chlorophyll a values for each treatment (ug/cm^2)

	Mean	Median	Stand. Dev.	Min.	Max.	Count	Co.Var
Nitrogen	1.31	1.32	0.48	0.61	2.15	10	0.37
Phosphorus	1.63	1.45	0.48	1.12	2.53	9	0.30
N&P	1.71	1.65	0.71	1.05	3.48	10	0.42
Control	1.95	1.65	0.71	1.48	3.84	10	0.36

Chlorophyll a values and Standard Deviations for each glass vial.

Vial	Nitrogen
C-11	0.61
D-11	0.73
D-6	1.02
C-6	1.08
B-5	1.30
C-3	1.34
B-10	1.37
A-3	1.54
B-3	1.92
A-6	2.15

Vial	Phosphorus
A-8	1.12
D-7	1.15
B-1	1.35
C-12	1.44
A-4	1.45
C-5	1.53
D-12	1.92
C-4	2.21
B-12	2.53

Vial	N&P
C-8	1.05
C-9	1.10
B-8	1.19
B-9	1.29
A-7	1.60
C-2	1.70
D-8	1.75
B-2	1.89
D-10	2.07
A-1	3.48

Vial	Control
D-5	1.48
D-9	1.54
C-10	1.59
C-7	1.59
B-4	1.65
A-5	1.66
B-7	1.79
C-1	2.11
B-11	2.22
A-2	3.84

One Standard Deviation ---------

Two Standard Deviations .-.-.-.

Lower Spavinaw Creek- Sampling between August 26 and September 9, 1999

Chlorophyll a values for each treatment (ug/cm^2)

	Mean	Median	Stand.De	Min.	Max.	Count	Co.Var.
Nitrogen	3.42	3.33	0.88	2.51	5.02	10	0.26
Phosphorus	3.21	3.29	0.64	2.26	3.97	10	0.20
N&P	3.39	3.14	0.80	2.20	4.51	10	0.24
Control	3.17	3.31	0.77	1.38	4.08	10	0.24

Chlorophyll a values and Standard Deviations for each glass vial.

Vial	Nitrogen	Vial	Phosphorus	Vial	N&P		Vial	Control
C-1	2.51	C-10	2.26	B-6	2.20		D-12	1.38
D-5	2.51	D-10	2.43	D-9	2.56	overed	A-5	2.63
A-6	2.70	A-1	2.47	D-6	2.97		A-3	2.87
A-4	2.87	B-5	3.11	A-2	3.03		D-8	3.08
B-4	3.26	B-9	3.20	C-7	3.07		B-8	3.30
C-5	3.40	B-1	3.39	B-2	3.21		C-11	3.31
D-11	3.50	C-2	3.45	A-7	3.63		B-3	3.63
B-7	3.69	A-8	3.88	C-3	4.30		C-4	3.73
C-9	4.79	C-6	3.90	C-12	4.45		B-11	3.73
B-12	5.02	D-7	3.97	B-10	4.51		C-8	4.08

One Standard Deviation ------------
Two Standard Deviations _ . _ . _

Dry Creek- Sampling between November 30 and December 12, 1999

Chlorophyll a values for each treatment (ug/cm^2)

	Mean	Median	Stand. Dev.	Min.	Max.	Count	Coeff.Var
Nitrogen	0.14	0.15	0.08	0.03	0.28	10	0.58
Phosphorus	0.16	0.16	0.10	0.02	0.31	10	0.63
N&P	0.15	0.13	0.09	0.05	0.37	10	0.62
Control	0.11	0.10	0.08	0.01	0.23	10	0.74

Chlorophyll a values and Standard Deviations for each glass vial

Vial	Nitrogen
B-10	0.03
B-8	0.05
A-7	0.05
D-12	0.11
C-10	0.14
A-2	0.15
C-7	0.17
D-8	0.18
B-4	0.21
C-2	0.28

Vial	Phosphorus
A-8	0.02
B-12	0.05
B-2	0.07
B-5	0.12
D-11	0.13
C-8	0.19
A-3	0.20
C-4	0.22
D-7	0.30
C-9	0.31

Vial	N&P
A-6	0.05
B-9	0.07
B-7	0.12
D-10	0.12
A-1	0.13
C-3	0.13
C-11	0.13
B-3	0.15
C-5	0.25
D-6	0.37

Vial	Control
A-5	0.01
B-11	0.02
A-4	0.05
C-12	0.05
B-1	0.09
B-6	0.12
C-1	0.12
C-6	0.22
D-5	0.22
D-9	0.23

One Standard Deviation __________
Two Standard Deviations - - — - — - -

Cloud Creek- Sampling between November 30 and December 12, 1999

Chlorophyll a values for each treatment (ug/cm^2)

	Mean	Median	Stand. Dev.	Min.	Max.	Count	Coeff.Var
Nitrogen	0.08	0.05	0.10	0.00	0.33	10	1.28
Phosphorus	0.05	0.01	0.07	0.00	0.22	10	1.63
N&P	0.04	0.02	0.04	0.00	0.12	10	0.99
Control	0.02	0.01	0.04	-0.01	0.10	10	1.50

Chlorophyll a values and Standard Deviations for each glass vial

Vial	Nitrogen
D-5	0.00
B-3	0.00
C-12	0.01
D-9	0.02
C-3	0.03
C-8	0.07
B-9	0.07
B-7	0.09
A-4	0.14
A-8	0.33

Vial	Phosphorus
C-11	0.00
D-6	0.00
B-1	0.00
C-4	0.01
B-10	0.01
C-7	0.01
B-5	0.02
D-10	0.04
A-2	0.14
A-7	0.22

Vial	N&P
C-1	0.00
B-4	0.01
B-11	0.01
D-8	0.01
C-5	0.02
D-11	0.02
C-9	0.05
A-5	0.05
A-1	0.10
B-8	0.12

Vial	Control
B-2	-0.01
C-2	0.00
D-7	0.00
D-12	0.00
C-6	0.01
C-10	0.01
A-6	0.02
B-6	0.02
B-12	0.07
A-3	0.10

One Standard Deviation ------------

Two Standard Deviations - - — - — - -

Cherokee Creek Sampling between November 30 and December 12,1999

Chlorophyll a values for each treatment (ug/cm^2)

	Mean	Median	Stand. Dev.	Min.	Max.	Count	Coeff.Var
Nitrogen	0.11	0.10	0.04	0.05	0.19	10	0.40
Phosphorus	0.27	0.26	0.16	0.06	0.54	10	0.61
N&P	0.13	0.11	0.06	0.05	0.23	10	0.49
Control	0.13	0.08	0.12	0.03	0.45	10	0.92

Chlorophyll a values and Standard Deviations for each glass vial

Vial	Nitrogen
D-10	0.05
B-7	0.06
B-10	0.08
B-1	0.08
C-12	0.09
A-1	0.12
D-6	0.12
C-1	0.13
C-6	0.15
A-8	0.19

Vial	Phosphorus
B-11	0.06
D-9	0.08
C-2	0.10
B-8	0.18
D-5	0.23
A-2	0.29
A-5	0.37
C-5	0.40
C-11	0.41
B-4	0.54

Vial	N&P
B-2	0.05
B-5	0.07
D-12	0.09
B-9	0.09
C-9	0.10
C-7	0.11
C-3	0.14
D-8	0.20
A-4	0.21
A-7	0.23

Vial	Control
B-6	0.03
C-8	0.06
D-11	0.06
B-12	0.07
C-10	0.07
A-6	0.09
C-4	0.15
B-3	0.16
A-3	0.20
D-7	0.45

One Standard Deviation __________

Two Standard Deviations _ _ — _ — _

Beaty Creek- Sampling between November 30 and December 12,1999

Chlorophyll a values for each treatment (ug/cm^2)

	Mean	Median	Stand.Dev	Min.	Max.	Count	Coeff.Var
Nitrogen	0.99	0.89	0.43	0.37	1.78	9	0.43
Phosphorus	0.86	0.86	0.20	0.59	1.17	9	0.23
N&P	0.80	0.62	0.40	0.37	1.46	8	0.50
Control	0.88	0.92	0.31	0.48	1.22	6	0.36

Chlorophyll a values and Standard Deviations for each glass vial

Vial	Nitrogen
C-2	0.37
D-7	0.64
B-11	0.71
B-4	0.79
A-3	0.89
A-8	1.15
C-5	1.20
B-5	1.34
C-11	1.78

Vial	Phosphorus
D-8	0.59
B-3	0.65
B-12	0.66
A-5	0.80
A-4	0.86
D-9	0.91
B-8	0.95
C-3	1.10
C-7	1.17

Vial	N&P
A-2	0.37
C-9	0.50
B-2	0.54
D-12	0.62
D-5	0.63
B-10	1.01
C-8	1.27
A-7	1.46

Vial	Control
D-10	0.48
D-6	0.57
B-9	0.79
C-4	1.04
B-6	1.16
C-10	1.22

One Standard Deviation ------------

Two Standard Deviations - - — - — - -

Upper Spavinaw Creek- Sampling between November 30 and December 12, 1999

Chlorophyll a values for each treatment (ug/cm^2)

	Mean	Median	Stand. Dev.	Min.	Max.	Count	Coeff.Var
Nitrogen	0.66	0.68	0.19	0.30	0.87	10	0.28
Phosphorus	0.60	0.62	0.15	0.35	0.78	10	0.24
N&P	0.71	0.75	0.27	0.21	1.08	10	0.38
Control	0.48	0.51	0.22	0.10	0.80	10	0.46

Chlorophyll a values and Standard Deviations for each glass vial

Vial	Nitrogen	Vial	Phosphorus	Vial	N&P	Vial	Control
A-3	0.30	A-1	0.35	B-2	0.21	B-12	0.10
C-10	0.45	C-9	0.35	C-8	0.37	A-6	0.22
D-8	0.56	A-7	0.60	B-11	0.60	B-4	0.29
C-6	0.58	C-1	0.60	D-5	0.65	A-4	0.46
B-8	0.64	B-5	0.60	C-12	0.74	C-7	0.47
A-5	0.71	D-9	0.64	D-12	0.77	C-11	0.55
B-3	0.76	C-5	0.68	A-8	0.77	D-11	0.57
C-4	0.81	B-1	0.69	B-7	0.92	C-2	0.65
B-10	0.86	B-9	0.74	A-2	0.97	B-6	0.69
D-10	0.87	D-7	0.78	C-3	1.08	D-6	0.80

One Standard Deviation ____________

Two Standard Deviations - - — - — - -

Lower Spavinaw Creek- Sampling between November 30 and December 12, 1999

Chlorophyll a values for each treatment (ug/cm^2)

	Mean	Median	Stand. Dev	Min.	Max.	Count	Coeff.Var
Nitrogen	0.60	0.55	0.22	0.38	0.98	10	0.37
Phosphorus	0.54	0.52	0.14	0.37	0.84	10	0.26
N&P	0.64	0.57	0.24	0.36	1.21	10	0.38
Control	0.53	0.42	0.29	0.32	1.18	10	0.55

Chlorophyll a values and Standard Deviations for each glass vial

Vial	Nitrogen
C-6	0.38
B-3	0.38
C-3	0.39
D-7	0.42
C-10	0.50
D-10	0.59
B-5	0.69
A-5	0.73
B-10	0.92
A-3	0.98

Vial	Phosphorus
C-9	0.37
B-2	0.41
C-4	0.43
B-8	0.46
D-12	0.51
C-7	0.53
B-9	0.57
D-8	0.58
A-1	0.70
A-8	0.84

Vial	N&P
C-8	0.36
B-6	0.48
B-4	0.50
A-7	0.52
A-4	0.57
D-9	0.57
D-5	0.66
C-1	0.69
C-12	0.88
B-11	1.21

Vial	Control
C-11	0.32
B-7	0.33
C-5	0.33
A-2	0.39
C-2	0.42
D-6	0.42
B-1	0.47
D-11	0.50
A-6	0.97
B-12	1.18

One Standard Deviation ---------

Two Standard Deviations - - — - — - -

Dry Creek - Sampling between February 25 and March 8, 2000

Chlorophyll a values for each treatment (ug/cm^2)

	Mean	Median	Stand. Dev.	Min.	Max.	Count	Coeff. Var
Nitrogen	5.25	5.49	1.10	2.93	6.90	9	0.21
Phosphorus	5.31	5.39	1.22	3.75	7.64	7	0.23
N&P	5.88	5.54	1.40	4.14	8.24	9	0.24
Control	4.97	4.84	1.34	2.87	7.53	10	0.27

Chlorophyll a values for each glass vial and Standard Deviations

	Vial	Nitrogen
	D-11	2.93
	B-1	4.65
covered	B-5	4.78
	A-6	5.26
	A-2	5.49
	C-4	5.51
	C-7	5.69
	D-7	6.07
	B-9	6.90

Vial	Phosphorus
A-3	3.75
C-6	4.28
B-3	5.20
A-8	5.39
B-7	5.42
D-5	5.48
D-10	7.64

	Vial	N&P
covered	A-1	4.14
	B-8	4.52
	A-5	4.90
	B-2	5.29
	C-8	5.54
	D-8	5.78
covered	C-1	7.18
	B-10	7.33
	C-9	8.24

Vial	Control
C-11	2.87
B-6	3.51
A-4	4.23
C-3	4.72
B-4	4.84
B-11	4.84
C-5	5.32
A-7	5.48
D-6	6.39
D-9	7.53

One Standard Deviation ___________

Two Standard Deviations _ _ _ _ _ _ _

Cloud Creek - Sampling between February 25 and March 8,2000

Chlorophyll a values for each treatment (ug/cm^2)

	Mean	Median	Stand. Dev.	Min.	Max.	Count	Coeff. Var
Nitrogen	6.72	6.20	1.76	5.28	8.67	3	0.26
Phosphorus	4.21	3.41	1.41	3.39	5.85	3	0.34
N&P	4.56	2.80	3.60	2.18	8.70	3	0.79
Control	5.22	5.22	X	5.22	5.22	1	X

Chlorophyll a values for each glass vial and Standard Deviations

Vial	Nitrogen
C-12	5.28
D-12	6.20
B-12	8.67

Vial	Phosphorus
D-11	3.39
B-10	3.41
C-11	5.85

Vial	N&P
D-10	2.18
C-9	2.80
B-11	8.70

Vial	Control
C-10	5.22

One Standard Deviation ________

Two Standard Deviations - - — - — - -

Cherokee Creek - Sampling between February 25 and March 8,2000

Chlorophyll a values for each treatment (ug/cm^2)

	Mean	Median	Stand. Dev	Min.	Max.	Count	Coeff. Var
Nitrogen	0.27	0.17	0.24	0.06	0.68	10	0.89
Phosphorus	0.24	0.19	0.18	0.05	0.60	10	0.74
N&P	0.51	0.14	0.65	0.04	1.62	10	1.28
Control	0.29	0.13	0.30	0.05	0.98	10	1.07

Chlorophyll a values for each glass vial and Standard Deviations

Vial	Nitrogen
D-7	0.06
B-11	0.08
C-7	0.08
A-6	0.14
A-1	0.17
B-4	0.17
D-12	0.19
B-8	0.43
C-3	0.68
C-12	0.68

Vial	Phosphorus
D-8	0.05
C-6	0.07
A-3	0.13
D-11	0.16
B-3	0.17
B-9	0.20
C-11	0.23
C-4	0.29
B-6	0.47
A-5	0.60

Vial	N&P
C-9	0.04
D-10	0.06
C-8	0.12
A-8	0.13
B-10	0.13
D-5	0.15
A-2	0.16
C-2	1.13
B-2	1.57
B-7	1.62

Vial	Control
B-12	0.05
D-9	0.07
A-4	0.09
D-6	0.09
C-10	0.13
C-5	0.14
B-5	0.23
A-7	0.48
B-1	0.59
C-1	0.98

One Standard Deviation __________

Two Standard Deviations _ . _ . _ .

Columbia Hollow- Sampling between February 25 and March 8

Chlorophyll a values for each treatment (ug/cm^2)

	Mean	Median	Stand. Dev.	Min.	Max.	Count	Coeff. Var
Nitrogen	0.81	0.71	0.28	0.53	1.36	9	0.34
Phosphorus	0.73	0.79	0.21	0.39	1.06	10	0.29
N&P	0.81	0.79	0.23	0.45	1.19	10	0.28
Control	0.77	0.79	0.26	0.34	1.06	9	0.33

Chlorophyll a values for each glass vial and Standard Deviations

	Vial	Nitrogen
	C-9	0.53
	A-6	0.56
	D-12	0.60
	D-7	0.61
	B-8	0.71
debris	B-1	0.92
debris	A-3	0.96
	B-9	1.05
debris	C-1	1.36

	Vial	Phosphorus
	B-11	0.39
	C-10	0.44
	C-7	0.62
	A-5	0.65
debris	C-2	0.78
	A-4	0.80
	D-11	0.81
debris	B-3	0.82
	B-7	0.96
	D-8	1.06

	Vial	N&P
	C-12	0.45
	B-5	0.61
	B-10	0.66
	D-9	0.77
	B-4	0.78
	C-4	0.79
	D-6	0.83
	A-7	0.92
	C-6	1.14
debris	A-2	1.19

	Vial	Control
	B-12	0.34
	D-10	0.52
	C-11	0.53
debris	B-2	0.77
	A-8	0.79
	B-6	0.83
debris	C-3	1.02
	D-5	1.03
debris	A-1	1.06

One Standard Deviation ----------

Two Standard Deviations - - — - — - -

Beaty Creek- Sampling between February 25 and March 8, 2000

Chlorophyll a values for each treatment (ug/cm^2)

	Mean	Median	Stand. Dev	Min.	Max.	Count	Coeff. Var
Nitrogen	2.84	2.96	0.54	1.81	3.34	10	0.19
Phosphorus	2.69	2.40	0.76	1.88	4.02	10	0.28
N&P	2.20	2.04	0.70	1.24	3.50	10	0.32
Control	2.24	2.04	0.86	1.45	4.26	10	0.39

Chlorophyll a values for each glass vial and Standard Deviations

Vial	Nitrogen
C-8	1.81
B-4	2.04
A-7	2.67
D-11	2.73
C-1	2.86
B-7	3.07
A-1	3.24
B-12	3.30
C-9	3.33
D-8	3.34

Vial	Phosphorus
A-6	1.88
B-3	2.03
A-2	2.07
B-5	2.19
C-2	2.30
C-7	2.49
D-7	2.85
D-12	3.25
C-12	3.78
B-11	4.02

Vial	N&P
A-5	1.24
D-6	1.61
A-3	1.65
C-5	1.95
B-10	1.96
C-3	2.12
C-10	2.24
B-1	2.61
B-8	3.11
D-10	3.50

Vial	Control
A-4	1.45
C-4	1.53
A-8	1.67
B-9	1.69
D-9	2.00
B-2	2.08
B-6	2.27
D-5	2.30
C-6	3.14
C-11	4.26

One Standard Deviation ________

Two Standard Deviations -.-.-.-.-

Upper Spavinaw Creek- Sampling between February 25 and March 8, 2000

Chlorophyll a values for each treatment (ug/cm^2)

	Mean	Median	Stand. Dev.	Min.	Max.	Count	Coeff. Var
Nitrogen	2.56	2.68	0.81	0.78	3.58	10	0.32
Phosphorus	2.54	2.51	0.59	1.45	3.69	10	0.23
N&P	2.66	2.34	0.82	1.80	4.23	10	0.31
Control	2.41	2.33	0.55	1.52	3.16	9	0.23

Chlorophyll a values for each glass vial and Standard Deviations

Vial	Nitrogen
A-4	0.78
C-4	1.85
C-10	2.30
B-4	2.47
D-12	2.57
C-8	2.80
B-12	2.81
D-8	3.00
B-6	3.47
A-8	3.58

Vial	Phosphorus
B-1	1.45
A-3	1.99
D-10	2.37
C-6	2.49
B-5	2.50
A-6	2.53
C-9	2.63
C-3	2.79
B-10	3.01
D-7	3.69

Vial	N&P
C-2	1.80
C-12	1.87
D-5	2.06
D-11	2.27
A-2	2.29
B-8	2.40
B-3	2.72
B-11	3.07
C-7	3.84
A-7	4.23

Vial	Control
A-1	1.52
C-5	1.92
B-2	2.01
D-6	2.25
B-7	2.33
D-9	2.51
C-11	2.97
A-5	3.01
B-9	3.16

One Standard Deviation ----------

Two Standard Deviations -.-.-.-

Lower Spavinaw Creek- Sampling between February 25 and March 8, 2000

Chlorophyll a values for each treatment (ug/cm^2)

	Mean	Median	Stand. Dev.	Min.	Max.	Count	Coeff. Var
Nitrogen	2.39	2.31	0.50	1.46	3.22	10	0.21
Phosphorus	2.35	2.49	0.73	0.61	3.10	10	0.31
N&P	2.41	2.34	0.58	1.55	3.44	8	0.24
Control	2.81	2.86	0.62	1.97	3.71	7	0.22

Chlorophyll a values for each glass vial and Standard Deviations

Vial	Nitrogen	
A-4	1.46	
D-10	2.12	
A-8	2.13	
B-12	2.14	part.cover
B-8	2.23	
B-3	2.40	
C-7	2.45	
D-8	2.81	
C-3	2.95	
C-12	3.22	

Vial	Phosphorus
D-6	0.61
B-4	1.79
A-7	2.22
A-3	2.27
B-6	2.44
C-5	2.54
B-11	2.66
C-9	2.91
C-2	3.00
D-9	3.10

Vial	N&P
A-6	1.55
B-7	2.04
D-12	2.09
D-7	2.34
B-10	2.35
C-8	2.49
C-11	2.99
C-4	3.44

Vial	Control
B-5	1.97
D-5	2.34
D-11	2.42
C-10	2.86
C-6	2.97
A-5	3.40
B-9	3.71

One Standard Deviation ------------

Two Standard Deviations - - — - — - -

APPENDIX K. UTM COORDINATES FOR SAMPLING SITES

Table K-1. Universal Transverse Mercator coordinates for each sampling site. Zone 15.

Stream Name	X Coordinate	Y Coordinate
Dry Creek	335,203	4,020,509
Cloud Creek	342,111	4,020,753
Cherokee Creek	351,278	4,017.510
Columbia Hollow	365,232	4,022,690
Beaty Creek	340,668	4,024,617
Upper Spavinaw Creek	370,290	4,028.812
Lower Spavinaw Creek	340,513	4,023,711

APPENDIX L. QUALITY CONTROL

Table L-1. Quality Control for Soluble Reactive Phosphorus. Detection limit = 0.01mg/L. Biosystems and Agricultural Engineering Laboratory.

Date	Sample #	Sample Estimate (mg/L)	Duplicate Estimate (mg/L)	% Difference	Accept ± 10%	Reject >± 10%
August 6,1999	Dry Creek	0.03	0.04	33		X
	Cherokee Creek	0.03	0.03	0	X	
	Cloud Creek	0.04	0.04	0	X	
	Blank	0.00	0.00	0	X	
	Blank	0.00	0.01	0	X	
August 26,1999	Beaty Creek	0.03	0.07	133		X
	Blank	0.00	0.00	0	X	
	Blank	0.00	0.01	0	X	
	Upper Spavinaw Creek	0.03	0.04	33		X
December 2,1999	Upper Spavinaw Creek	0.02	0.02	0	X	
	Cloud Creek	0.02	0.03	50		X
	Lower Spavinaw Creek	0.01	0.03	200		X
	Blank	0.00	0.01	0	X	
December 15,1999	Cherokee Creek	0.02	0.02	0	X	
	Dry Creek	0.01	0.02	100		X
	Lower Spavinaw Creek	0.05	0.05	0	X	
	Blank	0.00	0.01	0	X	
	Blank	0.00	0.01	0	X	
February 25,2000	Dry Creek	0.01	0.01	0	X	
	Upper Spavinaw Creek	0.03	0.02	33		X
	Lower Spavinaw Creek	0.03	0.03	0	X	
	Blank	0.00	0.00	0	X	
	Blank	0.00	0.00	0	X	
March 6,2000	Lower Spavinaw Creek	0.06	0.05	17		X
	Dry Creek	0.01	0.05	400		X
	Beaty Creek	0.03	0.01	67		X
	Blank	0.00	0.00	0	X	
	Blank	0.00	0.00	0	X	

Note: Due to sample concentrations near detection limit, the data are still deamed acceptable for my statistical analysis.

Table L-2. Quality Control for NO_3-N. Detection level = 0.1mg/L. Soil, Water and Forage Analytical Laboratory.

Date	Sample #	Sample Estimate (mg/L)	Duplicate Estimate (mg/L)	% Difference	Accept ± 10%	Reject >± 10%
July 23, 1999	Dry Creek	0.6	0.6	0	X	
	Cloud Creek	1.6	1.6	3	X	
	Lower Spavinaw Creek	3.3	3.3	0	X	
August 9,1999	Cloud Creek	1.5	1.4	7	X	
	Dry Crek	0.6	0.6	0	X	
	EPA	1.1*	1.1	0	X	
	Blank	0.0	0.0	0	X	
	Blank	0.0	0.0	0	X	
	Blank	0.0	0.1	0	X	
August 27,1999	Lower Spavinaw Creek	2.8	2.8	0	X	
	Beaty Creek	1.9	1.9	0	X	
	Dry Creek	0.7	0.7	0	X	
	EPA	1.1*	1.1	0	X	
	Blank	0.1	0.1	0	X	
	Blank	0.0	0.1	0	X	
	Blank	0.0	0.1	0	X	
	Blank	0.0	0.1	0	X	
September 13,1999	Lower Spavinaw Creek	2.7	2.6	4	X	
	Cloud Creek	1.7	1.7	0	X	
	EPA	2.1*	2.09	0	X	
	EPA	1.1*	1.1	0	X	
	Blank	0.0	0.0	0	X	
	Blank	0.0	0.0	0	X	
	Blank	0.0	0.0	0	X	
	Blank	0.0	0.0	0	X	
	Blank	0.0	0.0	0	X	
December 7,1999	Lower Spavinaw Creek	2.7	2.7	0	X	
	Columbia Hollow	0.5	0.5	0	X	
	EPA	0.03*	1.1	3567		X
	Blank	0.0	0.1	0	X	
	Blank	0.0	0.1	0	X	
	Blank	0.0	0.1	0	X	
	Blank	0.0	0.1	0	X	
	Blank	0.0	0.1	0	X	
	Blank	0.0	0.0	0	X	
December 15,1999	Cherokee Creek	2.8	2.8	0	X	
	Cloud Creek	2.4	2.5	4	X	
	EPA	1.1*	1.1	0	X	
March 13,2000	417	3.0	2.1	30		X
	426	0.1	0.9	800		X
	436	6.1	6.9	13		X
	EPA	1.1*	1.1	0	X	
	EPA	6.0*	6.1	2	X	

* EPA Certified Concentrations

Table L-3. Quality Control for NH_4-N. Detection level = 0.03mg/L. Soil, Water and Forage Analytical Laboratory.

Date	Sample #	Sample Estimate (mg/L)	Duplicate Estimate (mg/L)	% Difference	Accept ± 10%	Reject >± 10%
July 23, 1999	Dry Creek	0.01	0.02	100		X
	Cloud Creek	0.10	0.10	0	X	
	Lower Spavinaw Creek	0.07	0.07	0	X	
August 9,1999	Cloud Creek	0.03	0.01	67		X
	Dry Creek	0.00	0.01	0	X	
	EPA	0.84*	0.84	0	X	
	Blank	0.00	0.06	0	X	
	Blank	0.00	0.02	0	X	
	Blank	0.00	0.03	0	X	
August 27,1999	Lower Spavinaw Creek	0.07	0.07	0	X	
	Beaty Creek	0.24	0.24	0	X	
	Dry Creek	0.00	0.00	0	X	
	EPA	0.84*	0.84	0	X	
	Blank	0.00	0.03	0	X	
	Blank	0.00	0.02	0	X	
	Blank	0.00	0.02	0	X	
	Blank	0.00	0.03	0	X	
September 13,1999	Lower Spavinaw Creek	0.14	0.15	7	X	
	Cloud Creek	0.05	0.06	20		X
	EPA	3.31*	3.28	1	X	
	EPA	0.91*	0.84	8	X	
	Blank	0.00	0.01	0	X	
	Blank	0.00	0.04	0	X	
	Blank	0.00	0.01	0	X	
	Blank	0.00	0.08	0	X	
	Blank	0.00	0.03	0	X	
December 7,1999	Cloud Creek	0.06	0.07	17		X
	Dry Creek	0.09	0.06	33		X
	EPA	0.87*	0.84	3	X	
	Blank	0.00	0.05	0	X	
	Blank	0.00	0.05	0	X	
	Blank	0.00	0.05	0	X	
	Blank	0.00	0.04	0	X	
	Blank	0.00	0.06	0	X	
December 15,1999	Lower Spavinaw	-0.02	-0.04	100		X
	Dry Creek	-0.02	-0.04	100		X
	EPA	0.79*	0.84	6	X	
March 13,2000	Lower Spavinaw Creek	0.05	0.04	20		X
	Dry Creek	0.03	0.04	33		X
	Columbia Hollow	0.33	0.33	0	X	
	EPA	0.89*	0.84	6	X	

Note: Due to Sample Concentrations near detection limit, the data are still deamed acceptable for my statistical analysis. * EPA Certified Concentrations

VITA

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