ABSTRACT

SMELTZ, HEATHER L. Water Quality Assessment of a Degraded Stream Prior to Restoration and Nitrate Reduction through Controlled Drainage (under the direction of Robert O. Evans)

Best management practices are often necessary to minimize non point source water quality problems. The Core Creek Project implemented and evaluated best management practices (BMPs) throughout the upper watershed to reduce nutrient loading to the Neuse River. A portion of the Core Creek Project, involving the evaluation and restoration of a degraded, channelized, pasture stream, was initiated in 2003. Beef cattle (*Bos taurus)* had unrestricted access to the waterway, severely degrading the stream bank and streambed. In preparation for stream restoration, the existing water quality was monitored and assessed. Near the end of the background evaluation study, the beef cattle were removed from the pasture.

The nitrogen concentrations downstream of the pasture were generally lower than those upstream, but these differences were not significantly different. The downstream phosphorus concentration was generally higher than the upstream concentration. This difference was significant for orthophosphate. Fecal coliform levels were significantly higher downstream than upstream, before cattle exclusion. After exclusion, there was a statistically significant reduction in fecal levels downstream, dropping an average of 83%. The average daily and maximum daily water temperatures at the downstream sampling location were significantly higher by an average of 2.5^{o} C than the upstream temperatures. Macroinvertebrate sampling indicated that the quality of the stream was severely stressed, both during 2003 and 2004.

A monthly grab sampling scheme predicted a significantly different nutrient load than continuous weekly composite sampling. Total Kjeldahl nitrogen, ammonium, total phosphorus, orthophosphate and total suspended solids were 47%, 95%, 49%, 62%, and 54% lower, respectively, using the monthly sampling protocol. Nitrate was 51% higher when using the monthly sampling scheme.

An additional component of the Core Creek Project evaluated the reduction of NO_3-N leaving the Core Creek watershed due to the implementation of controlled drainage and nitrogen management plans. DRAINMOD-N was calibrated and extrapolated on a field by field basis to predict long-term hydrology and nitrate losses based on BMPs implemented and crops grown throughout the watershed.

Predicted nitrate-nitrogen reduction was most effectively accomplished when controlled drainage and a nitrogen management plan were used in conjunction with one another. If implemented separately, a nitrogen management plan was predicted to be more effective than controlled drainage alone. The cropping system also impacted the drainage rate and nitrate loss from the fields. Potentially, a 30% and 75% nitrate reduction can be achieved growing cotton or soybeans, respectively, as compared to corn. Controlled drainage reduced the drainage outflow by 6.8 centimeters (21.3%), annually, compared to conventional drainage. This flow reduction accounted for 11.5% of the NO_3-N reduction leaving the watershed.

Water Quality Assessment of a Degraded Stream Prior to Restoration and Nitrate Reduction through Controlled Drainage

by

Heather L. Smeltz

A thesis submitted to the Graduate Faculty of
North Carolina State University
In partial fulfillment of the
Requirements for the Degree of Master of Science

BIOLOGICAL AND AGRICULTURAL ENGINEERING
Raleigh, North Carolina
2004

APPROVED BY:

Robert O. Evans, Chairperson
Biological & Agricultural Engineering

Deanna Osmond, Minor Advisor
Soil Science

Greg D. Jennings
Biological & Agricultural Engineering

For Larry, whose love and support got me though graduate school

For my biggest cheerleaders, my parents, who think I can do anything and are not afraid to let me know it

For my God, who is always there and has blessed me more than I deserve

Biography

Agriculture was second nature to Heather Schaetzle, as her grandparents had a small dairy farm in rural Pennsylvania. Being active in FFA led Heather to further her agricultural interests at the Pennsylvania Governor's School of Agricultural Science at Penn State during her junior year of high school. While there, she acquired a taste for the environmental side of agriculture and eventually applied to Penn State. Heather was accepted into the Agricultural and Biological Engineering major, emphasizing structures and the environment and natural resources. Her cooperative engineering experience with the Natural Resources Conservation Services (NRCS) in Lebanon, PA, was a perfect fit for her major. After working for the NRCS for a year, Heather graduated from Penn State in 2002. Her honors there include being the Outstanding Senior in the College of Agricultural Sciences as well as the Outstanding Senior in Agricultural and Biological Engineering.

Opting to go onto graduate school instead of immediately returning to the NRCS, Heather began her Master's studies at North Carolina State University. In December of 2004, she finished her thesis and returned to Pennsylvania to be married to Larry Smeltz. Heather graduated from NC State with a Master of Science in Biological and Agricultural Engineering in May of 2005. She is currently working for the NRCS in Pennsylvania.

Acknowledgements

The author would like to express deep appreciation to the many people who contributed to her research. She would like to thank her advisor, Dr. Robert Evans, for his guidance and support, especially when her primary research project was delayed. Many thanks as well to her committee members, Dr. Gregory Jennings and Dr. Deanna Osmond, for their insight and guidance.

The author would also like to thank those people who were directly involved with the field research. Thanks to Mr. Charley Humphrey, the Cooperative Area Extension Agent for helping both the stream restoration and the controlled drainage sites. His intervention with the farmers and occasional water sampling resulted in pleasant working conditions. He also provided invaluable data regarding the water control structures installed in the study site. Thanks to Mr. Humphrey for filling out applications, asking for extensions, and completing paperwork relating to the stream restoration.

Mr. L.T. Woodleif aided in installation of Infinity® monitoring devices, automated water samplers, and surveying. Thanks also to Mr. Jonathan Smith for his equipment installation, instrumentation advice and experience, sampling, surveying, and stake out assistance. Mr. Michael Addcock was also invaluable installing equipment, surveying, collecting water samples, and downloading data acquisition equipment.

The author would like to thank Mr. Kristopher Bass, P.E., the engineer responsible for designing the stream restoration. Dr. Michael Burchell should be thanked for his help with surveying and staking out the site.

The author would also like to thank Dr. George Chescheir for his GIS mapping of the Core Creek watershed. Dr. Chescheir was also instrumental in developing the DRAINMOD models used for the nitrate reduction simulations.

Thanks to Dr. Mohamed Youssef for his advice and assistance calibrating the DRAINMOD models and ensuring that the extrapolation was performed correctly.

Ms. Melanie Carter and Mr. David Penrose deserve thanks for their help with the benthic macroinvertebrate study, including field collection and identification.

The author would also like to thank the various students who helped with field work: Mr. Jon Hathaway, Mr. Nicholas Lindow, Ms. Amy Moran, Ms. Kathleen Powers, Ms. Jennifer Shelby, Mr. Adam Vallenti, and Mr. Jason Wright. Mr. Jon Hathaway was also instrumental in transforming this thesis to a .pdf in order to submit it to the graduate school.

Thanks to Ms. Rachel Huie and her Environmental Analysis Laboratory for analyzing the monthly and weekly water samples.

The author would like to thank Dr. Garry Grabow for his statistical guidance on this research project.

Special thanks go to Mr. Larry Smeltz for his survey assistance and continued support of the author and this project. Thanks also to the author's friends and family for all the support throughout the term of this research.

Table of Contents

List of Tables

List of Figures

1.0 WATER QUALITY ASSESSMENT OF A DEGRADED STREAM PRIOR TO RESTORATION

The Core Creek Project, funded by the North Carolina Clean Water Management Trust, implemented and evaluated best management practices (BMPs) throughout the upper watershed to reduce nutrient loading to the Neuse River. A portion of the Core Creek Project, involving the evaluation and restoration of a degraded, channelized, pasture stream, was initiated in 2003. Beef cattle (*Bos taurus)* had unrestricted access to the waterway, severely degrading the stream bank and streambed. In preparation for stream restoration, the existing water quality was monitored and assessed. Near the end of the evaluation study, the beef cattle were removed from the pasture.

The nitrogen concentrations downstream of the pasture were generally lower than those upstream, but these differences were not significantly different. The downstream phosphorus concentration was generally higher than the upstream concentration. This difference was significant for orthophosphate. Fecal coliform levels were significantly higher downstream than upstream, before cattle exclusion. After exclusion, there was a significant reduction in fecal levels downstream, dropping an average of 83%. The average daily and maximum daily water temperatures at the downstream sampling location were significantly higher by an average of 2.5^{o} C than the upstream temperatures. Macroinvertebrate sampling indicated that the quality of the stream was severely stressed, both during 2003 and 2004.

A monthly grab sampling scheme predicted a significantly different nutrient load than continuous weekly composite sampling. Total Kjeldahl nitrogen, ammonium, total phosphorus, orthophosphate and total suspended solids were 47%, 95%, 49%, 62%, and 54%

lower, respectively, using the monthly sampling protocol. Nitrate was 51% higher when using the monthly sampling scheme.

1.1 INTRODUCTION

According to the Environmental Protection Agency (EPA), agriculture is the leading source of pollution in surface waters (2002). In rivers and streams, this primarily takes the forms of sediment, bacteria, and nutrients. These pollutants destroy habitat, cause rapid algal blooms, and decrease economic values of the waters. Approximately 40% of surveyed lakes, rivers, and estuaries are not clean enough for uses such as swimming or fishing (US Environmental Protection Agency 2002).

Because poultry and swine are housed, the animals have no direct access to surface water. However, beef cattle are frequently pastured near water sources, such as a creek or pond. The cattle use the water for drinking and as a source of cooling during hot weather. Due to this access, stream bank structure is destroyed, contributing additional sediment load to the surface water. The stream typically undergoes morphological changes including widening and becoming shallower. Fecal material is deposited in the water, contributing nutrients and bacteria. These nutrients, specifically nitrogen (N) and phosphorus (P), are the main contributors to eutrophication, causing the advanced aging of surface waters. Also, runoff waters carry fecal material and sediment to the stream or pond.

In December 1997, the N.C. Environmental Management Commission adopted the Neuse River Basin Nutrient Sensitive Waters Management Strategy. The goal of the policy was to decrease the average annual load of nitrogen delivered to the Neuse River Estuary from nonpoint and point sources by at least 30 percent of the average annual load. To accomplish this, best management practices (BMPs) have been installed throughout the river

basin. Best management practices are the main mode of reducing the pollution to waterways from nonpoint sources. By utilizing such applications as riparian buffers and stream bank fencing, nonpoint source pollution (NPS) can be significantly decreased.

The Core Creek Project implemented and evaluated BMPs throughout the upper watershed to reduce nutrient loading to the Neuse River. Those BMPs used were nitrogen management, controlled drainage, and wetlands restoration. Monitoring of the watershed occurred for several years to determine the before and after effects of the BMPs on nutrient reduction in the Core Creek watershed.

A portion of the Core Creek Project involves the restoration of a degraded pasture stream. The pasture is located on an unnamed tributary to Grape Creek, a tributary to Core Creek and the Neuse River. The intermittent stream had been channelized and ditched. Beef cattle had unrestricted access to the waterway, severely degrading the stream bank and streambed. Sediment from the stream banks was agitated and transported downstream. N and P were added to the stream in the forms of urine and feces. The fecal material also contributed bacteria to the watershed.

The main focus of this project was to determine the water quality of the tributary to Grape Creek. To accomplish this, surface and subsurface water was monitored for quality and hydrology pre-restoration of the channelized stream. Near the end of the study, the cattle were removed from the site.

1.2 LITERATURE REVIEW

1.2.1 Benthic Macroinvertebrate as Water Quality Indicators

The presence of macroinvertebrates is a good qualitative indicator of water quality. They have high species diversity, ubiquitous occurrence, and are functionally important in a natural ecosystem (Rosenberg et al. 1986). Different species have different water quality tolerances. They reflect the conditions over an extended period of time, not at just the time of sampling.

Land use is an important factor in determining the structure of the aquatic community. Agricultural streams generally have a lower Ephemeroptera – Plecoptera – Trichoptera (EPT) taxa richness, a measure of intolerant insect species, than a forest stream (Lenat and Crawford 1994). However, there is a higher affluence of tolerant groups in agricultural streams, possibly due to pollutant enrichment (Lenat and Crawford 1994). Depending upon the streambed substrate stability and flow rate, sediment affects benthic macroinvertebrates in two primary ways: (1) at low stable flows, small grazers rapidly colonize an area and reproduce, increasing the taxa richness; (2) high flows move sediment, decreasing the available habitat. Land use type may affect the aquatic food web (Lenat and Crawford 1994). The community population is lower with respect to unstressed areas, but qualitatively similar (Lenat et al. 1981).

1.2.2 Agricultural Pollutants

In 1977, Section 208 of the Clean Water Act (Water Pollution Control Act (PL 92-500)) was amended by the United States' Congress to include nonpoint sources as major

contributors of sediment, bacteria, and nutrient loads to freshwater ecosystems. However, agriculture continues to be the leading source of pollution in rivers, streams, lakes, ponds, and reservoirs (US Environmental Protection Agency 2002). The contributed pollutants (nutrients, sediment, and bacteria) destroy habitat, cause rapid algal blooms, and decrease economic values of the waters.

1.2.2.1 Nutrients

Nonpoint source pollution can cause eutrophication, the rapid aging of freshwater bodies (Rostagno and Sosebee 2001; Sharpley et al. 1999). In 1840, Justus Liebig developed "Liebig's Law of the Minimum," stating that vegetative growth is controlled by the most limiting nutrient (Welsch 1991). Due to their fast growth rate and nutrient cycling abilities, bacteria and microalgae are indicators of an aquatic ecosystem's status. The organisms are sensitive to changes in nutrient concentrations, other pollutants, sediment loads, hydrology, and optical quality (Paerl et al. 2002).

In North Carolinian estuarine waters, nitrogen (N) is often the limiting nutrient for algal blooms (Paerl et al. 2002; Ryther and Dunstan 1971; Welsch 1991). Phosphorus (P), mainly from agricultural runoff, is the limiting nutrient and main culprit for eutrophication of freshwater systems (Sharpley et al. 1999; Welsch 1991).

Cattle within a riparian zone contribute N and P to the water through their excrement. By decreasing the amounts of plants around the creek (either through trampling or consumption), the cattle limit the nutrient uptake capacity of the vegetation on the site. Runoff can also carry N and P-bound sediment to the surface water.

1.2.2.1.1 Nitrogen

As in most estuarine and coastal waters, N is the limiting nutrient in the Neuse Estuary and Pamlico Sound (Paerl et al. 2002). The concentration of N in the waters controls the productivity, tropic state, and water quality of the area (Paerl et al. 2002). While N is necessary for aquatic life, excessive inputs lead to eutrophication (Pickney et al. 2001). In estuaries, NPS drives the N concentration in the waters (Ryther and Dunstan 1971). Nonpoint source pollution contributes approximately 80% of the 'new' N introduced to the Neuse River/Pamlico Sound, with wastewater and industrial effluent responsible for the remaining 20% (Paerl et al. 2002). The 'new' N is primarily transported to the water sources through atmospheric deposition and shallow groundwater (Paerl 1997).

Nitrogen is a component of animal manure, a common organic fertilizer used to enhance crop growth. When N is added to the soil in this organic form, it is attacked by enzymes and broken down into smaller units. These units can then be used by microbes and be mineralized as inorganic NH_4^+-N. Mineralization occurs under both aerobic and anaerobic conditions. Using urea as the organic N source, NH_4^+ is produced through the following reactions:

Equation 1-1 $$NH_2 \cdot CO \cdot NH_2 + H_2O \rightarrow 2NH_3 + CO_2$$

and in an aqueous system

Equation 1-2 $$NH_3 + H_2O \rightarrow NH_4^+ + OH^-$$

Nitrification transforms the relatively immobile NH_4^+ into NO_3-N. In the form of nitrate-nitrogen (NO_3^--N), N is easily transported in aqueous solutions, used by plants, or denitrified. Obligate aerobic bacteria are necessary to arbitrate the two-step process.

Nitrosomonas and *Nitrobacter* are the primary mediators of the first and second steps, respectively (Jarrett 2001).

Equation 1-3 $2NH_4^+ + O_2 \rightarrow 2NO_2^- + 2H_2O + 4H^+ + energy$

Nitrite is further oxidized, yielding NO_3-N.

Equation 1-4 $2NO_2^- + O_2 \rightarrow 2NO_3^- + energy$

If NO_3-N^- is not immediately incorporated in plants or microbes, it will move with the soil water. If the NO_3-N^- water reaches an energy source in an anaerobic environment, denitrification may occur. Under the anaerobic conditions, NO_3^--N acts as an electron acceptor for microbes. The N is converted to nitrous oxide (N_2O) and then sometimes to molecular N (N_2).

Equation 1-5 $C_6H_{12}O_6 + 4NO_3^- \rightarrow 6CO_2 + H_2O + 2N_2$

In coastal and offshore waters, NO_3-N reduction is an important step in limiting N assimilation and the resultant growth of algae and phytoplankton (Paerl et al. 1999; Pinay et al. 1994). Lowering the ratio of dissolved inorganic N (NO_x) to dissolved inorganic P resulted in an increase of N_2 fixation (Piehler et al. 2002).

Headwater streams in agricultural areas may be polluted above the critical limits. Excess NO_3-N in surface waters can result from N in water leaving fertilized or animal-occupied sites. Additional N in estuarine systems causes blooms of algae and an overabundance of oxygen-dependant bacteria that deplete the water of oxygen. In addition to causing fish kills, the algae can produce toxins that are harmful to humans. Because NO_3-N is water-soluble and does not adsorb to soil particles, it can also leach through the soil profile

and enter the groundwater systems. Nitrate contamination of ground waters is a concern as shallow groundwater returns to contribute to surface flow.

Livestock increase the concentration of N and P in waters through a variety of ways (Scrimgeour and Kendall 2002):

1. Increased overland flow during rain events due to soil compaction and vegetation removal
2. Lower denitrificaiton rates within a riparian zone
3. Less nutrient uptake by vegetation
4. Higher N an P inputs to the stream from "voided wastes"
5. Mobilizing N and P in streambanks and sediments

1.2.2.1.2 Phosphorus

In freshwater ecosystems, P is the limiting nutrient resulting in eutrophication. Due to the chemical properties of P, it mainly bonds to soil particles. Eutrophication arises when the P disassociates from the soil in a water solution and becomes bioavailable (Sharpley et al. 1999). Sharpley et al (1999) estimates that only 30% of the fertilizer and feed P that enters a farming system are seen as outputs in the crop and animal productions. He further shows that only 1-2% of the P applied to agricultural fields makes its way into water sources. Lake water concentrations between 0.01 and 0.02 ppm are considered critical values, any higher and the rate of eutrophication is increased (Sharpley et al. 1999). An overabundance of P results in similar results as N in estuarine waters; algal blooms, fish kills, and the accelerated aging of the water body.

Grazing livestock can increase P concentrations in surface waters. The concentration of total P (TP) in surface waters was significantly higher in all season livestock grazing, versus a control (Scrimgeour and Kendall 2002). Scrimgeour and Kendall (2002) also found that the soluble reactive P was higher than the control. Beef cattle contribute N and P to the

water through their excrement. By decreasing the amounts of plants around the creek (either through trampling or consumption), the cattle limit the nutrient uptake capacity of the vegetation on the site. Runoff can also carry N and P-bound sediment to the surface water.

1.2.2.2 Sediment

Sediment is the number one pollutant within fresh water ecosystems. It carries excess nutrients into streams, rivers, and lakes. It increases turbidity and reduces light penetration through the water column, decreasing the photosynthetic abilities of aquatic plants. Sediment destroys habitats and can harm aquatic organisms. At concentrations of over 20,000 ppm in the water column, mortality is caused in adult fish by clogging their gill filaments (Welsch 1991). While that level is very high, sediment concentrations over 200 ppm can lead to abrasions and gill damage (Welsch 1991). Deposited sediment interferes with the feeding and reproduction of bottom dwelling organisms. A study in the Mississippi Valley Loess Plains found that as the duration of the concentration of suspended sediment increased to 100 mg/L or higher, the total number and taxa of benthic organisms decreased (Kuhnle et al. 2001).

Lowrance et al determined that stream order was correlated to volume of sediment eroded and deposited off site (1986). Approximately 85% of the lengths of running water are first through third order streams (Welsch 1991). Lowrance et al observed that agricultural activities tend more often to occur near first order waters than second or third order streams, reinforcing the need to shield these lower order streams from erosion (1986).

Soils can be protected and erosion reduced in various ways. Preventing the detachment of the soil particles is the first step towards reducing soil erosion. Surface cover,

in the forms of plants or residue, dissipates the energy of the rainfall, sheltering the aggregates from the direct pounding force of rain. By maintaining a well-aerated soil with a high organic content, the rain can infiltrate the soil, reducing the effects of runoff.

No matter how thick and protective the ground cover, some soil detachment will occur. The flow of water containing these particles should be sufficiently slowed to allow the soil to drop out before it reaches surface waters. By reducing the velocity of the runoff down the slope, the energy of the flow is reduced. Slow moving water cannot transport as much sediment as fast moving water. Also, the slower the speed, the more time for infiltration, reducing the peak outflow of the storm. Longer distances of travel on shallow slopes allow sediment to drop out of the flow. In a study performed by Cooper et al, it was shown that 50% of the soil eroded from the agricultural lands re-deposited itself within 100 meters of the exit of the cultivated field (1987). Over 75% of the sediment dropped out upstream of a flood plain swamp that was 2-3 kilometers down site (Cooper et al. 1987).

While soil erosion is a natural process, man and beast can accelerate the progression. Baring ground allows wind and water access to the soil aggregates. Soil can become lodged in or kicked up by a shoe or a hoof and carried off site. Cattle can degrade streambanks and streambeds, increasing the amount of erosion at that site. By reducing the amount of vegetation around a stream, through feeding or trampling, cattle decrease the water-velocity-reducing potential of the ground cover. This allows more upland soil particles to enter the waterway.

The quality and quantity of the sediment in the overlying water is significantly related to time that cattle spend in the stream (Sherer et al. 1998). Livestock weaken the stream

bank's structure via trampling and forage removal. High water has a more erosive impact in these areas. Streambank ratings were found to be better in ungrazed riparian areas (Platts and Nelson 1985). Significantly higher losses from streambanks were found in areas in which cattle had access. This was in the form of larger disturbance indices, lower undercuts, and higher annual bank slough off (Kauffman et al. 1983).

Soil erosion influences the short-term changes in the bank morphology (Kauffman et al. 1983). When cattle have access to banks, the streams widen and become shallower. Ungrazed stream sections were found to be significantly deeper with differing pool and riffle amounts than grazed areas (Platts and Nelson 1985).

There are indications that the degree of streambank erosion from livestock is site specific. Marlow et al found that changes in the channel profile decreased as the percentage of time that the cattle spent in the riparian zone increased (1987).

1.2.2.3 Bacteria

Manures contain microorganisms from the animal's digestive system. They are the potential source of about 150 diseases, including cholera, anthrax, foot and mouth, polio, and mastitis (Ritter 2001). While there is the potential for transmission, the frequency of human incidents is normally low. This changes, however, when the manures and bacteria are in waters used by humans.

E. coli, especially species O157:H7, is a concern in surface and groundwater. It can cause severe bloody diarrhea, abdominal cramps, and result in death in the very young or elderly. Cryptosporidium leads to severe diarrhea in both humans and animals. Both of

these pathogens are found in the digestive tract of healthy cattle. Other waterborne pathogenic diseases include typhoid fever, viral and bacterial gastroenteritis and hepatitis A.

The presence of fecal coliform is an indicator of fecal material in that aquatic system. If found in high enough concentrations, there is a potential health risk to humans from the contaminated water. In North Carolina, the Department of Environment and Natural Resources – Division of Water Quality established the limit of 200/100 ml (membrane filter technique) for human contact (NC DENR 2003).

Beef cattle kept on pasture are able to defecate directly into or adjacent to water bodies. Over 90% of the organisms in fecal material deposited directly in surface waters remain near the site (Sherer et al. 1992). Line (2003) found fecal coliform and enterocci levels over 300 times higher downstream of a livestock pasture than upstream. Stream velocity is important in the equilibrium between bacterial concentrations in the sediment and overlying waters. Streptococci move downstream more freely than fecal coliform and survive longer under adverse temperatures (Sherer et al. 1992). Detritus and sediment allows enteric bacteria to survive for months, as compared to days in surface water. When incubated with sediment, studies have shown that coliform and streptococci have half-lives of 11 to 30 days and 9 to 17 days, respectively (Sherer et al. 1998). Mixing of the bacteria and overlying water will occur when stream flow increases. Animal traffic also magnifies turbulence, re-suspending sediment and bacteria. The concentration of bacteria in the overlying water increases, averaging 17.5 times for fecal coliform and 4.6 times for streptococci (Sherer et al. 1992).

The possibility of bacteria from manures reaching waters is dependent upon the site and climate. More viable pathogens will reach surface waters from rain onto freshly applied manure or manure on frozen ground than when manures are land-applied on hot, sunny days. On the research site, manure can be directly excreted into the creek or deposited upland, entering the waterway through runoff.

1.2.3 Best Management Practices

Forested watersheds are the accepted benchmark of quality for water resources (Welsch 1991). Nutrient concentrations in forest outflows are generally low versus typical values for other land uses. Chescheir et al (2003) found that the annual total nitrogen (N_T) exported from coastal plain forested sites, both natural and managed, is less than 6.5 kg/ha, with organic N being the predominant form.

Lowrance and Leonard (1988) state "conditions that change hydrologic responses of watersheds may change the nonpoint source pollution of nutrients by changing water volumes and by altering processes that create nutrient concentrations in stream flow." Best management practices and changes in land use resulted in decreases of 70-75% mean TP and 70% fecal coliform levels in the Long Creek Watershed, NC (Line 2002; Line and Jennings 2002). The biological processes in a riparian buffer have a direct and indirect effect on the nutrient concentration in surface and shallow ground water. This is through nutrient uptake/utilization, transpiration, and denitrification (Lowrance et al. 1984b).

1.2.3.1 Riparian Buffers and Riparian Wetlands

Riparian buffers generally are vegetated sections adjoining surface waters that protect the quality of the water, stabilize the bank, and provide aquatic and wildlife management, Figure 1.1. Naturally occurring buffers are compiled of grasses, shrubs, trees, or mixed flora. If managed properly, they can be grown and maintained to coexist with most land uses. Vegetated riparian areas may be the most important factor controlling sediment and nutrient loadings in streams from nonpoint sources (Gilliam 1994). Riparian forest ecosystems can serve as a short-term filter for nitrogen, calcium, phosphorus, and magnesium (Lowrance et al. 1984a; Lowrance et al. 1984c).

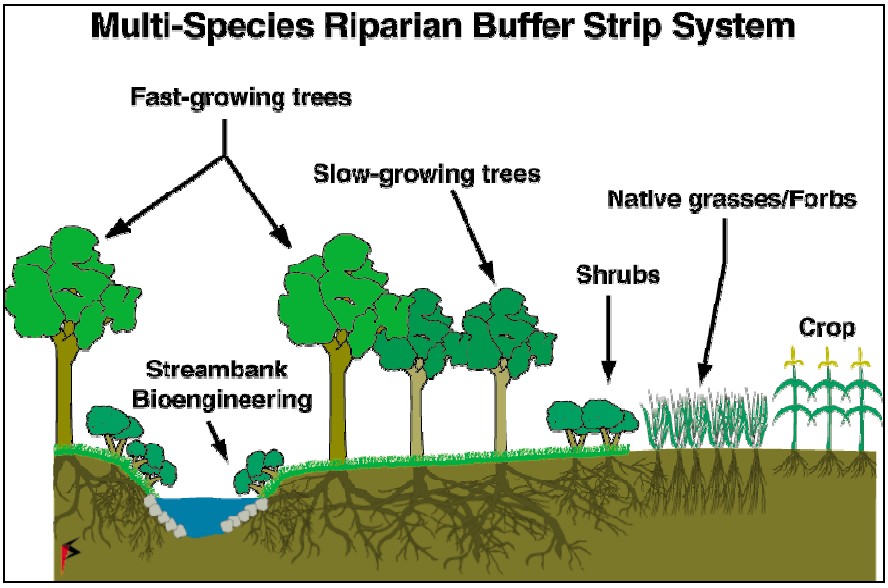


Figure 1.1 Riparian/vegetated buffer between waterway and crops, courtesy of Iowa State University Forestry Extension (2001)

Most buffers in North Carolina are predominantly forest integrated with grass or shrub. Grass is effective at intercepting sediment and soil-bound P in runoff. The sheet flow is slowed enough to allow these particles to settle out. The grass portion acts as a vegetated filter strip for sediment removal. If the water channelizes and moves through the buffer too

rapidly, the buffer will be rendered less effective. When functioning properly and well maintained, riparian buffers can remove as much as 60-90% of the sediment (Daniels and Gilliam 1996). Because P is mainly soil bound, by removing sediment, the majority of the P is also removed (Dillaha et al. 1989). Some infiltration occurs, allowing for the reduction in dissolved N and P. A mixture of switch grass and woody buffers increased the infiltration capacity by 17% as compared to non-buffered sites (Lee et al. 2000). In a study performed by Sovell et al (2000), the mean turbidity levels in surface water were lower when a grass buffer was used as compared to a wooded buffer. Grass buffers, combined with forested areas, reduce both sediment and sediment bound P most effectively.

Riparian wetlands are a subset of riparian buffers where the substrate is hydric soil. Some processes such as denitrification are more effective in riparian wetlands than riparian buffers, in general. Riparian wetlands behave similar to riparian buffers performing nutrient attenuation. The flora and soil subjected to continual nutrient loading will eventually reach saturation (Helfield and Diamond 1997). On a newly constructed riparian wetland, Casey and Klaine (2001) found that PO_4^{3-} was initially rapidly and completely attenuated after infiltration. Nitrate attenuation occurred after a lag-phase of several hours. While the efficiency of the wetlands on nitrate was initially less than 60%, it eventually increased to 100% attenuation. After 11 rain events, NO_3-N and PO_4 attenuation was 80% and 74%, respectively (Casey and Klaine 2001). Casey and Klaine (2001) theorized that intermittent inputs, of NO_3-N and PO_4 through storm events could be successfully attenuated in a riparian wetland.

Buffers are not as effective at filtering out dissolved nutrients in runoff as compared to sediment (Lee et al. 2000). It is estimated that riparian buffers remove 50-60% of the total P load (Daniels and Gilliam 1996). Other studies showed a riparian buffer retaining 80% of the P passing through it (Peterjohn and Correll 1984; Welsch 1991). Equilibrium P content is eventually reached between the buffer and the runoff traveling through it. If the concentration of P in the runoff is lower than that equilibrium content, it may actually adsorb P from the buffer to achieve that equilibrium. In this case, it is possible that more dissolved P leaves the buffer than enters, for that runoff event. Part of the reason is that P binds to clay particles extremely well. Clays are the last particles to be settled or filtered out of the runoff solution and the most likely to reach the surface waters. The greater the distance the water flows through the buffer's grass filter strips, the greater the removal of total sediment, including silts and clays, however the relationship is not linear (Daniels and Gilliam 1996). Land slope and vegetation density must be sufficient so that the overland flow's velocity is decreased enough to allow the particles to settle out.

An in-stream Coastal Plain wetland was found to retain and then release dissolved P (Novak et al. 2004). During flooding, high amounts of dissolved P were transported into the wetland (high rainfall remobilized P from upstream). While the flooded wetland retained 52% of the 58.2 kg dissolved P, when it drained, 13 kg was released to the surface water (Novak et al. 2004). Sediment-bound chemicals can be remobilized and loaded into the water column. This concentration of dissolved P in the water column may remain high until the P stored in the wetland sediments reach equilibrium or the P-laden water passes from the

wetland (Helfield and Diamond 1997; Novak et al. 2004). The wetland in Novak et al's study (2004) was not effective for long-term retention of P.

Kadlec and Hey (1994) determined that there was "potential of constructed wetlands for controlling nonpoint source pollution at an intermediate position in the watershed." They performed a study on the Des Plaines River, an agricultural and urban watershed, pumping ≤ 40% of the average stream flow to four wetlands. Sediment, P, and atrazine were reduced and there was a seasonal component to the reduction for sediment and P, Table 1.1. (Kadlec and Hay 1994). James et al. (1990) found a 70% reduction in the mean NO_3-N concentration in an in-stream wetland. Wetlands were found to be most effective during warmer months, indicated by a large change in NO_3/Cl ratio, representing a seasonal variability (Hunt et al. 1999).

Table 1.1 Seasonal Pollutant Removal Efficiency of Four Wetlands on the Des Plains River (Kadlec and Hay 1994)

Pollutant	Removal Efficiency	
	Summer	Winter
Sediment	86-100%	38-95%
Phosphorus	60-100%	27-100%
Atrazine	~ 50%	

Leached from fields, NO_3-N can be removed from the shallow aquifer in the riparian zones (Lowrance et al. 1984c). As stated by Correll and Weller (1989), the "wetland process cannot be studied in isolation but must be related to factors that may limit this process." They describe the wetland process using a three-zone analogy. Similar to the processes in a riparian buffer, groundwater enters Zone 1, immediately adjacent to cropland. Here, respiration dominates the microbial processes. Dissolved oxygen enters this zone through groundwater, rainwater, and diffusion.

Denitrification and transpiration are the main reactions occurring in Zone 2. The woody vegetation transport water and nitrate from the roots to the leaf stoma. Transpiration increases the hydronium ion concentration. Vegetation is believed to provide the dissolved organic carbon (C) for microbes that perform denitrification, reducing the NO_3 to N_2, N_2O, or NO (Spruill 2000). Organic material and NO_3-N are used as electron acceptors (NO_3-N is reduced to N_2 gas). Denitrification, the main nitrogen removal process, occurs most efficiently in the anaerobic root-zone of soil. According to Jacobs and Gilliam (1985), "Removal through this process is largely responsible for the loss of most of the nitrogen from agricultural drainage water in the Coastal Plain [North Carolina]."

Denitrification slows as groundwater passes into the Zone 3. Nitrate concentration decreases in Zone 3. Sulfate reduction takes over as the E_h is lowered. These zones vary seasonally and with the hydrologic conditions (Correll and Weller 1989). Cultivation upland and fertilization can induce year-round high rates of denitrification due to the higher rates of hydronium ions that are released (Correll and Weller 1989).

In a study performed by Lowrance (1992b), the maximum monthly subsurface N losses were over an order of magnitude higher than surface N losses. Peterjohn and Correll showed a 90-98% reduction in the mean annual NO_3-N concentrations through a natural forested riparian buffer (1984). Jordan et al (1993) found that the concentration of NO_3-N in the groundwater was much lower in a riparian forest than in the adjacent croplands. This is also supported by Lowrance et al (1984a). Under baseflow conditions, most of the influent NO_3-N can be denitrified in an organic-rich riparian zone (Cooke and Cooper 1988). Compared to water passing through a riparian zone, the water from drainage tile in a field

had a higher concentration of N (Jacobs and Gilliam 1985). No denitrification occurred to the water in the drainage tile.

Nitrate in shallow ground water is the primary pathway of nitrogen entering surface waters in North Carolina. Haycock and Pinay showed that riparian buffers are effective at removing NO_3-N from the subsurface flow, especially during the winter months (1993). Seasonal variations in denitrification rates are common. The actual effectiveness of the buffer at removing NO_3-N is dependent upon the hydrology of the site. It is a common misconception that buffers work equally well in all situations. On some sites most or all of the groundwater passes below the root zone. At other locations, shallow ground water flow is not always towards the drainage ditches or stream, as assumed. The water table may not be located close enough to the soil surface to promote an anaerobic status in an active zone. In these cases, denitrification is not facilitated. This is due to the water's limited access to an organic C source. With deep water tables, there is little chance for direct plant uptake of the NO_3-N. At lower depths, denitrification that does occur is probably not a direct result of the buffer. Instead, organic C may have been present in the soil, providing hospitable conditions for the bacteria.

Surface runoff and subsurface flow through the riparian zone occur primarily during the winter and spring months (Lowrance 1992a). Denitrification may be inhibited during summer and fall months when water tables are typically lower (Pinay et al. 1993). Higher NO_3-N concentrations are often in subsurface water leaving cropland during the winter months for a variety of reasons (Lowrance et al. 1984b):

1. High rainfall and low evapotranspiration increase the movement of readily leached ions into the subsurface flow.

2. Low microbial activity reduces the reduction of NO_3-N to gaseous forms.
3. Low uptake of the nutrients by plants due to dormancy and crop removal.

In some cases, the landscape position and soil conditions influence treatment more than the vegetation in the riparian buffer (Dukes et al. 2003). The geographic position of the site with respect to the ground water flow determines the importance of the NO_3-N source (Pinay et al. 1993). Buffers have the potential to reduce more N on streams when a majority of NO_3-N input is from shallow ground water (allochthonous) as compared to organic matter decomposition in the stream being the main NO_3-N source (autochthonous) (Pinay et al. 1993).

Different hydrologic conditions produce various levels of denitrification. A study performed by Lowrance (1992b) showed that rates increased after irrigation. Compared to a control plot, denitrifying activity in an irrigated plot was two to three times higher (Kralova et al. 1992). Under saturated conditions, the vertical diffusion of NO_3-N into the soil is a dominant factor controlling the denitrification potential of a soil (Ambus and Christensen 1993). Denitrifiaction stopped when the soil moisture content decreased to approximately 80% of the water filled pore space (Ambus and Christensen 1993).

The extent of the denitrification potential also depends on the soil (Ambus and Lowrance 1991). The soil organic content (mineral versus organic) produces a variation in hydrology and water quality (Chescheir et al. 2003). The rates of denitrification can vary due to soil texture, precipitation, and groundwater fluctuations (Pinay et al. 1993). In a comparison of Coastal Plain soils, Kinston (fine, sandy loam), a more poorly drained soil, had a denitrification rate potential three times greater than Alapaha (loamy sand) (Ambus and Lowrance 1991). In more poorly drained, organic soils, denitrification was controlled by the

depth of the water table from the ground surface (Ambus and Lowrance 1991). Better-drained soils were more dependent upon C-cycling of leaf litter in the fall and rooting depth (Ambus and Lowrance 1991).

Lowrance (1992b) showed a positive relationship between denitrification rates and soil moisture, soil NH_4-N levels, and depth. The potential was over two orders of magnitude higher at the soil surface than at the top of the aquifer (Lowrance 1992a). Denitrifying enzyme activity was stratified within the top 10 centimeters, with 88% within the top two centimeters of the soil (Ambus and Lowrance 1991). This stratification also coincided with stratification of N and C from litter and roots (Lowrance 1992a).

Another factor affecting denitrification potential of a buffer is vegetation. Verchot et al (1997) suggest that a riparian forest may be more efficient at removing NO_3-N from groundwater than grass vegetation alone. Leguminous trees, such as the black locust, may increase subsurface NO_3-N concentrations. James et al (1990) observed that the concentration of NO_3-N in shallow ground water decreased after black locust trees in a buffer were cut and the regrowth prevented. Young perennial plants (including trees) may take several years before they affect denitrificaiton rates and groundwater quality (Dukes et al. 2002).

In addition to nutrient uptake, vegetation provides the C source for microbes that control denitrification. Vegetation can also supply C as leaf litter or organic material to the stream sediments through which old, deep groundwater passes (Spruill 2000). Adequate dissolved organic C is available to the shallow groundwater from decaying litter. In a forest soil, the availability of C to denitrifying bacteria may limit the process more than previously

thought (Groffman et al. 1991). Groffman et al (1991)showed that larger and/or more active populations of denitrifying bacteria resided in grass plots than forest. It was thought that the repeated N inputs and lime (fertilizer) created a more hospitable environment in the grass.

Buffers provide valuable control over the stream environment (Ambus and Christensen 1993; Osmond et al. 2002). The streamside vegetation stabilizes the streambanks, limiting channel erosion. Non-vegetated bends are almost five times more likely to have detectable erosion as compared to vegetated bends (Beeson and Doyle 1995). The vegetation also helps determine the food sources available for the aquatic organisms, maintaining high productivity and diversity in the stream (Welsch 1991). Detritus and algae are the primary foodstuffs for microorganisms. The majority of vegetation that falls into the stream is highly localized to that section, providing a consistent source of food. The overhead vegetation also stabilizes the temperature by controlling the amount of sunlight reaching the water. In low order streams, a grass buffer may supply the equivalent canopy-effect like that of a forest (Sovell et al. 2000). Tree roots and woody debris can form riffles and pools providing habitat for macro-invertebrates and fish.

Besides aquatic organisms, riparian buffers provide habitat for wildlife. Due to the diversity of vegetation (grass to shrubs to trees), many different species of wildlife can be supported. Buffers provide food, water and cover, if managed properly. They also link the dryer upland to the wetter bottomlands.

The width of the buffer is an important determinant of the effectiveness of reducing the nitrogen load (Dillaha et al. 1989). Nitrate loss may occur within the first few meters from the field (Haycock and Burt 1993). Dillaha *et al* (1989) showed 70-98% sediment

removal for buffer widths of 9.1 meters compared to 53-86% removal with 4.6 meters. Peterjohn and Correll (1984) have estimated that most of the total change in nutrient concentration in surface water occurs within the first 19 meters of a riparian buffer from the field. Buffers that are too narrow may not efficiently protect stream banks. Those that are too wide take up more land than necessary, land that could be used for other purposes such as agriculture. Doubling the buffer width (from 8 to 15 meters) resulted in a 30% higher NO_3-N reduction, which suggest that there is a non-linear relationship between buffer width and NO_3-N removal (Dukes et al. 2002; Dukes et al. 2003).

A three-zone buffer model is one of the most widely used and recommended, as seen in Figure 1.2 and Table 1.2 (Welsch 1991). The first zone begins at water edge and extends at least five meters perpendicular to the watercourse. The main vegetation is woody vegetation suited for the site and its purpose. The second zone begins where Zone 1 ends. It extends at least 18.5 meters perpendicular to the water. The vegetation here is similar to Zone 1, woody vegetation and shrubs. However, this section can be maintained, where as it is recommended that Zone 1's vegetation not be removed (to ensure bank stabilization). Zone 3 extends at least 6 meters from Zone 2's edge. The vegetation comprises of grasses that aid in filtering sediment, nutrient uptake, and transferring concentrated flow to sheet flow. The grass area above the forested zone can be an effective NO_3-N filter, possibly having denitrification rates greater than a newly restored forest, providing the landscape position (Lowrance et al. 1995). For best performance, the buffers should be built so that infiltration and sheet flow are maximized.

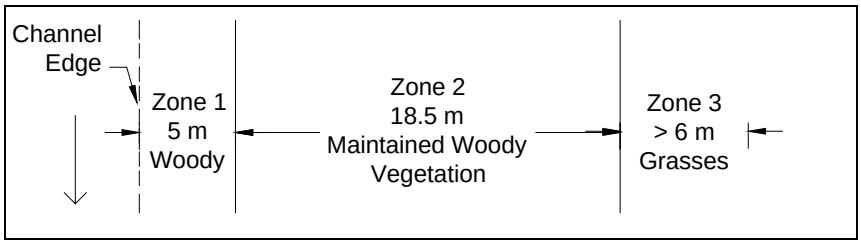


Figure 1.2 Three-zoned riparian buffer model (Welsch 1991)

Table 1.2 Three-zoned riparian buffer specifications (Welsch 1991)

Zone	Width	Type	Purpose	Characteristics
1	5 m [1]	Unmanaged Forest	Stream stabilization, provide leaf fall	Sheet/subsurface flow only
2	18.5 m [1,2]	Periodically Managed Forest	Provide contact time and carbon source, long term nutrient removal in trees	Sheet/subsurface flow Riparian trees and shrubs (native)
3	≥ 6 m	Grazed/Ungrazed Grassland	Sediment filtration, nutrient uptake, convert concentrated flow to sheet flow	Dense grass for structure, stabilization, sediment control, and nutrient uptake

[1] The minimum combined width of Zones 1 and 2 is 23 meters (75 feet).
[2] The minimum combined width of Zones 1 and 2 should be equal to at least one-third of the slope distance from the streambank to the top of the pollutant source area. This can be achieved by increasing the width of Zone 2

In the Coastal Plains and Piedmont regions, existing riparian ecosystems can increase productivity and pollution control capacity (Lowrance et al. 1985). Riparian buffers can have "substantial economic value in maintaining water quality" when implemented properly (Qui and Prato 1998). Riparian restoration has been a cost effective way of controlling NPS pollution in the western and midwestern United States (Lowrance et al. 1985). Riparian ecosystems may have a higher potential for controlling water quality in the Coastal Plains, compared to the Midwest, due to the area's land use and hydrology (Lowrance et al. 1985). Constructed wetlands can also be a cost-effective way to reduce nutrients from an agricultural watershed from reaching the receiving streams (Brenner and Brenner 1998).

1.2.3.2 Stream Channel Restoration

Historically, streams have been straightened to suit man's intent for the land. Channelization on agricultural lands maximizes the farmable area and increases water carrying capacity. Trenches and ditches in North Carolina transect fields, draining the water table to enable crop growth. These unnaturally straight reaches contain no meanders, few bends, and are often a constant slope. While efficient for water flow, they can also carry higher loads of sediment than natural streams. Floodwaters can cause higher amounts of streambank erosion due to the lower stability of straightened channels. Animal access to streams can degrade the banks and stir up the bed material. Fecal material may make reaches of the surface water inhospitable to benthic biota.

The goals of restoration vary, but ultimately focus on remeandering the channelized flow and stabilizing the stream. Different objectives of stream channel restoration may include channel stabilization, bank erosion control, habitat enhancement, and water quality improvement. Channel stabilization focuses on creating narrow, meandering waterways instead of wide, shallow, braided channels. Bank erosion control may be through natural (vegetation, wattles, cabling dead trees along eroding banks, root wads, etc.) or more 'engineered' (gabions, rip rap, concrete or masonry walls, etc) practices. Stream restoration may restore habitat to benthic biota, fish, insects, and mammals using the water. Habitat structure and macroinvertebrate populations are relatively quick in returning to restored streams (Muotka et al, 2002). By reducing the sediment and turbidity of the water, through restoration, water quality is improved.

According to Jennings and Doll (2002), a stream restoration design "must include systems of measures to prevent pollution, establish riparian vegetation, and address channel stability". For a channel to be relatively stable, three physical relationships must be met; continuity of sediment, continuity of water, and flow resistance (Byars and Kelly 2001). A natural channel design addresses the hydraulic capacity and the sediment transport of the stream in order to maintain channel stability.

Traditionally there have been three main approaches to natural channel design (NCD): analog, empirical, and analytical. Skidmore et al (2001) offers a summary of these design methods, as seen in Table 1.3. Dave Rosgen integrates aspects of the analog and empirical approached in his classification-based design approach (Miller and Skidmore 2001). A reference reach is identified and various channel parameters are measured. The width, depth, slope, bed material, gradation, width, sinuousity, and flood prone width help classify the reference reach. The differences between the design and reference reaches are compared. The design process works to match the subject reach's conditions to those of the reference stream's classification type (Miller and Skidmore 2001).

Table 1.3. Brief characterization of analog, empirical, and analytical natural channel design approaches (Skidmore et al. 2001)

Method	Description	Assumptions	Unapplicable Sites
Analog	Uses existing channel characteristics are template for design	Equilibrium between channel form and hydrologic and sediment inputs	Actively changing watersheds (urban) or where unstable channel conditions exist
Empirical	Uses equations to relate channel characteristics based upon regionalized data	Equilibrium between channel form and hydrologic and sediment inputs	Unstable channels and where site conditions restrict channel movement over time
Analytical	Uses hydraulic and sediment transport models to determine equilibrium conditions	No equilibrium assumptions	Input variables cannot be accurately determines or the model is inapplicable

There is a lack of standard practice for channel design. Some of the reasons for this include (Miller and Skidmore 2001):

- the physical variables controlling river channels vary spatially and temporally.
- the science of river restoration has yet to mature.
- the design of a channel involves a variety of disciplines.
- typically, there are very different and undefined levels of acceptable risk associated with the design projects.

Various uncertainties contribute to the lack of NCD standards. Lack of confidence may be caused by the model used, parameter estimates, randomness, and human error (Johnson and Brown 2001). Natural channel design focusing on one main method may risk not sufficiently addressing fluvial function (Miller and Skidmore 2001).

1.2.3.3 Livestock Exclusion

Beef cattle kept on pasture can cause intense water pollution due to high stocking densities (Miner et al. 2000). Animals are able to defecate directly into or adjacent to water bodies. Runoff can cause more water quality problems due to vegetation removal and trampling (Miner et al. 2000).

Livestock grazing significantly decreases streambank stability, biomass of riparian vegetation, and the extent of aquatic vegetation covering the stream channel (Scrimgeour and Kendall 2002). Livestock have an adverse impact on woody vegetation through browsing (Rickland and Cushing 1982). Over browsing by herbivores can severely decrease seed production, plant establishment, plant vigor, and survival. Low shrub communities are particularly vulnerable due to their accessibility and palatability (Case and Kauffman 1997). Higher amounts of litter have been found in grazed versus ungrazed areas (Shultz and Leininger 1990). Cattle also have a significant effect on the density and height of woody species on gravel bars, decreasing plant reproduction and establishment (Green and Kauffman 1995). These livestock disturbances create conditions suitable for exotic and ruderal species, increasing species richness (Green and Kauffman 1995). Riparian habitat was found to be significantly better on ungrazed sites; bank stabilization by vegetation was more extensive (Platts and Wagstaff 1984).

The time that cattle are in the stream significantly impacts the quality of the sediment and overlying waters (Sherer et al. 1998). Preventing cattle access to surface waters will reduce streambank degradation, direct bacterial inputs, and direct nutrient loading. It is suggested that the negative impacts of the cattle may not last long after the fencing occurs (Owens et al. 1996). In a study performed by Line et al (2000), exclusion resulted in a significant reduction in total Kjeldahl N (TKN), total P, total suspended solids, and total solids, as seen in Table 1.4. The average annual soil loss decreased 40%, even with a 30% increase in rainfall when cattle were excluded from the surface water and nearby riparian area (Owens et al. 1996). Fecal coliform and enterocci levels dropped 65.9% and 57%,

respectively, after livestock fencing (Line 2003). Turbidity and suspended sediment levels also dropped significantly, 49.2% and 60.2%, respectively (Line 2003).

Table 1.4. Percentage reductions in pollutant loading to surface waters due to excluding cattle

Pollutant[1]	Fencing [2]	Fencing [3]	Fencing and Buffers[4]
TKN	78.5%	--	75%
NO_3-NO_2	32.6%[*]	+ 26%	43%
TP	75.6%	20%	74%
TSS	82.3%	--	85%
TS	81.7%	85%	--
FC	--	--	90%

[1] *TKN – total Kjeldahl nitrogen;* NO_3-NO_2 *– nitrate-nitrite; TP – total phosphorus; TSS – total suspended solids; TS – total solids; FC – fecal coliform*
[2] *(Line et al. 2000)*
[3] *27% decrease in particulate P, 26% decrease in soluble 9< 40% decrease in particulate N, (Miner et al. 2000)*
[4] *(Line and Jennings 2002)*
[*] *Not Statistically Significant*

Removing cattle as a stress is often enough to allow tree and shrub communities to develop. In a study by Rickard and Cushing (1982), vegetation reestablished within 10 years of removing livestock. Bank stabilization by vegetation is more extensive in ungrazed riparian habitats. Woody species increase rapidly when protected from grazing. Willow canopy coverage was 8.5 times greater than that in grazed areas (Shultz and Leininger 1990). Green and Kauffman (1995) found that in the absence of livestock, the species richness and diversity decreased in dry and most meadow communities, returning to a more natural ecosystem. Fencing riparian zones "provides the maximum protection and best chance for rehabilitation in the shortest time" (Platts and Wagstaff 1984).

The negative impacts of the cattle may not last long after the fencing occurs (Owens et al. 1997; Platts and Nelson 1985). Five years after a beef herd was fenced out of a stream the annual sediment concentration and the annual soil loss decreased by over 50% and 40%,

respectively (Owens et al. 1996). The soil loss in Owens et al's (1996) study was reduced from 2.5 to 1.4 megagrams per hectare under similar precipitation.

In a study performed by Meals (2001), the first year after livestock exclusion, streambank restoration, and riparian zone protection, there was a significant decrease in TP concentration (25%), indicator bacteria counts (46-52%), and TP export (42%). Two years post-installation saw an approximately 20% decrease in mean TP concentration and 20-50% decrease in the mean TP loading (Meals and Hopkin 2002). This is further evidence that riparian zone restoration may be effective for decreasing the NPS loads from sites used for livestock grazing.

Channel restoration is one alternative to repair the damage done to Grape Creek tributary. The riparian buffer/wetland will reduce the soil, nutrients, and fecal bacteria reaching the water from the fenced-out cattle. One BMP alone may not address the entire water quality problems of the entire site. By incorporating several BMPs, the entire cattle pasture can be treated and the ecosystem improved at a faster rate than would occur in a natural system.

1.3 RATIONALE AND SIGNIFICANCE

The proposed project involves the restoration of a degraded pasture stream, an upper reach of Grape Creek, a tributary to the Neuse River which is classified as Nutrient Sensitive Waters. Beef cattle have had unrestricted access to the waterway, severely degrading the stream bank and streambed, Figure 1.3. Sediment from the stream banks has been agitated and transported downstream. Nitrogen and P have been added to the stream in the forms of urea and feces. The fecal material has also contributed bacteria to the stream.

Figure 1.3 Bank damage to pasture tributary from beef cattle.

By installing a combination of BMPs, it is hypothesized that the sediment load, nutrients, and bacteria from the cattle reaching Grape Creek will be greatly reduced. Accurate background levels of the pollutants must be determined before any change, attributed to the BMPs, can be realized.

1.4 METHODS AND MATERIALS

The Core Creek Project, funded by the Clean Water Management Trust Fund, implemented and evaluated BMPs throughout the upper watershed to reduce nutrient loading to the Neuse River. The BMPs used were nitrogen management, controlled drainage, and wetlands restoration. A portion of the Core Creek Project involved the restoration of a degraded pasture stream. The stream had been channelized and ditched. Beef cattle had unrestricted access to the waterway, severely degrading the stream bank and streambed. As a precursor to the installation, an assessment was performed to determine background water quality conditions.

1.4.1 Research Site Description

The 300-meter length tributary of Grape Creek in this study is located between U.S. Route 70 and County Road 1237 south of Cove City, in eastern North Carolina. Grape Creek is a perennial tributary for Core Creek, which eventually outlets into the Neuse River. Both Core Creek and the Neuse River are classified as "Nutrient Sensitive Waters." Grape Creek's uplands drain approximately 0.75 square kilometers of agricultural fields primarily farmed in cotton, corn, and soybeans. The uplands of the research site drain a managed pine plantation and cattle pasture and portions of U.S Route 70. The creek has been channelized and subsequently degraded and widened by beef cattle. The pasture through which Grape Creek flows is primarily used as a beef lot for a cow-calf and heifer operation. The constant access of the cattle to the creek over the past twenty years has degraded the stream banks (Figure 1.3), channel bottom, and added nutrients, sediment, and bacteria to the surface water.

1.4.2 Background Monitoring

Surface water was monitored for 16 months prior to the installation of any BMPs. Water chemistry, specifically sediment and nutrients, and bacterial loadings was monitored monthly through grab samples and weekly via automatic samplers. The following subsections detail the monitoring strategy shown in Table 1.5.

Table 1.5. Summary Table of Background Monitoring Strategy

Management Area	Description of collected data[1]	Sample Type	Sample Frequency and Period
Upstream and downstream on Grape Creek tributary	Water Chemistry NO_3, NH_4, TKN, TP, Ortho-P, pH, TSS	grab from midpoint of stream	monthly (May '03 - Sept '04)
		weekly composite [2]	daily (May '03 - Sept '04)
	Fecal Coliform	grab from midpoint of stream	weekly (May '03 - Sept '04)
	Temperature	continuous	every 20 minutes (May '03 - Sept '04)
Downstream of Grape Creek tributary	Hydrology	continuous	every 20 minutes (May '03 - Sept '04)
	Rainfall	amount and intensity during each rainfall	each event (May '03 - Sept '04)

[1] NO_3 – nitrate; NH_4 – ammonium; TKN – total Kjeldahl nitrogen; TP – total phosphorus; Ortho-P – orthophosphate; pH – pH; TSS – total suspended solids

[2] Weekly composite samples not analyzed for pH due to sulfuric acid used as preservative.

1.4.2.1 Surface Water Hydrology Monitoring

A flashboard riser water control structure was installed at the lower end of the channelized creek, below the surface water-sampling location. An Infinity® automated stage recorder continuously monitored the water level in the creek. Flow depth was determined and recorded every 20 minutes by a pressure transducer. Water level was referenced to the top of the water control structure. The Infinity® was downloaded and calibrated monthly. The distance to water and distance to the weir invert was manually measured at the time of each download.

A rain gauge measured rainfall on the site. A tipping bucket collected rainfall and a HOBO® data recorder registered the time of every 0.25 millimeters of rainfall.

1.4.2.2 Surface Water Chemistry Monitoring

Monthly grab samples, representative of the water column, were taken from the center of the study tributary. Samples were taken at sites immediately above and below cattle access to the creek to prevent cattle interference with the monitoring equipment, Figure 1.4. Surface water samples were transported, on ice, to the Environmental Analysis Laboratory in Weaver Laboratories at NC State University.

Daily 100 mL water samples were collected above and below the pasture at 12:00 PM by ISCO® automatic water samplers. These samples were then combined to create a weekly composite sample. It was assumed that flow was similar at each automatic sampler, i.e. no additional water was added to the system. Sulfuric acid (36 N strength) was used as a preservative to treat the sample bottles. These were collected monthly and transported, on ice, to the Environmental Analysis Laboratory in Weaver Laboratories at NC State University. Nitrate, NH_4, TKN, TP, OP, pH, and TSS were determined for the monthly and weekly composite samples. Gaps in data are primarily due to low flows when the automatic sampler was unable to collect a sample.

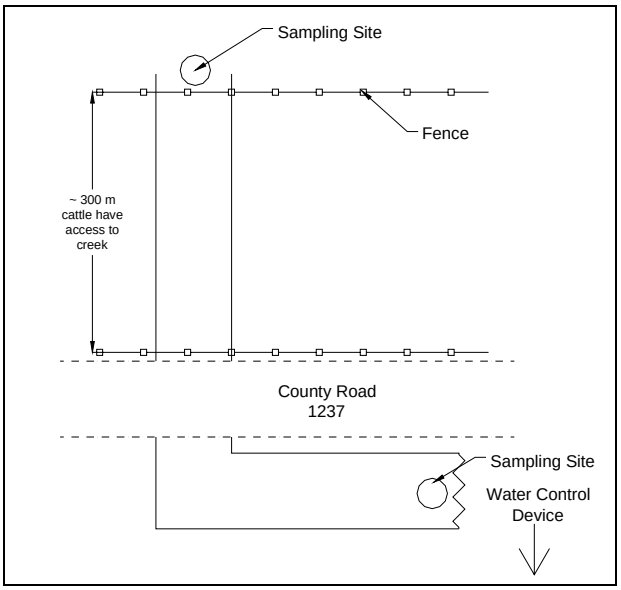


Figure 1.4 Surface Water Sampling Configuration (not to scale)

Surface water samples were collected bi-monthly for fecal determination and taken to the Craven County (NC) Department of Health.

The upstream monitoring location was located approximately 75 meters north of US Route 70, in a forested area. The downstream sampling site was sited in a drainage ditch north of County Road 1237, bordering a field.

1.4.2.3 Surface Water Temperature Monitoring

HOBO® temperature sensors were used to measure surface water temperatures which were recorded by a HOBO® data logger. The sensor was located at the same location as the intake for the automated samplers. Temperatures were recorded every 20 minutes.

1.4.2.4 Benthic Macroinvertebrate Monitoring

The macroinvertebrate collection followed that of the Swamp Method documented by NC DENR (2001). Three samples were collected from each of the macrophyte, root

mats/undercut bank, and detritus deposits. Kick net, sweep-net, and sand samples were collected at each of the habitats, for a total of nine samples. This incorporated a variety of collection techniques to catalog the macroinvertebrates in the pasture stream.

In the field, the samples were poured into white plastic trays and macroinvertebrate were extracted using forceps. The organisms were stored in 95% ethanol until the proper identification was made in the laboratory.

The tributary to Grape Creek is located in Region A of the swamp regions of North Carolina (NC DENR 2003). Swamp streams are not evaluated the same way as other North Carolina streams due to a higher natural variability making it more difficult to evaluate minor changes. Instead, three metrics are used in combination with the coastal plain form habitat value. Each metric's value is used to calculate a final site score.

The Ephemeroptera, Plecoptera, Trichoptera (EPT) metric is a simple means of determining species richness, associating high water quality with high taxa diversity of sensitive insects. Total taxa richness (EPT S) was used for the Swamp Stream metric. While reflecting the influence of chemical pollutants, sediment is not as well assessed due to the sampling of different habitats at various heights in the stream.

The Biotic Index (BI) is a method of biotic classification independent of the EPT S. The BI is a summary measure of the tolerance values of organisms found within the sample, with relation to their abundance. It can be derived by the following formula (NC DENR 2003):

Equation 1-6

$$BI = \frac{\sum (TV_i)(n_i)}{N}$$

TV_i = i^{th} taxa's tolerance value

n_i = i^{th} taxa's abundance value (1, rare; 3, common; 10, abundant)
N = sum of all abundance values

The taxa richness metric is a count of the different taxa identified from the sampling. A value is determined by comparing the total taxa richness value to the pH for the swamp stream type.

The biotic index, EPT-S, and taxa richness are factored into a total site score:

Equation 1-7 $$SiteScore = \frac{(2(BI) + Habitat + EPT + TR - 5)}{2}$$

BI = Biotic Index Score (5, Natural; 3, Moderate; 1 Severe)
Habitat = Habitat Score (5, Natural; 3, Moderate; 1 Severe)
EPT = EPT S Score (5, Natural; 3, Moderate; 1 Severe)
TR = Taxa Richness Sore (5, Natural; 3, Moderate; 1 Severe)

1.4.3 Site Design

The overall goal of the project was to design and implement the appropriate BMPs to be installed on Grape Creek tributary. Kristopher Bass, PE, Water Quality Extension Associate in Biological and Agricultural Engineering at North Carolina State University designed the stream restoration and wetlands. Various methods were used to create the restoration design. Innovative features, including cross vane placement and bank berms, were implemented to improve bank stability and wetland hydrology. A more complete description of the design process is located in Appendix A.

1.4.4 Data Analysis

Mean average monthly data concentrations from the background monitoring were analyzed to determine significant trends. A t-test was used to test for changes in concentrations levels of the pollutants in the water above and below the site. From this

analysis, the actual quantity of P, N, and bacteria that entered Grape Creek prior to the stream restoration was calculated.

1.5 RESULTS AND DISCUSSION

1.5.1 Nutrient Concentrations

1.5.1.1 Weekly Composite Samples

Total Kjeldahl nitrogen, NH_4-N, and NO_3-N concentrations are shown in Figure 1.5 through Figure 1.7. At times, the upstream concentrations were lower than downstream. In some cases the downstream concentration was lower than that upstream. There was no noticeable change in the downstream concentrations after the cattle were removed, indicating that they may not have been a significant source of N in the stream. The differences in upstream and downstream concentrations were plotted (Appendix D). For TKN, NH_4-N, and NO_3-N, the differences were generally within ± 5 mg/L, ± 2mg/L, and ± 1 mg/L, respectively. The plotted concentration ratios (upstream/downstream) reflect similar trends. For each form of N, the mean concentration downstream was not significantly different than that upstream, at $\alpha = 0.05$.

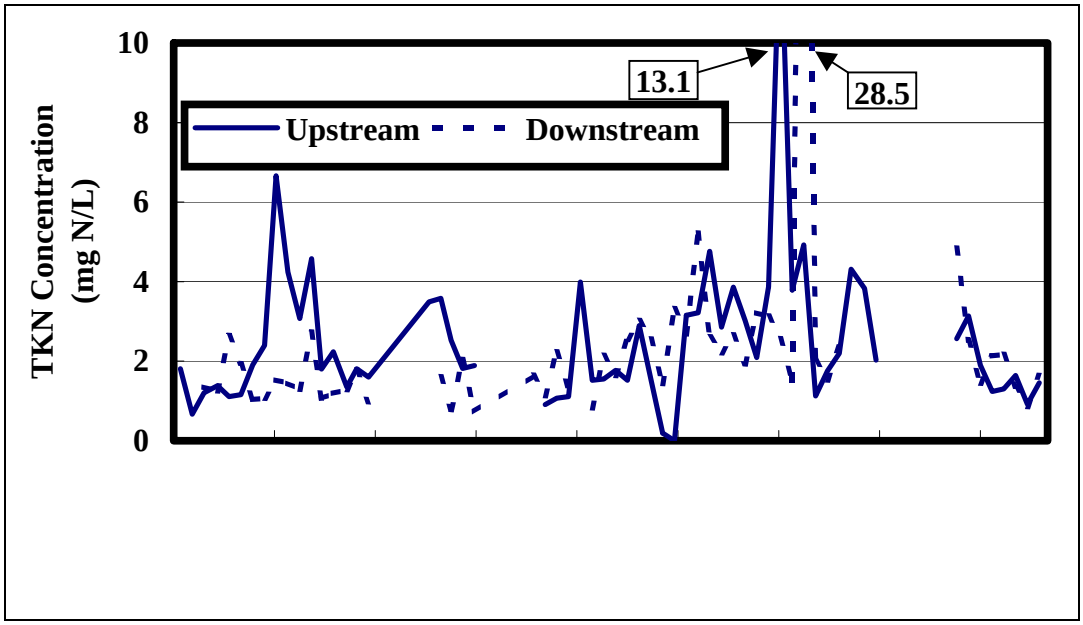


Figure 1.5 Total Kjeldahl nitrogen concentrations above and below the beef pasture determined from a weekly composite of daily samples.

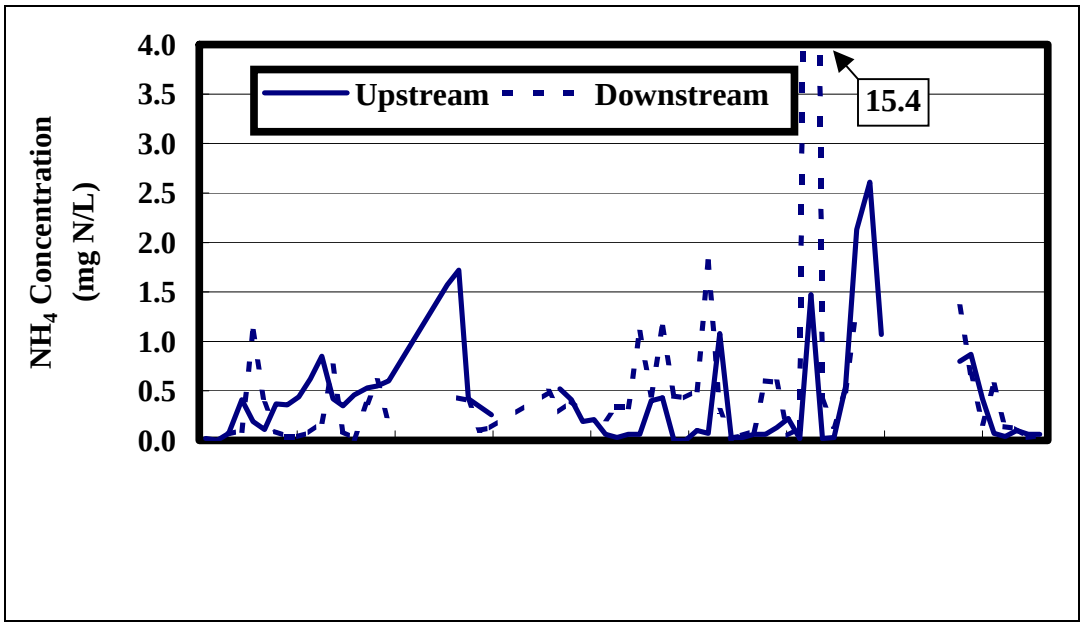


Figure 1.6 Ammonium nitrogen concentrations above and below the beef pasture determined from a weekly composite of daily samples.

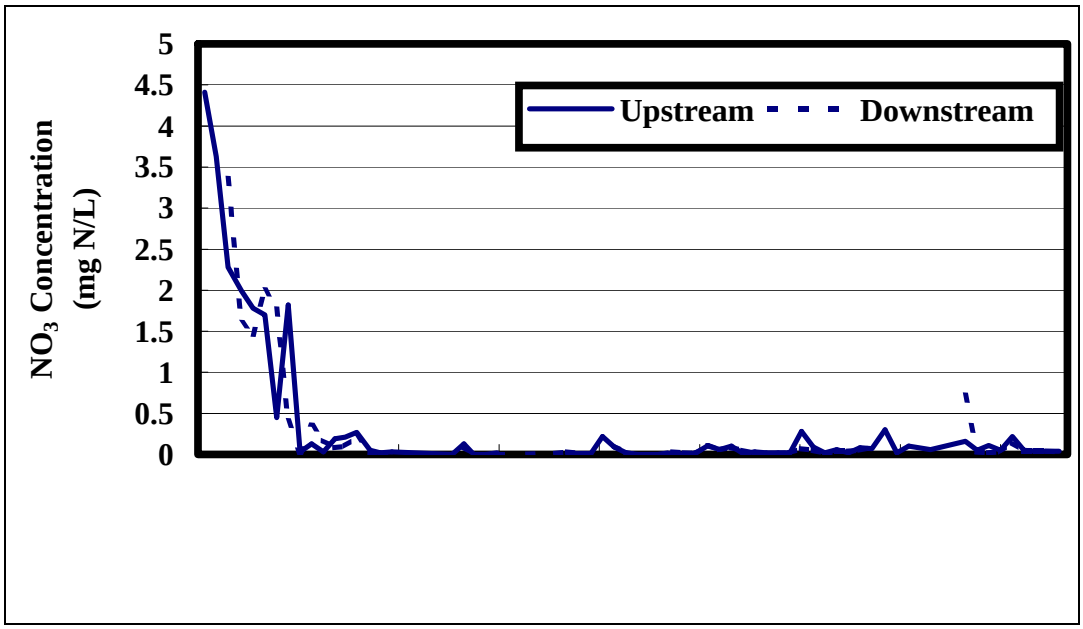


Figure 1.7 Nitrate nitrogen concentrations above and below the beef pasture determined from a weekly composite of daily samples.

The NH_4-N graph is similar to the TKN graphs, as expected since NH_4-N is a component of TKN. The elevated downstream NH_4-N levels are indicative of animal manure, as expected from the cows on the site. The higher concentrations in 2004 show that, while the animals were removed in 2003, their contributions to the organic-N load remain. At the start of sampling nitrate was elevated, both upstream and downstream, Figure 1.7. Nitrate concentration at both locations dropped sharply to below 0.5 mg/L within the first two months. There is no explanation for this sudden drop.

Upstream and downstream phosphorus are shown in Figure 1.8 and Figure 1.9. Upstream P concentrations were generally lower than those downstream, however the differences were only significant for the orthophosphate concentrations ($\alpha = 0.05$). There was no significant difference between upstream and downstream TP levels after the cattle were removed from the pasture ($\alpha = 0.05$). The difference in upstream and downstream TP

and orthophosphate concentrations was generally within ± 2 mg/L and ± 1 mg/L, respectively (Appendix D). While the actual differences in concentrations were not large, the concentration ratio (upstream/downstream) for orthophosphate was varied. However, these elevated concentrations (above 0.5 ppm) are high enough to contribute to eutrophication.

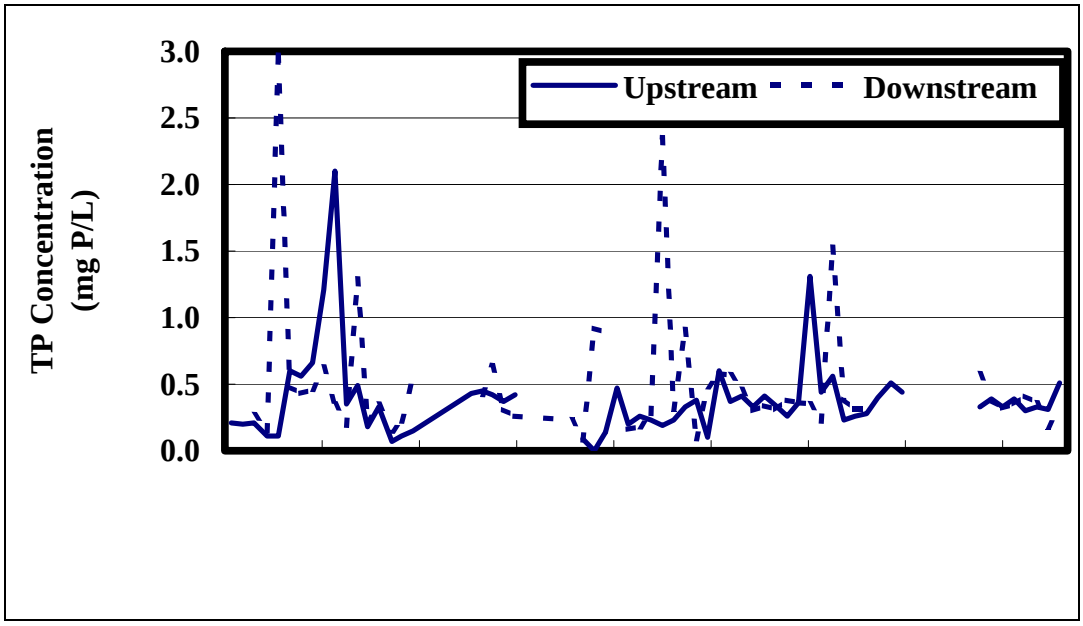


Figure 1.8 Total phosphorus concentrations above and below the beef pasture determined from a weekly composite of daily samples.

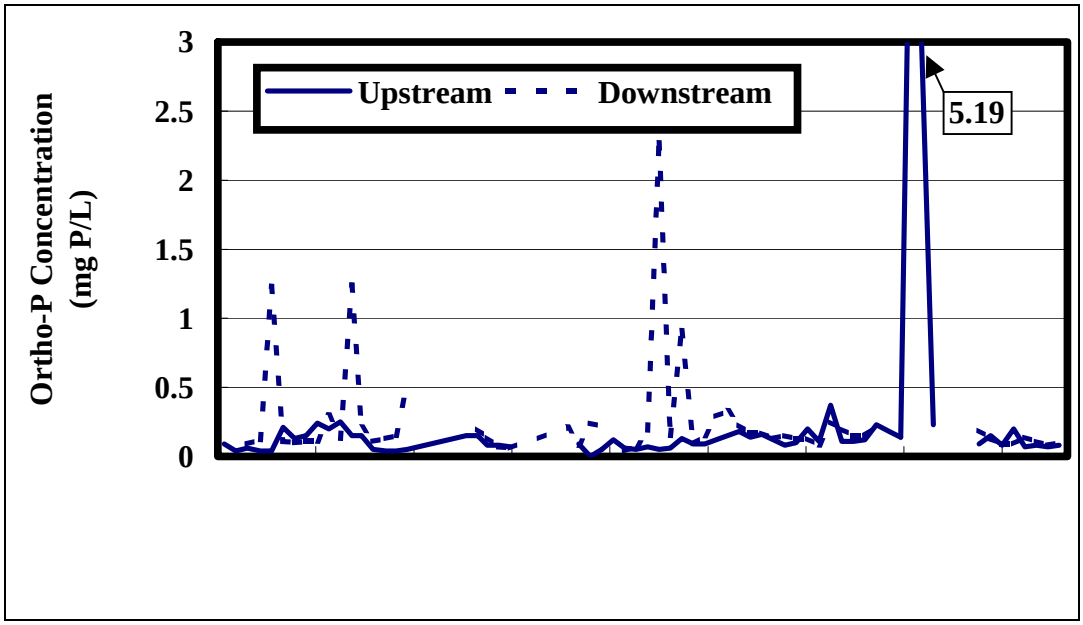


Figure 1.9 Orthophosphate concentrations above and below the beef pasture determined from a weekly composite of daily samples.

Table 1.6 shows that the average nutrient concentrations downstream are similar to those upstream. Only the orthophosphate value was significantly higher downstream (α = 0.05). The TKN and NO_3-N concentrations downstream were similar to upstream as there were no observable riffles or tumbling waters that might remove the nitrogen. The higher NH_4-N and ortho-P concentrations downstream are indicative of animal manure being contributed to the stream.

Table 1.6 Outflow Seasonal Nutrient and Total Suspended Solids Concentration in Drainage Water (weekly composite samples), mg/L

Nutrient	Forest + Road [1] (Upstream of pasture)	Downstream of Pasture	Forested Lands [2]
Total N	2.45	2.45	< 1.5
$NO_3 - N$	0.33	0.32	< 0.1
$NH_4 - N$	0.33	0.65	< 1.1
Total P	0.38	0.50	< 0.07
Ortho-P [3]	0.11	0.25	–
TSS [3]	96.9	46.3	–

[1] Managed Forest & U.S. Route 70
[2] (Chescheir et al. 2003)
[3] Statistically Significant

The observed constituent concentrations in the stream flow shown in Table 1.6 were higher than the mean seasonal outflow concentrations for a forest (Chescheir et al. 2003). This was expected downstream of the pasture. The higher upstream concentrations could be impacted by runoff from U.S. Route 70. The road and its right-of-way contribute approximately 11 hectare (10%) to the watershed upstream of the pasture sampling site.

1.5.2 Total Suspended Solids

Total suspended solids upstream were significantly higher than downstream (α = 0.05), Figure 1.10. The upstream sampling may include partial bedload. The downstream sampling site was deep and narrow. The intake to the sampler was located at the approximate midpoint of low flow depth, avoiding bedload movement. The upstream location was wide and shallow. The sampler intake was located approximately 1.5 cm from the channel bottom to ensure sampling in low flow conditions. This could have led to bedload being sampled. The difference in upstream and downstream TSS concentrations was generally within ± 200 mg/L (Appendix E). The concentration ratios (upstream/downstream)

were generally high, ranging from 0 to 15.6. These extreme values contributed to the significantly different upstream and downstream concentrations.

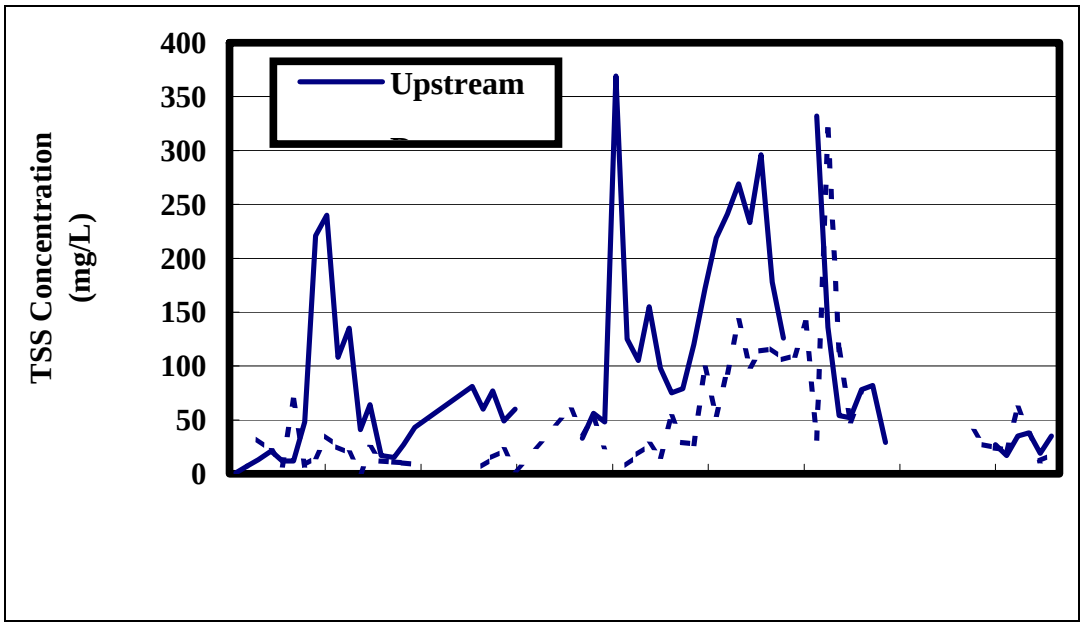


Figure 1.10 Total suspended solids concentrations above and below the beef pasture determined from a weekly composite of daily samples.

1.5.3 Monthly Grab versus Weekly Composite Sampling

Monthly grab samples and weekly composite samples were collected at the downstream site for the 17 month period of 23 April 2003 to 15 September 2004. These samples were used in conjunction with the daily flow volumes (Figure 1.11) to determine the flow-based nutrient loadings for each sampling method.

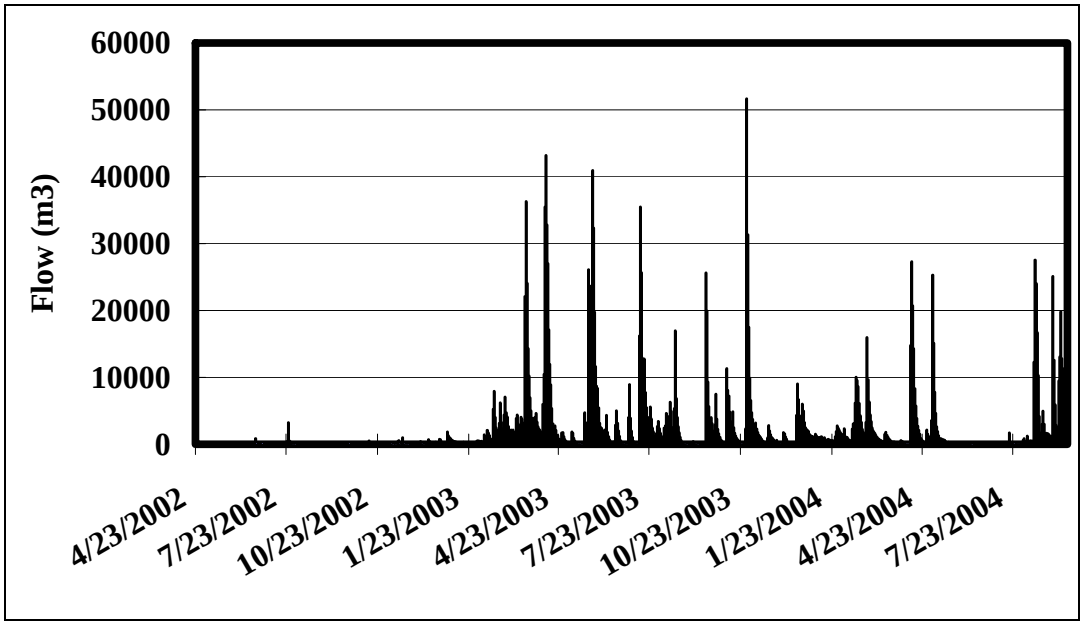


Figure 1.11 Daily flow rates used for nutrient loading calculations at downstream pasture site.

Loads determined from the monthly grab samples are based on one grab sample concentration per month for all flow during the month. The concentration value was used with the flow that occurred from halfway before until halfway after the next grab sample. This one concentration may not be representative of the average concentration occurring during the sampling period. As a result, the load computed from this one concentration could significantly overestimate or underestimate the monthly load. The weekly composite samples on the other hand are composed of a sample for each day that week. Loads from the weekly composite samples were calculated using the weekly composite concentration and the flow during that sampling week.

Generally, the weekly sampling resulted in higher cumulative nutrient loads, as seen in Figure 1.12 through Figure 1.17. The nutrient loads, based on monthly grab samples, were statistically lower than the loads determined using the weekly composite samples, excluding nitrate ($\alpha = 0.05$).

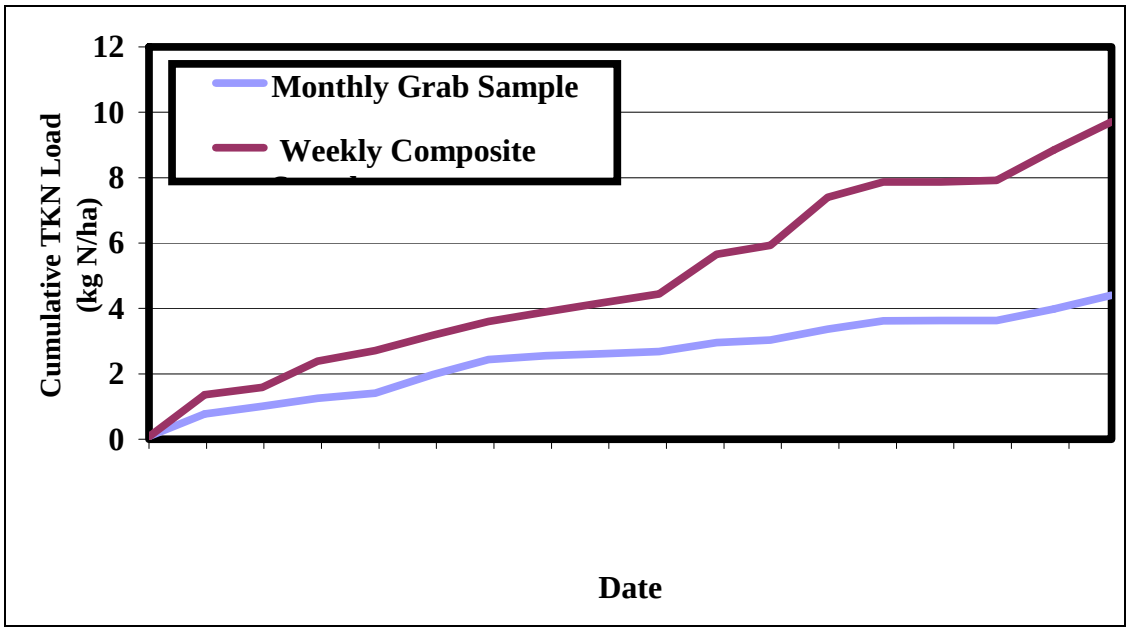


Figure 1.12 Cumulative yearly total Kjeldahl nitrogen loads, per hectare, based on weekly composite and monthly grab sampling schemes

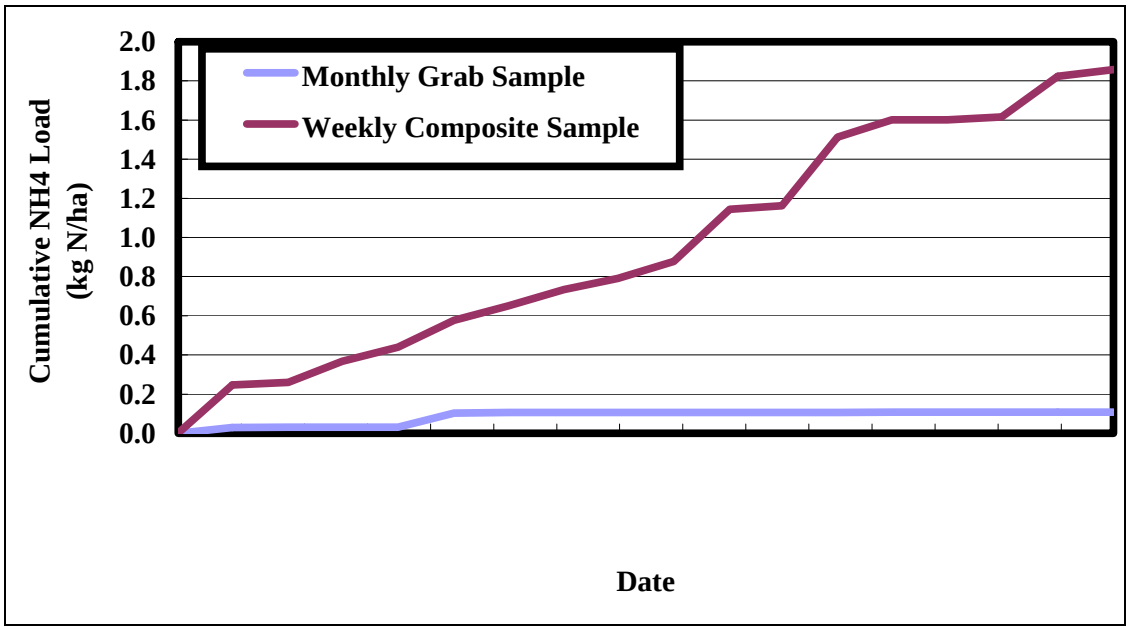


Figure 1.13 Cumulative yearly ammonium loads, per hectare, based upon weekly composite and monthly grab sampling regimes.

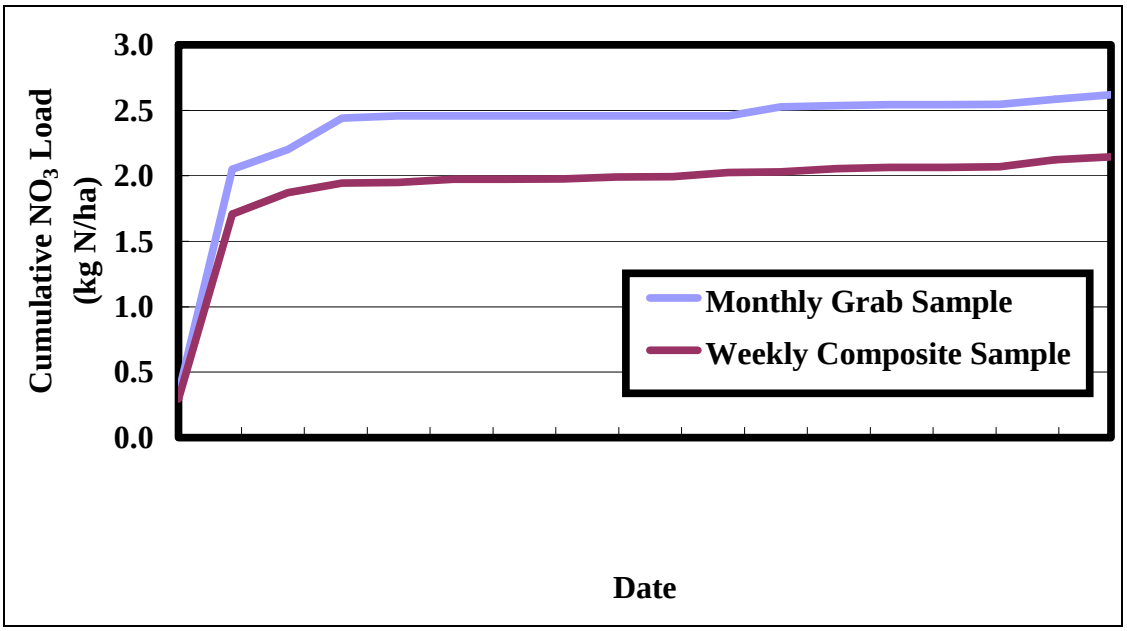


Figure 1.14 Cumulative yearly nitrate-nitrogen loads, per hectare, based on weekly composite and monthly grab sampling schemes.

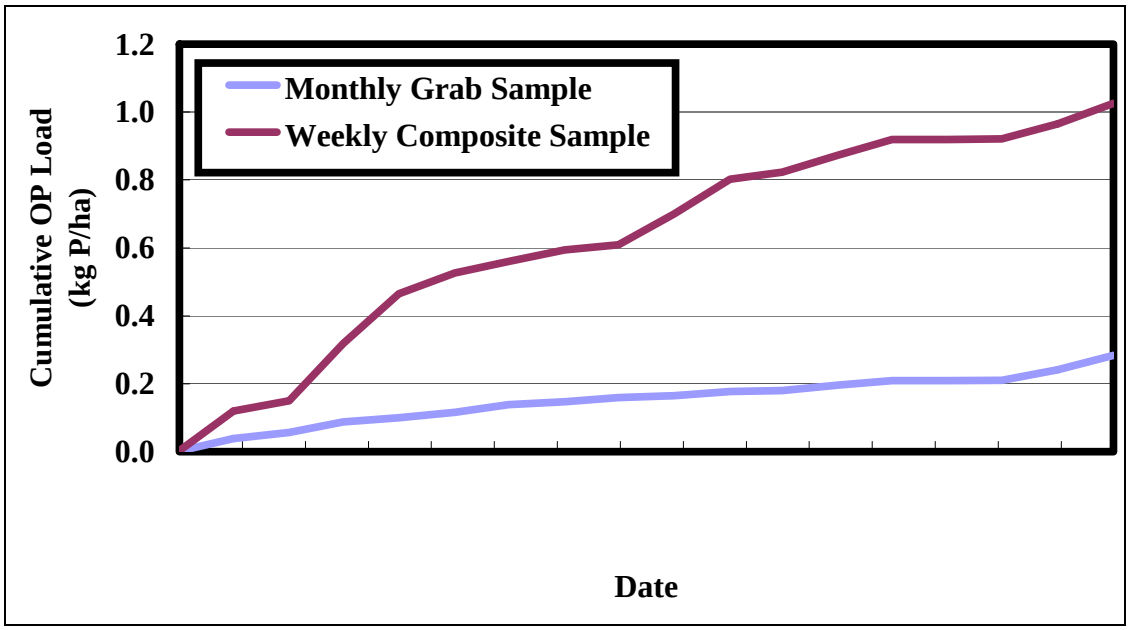


Figure 1.15 Cumulative yearly orthophosphate loads, per hectare, based upon weekly composite and monthly grab sampling regimes.

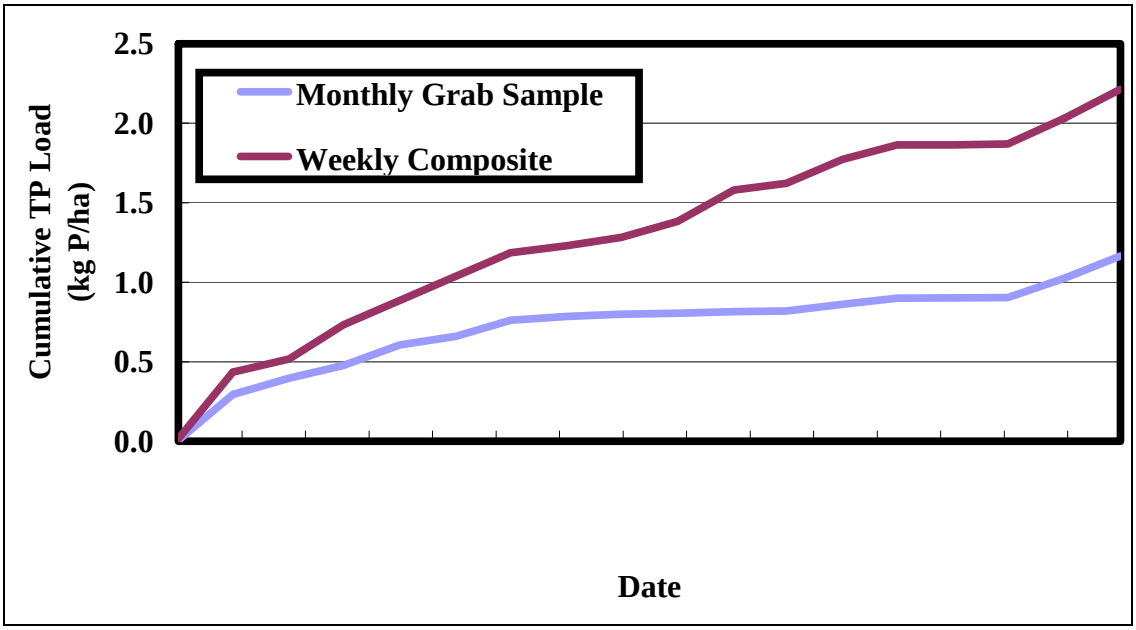


Figure 1.16 Cumulative yearly total phosphorus loads, per hectare, based on weekly composite and monthly grab sampling schemes.

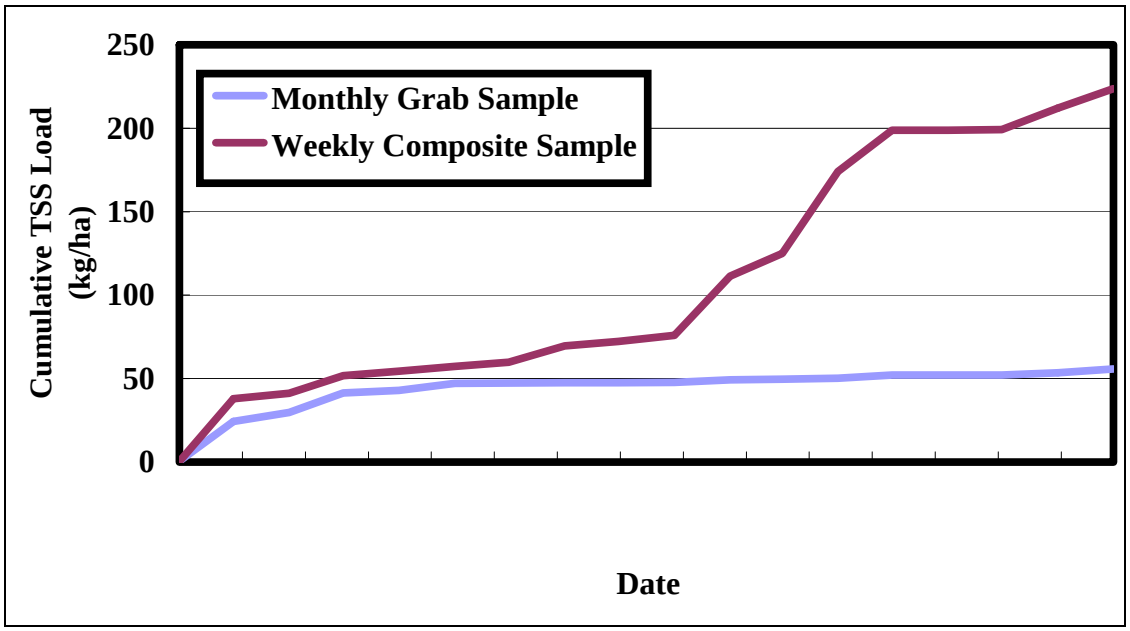


Figure 1.17 Cumulative yearly total suspended solids loads, per hectare, based upon weekly composite and monthly grab sampling regimes.

Generally, the individual nutrient concentrations in each sample type were consistent over time throughout the 17 month sampling period. Interestingly, the grab samples rarely had NH_4-N, as compared to the weekly composite samples, Figure 1.13. These values were compared to the grab samples taken directly at the water control structure where flow was measured, Table 1.7. Values were generally similar at both locations. If the composite samples were not adequately preserved (i.e., acidity was not low enough to surpress biological activity), the TKN could have broken down into NH_4-N, resulting in the elevated levels as compared to the grab sample concentrations. Elevated TKN may have resulted from the breakdown of organic matter within the sample.

Another explanation may arise from the sampling methodology. The grab samples are traditionally taken from water flow over the weir at the sampling location. The aeration in the flow may be enough to transform the NH_4-N to NO_x-N.

Table 1.7 NH_4-N concentrations below pasture and at water control structure, downstream

Date	Downstream Of Pasture	Water Control Structure
4/16/2003	0	0
5/20/2003	0.04	0.02
6/19/2003	0	0
7/16/2003	0	0
8/18/2003	0	0
9/17/2003	0.22	0.01
10/23/2003	0	0.01
11/24/2003	0	0
12/9/2003	0	0
2/23/2004	0	0
3/17/2004	0	0
4/21/2004	0	0
5/17/2004	0.01	0
8/18/2004	0	0.01
9/15/2004	0	0

Monthly estimated NO_3-N loads were generally higher than those estimated weekly (Table 1.8 and Figure 1.14). May 2003 showed high nitrate loads, compared to the other months, possibly causing the analysis to be skewed. Excluding this month, NO_3-N was higher using the monthly grab sampling. When May 2003 is compared to other nutrients, this peak does not seem abnormal. The other nutrient loads were also shown to be high during this sampling period (Figure 1.12 through Figure 1.17).

Table 1.8 Average monthly percentage difference in nutrient load based upon weekly and monthly sampling regimes.

Nutrient	Percentage Difference [1]
Total Kjeldahl Nitrogen	46.8%
Ammonium	95.1%
Nitrate	-50.8% [2]
Total Phosphorus	49.2%
Orthophosphate	61.7%
Total suspended solids	54.4%

[1] % Difference = average{(weekly load – monthly load)/weekly load}
[2] Without May 2003 sample, percentage difference is –52.5%

It was theorized that the sampling methods might have resulted in some of the nutrient differences. The monthly grab samples are weather related, i.e. sampling does not typically occur during rainfall. For this reason, the grab sampling may have been sampling a more base-flow condition than the automated samplers. As the automated samplers take a sample no matter the weather, the concentrations in the composite samples should be reflective of base and surface flows. In this case, higher nitrate concentrations would be expected in the grab samples from baseflow drainage waters. Higher TKN, NH_4-N, TP, and ortho-P levels would be expected from surface flows, as reflected in the composite samples.

Nutrient concentrations were paired with the instantaneous flow rate at the time of sampling (Appendix F). The instantaneous flow rate at the time of each sample was

averaged over the number of samples taken in each composite. From this data, concentration was very weakly correlated to flow rate, for all nutrients (-0.10 – 0.10). The data did not support a flow-related concentration relationship. It is possible that the sampling period was not long enough to show this.

While the daily sample may not accurately represent the average during the period, the compounded error is less due to the shorter time interval, 24-hours, between samplings. Over a long enough period, the monthly grab sampling scheme should balance out, approximating the loads determined from weekly composite sampling. This sampling period was not long enough to show this.

These data suggest that more frequent sampling is necessary to accurately represent the nutrient loading of a stream, for a shorter length of monitoring. Monthly or bi-monthly sampling can create large errors if those concentrations are extrapolated over the monitoring period.

1.5.4 Fecal Monitoring

Water samples for fecal analysis were collected bi-monthly beginning on 16 April 2003. Samples were taken from the tributary of Grape Creek above and below the pasture. The cattle were permanently removed on 18 November 2003. Sampling continued until 15 September 2004. It was assumed that the flow volume was about the same at both the upstream and downstream sampling locations, making the fecal coliform concentrations of each directly comparable (Figure 1.18). The upstream concentrations were significantly lower than downstream concentrations ($\alpha = 0.05$).

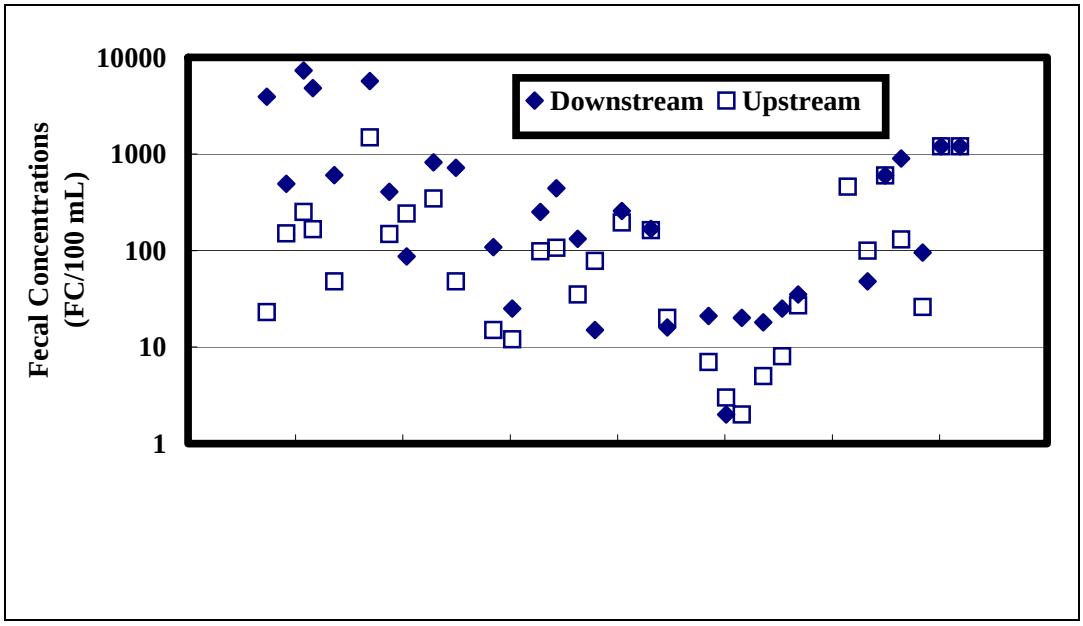


Figure 1.18 Fecal coliform concentrations above and below tributary to Grape Creek cattle pasture

The downstream fecal concentration decreased rapidly after the cattle were removed (18 November 2003). This reduction is noticeable in Figure 1.19, as the ratio between the upstream and downstream concentration is closer to 1 after November 2003. Downstream concentrations were significantly lower ($\alpha = 0.05$). On average, the fecal coliform level was reduced 83% after cattle exclusion. This is similar to that found by Line et al (2000)and Line and Jennings (2002). This portion of the study corroborates Owens et al (1996), in that that negative environmental effects may not last long after cattle have been removed from the stream.

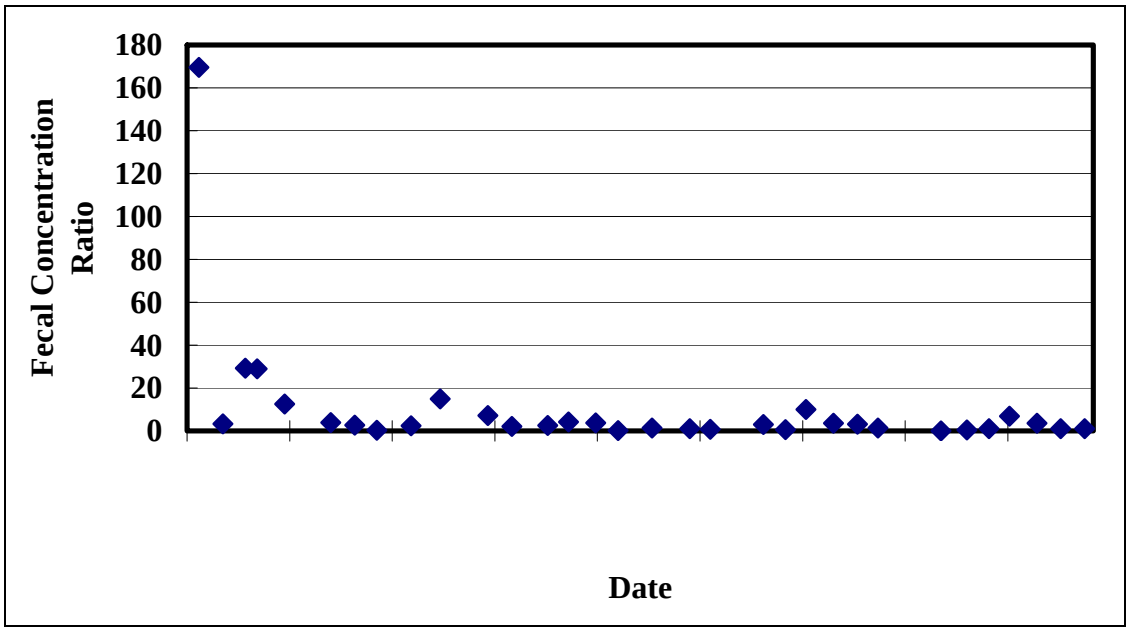


Figure 1.19 Concentration ratio (below/above) tributary to Grape Creek cattle pasture

1.5.5 Temperature Data

Upstream and downstream temperature data were collected three times per hour from 8 May 2003 to 5 June 2003 and 24 March 2004 to 3 September 2004. The daily average data from 2004 is shown in Figure 1.20. The complete data set is shown in Appendix G. General trends in 2003 were similar to that of 2004. Average temperatures upstream were shown to be significantly lower ($\alpha = 0.05$) than those downstream. The higher average temperatures downstream can be attributed to solar radiation, as there was little shade along the stream channel through the pasture. The daily averages include nighttime temperatures, creating a dampening effect as they are similar upstream and downstream.

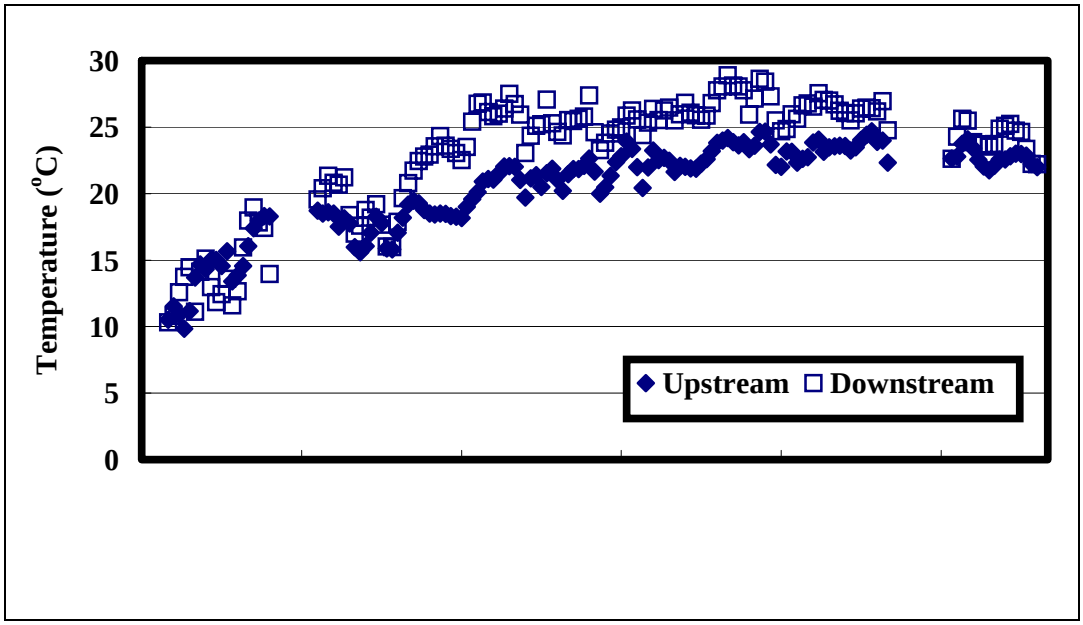


Figure 1.20 Average daily temperatures recorded above and below tributary to Grape Creek pasture.

1.5.6 Benthic Macroinvertebrate Results

A macroinvertebrate assessment was performed prior to cattle removal on 8 August 2003 and after cattle exclusion on 7 September 2004.

1.5.6.1 Site Score

A summary of the different metric's values for the stream is shown in

Table 1.9. Based upon this and NC DENR's criteria (2003), the stream was classified as under Severe Stress at both 2003 and 2004 sampling times. The low Biotic Index scores drove the stress classification to be Severe. A list of species identified with abundance and tolerance values is located in Appendices H and I.

Table 1.9. Benthic Macroinvertebrate Assessment for the Swamp Stream Tributary to Grape Creek, Using NC DENR's Metric (2003)

Metric	August 8, 2003	September 7, 2004

	Score	Classification	Score	Classification
Biotic Index	8.12	Severe Stress	8.13	Severe Stress
EPT S	4 [1]	Moderate Stress	4 [2]	Severe Stress
Taxa Richness (ST)	36 [1]	Moderate Stress	35 [2]	Moderate Stress
Habitat		Moderate Stress		Moderate Stress
Site Score	3	Severe Stress	2	Severe Stress

[1] pH was approximately 5.1
[2] pH was approximately 6.2

The macroinvertebrates collected prior to cattle exclusion were dominated by collectors/gatherers, suggesting a depositional area. The lack of filter feeders found suggests low flow. The tolerance values of the species present were higher, indicating a more tolerant community. This is also supported by the lower EPT value. From this data, the stream seems to be in a transitional phase, either improving or degrading, before the cows were removed.

The 2004 survey showed a higher abundance of macroinvertebrates within the stream. The taxa richness was similar to the 2003 survey, indicating that there was no change in water quality. There was a slight improvement in 2004 in the number of intolerant taxa, specifically the Hydroptilidae caddis fly. While the slight increase in the number of intolerant species and the more abundant EPT taxa in 2004 are an observational improvement, it was not statistically significant ($\alpha = 0.05$). The increase in the number of organisms in 2004 was a possible indication of better habitat, but the lack of taxa increase indicated that the water quality was still poor.

The overall water quality impacting benthic macroinvertebrates is controlled by chemistry and temperature. While the water chemistry was improving since cattle exclusion, maximum water temperatures downstream were significantly higher than the upstream temperatures ($\alpha = 0.05$), Figure 1.21. While not impacting the nutrient load, the warmer

waters have a lower capacity for dissolved oxygen, creating less hospitable conditions for benthic taxa.

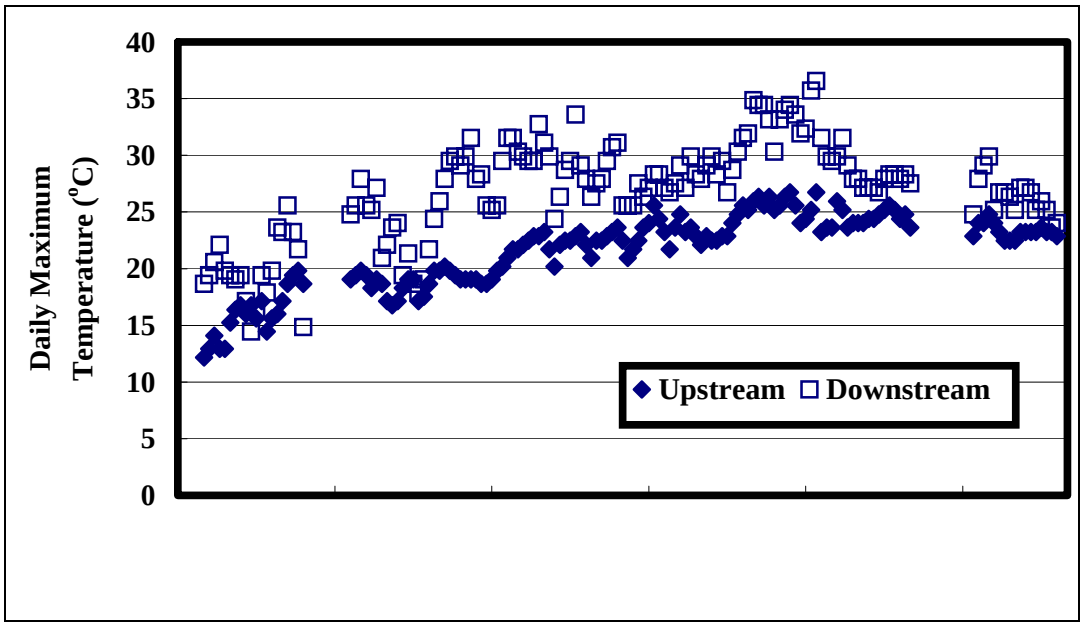


Figure 1.21 Daily maximum temperatures above and below tributary to Grape Creek cattle pasture.

The macrophyte habitat was the most productive habitat in 2003, housing a mayfly with common abundance. In 2004, two mayfly species were found to be common and abundant. The increase of *Ishnura* and Caenidae may be habitat related. While the water quality has not improved since cattle exclusion, a more stable macrophyte habitat has developed. A more abundant number of insects were found in this habitat in 2004 as compared to 2003.

The majority of insects found during both surveys are considered tolerant, supporting work done by Lenat and Crawford (1994). The benthic macroinvertebrates reflect the conditions over a long period of time, not at just the time of sampling.

1.6 CONCLUSIONS

There was no significant difference in nitrogen concentrations downstream of the pasture compared to those upstream. The average measured nitrogen constituent concentrations were higher than that published for a forest (Table 1.6). The average NH_4-N concentration downstream (0.65 mg/L) is indicative of animal manure in the stream system. While the cattle were removed in November 2003, the residual effects remained.

The downstream phosphorus concentration was generally higher than the upstream concentration. This difference was significant for orthophosphate. The average TP concentrations upstream and downstream were both higher than values published for a natural forest, Table 1.6.

The suspended solids concentrations downstream were significantly lower than that upstream. Higher loads upstream of the pasture were unexpected. Bedload may have contributed to the elevated upstream concentrations.

Fecal coliform levels were significantly higher downstream than upstream, before cattle exclusion. After exclusion, there was a significant reduction in fecal levels downstream. The fecal coliform level dropped an average of 83% and the downstream concentrations approached those upstream.

The upstream average daily and maximum daily water temperatures were significantly lower than downstream. Solar radiation was the main source of additional heat to the unshaded stream.

The macroinvertebrate sampling indicated that the quality of the stream was severely stressed, both before and after cattle exclusion. The biotic index, EPT S, and Taxa Richness scores for each year were similar. The cattle removal in November of 2003 improved habitat

and insect abundance in 2004. While the water chemistry improved after cattle removal, daily maximum temperatures may contribute to the low water quality. This poor water quality effect continued to be reflected by the low EPT and number of identified species. It may take several years for the macroinvertebrate population diversity increased. The insects reflect the conditions over a long period of time, not just at that of sampling.

A monthly grab sampling predicted significantly different nutrient load than the weekly composite sampling scheme. Total Kjeldahl nitrogen, ammonium, total phosphorus, orthophosphate and total suspended solids were under-predicted using the monthly sampling protocol. Nitrate was over predicted by 51% when using the monthly sampling method. For future research purposes, it is recommended to use a weekly composite sampling scheme as compared to monthly sampling.

1.6.1 Future Research Opportunities

This project provides the opportunity for long-term study of the BMP applications. Research could focus on length of time until full riparian buffer development. Other studies could relate to channel stability and rehabitation by aquatic organism. The effectiveness of various lengths of grassy vegetation on the riparian buffer could also be considered.

1.7 REFERENCES

Ambus, P., and Christensen, S. (1993). "Denitrification Variability and Control in a Riparian Fen Irrigated with Agricultural Drainage Water." *Soil Biology Biochemistry*, 25(7), 915-923.

Ambus, P., and Lowrance, R. (1991). "Comparison of Denitrification in Two Riparian Soils." *Soil Science Society of America Journal*, 55, 994-997.
Bass, K. (2004). Raleigh, NC.
Beeson, C. E., and Doyle, P. F. (1995). "Comparison of Bank Erosion at Vegetated and Non-Vegetated Channel Bends." *Water Resources Bulletin*, 31(6), 983-990.
Brenner, F. J., and Brenner, E. K. (1998). "A Watershed Approach to Agricultural Non-Point Source Pollution Abatement." Watershed Management: Practice, Policies, and Coordination, R. J. Reimold, ed., McGraw Hill, New York City, New York.
Byars, M. S., and Kelly, M. "Sediment Transport in Urban Stream Restoration Design." *Wetlands Engineering and River Restoration Conference*, 17-28.
Case, R. L., and Kauffman, J. B. (1997). "Wild Ungulate Influences on the Recovery of Willows, Black Cottonwood and Thin-leaf Alder Following Cessation of Cattle Grazing in Northeastern Oregon." *Northwest Science*, 71(2), 115-126.
Casey, R. E., and Klaine, S. J. (2001). "Nutrient Attenuation by a Riparian Wetland During Natural and Artificial Runoff Events." *Journal of Environmental Quality*, 30, 1720-1731.
Chescheir, G. M., Lebo, M. E., Amatya, D. M., Hughes, J., Gilliam, J. W., Skaggs, R. W., and Herrman, R. B. 2003. "Hydrology and Water Quality of Forested Lands in Eastern North Carolina." *ASAE Annual International Meeting*, Las Vegas, Nevada.
Cooke, J. G., and Cooper, A. B. (1988). "Sources and Sinks of Nutrients in a New Zealand Hill Pasture Catchment: III. Nitrogen." *Hydrological Processes*, 2, 135-149.
Cooper, J. R., Gilliam, J. W., Daniels, R. B., and Robarge, W. P. (1987). "Riparian Areas as Filters for Agricultural Sediment." *Soil Science Society of America Journal*, 51(2), 416-420.
Correll, D. L., and Weller, D. E. "Factors Limiting Processes in Freshwater Wetlands: An Agricultural Primary Stream Riparian Forest." *Freshwater Wetlands and Wildlife Conference - 8603101*, Oak Ridge, TN.
Daniels, R. B., and Gilliam, J. W. (1996). "Sediment and Chemical Load Reduction by Grass and Riparian Filters." *Soil Science Society of America Journal*, 60, 246-251.
Dillaha, T. A., Reneau, R. B., Mostaghimi, S., and Lee, D. (1989). "Vegetative Filter Strips for Agricultural Nonpoint Source Pollution Control." *Transactions of the ASAE*, 32(2), 513-519.
Dukes, M. D., Evans, R. O., Gilliam, J. W., and Kunickis, S. H. (2002). "Effect of Riparian Buffer Width and Vegetation Type on Shallow Groundwater Quality in the Middle Coastal Plain of North Carolina." *Transactions of the ASAE*, 45(2), 327-336.
Dukes, M. D., Evans, R. O., Gilliam, J. W., and Kunickis, S. H. (2003). "Interactive Effects of Controlled Drainage and Riparian Buffers on Shallow Groundwater Quality." *Journal of Irrigation and Drainage Engineering*, 129(2), 82-92.
Gilliam, J. W. (1994). "Riparian Wetlands and Water Quality." *Journal of Environmental Quality*, 23, 896-900.
Green, D. M., and Kauffman, J. B. (1995). "Succession and Livestock Grazing in a Northeastern Oregon Riparian Ecosystem." *Journal of Range Management*, 48(4), 307-313.

Groffman, P. M., Axelrod, E. A., Lemunyon, J. L., and Sullivan, W. M. (1991). "Denitrification in Grass and Forest Vegetated Filter Strips." *Journal of Environmental Quality*, 20, 671-674.

Haycock, N. E., and Burt, T. P. (1993). "The Sensitivity of Rivers to Nitrate Leaching: the Effectiveness of Near-Stream Land as a Nutrient Retention Zone." Landscape Sensitivity, D. S. G. Thomas and R. J. Allison, eds., John Wiley and Sons, Ltd.

Haycock, N. E., and Pinay, G. (1993). "Groundwater Nitrate Dynamics in Grass and Poplar Vegetated Riparian Buffer Strips During the Winter." *Journal of Environmental Quality*, 22, 273-278.

Helfield, J. M., and Diamond, M. L. (1997). "Use of a Constructed Wetland for Urban Stream Restoration: A Critical Analysis." *Environmental Management*, 21(3), 329-341.

Hunt, P. G., Stone, K. C., Humenik, F. J., Matheny, T. A., and Johnson, M. H. (1999). "In-Stream Wetland Mitigation of Nitrogen Contamination in a USA Coastal Plain Stream." *Journal of Environmental Quality*, 28(1), 249-256.

Iowa State University Forestry Extension. (2001). "Buffer Strips for Riparian Zones."

Jacobs, T. C., and Gilliam, J. W. (1985). "Riparian Losses of Nitrate from Agricultural Drainage Water." *Journal of Environmental Quality*, 14(4), 472-478.

James, B. R., Bagley, B. B., and Gallagher, P. H. "Riparian Zone Vegetation Effects on Nitrate Concentration in Shallow Groundwater." *New Perspectives in the Chesapeake System: A Research and Management Partnership*, 605-611.

Jarrett, A. R. (2001). *Land Application of Wastes*, Engineering Copy Center, University Park, PA.

Jennings, G. D., and Doll, B. A. "Natural Channel Design Applications for Restoring Incised Streams in North Carolina." *ASAE Annual International Meeting/CIGR XV World Congress*, Chicago, Illinois.

Johnson, P. A., and Brown, E. R. (2001). "Incorporating Uncertainty in the Design of Stream Channel Modifications." *Journal of the American Water Resources Association*, 37(5), 1225-1236.

Jordan, T. E., Correll, D. L., and Weller, D. E. (1993). "Nutrient Interception by a Riparian Forest Receiving Inputs from Adjacent Cropland." *Journal of Environmental Quality*, 22, 467-473.

Kadlec, R. H., and Hay, D. L. (1994). "Constructed Wetlands for River Water Quality Improvement." *Water Science Technology*, 29(4), 159-168.

Kauffman, J. B., Krueger, W. C., and Varva, M. (1983). "Impacts of Cattle on Streambanks in Northeastern Oregon." *Journal of Range Management*, 36(6), 683-685.

Kralova, M., Masscheleyn, P. H., Lindau, C. W., and Patrick Jr., W. H. (1992). "Production of Dinitrogen and Nitrous Oxide in Soil Suspension as Affected by Redox Potential." *Water, Air, and Soil Pollution*, 61, 37-45.

Kuhnle, R. A., Simon, A., and Knight, S. S. "Developing Linkages Between Sediment Load and Biological Impairment for Clean Sediment TMDLs." *Wetlands Engineering and River Restoration Conference*, 1021-1030.

Lee, K., Kenhart, T. M., Schultz, R. C., and Mickelson, S. K. (2000). "Multispecies Riparian Buffer Trap Sediment and Nutrients During Rainfall." *Journal of Environmental Quality*, 29(4), 1200-1205.

Lenat, D. R., and Crawford, J. K. (1994). "Effects of Land Use on Water Quality and Aquatic Biota of Three North Carolina Piedmont Streams." *Hydrobiologia*, 294, 185-199.

Lenat, D. R., Penrose, D. L., and Eagleson, K. W. (1981). "Variable effects of Sediment Addition on Stream Benthos." *Hydrobiologia*, 79, 187-194.

Line, D. E. (2002). "Changes in Land Use/Management and Water Quality in the Long Creek Watershed." *Journal of the American Water Resources Association*, 38(6), 1691-1701.

Line, D. E. (2003). "Changes in a Stream's Physical and Biological Conditions Following Livestock Exclusion." *Transactions of the ASAE*, 46(2), 287-293.

Line, D. E., Harman, W. A., Jennings, G. D., Thompson, E. J., and Osmond, D. L. (2000). "Nonpoint-Source Pollutant Load Reductions Associated with Livestock Exclusion." *Journal of Environmental Quality*, 29(6), 1882-1890.

Line, D. E., and Jennings, G. D. (2002). "Long Creek Watershed Nonpoint Source Water Quality Monitoring Project - Final Report." North Carolina State University, Raleigh, North Carolina.

Lowrance, R. (1992a). "Groundwater Nitrate and Denitrification in a Coastal Plain Riparian Forest." *Journal of Environmental Quality*, 21, 401-405.

Lowrance, R. (1992b). "Nitrogen Outputs from a Field-Size Agricultural Watershed." *Journal of Environmental Quality*, 21, 602-607.

Lowrance, R., Leonard, R., and Sheridan, J. (1985). "Managing Riparian Ecosystems to Control Nonpoint Pollution." *Journal of Soil and Water Conservation*, 40, 87-97.

Lowrance, R., and Leonard, R. A. (1988). "Streamflow Nutrient Dynamics on Coastal Plain Watersheds." *Journal of Environmental Quality*, 17(4), 734-740.

Lowrance, R., Sharpe, J. F., and Sheridan, J. M. (1986). "Long-Term Sediment Deposition in the Riparian Zone of a Coastal Plain Watershed." *Journal of Soil and Water Conservation*, 41(4), 266-272.

Lowrance, R., Todd, R., Fail Jr., J., Hendrickson Jr., O., and Asmussen, L. (1984a). "Riparian Forests as Nutrient Filters on Agricultural Watersheds." *Bioscience*, 34(6), 374-377.

Lowrance, R., Todd, R. L., and Asmussen, L. (1984b). "Nutrient Cycling in an Agricultural Watershed: II. Streamflow and Artificial Drainage." *Journal of Environmental Quality*, 13(1), 27-32.

Lowrance, R., Todd, R. L., and Asmussen, L. E. (1984c). "Nutrient Cycling in an Agricultural Watershed: I. Phreatic Movement." *Journal of Environmental Quality*, 13(1), 22-26.

Lowrance, R., Vellidis, G., and Hubbard, R. (1995). "Denitrification in a Restored Riparian Forest Wetland." *Journal of Environmental Quality*, 24(808-815).

Marlow, C. B., Pogacnik, T. M., and Quinsey, S. D. (1987). "Streambank Stability and Cattle Grazing in Southwestern Montana." *Journal of Soil and Water Conservation*, 42(4), 291-296.

Meals, D. W. (2001). "Water Quality Response to Riparian Restoration in an Agricultural Watershed in Vermont, USA." *Water Science Technology*, 43(5), 175-182.
Meals, D. W., and Hopkin, R. B. (2002). "Phosphorus Reductions Following Riparian Restoration in Two Agricultural Watersheds in Vermont, USA." *Water Science Technology*, 45(9), 51-60.
Miller, D. E., and Skidmore, P. B. 2001. "Natural Channel Design: How Does Rosgen Classification Based Design Compare with Other Methods?" *2001 Wetlands Engineering and River Restoration Conference*, 813-822.
Miner, J. R., Humenik, F. J., and Overcash, M. R. (2000). *Managing Livestock Wastes to Preserve Environmental Quality*, Iowa State University Press, Ames, Iowa.
NC DENR. (2001). "Standard Operating Procedures for Benthic Macroinvertebrates: Biological Assessment Unit." Division of Water Quality - Water Quality Section, Environmental Sciences Branch.
NC DENR. (2003). "North Carolina Water Quality Assessment and Impaired Waters List (2002 Integrated 305(b) and 303(d))." *021RMT04Ff*, Division of Water Quality Section - Planning Branch, Raleigh, NC.
Novak, J. M., Stone, K. C., Szogi, A. A., Watts, D. W., and Johnson, M. H. (2004). "Dissolved Phosphorus Retention and Release from a Coastal Plain In-Stream Wetland." *Journal of Environmental Quality*, 33, 394-401.
Osmond, D. L., Gilliam, J. W., and Evans, R. O. (2002). *Riparian Buffers and Controlled Drainage to Reduce Agricultural Nonpoint Source Pollution*, North Carolina State University, Raleigh, NC.
Owens, L. B., Edwards, W. M., and vanKeuren, R. W. (1996). "Sediment Losses from a Pastured Watershed Before and After Streambank Fencing." *Journal of Soil and Water Conservation*, 51(1), 90-95.
Owens, L. B., Edwards, W. M., and vanKeuren, R. W. (1997). "Runoff and Sediment Losses Resulting from Winter Feeding on Pastures." *Journal of Soil and Water Conservation*, 52(3), 194-198.
Paerl, H. W. (1997). "Coastal Eutrophication and Harmful Algal Blooms: Importance of Atmospheric Deposition and Groundwater as 'New' Nitrogen and Other Nutrient Sources." *Limnology Oceanography*, 45(5, part 2), 1154-1165.
Paerl, H. W., Dyble, J., Twomey, L., Pinckney, J. L., Nelson, J., and Kerkhof, L. (2002). "Characterizing Man-Made and Natural Modifications of Microbial Diversity and Activity in Coastal Ecosystems." *Antoine van Leeuwenhoek*, 81, 487-507.
Paerl, H. W., Willey, J. D., Go, M., Peierls, B. L., Pinckney, J. L., and Fogel, M. L. (1999). "Rainfall Simulation of Primary Production in Western Atlantic Ocean Waters: Roles of Different Nitrogen Sources and Co-Limiting Nutrients." *Marine Ecology Progress Series*, 176, 205-214.
Peterjohn, W. T., and Correll, D. L. (1984). "Nutrient Dynamics in an Agricultural Watershed: Observations on the Role of a Riparian Forest." *Ecology*, 65(5), 1466-1475.
Pickney, J. L., Paerl, H. W., Tester, P., and Richardson, T. L. (2001). "The Role of Nutrient Loading and Eutrophication in Estuarine Ecology." *Environmental Health Perspectives*, 109(Supplement 5), 699-706.

Piehler, M. F., Dyble, J., Moisander, P. H., Pickney, J. L., and Paerl, H. W. (2002). "Effects of Modified Nutrient Concentrations and Ratios on the Structure and Function of the Native Phytoplankton Community in the Neuse River Estuary, North Carolina, USA." *Aquatic Ecology*, 36, 371-385.

Pinay, G., Haycock, N. E., Ruffinoni, C., and Holmes, R. M. (1994). "The Role of Denitrification in Nitrogen Removal in River Corridors." Global Wetlands: Old World and New, W. J. Mitsch, ed., Elsevier Science B.V.

Pinay, G., Roques, L., and Fabre, A. (1993). "Spatial and Temporal Patterns of Denitrification in Riparian Forest." *Journal of Applied Ecology*, 30, 581-591.

Platts, W. S., and Nelson, R. L. (1985). "Stream Habitat and Fisheries Response to Livestock Grazing and In-Stream Improvement Structures, Big Creek, Utah." *Journal of Soil and Water Conservation*, 41, 374-379.

Platts, W. S., and Wagstaff, F. J. (1984). "Fencing to Control Livestock Grazing on Riparian Habitats Along Streams: Is It a Viable Alternative?" *North American Journal of Fisheries Management*, 4, 266-272.

Qui, Z., and Prato, T. (1998). "Economic Evaluation of Riparian Buffers in an Agricultural Watershed." *Journal of the American Water Resources Association*, 34(4), 877-890.

Rickland, W. H., and Cushing, C. E. (1982). "Recovery of Streamside Woody Vegetation After Exclusion of Livestock Grazing." *Journal of Range Management*, 35(3), 360-361.

Ritter, W. F. (2001). "Nonpoint Source Pollution and Livestock Manure Management." Agricultural Nonpoint Source Pollution, W. F. Ritter and A. Shirmohammadi, eds., Lewis Publishers, New York, NY, 135-168.

Rosenberg, D. M., Danks, H. V., and Lehmkuhl, D. M. (1986). "Importance of Insects in Environmental Impact Assessment." *Environmental Management*, 10(6), 773-783.

Rosgen, D. L. (1996). *Applied River Morphology*, Wildland Hydrology, Pasoga Springs, Colorado.

Rostagno, C. M., and Sosebee, R. E. (2001). "Biosolids application in the Chihuahuan Desert: Effects on Runoff Water Quality." *Journal of Environmental Quality*, 30, 160-170.

Ryther, J. H., and Dunstan, W. M. (1971). "Nitrogen, Phosphorus, and Eutrophication in the Coastal Marine Environment." *Science*, 171(3975), 1008-1013.

Scrimgeour, G. J., and Kendall, S. (2002). "Consequences of Livestock Grazing on Water Quality and Benthic Algal Biomass in a Canadian Natural Grassland Plateau." *Environmental Management*, 29(6), 824-844.

Sharpley, A. N., Daniel, T., Sims, T., Leymunyon, J., Stevens, R., and Parry, R. (1999). *Agricultural Phosphorus and Eutrophication*, National Technological Information Service, Springfield, IL.

Sherer, B. M., Miner, J. R., Moore, J. A., and Buckhouse, J. C. (1992). "Indicator Bacterial Survival in Stream Sediments." *Journal of Environmental Quality*, 21, 591-595.

Sherer, B. M., Miner, J. R., Moore, J. A., and Buckhouse, J. C. (1998). "Resuspending Organisms from a Rangeland Stream Bottom." *Transactions of the ASAE*, 31(4), 1217-1222.

Shultz, T. T., and Leininger, W. C. (1990). "Differences in Riparian Vegetation Structure Between Grazed Areas and Enclosures." *Journal of Range Management*, 43(4), 295-299.

Skidmore, P. B., Shields, F. D., Doyle, M. W., and Miller, D. E. 2001. "A categorization of approaches to natural channel design." *Wetlands Engineering and River Restoration Conference*, Reno, Nevada.

Sovell, L. A., Vondrack, B., Frost, J. A., and Mumford, K. G. (2000). "Impacts of Rotational Grazing and Riparian Buffers on Physiochemical and Biological Characteristics of Southeastern Minnesota, USA, Streams." *Environmental Management*, 26(6), 629-641.

Spruill, T. B. (2000). "Statistical Evaluation of Effects of Riparian Buffers on Nitrate and Groundwater Quality." *Journal of Environmental Quality*, 29, 1523-1538.

Sweet, W. M., and Geratz, J. W. (2003). "Bankfull Regional Curves for the Coastal Plain Physiographic Province of North Carolina." EcoScience Corporation.

United States Army Corps of Engineers. (2003). "HEC Hydrologic Modeling System." Visix Software Inc., Davis, California.

US Environmental Protection Agency. (2002). "Water Quality Conditions in the United States: A Profile from the 2000 National Water Quality Inventory." *EPA-841-F-02-003*.

Verchot, L. V., Franklin, E. C., and Gilliam, J. W. (1997). "Nitrogen Cycling in Piedmont Vegetative Filter Zones: II. Subsurface Nitrate Removal." *Journal of Environmental Quality*, 26, 337-347.

Welsch, D. J. (1991). "Riparian Forest Buffers: Function and Design for Protection and Enhancement of Water Resources." *NA-PR-07-91*, United States Department of Agricultural Forest Service, Northeast Area, Radnor, PA.

2.0 NITRATE REDUCTION THROUGH CONTROLLED DRAINAGE & NUTRIENT MANAGEMENT PLANS

The Core Creek Project implemented and evaluated best management practices (BMPs) throughout the upper watershed to reduce nutrient loading to the Neuse River. A portion of the Core Creek Project evaluated the reduction of NO_3-N leaving the Core Creek watershed due to the implementation of controlled drainage and nutrient management plans. DRAINMOD-N was calibrated and extrapolated on a field-by-field basis to predict long-term hydrology and nitrate losses based on BMPs implemented and crops grown throughout the watershed.

Predicted NO_3-N reduction was most effectively accomplished when controlled drainage and a nitrogen management plan were used in conjunction with one another. If implemented separately, a nitrogen management plan was predicted to be more effective than controlled drainage alone. The cropping system also impacted the drainage rate and nitrate loss from the fields. Potentially, a 30% and 75% nitrate reduction can be achieved growing cotton or soybeans, respectively, as compared to corn. Controlled drainage reduced the drainage outflow by 6.8 centimeters (21.3%) annually, compared to conventional drainage. This flow reduction accounted for 11.5% of the NO_3-N reduction leaving the watershed.

2.1 INTRODUCTION

The N.C. Environmental Management Commission adopted the Neuse River Basin Nutrient Sensitive Waters Management Strategy in December of 1997. The goal of the policy was to decrease the average annual load of nitrogen delivered to the Neuse River Estuary from nonpoint and point sources by at least 30% of the average annual load. To accomplish this BMPs were proposed to be installed throughout the watershed. BMPs are

the main mode of reducing the pollution to waterways from nonpoint sources. By utilizing such applications as nutrient management plans, riparian buffers, wetlands, and controlled drainage, nonpoint source pollution (NPS) can be significantly decreased.

The Core Creek Project, funded by the Clean Water Management Trust, implemented and evaluated BMPs throughout the upper watershed to reduce nutrient loading to the Neuse River. Those BMPs used were nitrogen management, controlled drainage, and wetlands restoration. Monitoring of the watershed occurred for several years to determine the before and after effects of the BMPs on nutrient reduction in the Core Creek watershed.

A portion of the Core Creek Project involved the installation of water control structures. Due to the flatness of North Carolina's Coastal Plains, most of the area uses ditches to drain excess water, making the land suitable for agriculture. During wet seasons, drainage is necessary to provide access to fields. However, lowering the water table during drier parts of the year may be undesirable. Controlled drainage allows the farmer to manage the soil water to increase crop profitability during the growing season and reduce NO_3-N losses to surface waters.

Another part of the Core Creek Project was to develop nitrogen management plans for the agricultural areas in the watershed. Nutrient management plans provide management plans for rate, source, timing, and form of applied nutrients. This helps increase crop utilization of the fertilizers, while decreasing the potential loss of nutrients to surface and shallow ground waters.

The following study is a modeled evaluation of the reduction of NO_3-N leaving the Core Creek watershed due to the implementation of controlled drainage and nitrogen management plans.

2.2 LITERATURE REVIEW

The following literature review focuses on nitrogen (N) and the impacts of controlled drainage and nitrate management plans on the nutrient.

2.2.1 Nitrogen

Nitrogen is a common fertilizer used to enhance crop growth. When N is added to the soil in an organic form it is attacked by enzymes and broken down into smaller units. These units can then be used by microbes and be mineralized as inorganic NH_4-N. Mineralization occurs under both aerobic and anaerobic conditions. Using urea as the organic N source, NH_4^+ is produced through the following reactions:

Equation 2-1 $$NH_2 \cdot CO \cdot NH_2 + H_2O \rightarrow 2NH_3 + CO_2$$

and in an aqueous system

Equation 2-2 $$NH_3 + H_2O \rightarrow NH_4^+ + OH^-$$

Nitrification transforms the relatively immobile NH_4^+ into NO_3-N. In the form of nitrate-nitrogen (NO_3^--N), N is easily transported in aqueous solutions, used by plants, or denitrified. Obligate aerobic bacteria are necessary to arbitrate the two-step process. *Nitrosomonas* and *Nitrobacter*, are the primary mediators of the first and second steps, respectively (Jarrett 2001).

Equation 2-3 $2NH_4^+ + O_2 \rightarrow 2NO_2^- + 2H_2O + 4H^+ + energy$

Nitrite is further oxidized, yielding NO_3-N.

Equation 2-4 $2NO_2^- + O_2 \rightarrow 2NO_3^- + energy$

If NO_3^--N is not immediately incorporated in plants or microbes, it will move with the soil water. If the NO_3^--N water reaches an energy source in an anaerobic environment, denitrification may occur. Under anaerobic conditions, NO_3-N acts as an electron acceptor for microbes. The N is converted to nitrous oxide (N_2O) and then to molecular N (N_2) during denitrification.

Equation 2-5 $C_6H_{12}O_6 + 4NO_3^- \rightarrow 6CO_2 + H_2O + 2N_2$

Headwater streams in agricultural areas may contain high levels of NO_3-N (Haycock and Burt 1993). Excess NO_3-N in surface waters can result from N in water leaving fertilized or animal-occupied sites. Additional N in estuarine systems causes blooms of algae and an overabundance of oxygen-dependant bacteria that deplete the water of oxygen. In addition to causing fish kills, the algae can produce toxins that are harmful to humans. Because NO_3-N is water-soluble and does not adsorb to soil particles, it can also leach through the soil profile and enter the shallow groundwater systems. Nitrate contamination of ground waters is a concern as shallow groundwater returns to contribute to surface flow.

Nitrogen is the limiting nutrient in the Neuse Estuary and Pamlico Sound (Paerl et al. 2002). The concentration of N in the waters controls the productivity, tropic state, and water quality of the area (Paerl et al. 2002). While N is necessary for aquatic life, excessive inputs lead to eutrophication (Pickney et al. 2001). In estuaries, NPS drives the N concentration in the waters (Ryther and Dunstan 1971). Nonpoint source pollution contributes approximately

80% of the 'new' N introduced to the Neuse River/Pamlico Sound, with wastewater and industrial effluent responsible for the remaining 20% (Paerl et al. 2002). The 'new' N is primarily transported to the water sources through atmospheric deposition and shallow groundwater (Paerl 1997).

2.2.2 Denitrification

Different hydrologic conditions produce various levels of denitrification. Under saturated conditions, the vertical diffusion of NO_3-N into the soil is a dominant factor controlling the denitrification potential of a soil (Ambus and Christensen 1993). This process stopped when the soil moisture content decreased to approximately 80% of the water filled pore space (Ambus and Christensen 1993).

The extent of the denitrification potential also depends on the soil (Ambus and Lowrance 1991). The soil organic content (mineral versus organic) produces a variation in hydrology and water quality (Chescheir et al. 2003). Groffman et al (1991) indicated that the denitrification ability of a site varied strongly with vegetation, soil type, and soil pH. The rates of denitrification can vary due to soil texture, precipitation, and groundwater fluctuations (Pinay et al. 1993). In a comparison of Coastal Plain soils, Kinston (fine, sandy loam), a more poorly drained soil, had a denitrification rate potential three times greater than Alapaha (loamy sand) (Ambus and Lowrance 1991). In more poorly drained, organic soils, denitrification was high when the water table was within 25-35 centimeters from the ground surface (Ambus and Lowrance 1991). Better-drained soils are more dependent upon C-cycling of leaf litter in the fall and rooting depth (Ambus and Lowrance 1991).

Lowrance (1992b) showed a positive relationship between denitrification rates and soil moisture, soil NH_4-N levels, and depth. Lowrance found that the potential is over two orders of magnitude higher at the soil surface than at a 60-cm depth (1992a). This was primarily found to result from N and C stratification from litter and roots (Lowrance 1992a). Denitrifying enzyme activity was stratified within the top 10 centimeters, with 88% within the top two centimeters of the soil (Ambus and Lowrance 1991). This stratification also coincides with stratification of N and C from litter and roots (Lowrance 1992a).

The rate of denitrificaiton decreases as the water table depth declines. Water table depth is typically highest during the winter and early spring when evapotranspiration is low. The water table then declines to its lowest levels during summer and fall (Pinay et al. 1993). Surface runoff and subsurface flow through riparian zones occur primarily during the winter and spring months when the water table is high (Lowrance 1992b). Gilliam and Skaggs (1986) found that approximately 50% of the drainage water leaves drained fields during the winter months.

Higher NO_3-N concentrations are often in subsurface water leaving cropland during the winter months for a variety of reasons (Lowrance et al. 1984b):

1. High rainfall and low evapotranspiration increase the movement of readily leached ions into the subsurface flow.
2. Low microbial activity reduces the reduction of NO_3-N to gaseous forms.
3. Low uptake of the nutrients by plants due to dormancy and crop removal.

By raising the water table during the winter months, denitrification potential may be increased, reducing the NO_3-N loads to surface waters.

2.2.3 Best Management Practices

2.2.3.1 Controlled Drainage

Improved drainage is needed in some states in over 50% of cropland to make them arable. Artificial drainage is often necessary in agricultural soils in flat locations with less than 0.5% slope (Osmond et al. 2002). High annual rainfalls, relatively flat topography, and the typically poor natural drainage on the coastal plains of North Carolina require drainage for the production of crops.

Drainage is needed to provide trafficable conditions for tillage, planting, spraying, and harvesting. Subsurface drainage lowers the water table, providing greater potential for water storage immediately following rainfall. This reduces the rate of surface runoff. A more aerable root zone typically results in more efficient utilization of soil water by the crops. However, excessive drainage can be detrimental when it decreases the soil water available to plants. Drainage waters can also leach fertilizer nutrients and transport them to surface waters.

Ditching, Figure 2.1, is the primary mode of water table control in the coastal plains of North Carolina. While ditches are known to improve surface drainage, the outflow of the canals in North Carolina contains both surface and subsurface flows. In the lower coastal plains, the fields are underlain by a highly permeable sand layer typically within 1 – 2 meters of the soil surface (Osmond et al. 2002). In this case, ditch drainage is predominantly subsurface flow.

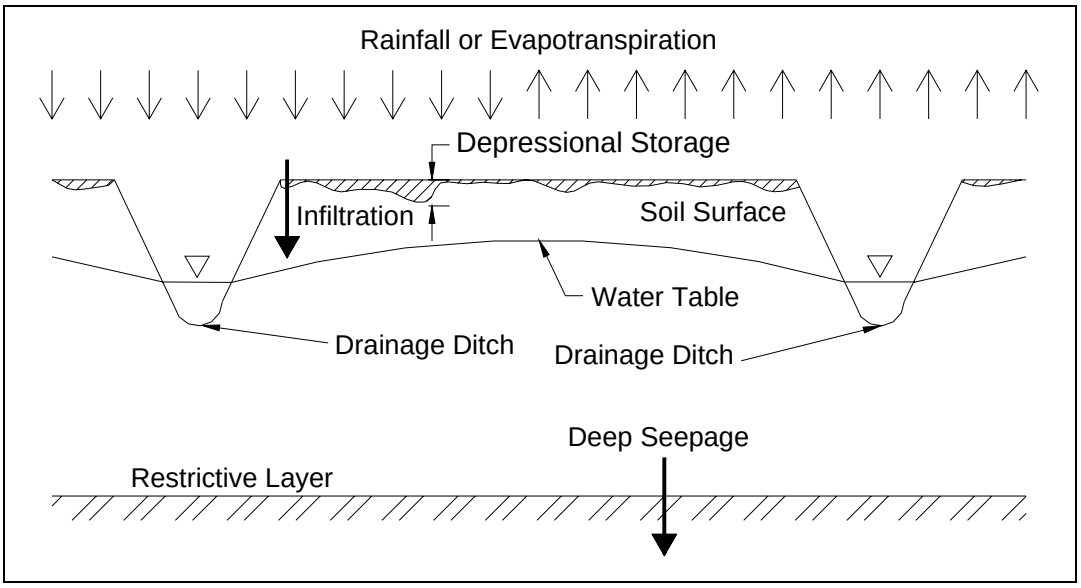


Figure 2.1 Schematic of water management system with drainage ditches that may be used for subsurface drainage (adapted from Skaggs 1991).

A conventional subsurface drainage system is used to lower the water table. This increases the pore space available for water infiltration during a rain event. The proportion of water rapidly leaving the site in runoff form decreases, increasing the proportion that leaves by slower subsurface drainage. Less surface ponding can also result from improving the subsurface drainage.

Intensive subsurface drainage will generally increase the outflow of water labile nutrients, such as NO_3-N and some salts. However, by reducing runoff and associated sediment transport, P, organic N, and sediment bound pesticides are also reduced in the outflow. Studies often attribute the higher loss of NO_3-N to increases in nitrification and decreases in denitrification due to lowering the water table (Evans et al. 1989; Gambrell et al. 1975b; Gilliam and Skaggs 1986; Gilliam et al. 1979).

Controlled drainage uses a water control structure to manage the water level in the drainage outlet. Controlled drainage can result in a decrease in peak outflow rates and less

runoff, as compared to conventional drainage. It increases the rainfall utilization efficiency of crops during the growing season by reducing drainage outflow. Holding water *in situ* increases evapotranspiration and vertical seepage (Thomas et al. 1992). Since 1985, 3,455 controlled drainage structures have been installed with cost-share assistance throughout eastern North Carolina (Evans and Skaggs 2004). In 2002, water control structures were used on 5,500 hectares of land in the Neuse Basin (Neuse River Basin Oversight Committee 2003).

During very dry years, outflow may be eliminated by controlled drainage. Under wet conditions, a control structure may have very little or no effect on total outflow, versus conventional drainage. During the growing season, outflow is generally only reduced by 15% using controlled drainage (Evans et al. 1995). The majority of the outflow reduction of NO_3-N occurs during the fallow cropping period. Controlled drainage can be used during this time to promote denitrification, minimizing the NO_3-N loss to drainage water (Kimmelshue et al. 1995).

As summarized by Kimmelshue et al (1995), lower water tables in spring, necessary for planting, and higher soil temperatures and microbial activity (resulting from tillage) can increase the mineralization of organic N to NO_3-N. By raising the water table over winter, denitrification of NO_3-N may occur. This helps to reduce the NO_3-N loss to ground and surface water (Kimmelshue et al. 1995).

The depth of the water table helps to regulate the denitrification rate of a soil system (Kliewer and Gilliam 1995). While denitrification may occur lower in the soil profile, Kliewer and Gilliam (1995) found that rates increase closer to the surface as NO_3-N becomes

rate limiting. This is under the condition that the volumetric water content is high enough to prevent O_2 from diffusing into the soil profile. As NO_3-N is transported through the field in agricultural drainage, using controlled drainage to keep the NO_3-N present allows more time for denitrification (Gambrell et al. 1975a; Gilliam et al. 1979).

By using flashboard risers like in Figure 2.2, Gilliam et al (1979) was able to reduce NO_3-N loss in drainage waters by about 50% during the fallow months. Amatya et al (1998) found significant outflow and pollutant reductions using controlled drainage in a forested watershed. Drury et al (1996) realized similar results using a controlled drainage-subirrigation system: 24% reduction in outflow and 25% reduction of NO_3-N concentration. In a tile drainage study by Tan et al (1993), over 97% of the total NO_3-N lost from the site under conventional drainage was through the tile lines. When the water table was controlled, the NO_3-N concentration in the tile drainage decreased by 33%, and the total NO_3-N loss decreased 37% (Tan et al. 1993). Osmond et al (2002) states that approximately 45% of total N mass reduction can be achieved through controlled drainage.

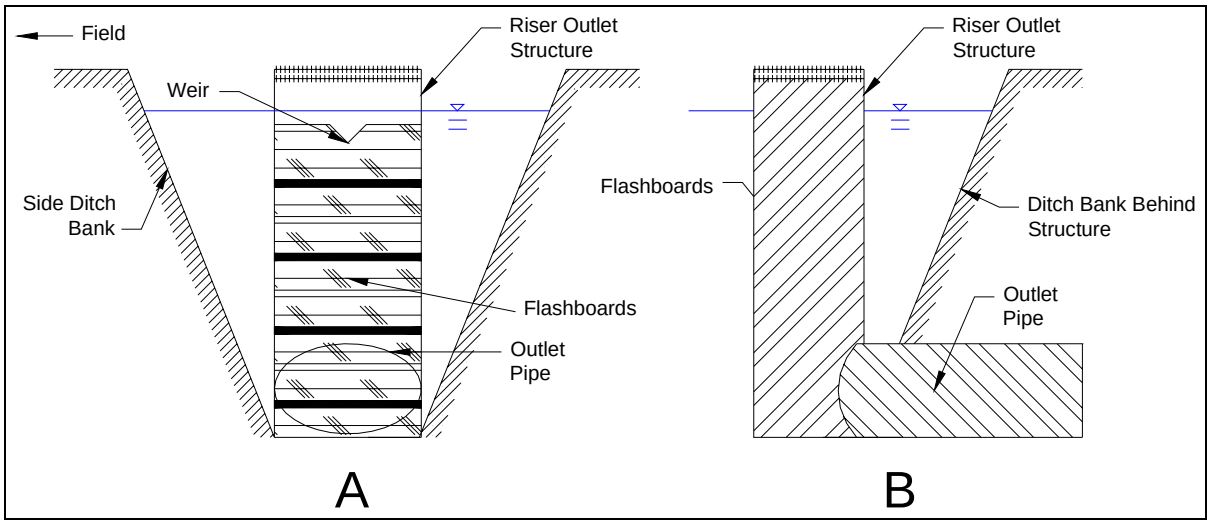


Figure 2.2 Flashboard riser type water control structure, front view (A) and side view (B)

Higher water table has little impact on the total N concentration in the subsurface outflow (Evans et al. 1989; Evans et al. 1995; Gilliam et al. 1979). Although NO_3-N concentrations were lowered, TKN concentrations were somewhat increased with higher water tables resulting in no net change in TN concentration. Controlled drainage reduces the overall drainage volume leaving a site. This effect on total outflow was the main cause of the NO_3-N load reduction (Amatya et al. 1998; Evans et al. 1989; Evans et al. 1995).

Raising the water table can increase the surface runoff and the nutrient concentration associated with runoff waters. The reduction of NO_3-N load due to controlled drainage is more than the additional nutrient input from runoff (Drury et al. 1996).

There are two primary management objectives of a controlled drainage system: optimum production efficiency (maximum nutrient utilization by the crop) and maximum water quality benefits (Osmond et al. 2002). The drainage design should be dependent upon soil properties, site parameters, crop factors, and climatological factors (Skaggs 1991). Ideally, all field ditches should have a 1-2 meter buffer of grassy or herbaceous vegetation to help maintain ditch structure and decrease sediment and nutrients from flow (Osmond et al. 2002). If utilized properly, controlled drainage can be an effective means of reducing total drainage outflows, and in so doing reduce the pollutant load leaving the field (Amatya et al. 1998).

2.2.3.2 Nutrient Management Planning

For many years, soil was fertilized to optimize crop yield at the least cost. Management was based upon the crop's expected response to additional nutrient input though the soil. No direct cost was associated with environmental quality (Beegle et al.

2000). Improper or untimely soil application of fertilizers can release nutrients into the water. There they no longer contribute to the sustainability of the crop and provide the potential for water quality problems downstream. Current nutrient management continues to focus on providing the crop with the needed nutrients at the lowest cost, but also considers potential effects of excess nutrients on environmental quality.

Nutrient management can help protect groundwater resources and decrease N loadings in surface water while meeting the crop's nutrient requirements (Shuyler 1994). While potentially increasing the producer's profit margin, nitrate management plans are one of the most effective ways of managing N (Shuyler 1994).

A difficulty of nutrient planning is that management strategies are not the same for each field. Each nitrate management plan developed is unique to the operation and the farm fields. Nutrient balances are different between farms. Concentrated animal operations often have an excess of some nutrients for the cropland. Conversely, a cash-crop operation may require nutrients for its fields.

The farms in the study area are considered cash crop, needing to purchase inorganic fertilizers to achieve optimum crop yield. Nutrients come onto the farm as fertilizer. Harvested crops leaving the fields take a portion of the nutrients off site. According to Beegle et al (2000), nutrient-deficient farms are not as likely to cause environmental problems unless there is gross mismanagement. A nitrate management plan emphasizes economic and agronomic efficiency, reducing the need for nutrients through proper timing, placement, form and application rates.

Some federal agencies often require a nitrate management plan before providing technical and cost-share services. The actual plan can either detail specific times, rates, and methods of nutrient application or establish performance criteria, such as maintaining soil test indices below a certain level.

A current issue in nutrient management is whether performance criteria should be based on N or phosphorus (P). Plans have traditionally been developed to meet the crop's N requirement. In animal operations, P has been over applied, leading to water quality issues. Applying organic fertilizers at P-required levels may require the purchase of additional inorganic fertilizer to meet N requirements of the crop. Current guidelines for determining the nutrient on which to base the management plan involves calculating the P rating for the soil by using the North Carolina Phosphorus Loss Assessment Tool (PLAT). If the PLAT rating is high, only crop removal rates of P can be added. A very high PLAT rating only allows for starter P application. Otherwise N is used for the nitrate management plan.

2.2.4 Modeling

Predicting the effects of controlled drainage and nitrogen management is often difficult. Hydrology and contaminant transport in an agricultural field are complex processes. Results based on monitored data typically measure short-term trends only and are highly dependent on short-term rainfall. Computer simulation models can help assess the mechanisms controlling these operations. This is particularly helpful when working with poorly drained soils with artificial drainage in the coastal plains of North Carolina. Hydrologic and water quality impacts are dependent upon such factors as soil type, land use, management practices, site conditions, and climate (Skaggs et al. 1994).

Various computer models have been developed to simulate hydrology and nitrogen transport through poorly drained soils. The WAVE (Water and Agrochemicals in the soil, crop, and Vadose Environment) model simulates 1-D water movement and fate/transfer of agrochemicals in the soil-crop system (Vanclooster et al. 1996). Both the WAVE and the SWAP models (Van Dam et al. 1997) use the same approach to describe water flow, based upon the Richards equation (El-Sadek et al. 2001). DRAINMOD was developed to simulate the performance of drainage and other forms of water table management (Skaggs 2001). In a comparison study performed by El-Sadek et al (2001), WAVE and SWAP models provided as good a prediction of the lateral subsurface flow to drains as DRAINMOD. DRAINMOD was able to yield a more accurate estimate of discharge (El-Sadek et al. 2001). The WAVE model is primarily used in Belgium; SWAP in the Netherlands. Compared to the WAVE model, DRAINMOD-N requires less input (El-Sadek et al. 2003). DRAINMOD was selected as the computer model used in this study based upon its accessibility, prevalence in the United States, and relative ease of use.

DRAINMOD-N is an N fate and transport model for artificially drained soils. A quasi two-dimensional flow model, DRAINMOD-N simulates the movement and fate of N in the shallow water table (Brevé et al. 1997). DRAINMOD-N assumes that there is only vertical transport in unsaturated zone and both vertical and lateral transport in the saturated zone. DRAINMOD, the flow modeling component, uses water balance calculations to calculate the average daily soil water fluxes and water contents (Skaggs 1978). These daily outputs function as inputs for the N simulations. Solute transport is derived from an explicit solution to the advective-disspersive-reactive equation (Brevé 1994). Rainfall deposition,

fertilizer dissolution, net mineralization, denitrification, plant uptake, runoff, and drainage loss quantifications are based upon functional relationships, Figure 2.3. Nitrate is the main form of N modeled, assuming that NH_4-N is quickly nitrified or stays fixed in the soil (Brevé 1994).

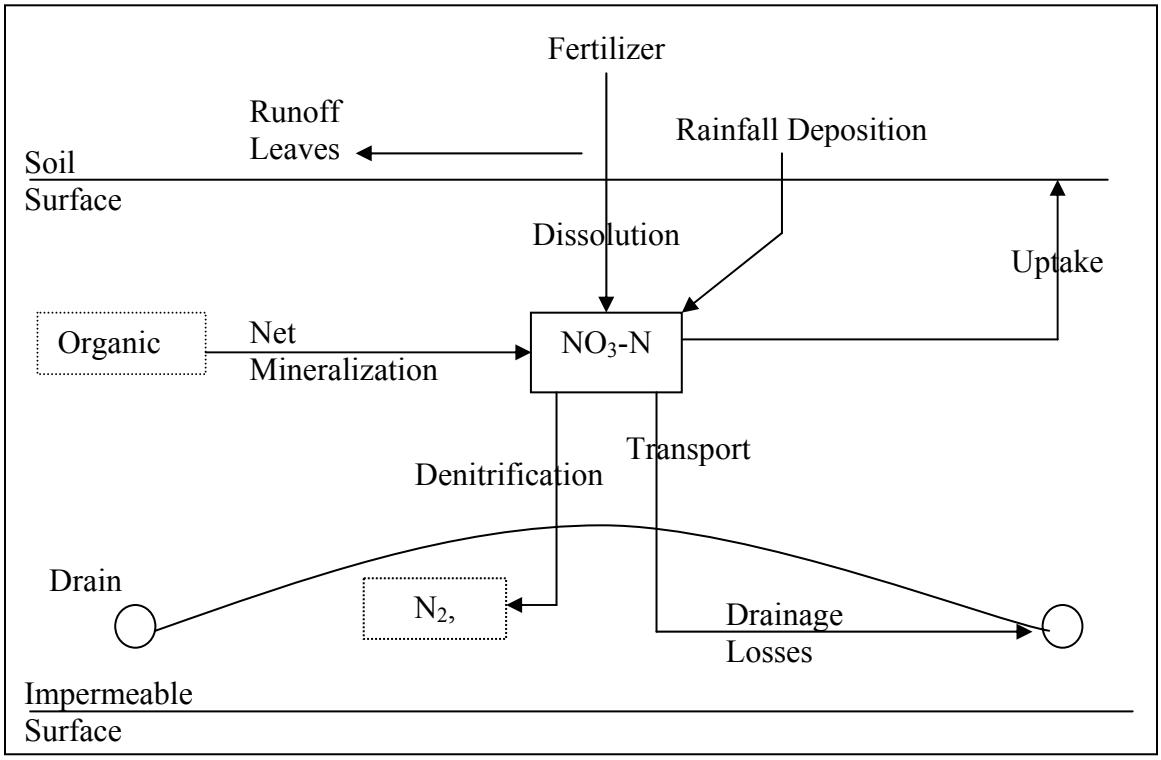


Figure 2.3 Nitrogen fate modeling by DRAINMOD-N (Brevé 1994)

A study performed by Brevé et al (1997) indicated that DRAINMOD-N can be used to simulate the water table management effects on N losses in artificially drained soils. However, DRAINMOD-N underestimates the NO_3-N concentration in the soil solution (Brevé et al. 1997). In a comparative study, DRAINMOD-N gave a fair description of the N dynamics in the root zone at field scale (El-Sadek et al. 2003).

2.3 RATIONALE AND SIGNIFICANCE

The agricultural watershed in this study was the headwaters of Core Creek, which has been designated "Nutrient Sensitive Waters" by the Division of Water Quality (DWQ) (NC DENR 2003). Nutrient effluent reduction is critical. Controlled drainage and nitrate management plans have been installed across the watershed over the past five years. This study discerns long-term N load reductions resulting from these BMPs as compared to before the BMPs were installed.

2.4 METHODS AND MATERIALS

2.4.1 Research Site Description

Originating in Jones County, North Carolina, and flowing northeastward to the Neuse River, Core Creek is a major agricultural watershed. The 30-kilometer (18.5 mile) main stem drains approximately 17,000 hectares (42,000 acres). Core Creek is designated as a high priority "Nutrient Sensitive Waters" by the DWQ (NC DENR 2003). Agriculture is the predominant land use (60%), followed by forestry (40%). Several small communities are also located throughout the watershed. Non-irrigated crop production, intensive animal feeding operations, animal holding/management areas, and channelization are considered primary sources of water quality impairment in Core Creek (NC DENR 2003).

This project focused on the implementation of BMPs on tributaries of Core Creek, including Grape Creek, south of old US 70 in Cove City, North Carolina. The upper main stem of Core Creek (approximately 6.4 kilometers), all of Grape Creek (4.8 kilometers), and approximately 48 kilometers of intermittent streams and ditches have been channelized.

Approximately 2,000 hectares of cropland (corn, soybeans, and cotton) and 1,200 hectares of forest are included in the project area.

Approximately 100 water control structures have been installed throughout the watershed. In the process of obtaining a water control structure, farmers also had to have a nitrate management plan written.

Several locations throughout the watershed were selected for instrumentation to monitor hydrology and water chemistry. The individual subwatershed above these points, primarily agricultural cropland, were mapped. The fields were identified by soil type and crops grown. The ditches were characterized by field slope, bottom depth, and side slope. The N loading upstream of each point was monitored, simulated, and compared across various sites.

2.4.2 Water Monitoring

One to two years of pre-BMP installation water quality data was collected. The sites were continuously monitored after the nitrogen management plans and controlled drainage were implemented.

2.4.2.1 Surface Water Hydrology Monitoring

Stream flow was measured at 15 locations within the watershed. An Infinity® automated stage recorder continuously monitored the level of water at the water control devices for a period of three years (Figure 2.4 and Figure 2.5). From this data, the drainage discharges were determined. Monitoring locations are shown in Figure 2.6. Flow depth over a weir (90^o, 120^o or broad crested) was determined and recorded every 20 minutes by a

pressure transducer. Drainage rates were computed using standard weir formulas. Water level was referenced to the top of the water control structure. The Infinity® was downloaded and calibrated monthly. The distance to water and distance to the weir invert was manually measured at the time of each download.

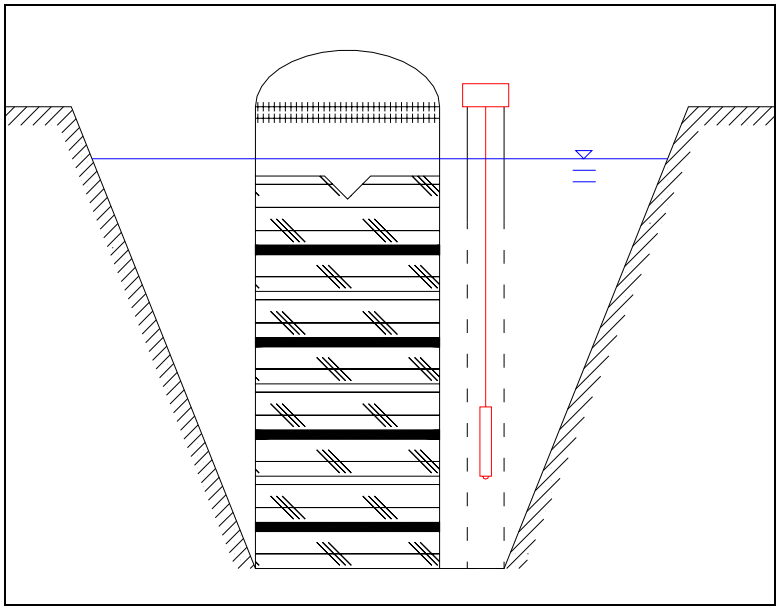


Figure 2.4 Flashboard riser and Infinity® used to measure water height above weir.

Figure 2.5 Flashboard riser, with 90° V-notch weir, and Infinity® located at monitoring site GCD3.

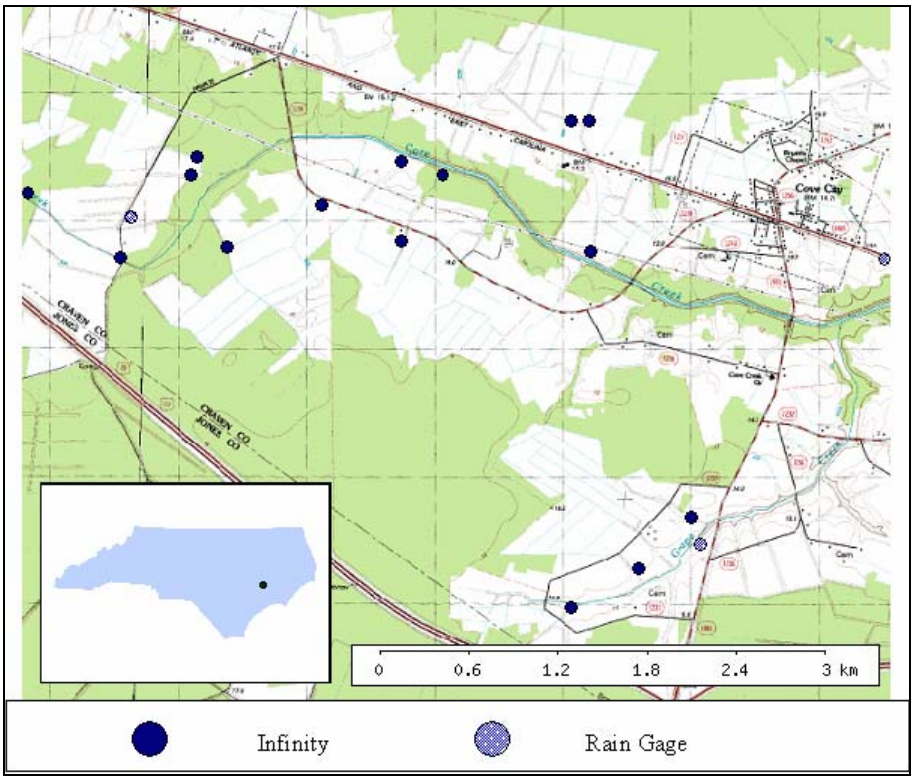


Figure 2.6 Infinity and rain gage monitoring sites in the Core Creek watershed, Cove City, North Carolina

Three automatic rain gauges measured rainfall at various locations across the watershed, (Figure 2.5). A tipping bucket collected rainfall and a HOBO® data recorder registered the time of every 0.25 millimeters of rainfall.

2.4.2.2 Surface Water Chemistry Monitoring

Surface water chemistry monitoring was initiated in September 1999. A summary of the background water chemistry-monitoring schedule is shown in Table 2.1. Grab samples, representative of the water column, were taken at each sample location every four to six weeks for a period of approximately 4.5 years (Table 2.1). Water samples were only collected during periods of flow; stagnant water was not sampled. These samples were transported, on ice, to the Environmental Analysis Laboratory in Weaver Laboratories at NC State University. Nitrate, ammonium, TKN, TP, orthophosphate (OP), pH, and total suspended solids (TSS) were determined using standard methods (US Environmental Protection Agency 2003). Several of the structures monitored were installed before the project began. Most of the older structures were not functioning correctly. The boards were not installed correctly and leaked significantly or not enough boards were installed to significantly raise the water table. As a result, most of the older structures were functioning as conventional drainage until new boards were installed in 2001 (Table 2.2). As a result, the duration of background monitoring varied from two to four years depending on when a structure was installed.

Table 2.1. Summary Table of Background Monitoring Strategy

Description of collected data[1]	Sample Type	Sample Frequency and Period
Water Chemistry NO_3, NH_4, TKN, TP, Ortho-P, pH, TSS	grab from midpoint of stream	every 4-6 weeks (Sept '99 - Aug '04)
Hydrology	continuous	every 20 minutes (Jan '02 - Aug '04)
Rainfall	frequency and intensity	each event (Jan '02 - Aug '04)

[1] NO_3 – nitrate; NH_4 – ammonium; TKN – total Kjeldahl nitrogen; TP – total phosphorus; Ortho-P – orthophosphate; pH – pH; TSS – total suspended solids

Table 2.2 Monitoring Data of Sampling Locations

Sampling Location	Water Quality Monitoring[1]	Date Structure Installed	Stage Monitoring[1]	Background Monitoring Period	Post-BMP Monitoring Period
CCD2B	2/15/2000	pre 1999	4/18/2002	2/00 - 4/02	4/02 - 9/04
CCD4A	1/12/2000	Spring 2001	4/18/2002	1/00 - 4/02	4/02 - 9/04
CCD5A	9/10/1999	Spring 2001	1/23/2002	9/99 - 1/02	1/02 - 9/04
CCD5B	2/15/2000	Spring 2001	4/22/2002	2/00 - 4/02	4/02 - 9/04
CCD7	12/5/2001	pre 1999	4/22/2002	12/00 - 4/02	4/02 - 9/04
CCD8	6/12/2001	pre 1999	7/12/2002	6/00 - 7/02	7/02 - 9/04
CCD15A	11/22/1999	pre 1999	1/24/2002	11/99 - 1/02	1/02 - 9/04
CCD15B	11/22/1999	pre 1999	1/24/2002	11/99 - 1/02	1/02 - 9/04
CCDPD4	11/22/1999	pre 1999	1/9/2003	11/99 - 1/03	1/03 - 9/04
CCDPD5	11/22/1999	pre 1999	4/23/2002	11/99 - 4/02	4/02 - 9/04
CCM0	11/22/1999	pre 1999	1/22/2002	11/99 - 1/02	1/02 - 9/04
CCM1	11/22/1999	pre 1999	1/21/2002	11/99 - 1/02	1/02 - 9/04
GCD3	9/10/1999	pre 1999	1/22/2002	9/99 - 1/02	1/02 - 9/04
GCD5	1/12/2000	Spring 2001	1/24/2002	1/00 - 1/02	1/02 - 9/04
GCD7A	9/10/1999	Spring 2001	1/22/2002	9/99 - 1/02	1/02 - 9/04

[1] Date when monitoring began

2.4.3 Hydrologic Modeling

The water management model DRAINMOD was used to simulate the hydrology and nitrogen transport for each monitored location. Predicted hydrology was compared to

monitored hydrology. Input parameters for the site were adjusted to calibrate the model to obtain the best fit to the monitoring data.

Three rain gages in the watershed yielded hourly rain data over the past 4 years. A complete rainfall record was developed by combining data from the 3 local gages. Holes in data were filled from a NOAA weather station in New Bern, N.C. weather stations, if all local gages were dysfunctional. Daily temperature data was supplied from the New Bern weather station. Soils data were obtained from the Craven County Soil Survey and published soil-water properties for each soil type from Skaggs (1980). Drain parameters such as depth, side slope, and channel bottom width, were measured on each site, Appendix J. Distances between drains were estimated from topographic maps. Crop data during the calibration period was based upon what was grown on the monitored site during the 2003 growing season.

A DRAINMOD input data set was created for each site, based upon the individual characteristics. A sample data set is located in Appendix M. The predicted yearly hydrology was compared to the observed. Surface roughness was initially estimated from field observation and was the primary factor adjusted to calibrate the model. The predicted annual estimates were calibrated to within ten percent of the observed flows. Daily predicted flows were then compared to daily observed flows. Surface roughness coefficients were again adjusted to reduce the sum of squares error between the predicted and observed daily flows.

A DRAINMOD-N simulation was then run for each manifold, using the calibrated DRAINMOD hydrologic simulation outputs. The soil nitrogen parameters used, Table 2.3, were based upon those suggested by Youssef (2004) and published by Brevé (1997). Crop

fertilization data obtained from a publication by the Neuse River Basin Oversight Committee (Table 2.4). Local farmers in the watershed confirmed these values and supplied the application data located in Table 2.5. It was assumed that the same starter rate would be used when a nitrogen management plan was not implemented, then side-dressed with a higher rate of nitrogen to reflect the baseline application rate in Table 2.4.

Table 2.3. DRAINMOD-N nitrogen input values (Brevé et al. 1997)

Parameter	Range/Value	Units
Rate coefficient of denitrification	0.05-1.00	d^{-1}
Rate coefficient of net mineralization	$10^{-5} – 10^{-4}$	d^{-1}
Soil Dispersivity (λ)	0.05-0.10 *	m
NO_3-N in rain	0.8	mg/L

* (Youssef 2004)

Table 2.4 Nitrogen application rates for the main crops grown in the Core Creek watershed (Neuse River Basin Oversight Committee 2003, Carroll 24 August 2004)

Crop	N Rate (kg/ha)	
	Baseline	Nitrogen Management Plan
Corn (for grain)	202	146
Cotton	123	90 [1]
Soybeans	22	0

[1] Carroll 2004

Table 2.5 Starter and side-dress nitrogen management plan fertilizer application data for Craven County, North Carolina (Carroll 2004)

Crop	Starter		Side-Dress	
	Date [1]	Rate	Date [1]	Rate
Corn (for grain)	April 15	22-33 kg/ha	June 15	113-124 kg/ha
Cotton	April 18	22-44 kg/ha	June 15	46-68 kg/ha
Soybeans	April 15	11-17 kg/ha [2]	-	-

[1] Approximate last date to apply
[2] Used on very rare occurrences

The predicted daily NO_3-N concentrations, from the DRAINMOD-N inputs, were then compared to the observed collected as monthly grab samples. Adjusting the N parameters in DRAINMOD-N minimized the root mean square error. The parameter values

were maintained within the appropriate range for the soil type. Due to the nature and infrequency of the grab samples, strong correlation was not observed. The inputs were calibrated for N as closely as the grab sampling would allow. The calibrated hydrology and N parameter inputs are located in Appendices K and L, respectively.

2.4.4 Model Application

The calibrated DRAINMOD-N inputs were applied over the 50+ years of weather data for New Bern, N.C. The weather station is located approximately 20 kilometers from the study area and represents the closest long-term climate data.

Nitrogen loads and timing before the BMPs were installed were simulated in the model as the control. Controlled drainage, nitrogen management plan, and the combination of a nitrogen management plan and controlled drainage were also simulated in DRAINMOD-N. These four scenarios were simulated on each of the different monitoring locations within the watershed. The baseline conditions in Table 2.4 were used to simulate pre-nitrogen management plan conditions. For implementing a nitrogen management plan, the dates in Table 2.5 were used in DRAINMOD-N as the application dates and rates. The predicted flows and loads are shown in Appendix N.

2.4.5 Data Analysis

To normalize the data, the predicted reduction in NO_3-N was determined by the following equation:

$$\% \text{ Reduction} = 100 \times (NO_3\text{-}N_{(control)} - NO_3\text{-}N_{(BMP)}) / NO_3\text{-}N_{(control)}$$

A two-sided t-test was used to compare the mean changes in the predicted N load reduction for each BMPs as follows:

1. NMP versus controlled drainage
2. NMP and controlled drainage versus controlled drainage
3. NMP and controlled drainage versus NMP
4. Corn versus cotton versus soybeans

2.5 RESULTS AND DISCUSSION

2.5.1 Observational Results

2.5.1.1 Drainage Outflow

The height of flow over a weir was measured and recorded by an Infinity® stage recorder every 20 minutes. This depth was then transformed into a flow rate using standard weir equations. This was then cumulated into daily and monthly flows expressed as equivalent drainage depths at each location. These were compared to the rainfall hyetograph, Figure 2.7. Outflow peaks were observed after rainfall and were approximately proportional to the rainfall depth. The trends in the hydrograph closely follow those of the observed rainfall, as expected.

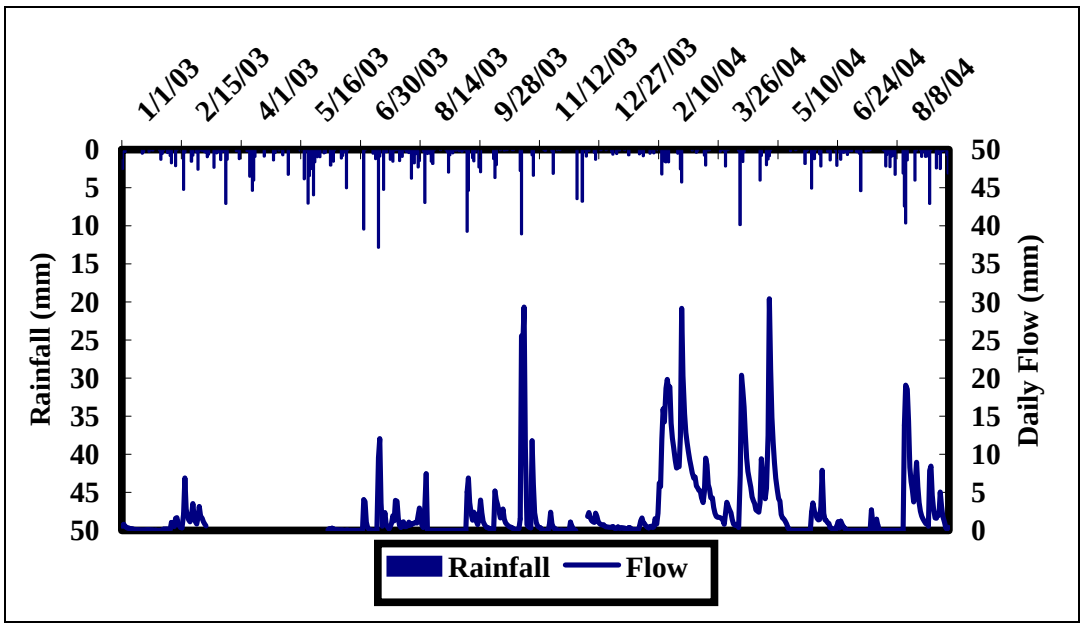


Figure 2.7 Rainfall hyetograph and daily flow depth for CCD2B, 1 January 2003 through 15 September 2004

Outflow from sites having fields managed under similar conditions were compared (same farm manager, cropping system). Daily flow depths for CCD5A and CCD5B are shown in Figure 2.8. CCD5A was located downstream, on the same drainage ditch, as CCD5B. Daily trends are similar between the two monitoring sites. In general, the outflow from CCD5A was higher than that of CCD5B. Natural variability could account for the two peaks in CCD5B that are higher than CCD5A. Similar results were observed for the other related site comparisons. As a general rule, observations between sites were reasonable.

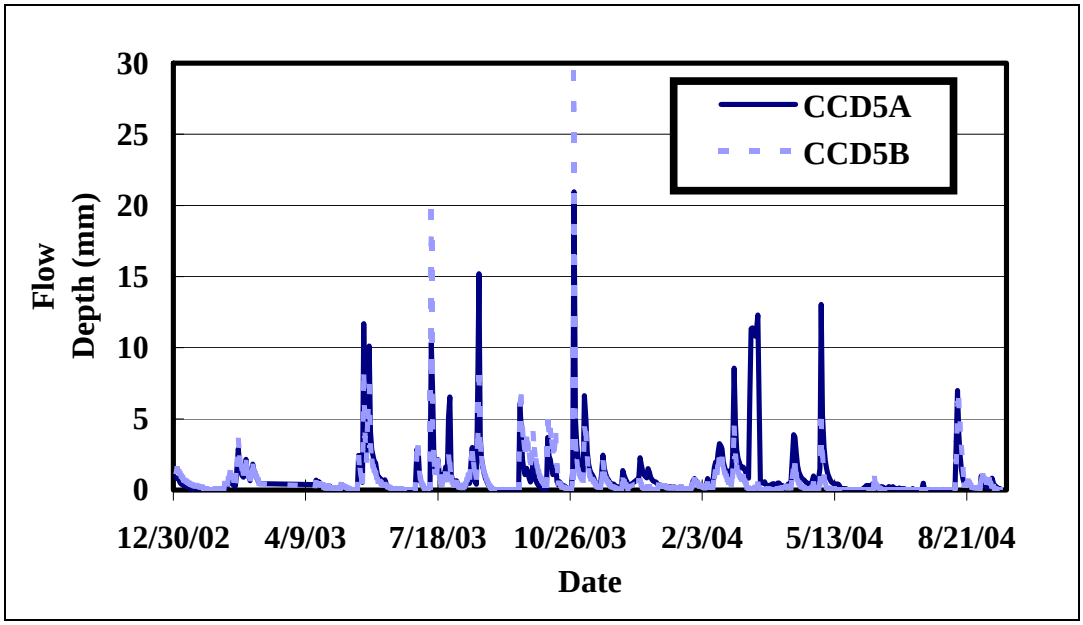


Figure 2.8 Daily flow depths for CCD5A and CCD5B, cropped in soybeans

Cumulative, individual drainage depths for fields were compared (Figure 2.9 and Figure 2.10). Comparison flow plots for CCD5A versus CCD5B and CCM0 versus CCM1 are located in Appendix O. A t-test was performed on the monthly flow depths. For each of the comparisons, there was no significant difference in mean monthly flow depths ($\alpha = 0.05$), indicating similar trends in data.

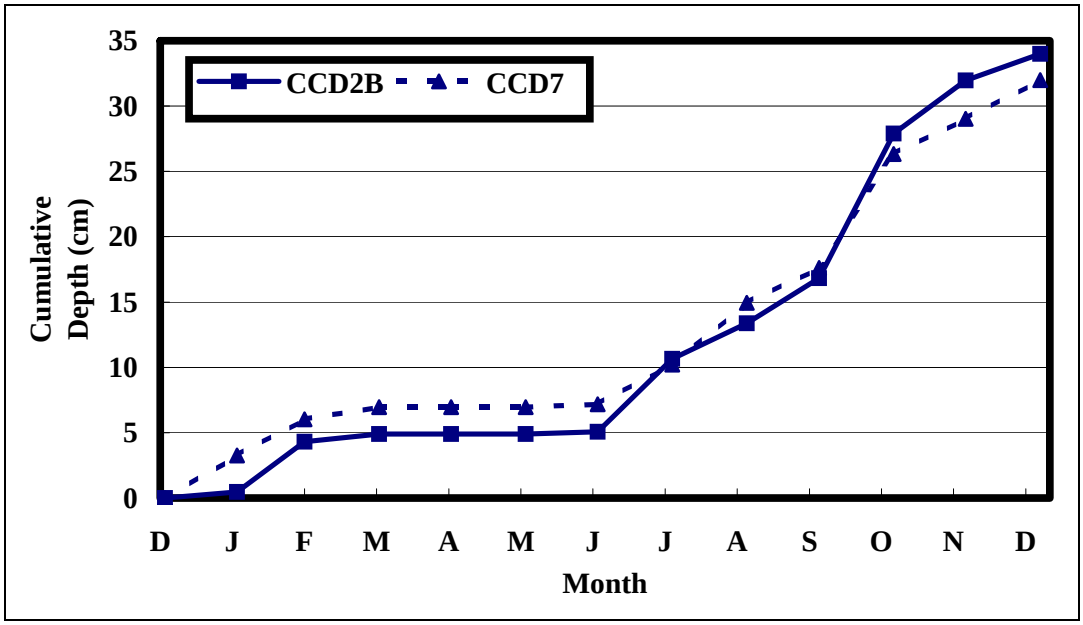


Figure 2.9 2003 Monthly cumulative drainage depths (including runoff and drainage) for CCD2B and CCD7, cropped in cotton

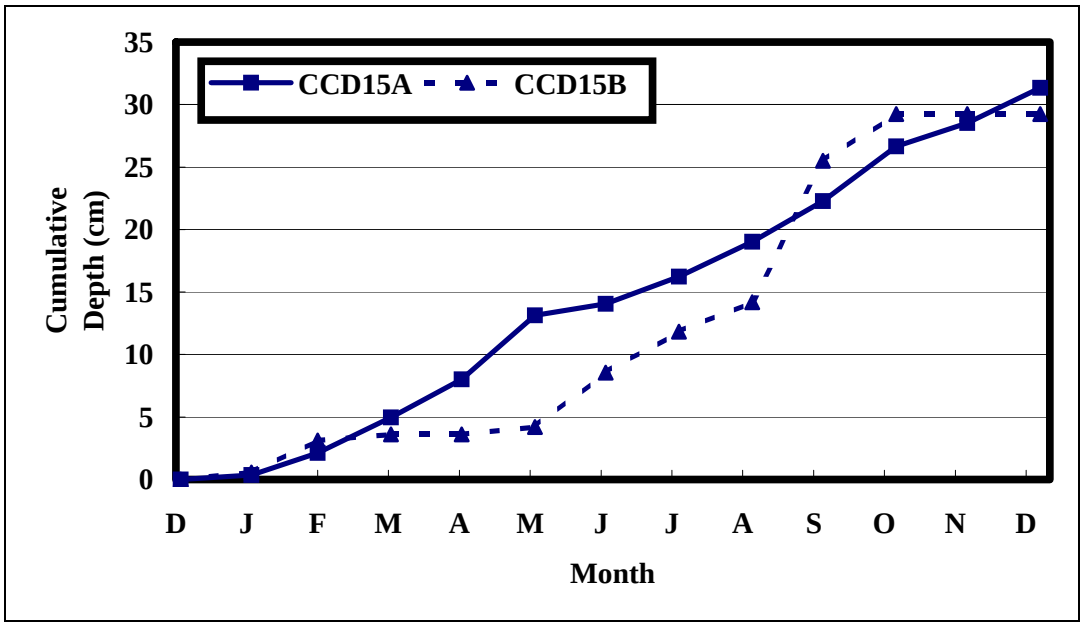


Figure 2.10 2003 Monthly cumulative drainage depths (including runoff and drainage) for CCD15A and CCD15B, cropped in corn

CCD2B, CCD7, and CCD15B showed similar observed trends to each other with little drainage between February and June 2003. CCD2B and CCD7 were managed under

the same operator on the same farm. The total cumulative depths for the year were within 2 cm.

Monthly outflows on CCD15A and CCD15B did not match exactly from month to month (Figure 2.10) but they were also within 2 cm total cumulative depth for the year. CCD15A increased monthly at a more even rate than CCD15B. CCD15A drains a larger watershed and the continued flow in March and April may represent a larger contribution from base flow.

Variability in the flow depths and rates were attributed to natural and management causes. Natural variability occurred due to nuances in individual field soil properties and topography. Different channel dimensions and weir depths (from the land surface) would also cause variability in the drainage amounts.

2.5.1.2 Nitrate Sampling

Monthly grab samples were collected at each sampling location and analyzed for NO_3-N. The drainage outflow nitrate concentrations were compared for monitoring sites under similar cropping systems, Figure 2.11 and Figure 2.12. (Comparison flow plots for CCD2B versus CCD7 and CCM0 versus CCM1 are located in Appendix O.) A t-test was performed on the grab sample concentrations. The mean NO_3-N concentrations of CCD2B were significantly different than CCD7, as were CCD15A and CCD15B, and CCM0 and CCM1 ($\alpha = 0.05$).

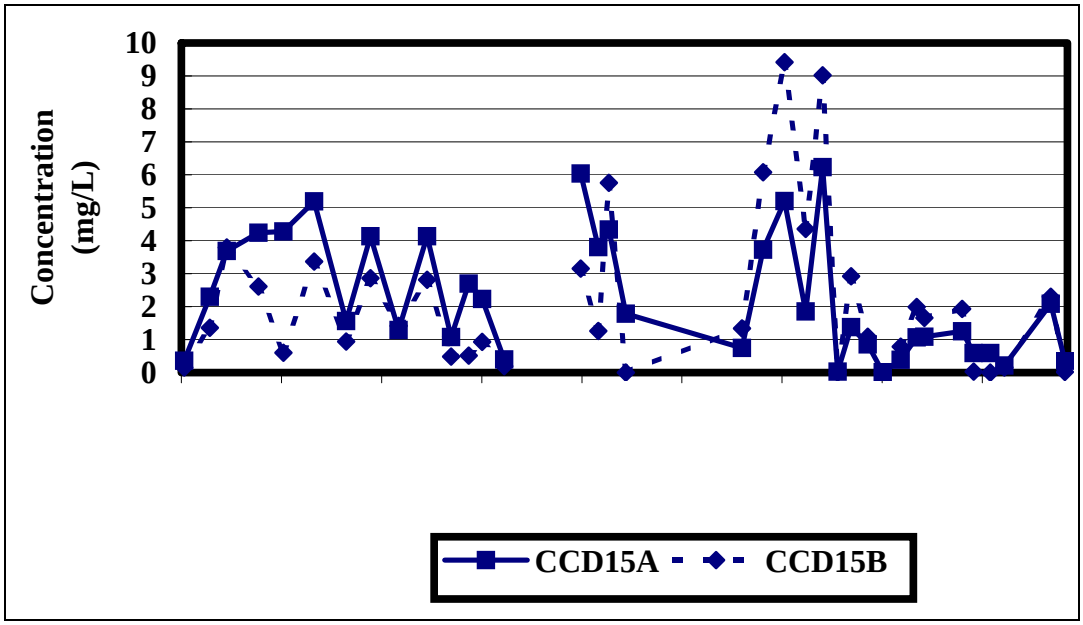


Figure 2.11 2003 Drainage outflow NO_3-N concentrations for CCD15A and CCD15B, cropped in corn

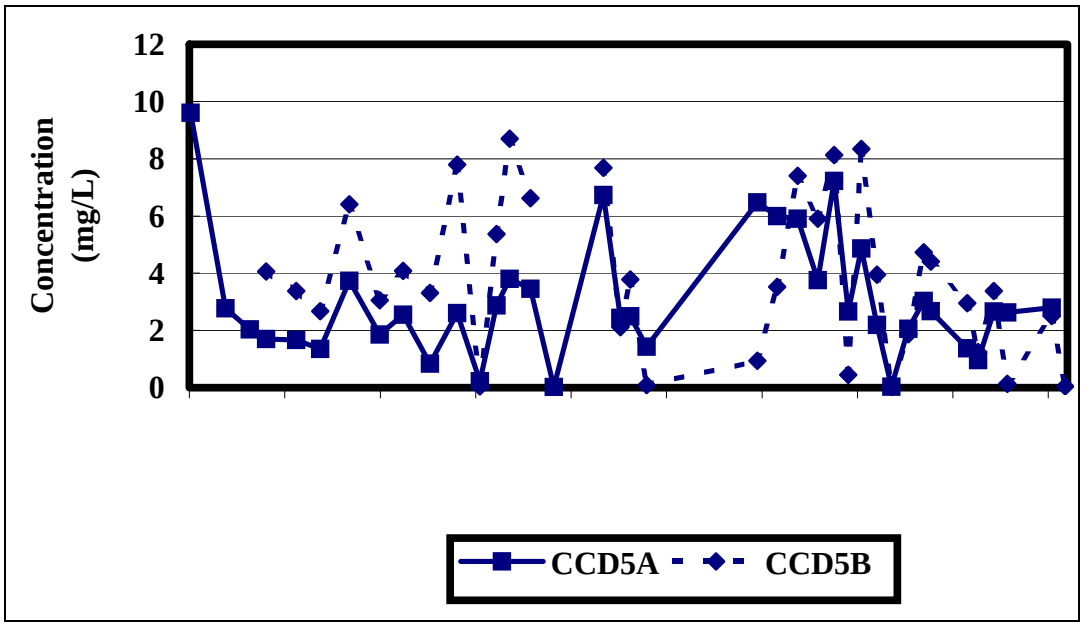


Figure 2.12 2003 Drainage outflow NO_3-N concentrations for CCD5A and CCD5B, cropped in soybeans

While general trends in nutrient concentrations are similar between CCD15A and CCD15B, the drainage water NO_3-N levels fluctuate (Figure 2.11). Ranges in concentration vary from 0 to 10 mg/L. These structures were installed prior to 1999, but were not

functioning correctly. New boards were installed in 2001 and 2002, which might explain the jump in NO_3-N concentrations. Also, crop could be a factor. Prior to January 2002, CCD15A concentrations are often almost twice those of CCD15B. This trend is reversed after January of 2003. As these are side-by-side sites, this variation is natural and appears reasonable. Peaks in concentrations appear, for both CCD15A and CCD15B, in February/March of 2000, 2001, and 2002. Peaks also occurred in July of 2001 and 2003. These peaks in off-years could be expected from a field where the crops are rotated, as this site may have been.

Trends in Figure 2.12 are similar to those of Figure 2.11. Nitrate concentration peaks in the drainage waters are occurring at similar times. Drainage concentrations ranged in value from barely detectable to 10 mg/L. CCD5B concentrations are generally higher than CCD5A. As CCD5A is downstream from CCD5B, dilution may have occurred, resulting in lower NO_3-N concentrations at CCD5A. Also, a significant contribution of flow on CCD5B is from drainage tile.

Variability in the nitrate concentrations was attributed to various causes. Natural variability occurred from individual field and crop properties. These included the amount of residual organic material, variations in crop growth/nutrient uptake, and variations in subsurface drainage to the ditches. Sources of man-made variability included sample collection time, fertilizer application rates and timing, and cropping system throughout the site's watershed.

The NO_3-N concentrations were used with the observed flow to determine monthly loads leaving the site. Trends and observed concentrations were reasonable and used to calibrate the DRAINMOD-N models.

2.5.1.3 Additional Nutrient Sampling

Representative plots of cumulative month-to-month TKN, NO_3-N, NH_4-N, TP, OP, and TSS loads are shown in Figure 2.13 through Figure 2.18. Month-to-month nutrient fluctuations were typical for N, with an increase following fertilizer application in the spring months. Nitrate loadings in 2004 were lower than those in 2003. Total phosphorus trends were similar to those of OP. The TSS loads increased in the spring months, following seedbed preparation for planting. Cumulative monthly load results for each of the monitoring sites are shown in Appendix P.

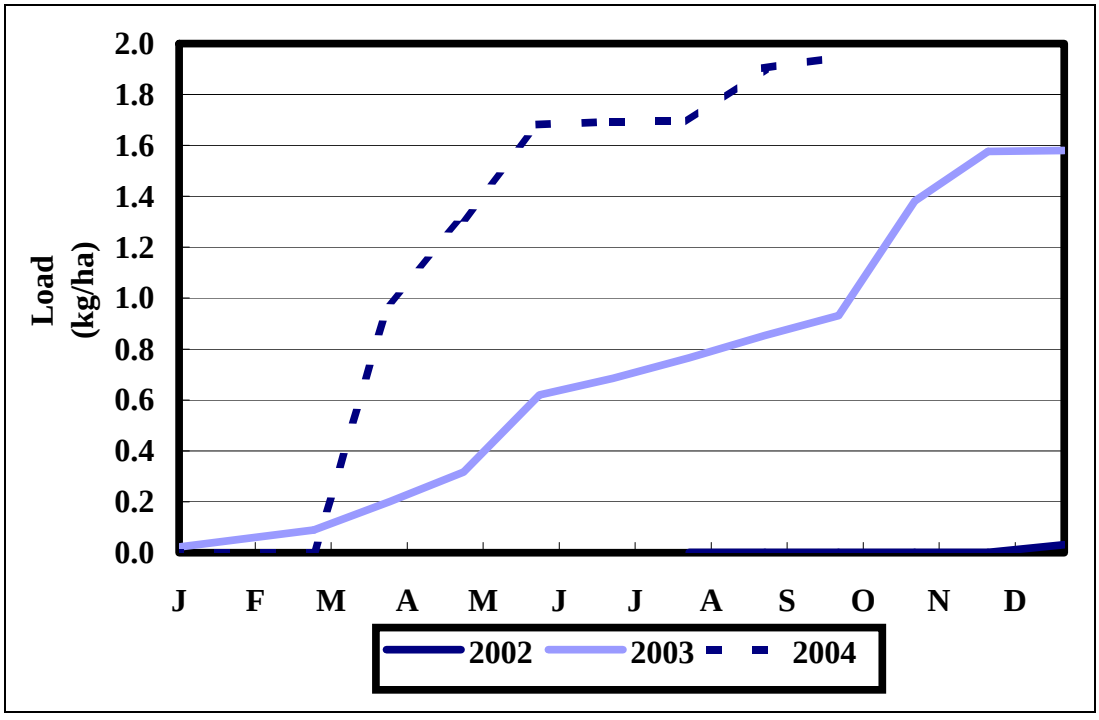


Figure 2.13 Cumulative total Kjeldahl nitrogen loads, kg/ha, (computed monthly) for monitoring site CCD8

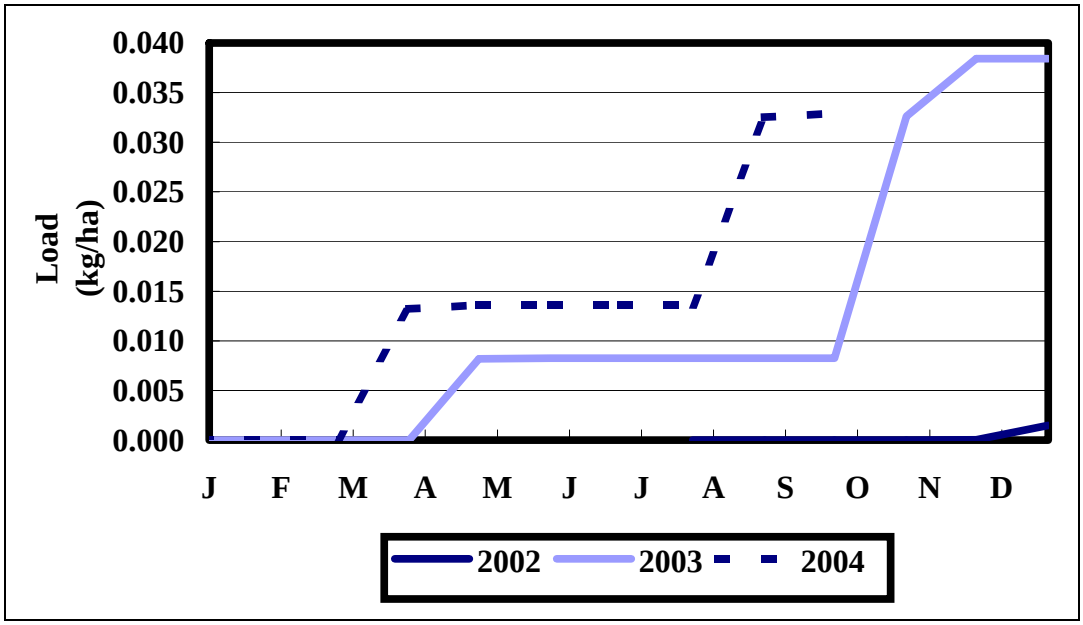


Figure 2.14 Cumulative ammonium nitrogen loads, kg/ha, (computed monthly) for monitoring site CCD8

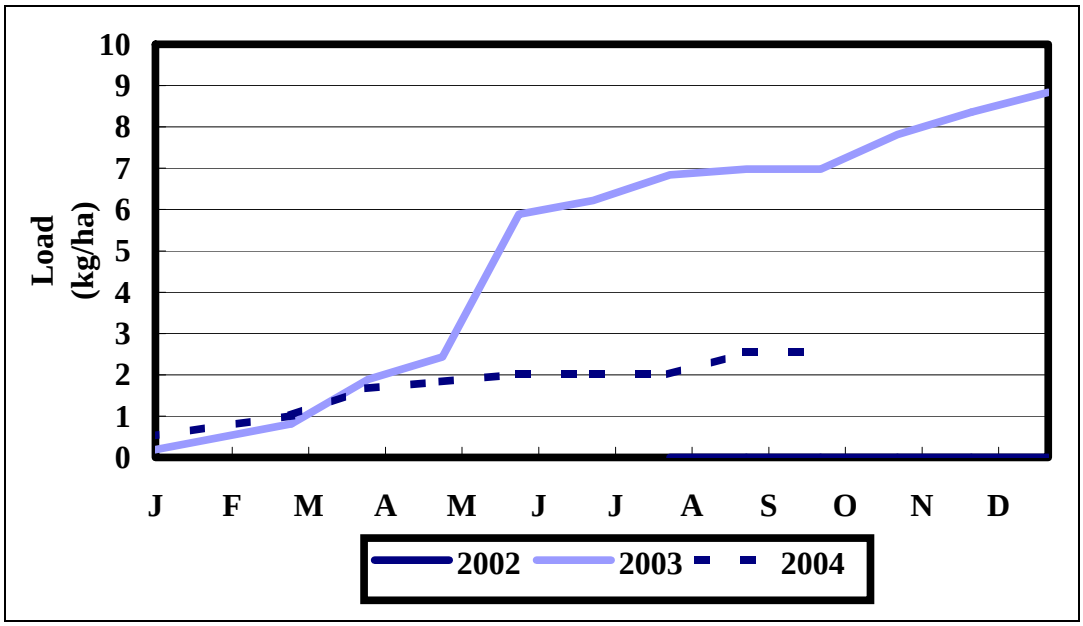


Figure 2.15 Cumulative nitrate nitrogen loads, kg/ha, (computed monthly) for monitoring site CCD8

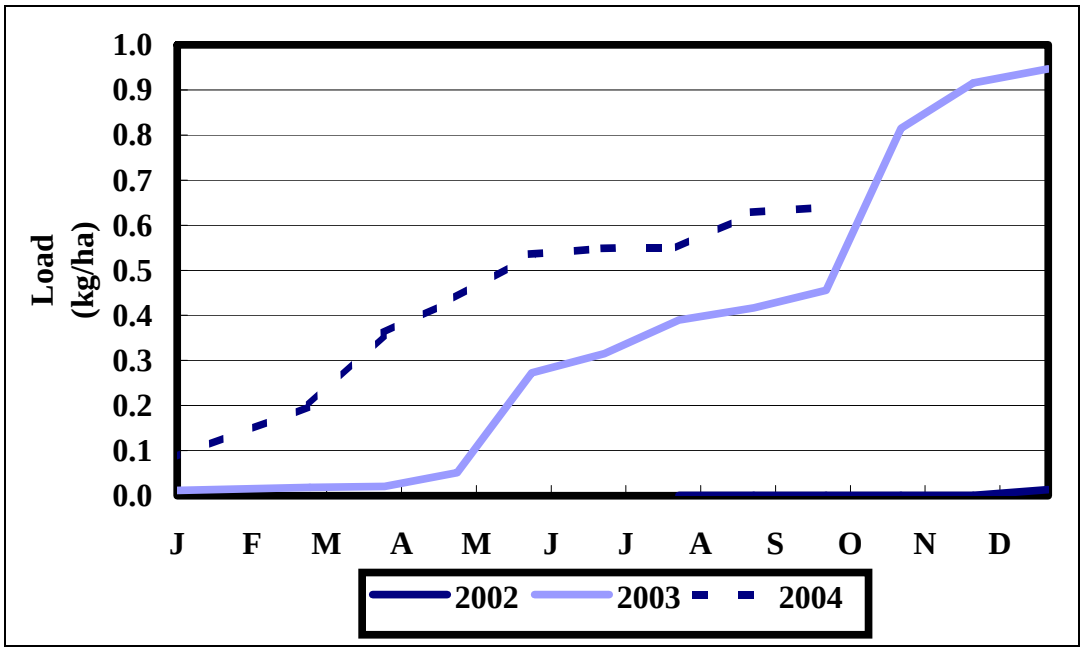


Figure 2.16 Cumulative total phosphorus loads, kg/ha, (computed monthly) for monitoring site CCD8

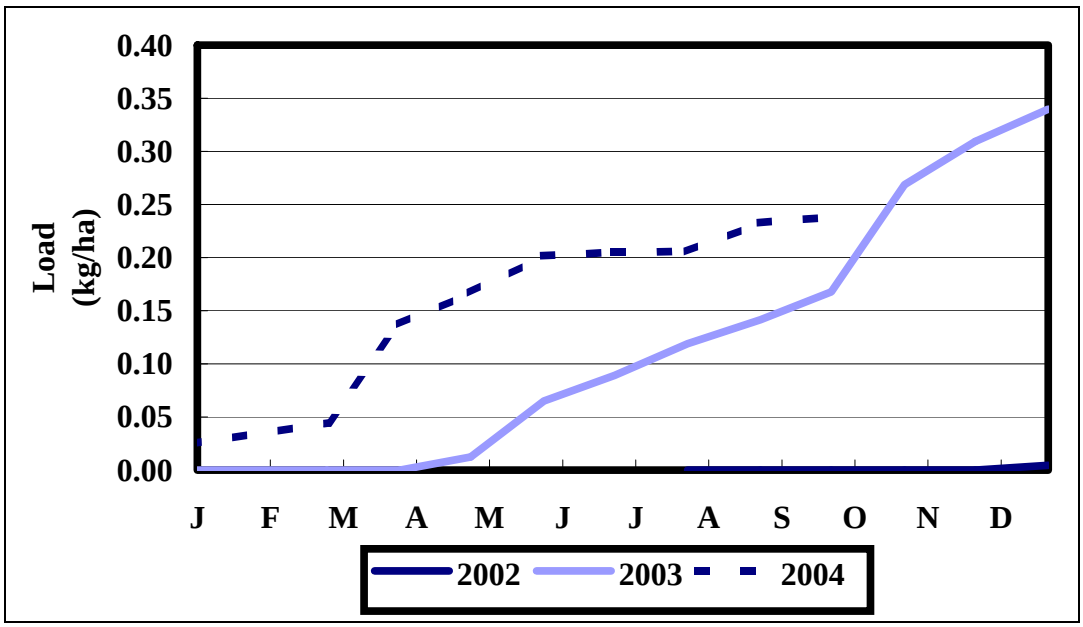


Figure 2.17 Cumulative orthophosphate loads, kg/ha, (computed monthly) for monitoring site CCD8

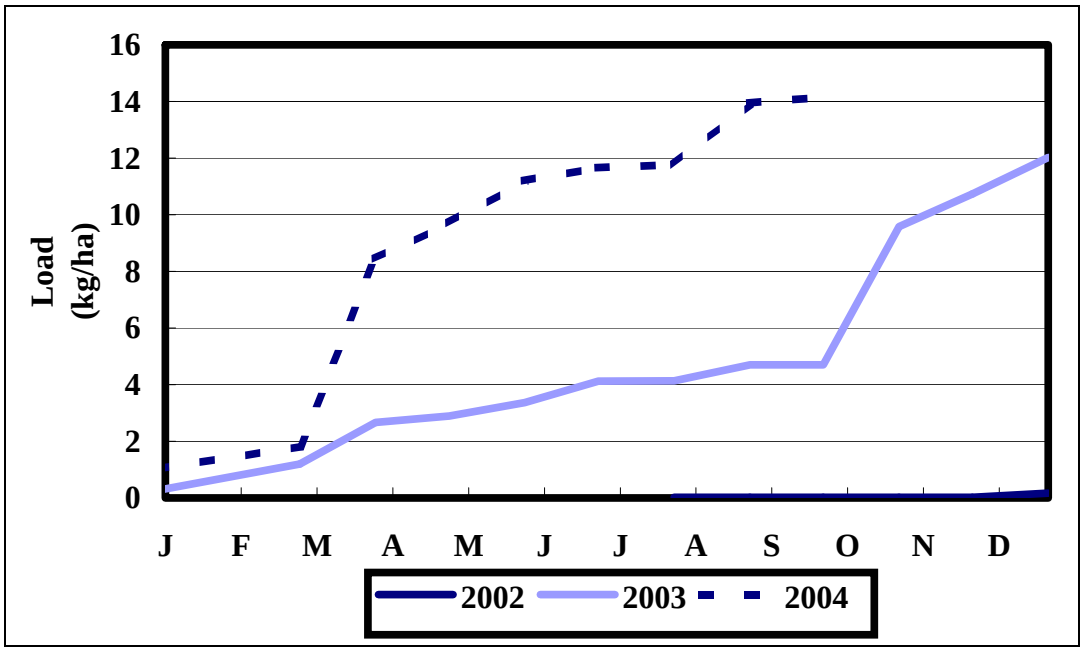


Figure 2.18 Cumulative total suspended solids loads, kg/ha, (computed monthly) for monitoring site CCD8

2.5.2 Simulated Drainage and Nitrate Transport

2.5.2.1 Drainage Outflow

The observed drainage depths were compared to DRAINMOD predicted drainage depths. Cumulative monthly plots for 2003 and 2004 are shown for four representative sites in Figure 2.19 through Figure 2.22.

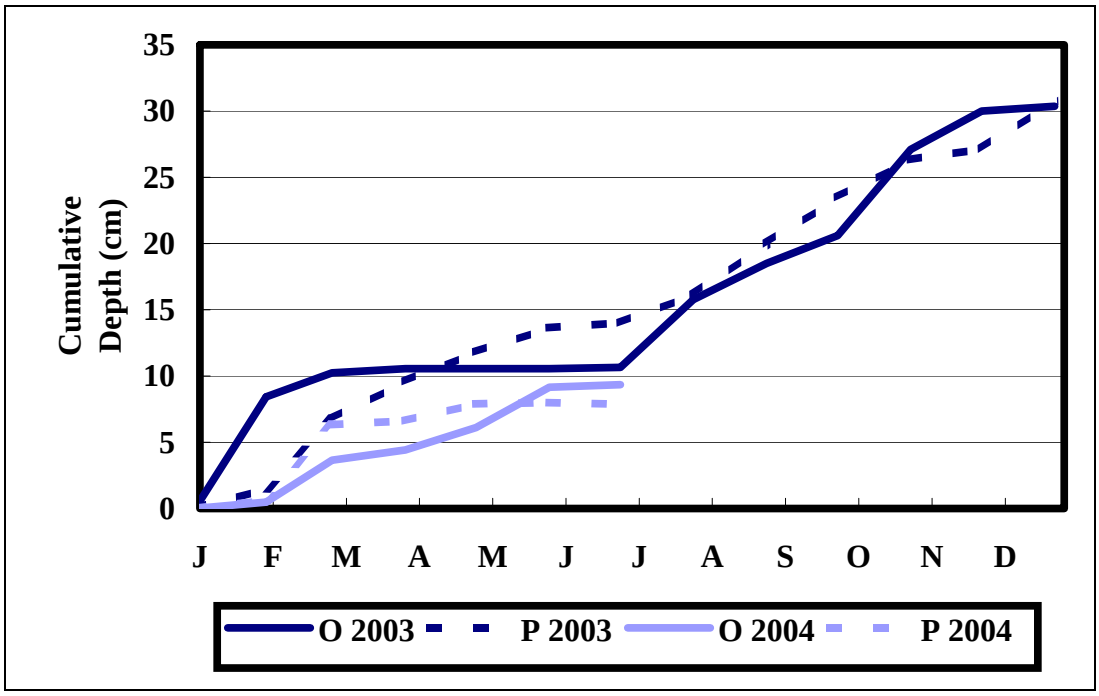


Figure 2.19 Observed and predicted monthly cumulative flows at CCD4A , 2003 and 2004

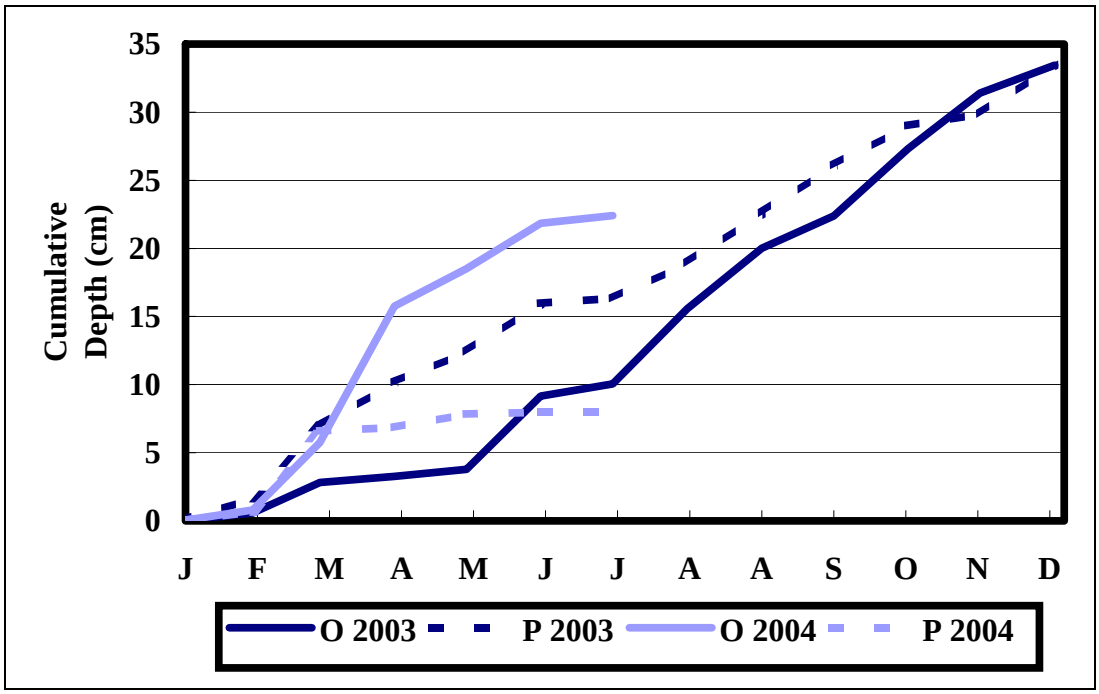


Figure 2.20 Observed and predicted monthly cumulative flows at CCD5A, 2003 and 2004

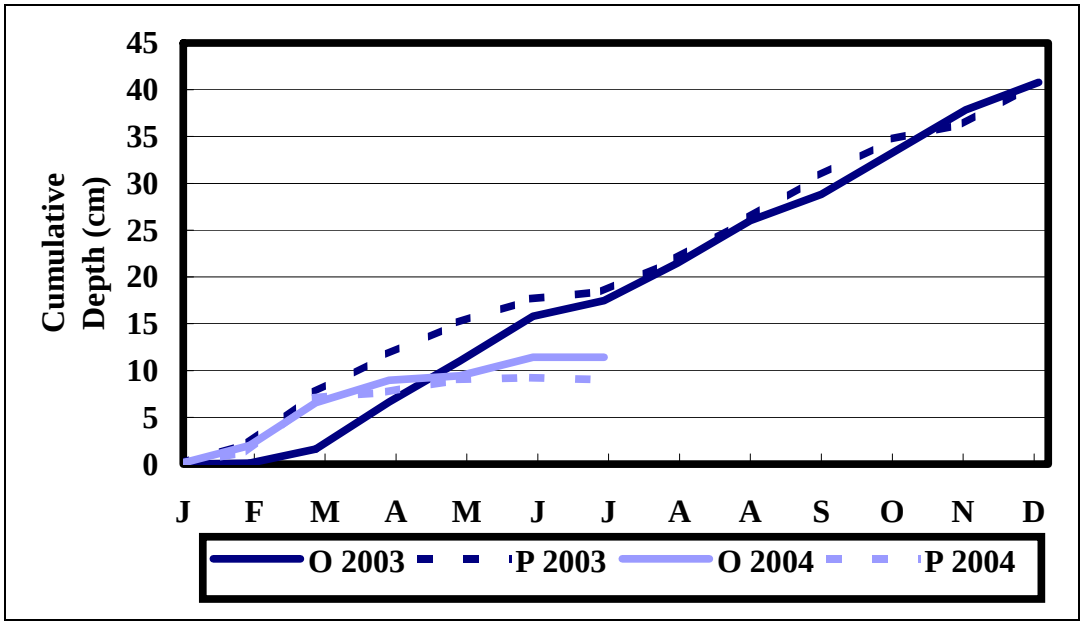


Figure 2.21 Observed and predicted monthly cumulative flows at GCD5, 2003 and 2004

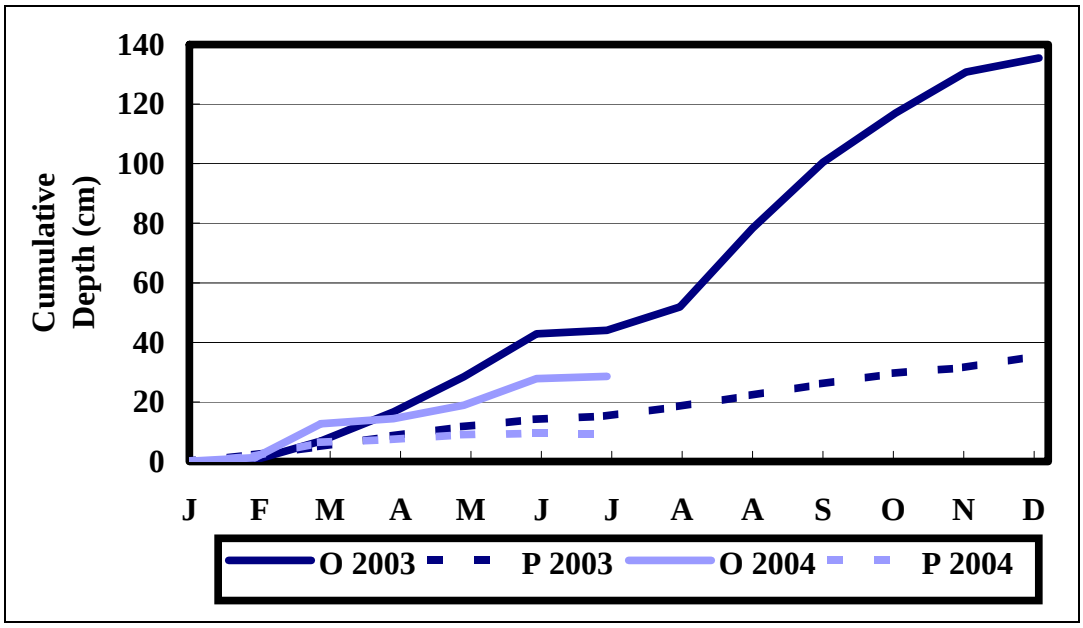


Figure 2.22 Observed and predicted monthly cumulative flows at CCM0, 2003 and 2004

Generally, simulated cumulative outflow match very well to observed values as seen in Figure 2.19 through Figure 2.21. Predicted and observed flows generally increased at similar rates. Cumulative observed and predicted monthly drainage depths for 2003 were

within generally within ±5% for 9 of the 15 sites (Table 2.6) and ranged from 30 cm to 40 cm annually.

Table 2.6 2003 Observed and predicted cumulative drainage depths for monitoring sites in Core Creek watershed

Sampling Site	Observed	Predicted	% Difference [1]
CCD2B	34	32.8	3.5%
CCD4A	30.4	30.8	-1.3%
CCD5A	33.4	33.5	-0.3%
CCD5B	33.6	35.4	-5.4%
CCD7	32	31.9	0.3%
CCD8	41.6	40.8	1.9%
CCD15A	31.3	31.8	-1.6%
CCD15B	29.2	30.0	-2.7%
CCDPD4 [2]	99.9	22.5	77.5%
CCDPD5 [2]	370.6	37.0	90.0%
CCM0 [2]	135.5	35.6	73.7%
CCM1 [2]	125.9	41.9	66.7%
GCD3	28.6	29.9	-4.5%
GCD5	40.8	40.9	-0.2%
GCD7A	49.1	34.8	29.1%
Average All Sites	74.4	34.9	21.8%
Average of Sites Without Beavers	34.9	33.9	1.71%

[1] % Difference = 100 x (Observed - Predicted)/Observed
[2] Sites with beavers

Four sampling sites are similar to Figure 2.22 (Appendix Q). Each of these four sites had extremely high flows, compared to the predicted depths. All four sites were located on the same farm with a history of beavers. The beavers routinely dammed up the water control structures (Figure 2.23), causing the stage recorders to read higher flows than were actually occurring. Note that the predicted flows at these four sites were in the same range (30 cm to 40 cm) as both the observed and predicted flows at the other 11 sites.

Figure 2.23 Blocked water control structure CCM1 from beavers (left) and free flowing structure after cleanout (right)

Daily observed flows were compared to daily-predicted flows (Figure 2.24). The timing of predicted peak flows matched well with observed peaks. The predicted flow was generally a good fit to observed.

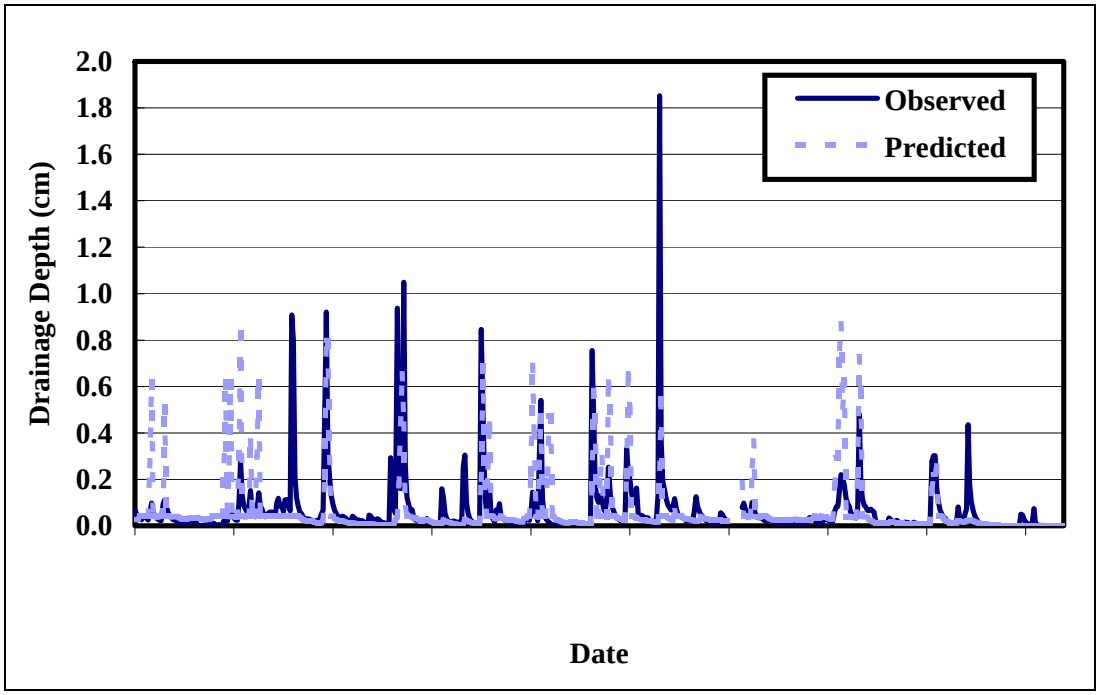


Figure 2.24 Daily observed and predicted drainage at GCD3

Root mean square error tests were used to minimize the errors between the predicted and observed (Table 2.6). Based upon the sampling and predicted data, DRAINMOD

predicted the outflow into the drainage ditches within an average of 0.21 cm, across all sampling sites. The variability in predictions is indicated by the higher RMSE values. Additional daily plots for the remaining monitoring sites are located in Appendix R. Excluding the 4 sites with beaver problems, the general DRAINMOD fit was good compared to the observed outflow, as reflected in Table 2.6 and Table 2.7.

Table 2.7 Root mean square error for daily observed and predicted drainage flows from the Core Creek watershed monitoring sites

Sampling Site	RMSE [1]
CCD2B	0.38
CCD4A	0.24
CCD5A	0.18
CCD5B	0.15
CCD7	0.14
CCD8	0.23
CCD15A	0.30
CCD15B	0.23
CCDPD4 [2]	0.48
CCDPD5 [2]	1.16
CCM0 [2]	0.47
CCM1 [2]	0.40
GCD3	0.24
GCD5	0.12
GCD7A	0.15
Average All Sites	0.32
Average of Sites Without Beavers	0.21

[1] RMSE = Root Mean Square Error
[2] Beaver Complicated Sites

2.5.2.2 Nitrate

Daily, simulated discrete NO_3-N concentrations were compared to those observed from grab sampling. Yearly predicted loads were not compared since sampling did not occur over a long time period. Monthly loads were not compared, since only one grab sample would be used to represent the flow load for the entire month. Instead, the grab sample

concentrations were compared to the predicted daily concentration of nitrate in the drainage waters from DRAINMOD-N (Figure 2.25 to Figure 2.27). Plots of the nitrate concentrations for each monitoring site are located in Appendix S. The predicted NO_3-N concentrations in drainage waters generally fit the observed well. In general, DRAINMOD-N predicted lower concentrations in the drainage outflow than what were observed,

Table 2.8.

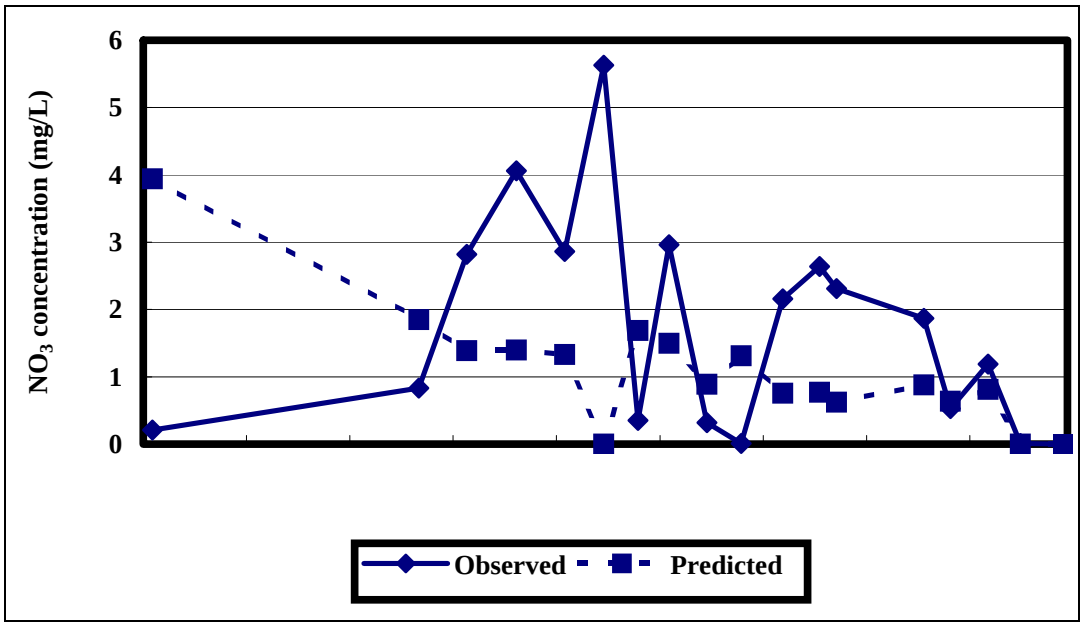


Figure 2.25 Observed and predicted nitrate concentrations in drainage outflow at CCD2B

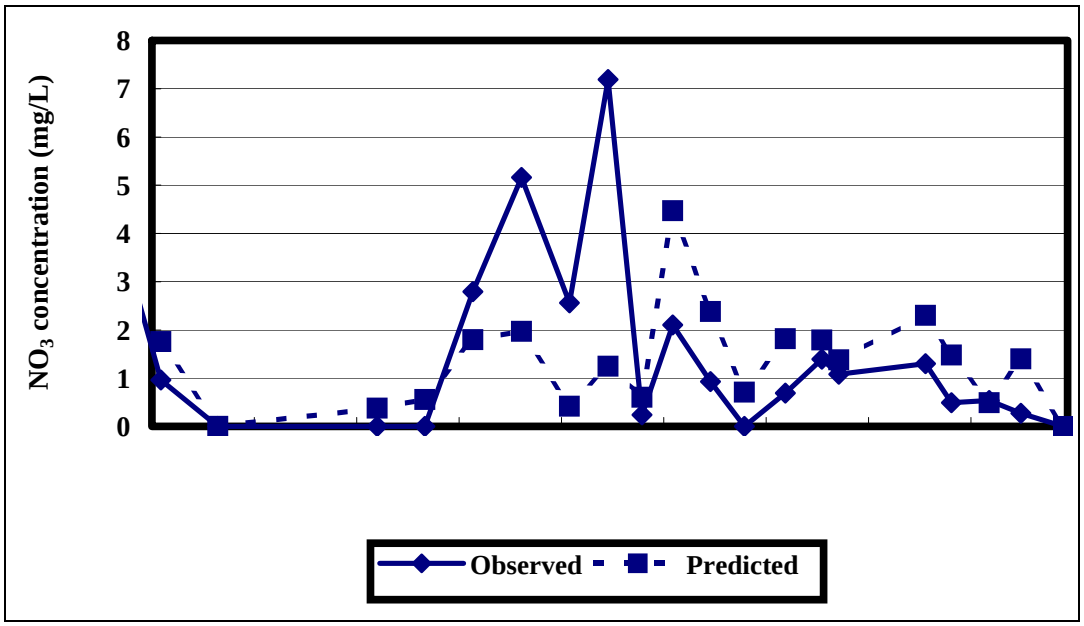


Figure 2.26 Observed and predicted nitrate concentrations in drainage outflow at CCD8

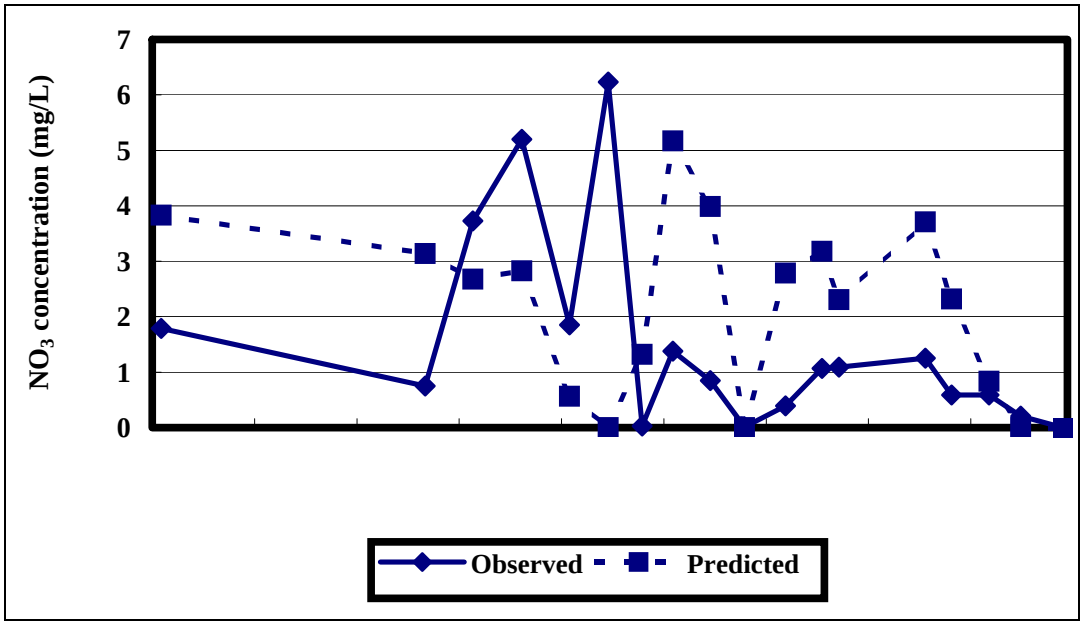


Figure 2.27 Observed and predicted nitrate concentrations in drainage outflow at CCD15A

Table 2.8 Mean observed and predicted nitrate concentrations (mg/L) by site for the Core Creek watershed

Sampling Site	Observed	Predicted
CCD2B	1.71	1.10
CCD4A	2.35	1.02
CCD5A	3.22	1.06
CCD5B	3.19	1.12
CCD7	3.15	0.91
CCD8	1.62	1.55
CCD15A	1.50	2.15
CCD15B	2.43	1.71
CCDPD4	1.14	0.89
CCDPD5	0.55	0.86
CCM0	0.64	0.29
CCM1	0.89	0.62
GCD3	2.25	1.22
GCD5	0.59	1.46
GCD7A	0.96	2.03

Root mean square error tests were used to minimize the errors between the predicted and observed (Table 2.9). Errors are much larger than for the drainage hydrology, as expected from Figure 2.25 through Figure 2.27. While Figure 2.26 appears to have a better fit of predicted versus observed drainage NO_3-N concentrations, the RMSE is relatively high. This is attributed to the smaller data set and variability of the observed nitrate concentrations. The RMSEs are larger at some sites than others. This is attributed to the natural variability in outflow concentrations, as seen in the above figures.

Table 2.9 Root mean square error for daily observed and predicted nitrate concentrations in drainage outflows from the Core Creek watershed monitoring sites

Sampling Site	RMSE [1]
CCD2B	2.08
CCD4A	2.84
CCD5A	2.92
CCD5B	3.65
CCD7	3.88
CCD8	1.78
CCD15A	2.47
CCD15B	3.29
CCDPD4	1.74
CCDPD5	1.28
CCM0	1.78
CCM1	1.53
GCD3	2.28
GCD5	1.47
GCD7A	2.61

[1] RMSE = Root Mean Square Error

2.5.3 Flow Reduction with Controlled Drainage

The DRAINMOD input files for each site were treated for conventional and controlled drainage. The model's hydrologic outputs for each treatment were then compared. The long-term average predicted reductions in drainage waters by incorporating the controlled drainage BMP into the farm management are shown in Figure 2.28. Across all sites, the total flow can be reduced by an average of 21.3%, Table 2.10. Taken over the entire watershed (2040 ha), this can reduce flow by an average of 1.4 million cubic meters annually (6.8 cm equivalent depth).

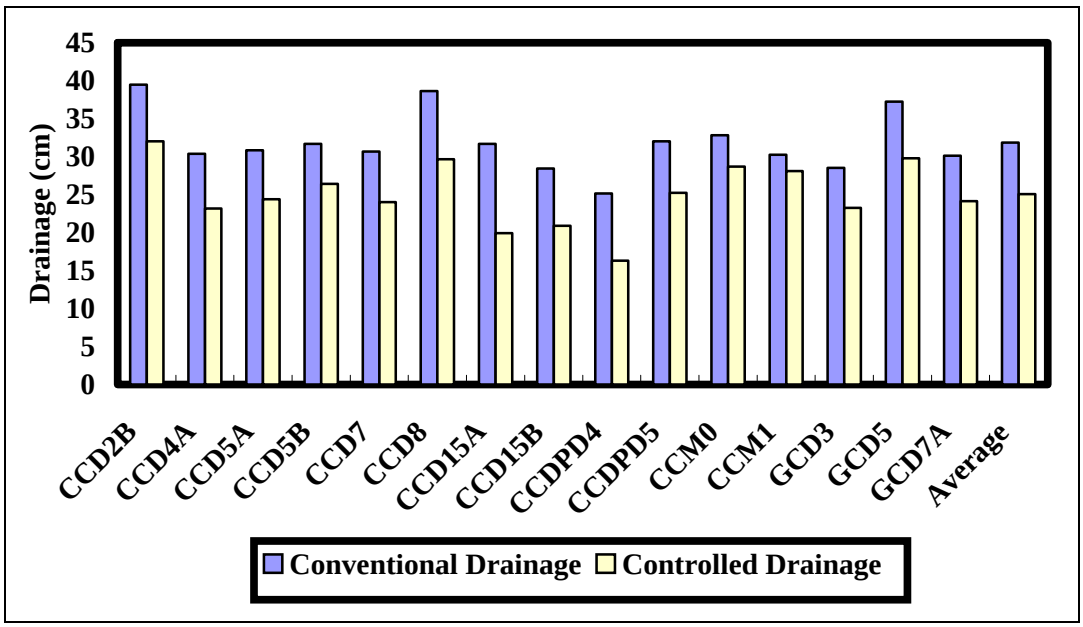


Figure 2.28 Predicted yearly drainage volumes, per site in the Core Creek watershed, operating under conventional and controlled drainage.

Table 2.10 Drainage volume reduction using controlled drainage

Site	Drainage	
	cm	%
CCD2B	7.5	18.9%
CCD4A	7.2	23.8%
CCD5A	6.5	20.9%
CCD5B	5.3	16.7%
CCD7	6.7	21.7%
CCD8	9.0	23.2%
CCD15A	11.8	37.1%
CCD15B	7.5	26.5%
CCDPD4	8.8	35.1%
CCDPD5	6.8	21.2%
CCM0	4.1	12.6%
CCM1	2.2	7.1%
GCD3	5.3	18.5%
GCD5	7.5	20.1%
GCD7A	6.0	19.9%
Average	6.8	21.3%

The mean flow attributed to controlled drainage is significantly lower than conventional drainage (α=.01). The average reduction is slightly lower than values published by Evans et al (1990) and Evans et al (1995), citing a 30% drainage water reduction using controlled drainage. Two sites were predicted to achieve at over 30%, but the remainder were lower (Table 2.10). The lower average may be attributed to the field slope. The slope of the land may have caused some portions of the fields to not operate under controlled drainage; while other portions of the field operated as conventional drainage. The net effect would be proportional to the relative proportion of each field operating in each mode. The seemingly high NO_3-N concentrations obtained from this study may be closer to the average of ideal controlled drainage and no controlled drainage.

2.5.4 Nitrate Reduction

The predicted long-term reductions of NO_3-N by incorporating the BMPs into the farm management are shown in Figure 2.29. Percentage reductions are seen in Table 2.11. Reductions were partially dependent upon crop due to varying fertilization requirements. Fields with lower predicted N transport (CCD5A, CCD5B) were planted to soybeans, requiring no additional N fertilization (using a NMP). Corn, the primary crop on CCM0 required 180 kg/ha N input.

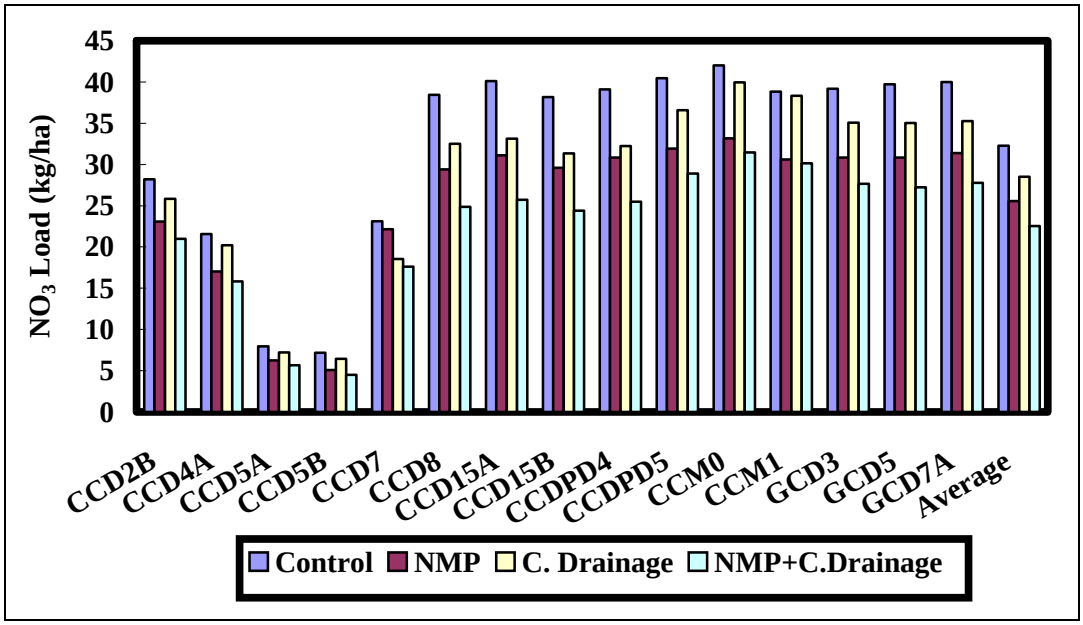


Figure 2.29 Predicted NO_3-N load in drainage waters for the different Core Creek watershed sites under different BMPs.

Table 2.11 Predicted NO_3-N load reductions in the Core Creek Watershed as determined at various monitoring sites.

Site	Crop	NMP		CD[1]		NMP & CD[1]	
		kg/ha	%	kg/ha	%	kg/ha	%
CCD2B	Cotton	5.1	18.2%	2.4	8.4%	7.2	25.6%
CCD4A	Cotton	4.6	21.1%	1.4	6.4%	5.7	26.6%
CCD5A	Soybeans	1.7	21.6%	0.7	9.1%	2.3	28.6%
CCD5B	Soybeans	2.1	29.3%	0.8	10.5%	2.7	37.3%
CCD7	Cotton	1.0	4.2%	4.6	19.8%	5.5	23.8%
CCD8	Corn	9.0	23.5%	5.9	15.4%	13.6	35.3%
CCD15A	Corn	9.0	22.4%	7.0	17.4%	14.4	35.9%
CCD15B	Corn	8.6	22.5%	6.8	17.9%	13.8	36.1%
CCDPD4	Corn	8.3	21.1%	6.9	17.6%	13.6	34.9%
CCDPD5	Corn	8.5	21.1%	3.9	9.5%	11.5	28.5%
CCM0	Corn	8.9	21.1%	2.1	4.9%	10.6	25.2%
CCM1	Corn	8.2	21.2%	0.5	1.4%	8.7	22.3%
GCD3	Corn	8.3	21.3%	4.1	10.4%	11.5	29.3%
GCD5	Corn	8.9	12.0%	4.7	11.8%	12.5	22.3%
GCD7A	Corn	8.6	21.5%	4.7	11.8%	12.2	30.5%
Average		6.7	20.1%	3.8	11.5%	9.7	29.5%

[1] C.D. – Controlled Drainage

The mean reduction resulting from the NMP is statistically higher than that of controlled drainage (α= 0.01). The mean reduction of NO_3-N using the combination of NMP and controlled drainage is statistically higher than either the NMP or controlled drainage alone (α= 0.01). This is supported by the average reduction values shown in Table 2.11. Using a NMP over the entire watershed can potentially reduce the NO_3-N load by 13,700 kg annually. For controlled drainage alone and the NMP-controlled drainage combination, the annual NO_3-N load could be reduced by 7,700 kg and 19,800 kg, respectively.

As seen in Figure 2.30, the use of a nutrient management plan alone caused a greater NO_3-N reduction than controlled drainage alone. The most effective management strategy to reduce NO_3-N leaving the fields is to use the combination of controlled drainage and a NMP.

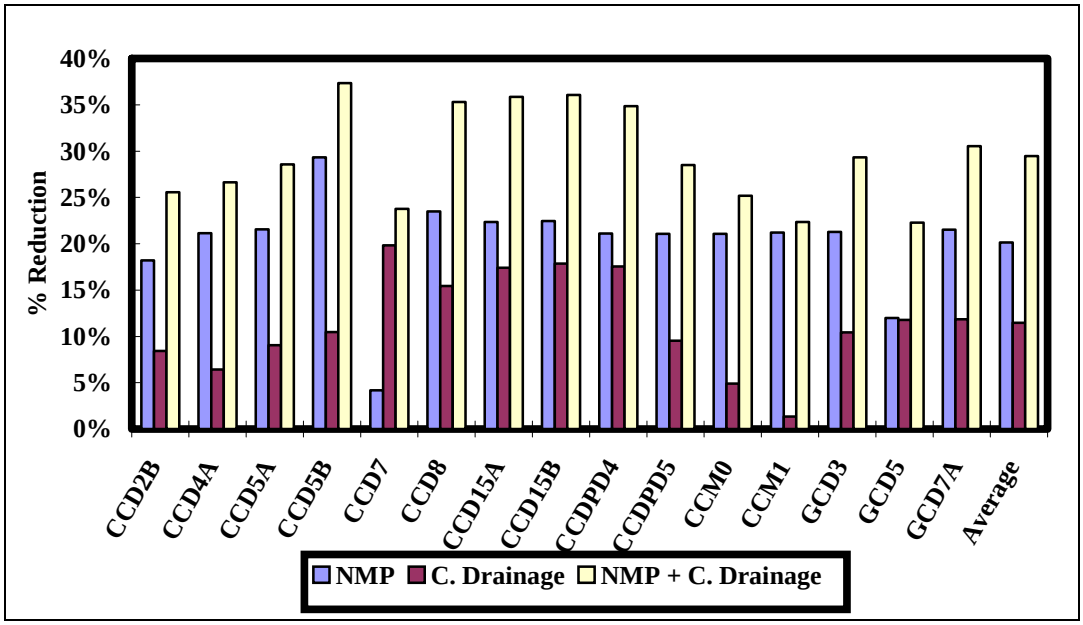


Figure 2.30 Percentage of NO_3-N reductions in drainage water at the different monitoring sites in the Core Creek watershed.

The average NO_3-N reductions are similar to those reported in literature (Drury et al. 1996; Evans et al. 1995; Gambrell et al. 1975b; Gilliam and Skaggs 1986; Gilliam et al.

1979; Osmond et al. 2002; Skaggs et al. 1994; Tan et al. 1996). Similar to other studies (Amatya et al. 1998; Evans et al. 1989; Evans et al. 1995), it was predicted that controlled drainage's effect on total outflow was the main cause of the NO_3-N load reduction.

2.5.5 Crop Impacts

Each DRAINMOD-N model was simulated for the primary crops in the watershed: corn, cotton, and soybeans. Controlled drainage and a nitrate management plan were also simulated.

For each crop under the different BMP treatments, similar drainage reductions were predicted using controlled drainage (Figure 2.31, Appendix T). Comparing the cropping effects under controlled drainage, the effect of soybeans on drainage reduction was less than that of cotton or corn ($\alpha = 0.05$). This is reflected in the average yearly drainage outflow depths, Table 2.12. The cropping system affects drainage waters in various ways. The land is fallow at different times. Crop water usage/requirements differ. Evapotranspiration rates are also different for each crop due to differences in crop coefficients as a function of stage development.

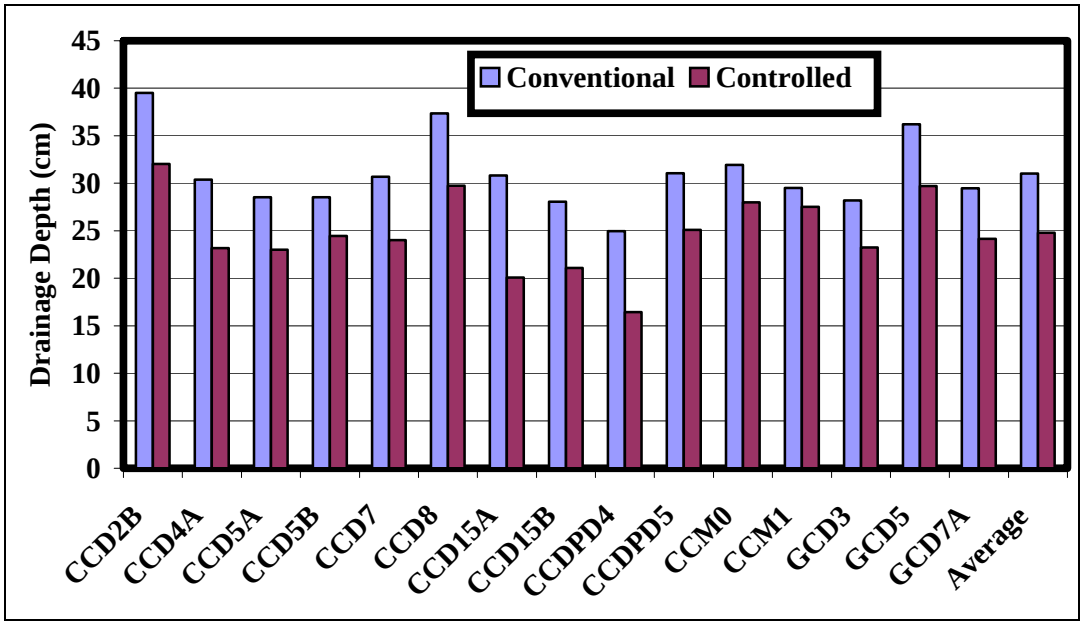


Figure 2.31 Controlled and conventional drainage depths for the Core Creek monitoring sites cropped in continuous corn

Table 2.12 Average drainage rates in the Core Creek watershed under different cropping systems

Crop	Conventional Drainage	Controlled Drainage
Corn	31.7 cm	24.8 cm
Soybeans	35.0 cm	26.4 cm
Cotton	31.0 cm	24.8 cm

Predicted nitrate losses were also estimated for each cropping system (Figure 2.32 through Figure 2.35). Nitrate loss from fields cropped under corn was significantly higher than that of cotton, which was significantly higher than soybeans ($\alpha = 0.05$). Model results indicate that using controlled drainage and a nutrient management plan, cropped under soybeans, an average yearly nitrate reduction of 75% was achieved, when compared to corn (Table 2.13). The main reason for the reduced nitrate load is due to the lower fertilizer requirements needed by soybeans, since they are leguminous, as corn.

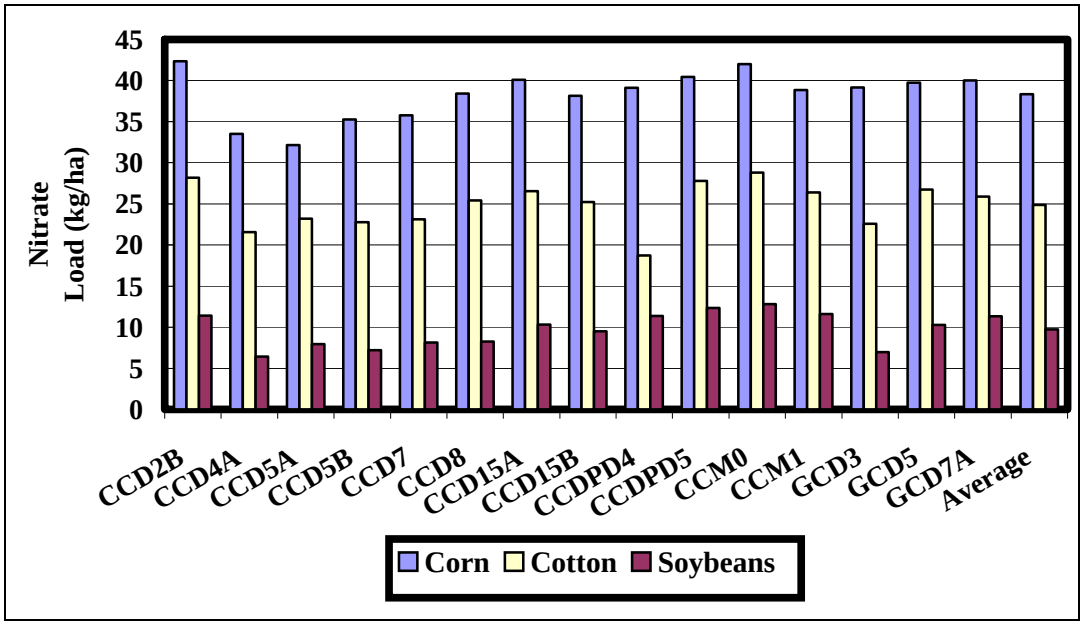


Figure 2.32 Yearly nitrate losses to drainage water for each monitoring site operating under conventional drainage and no nutrient management plan

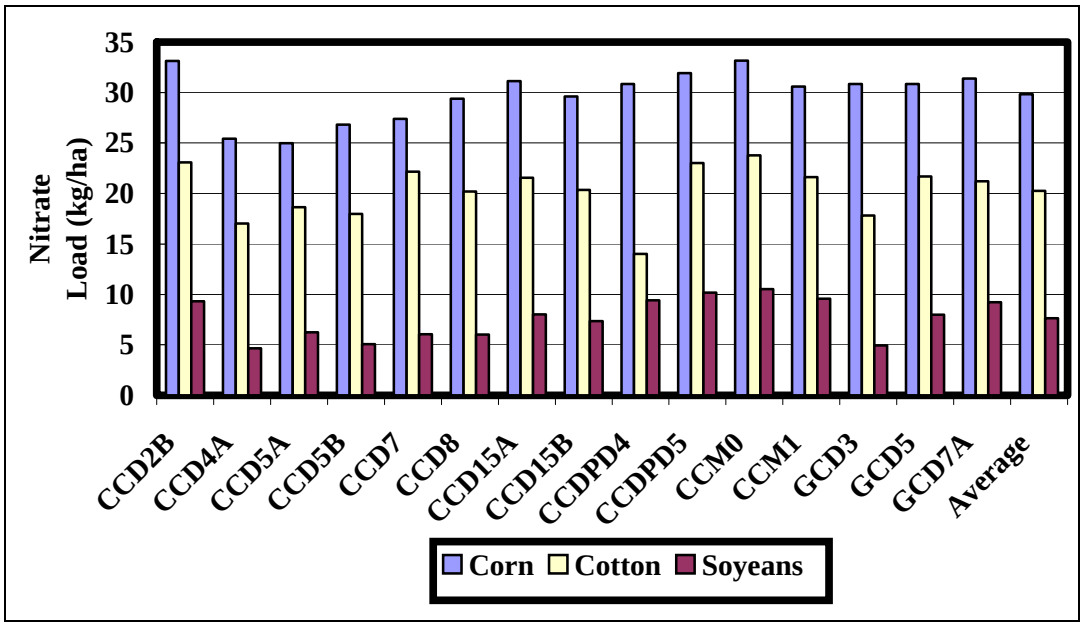


Figure 2.33 Yearly nitrate losses to drainage water for each monitoring site operating under conventional drainage and a nutrient management plan

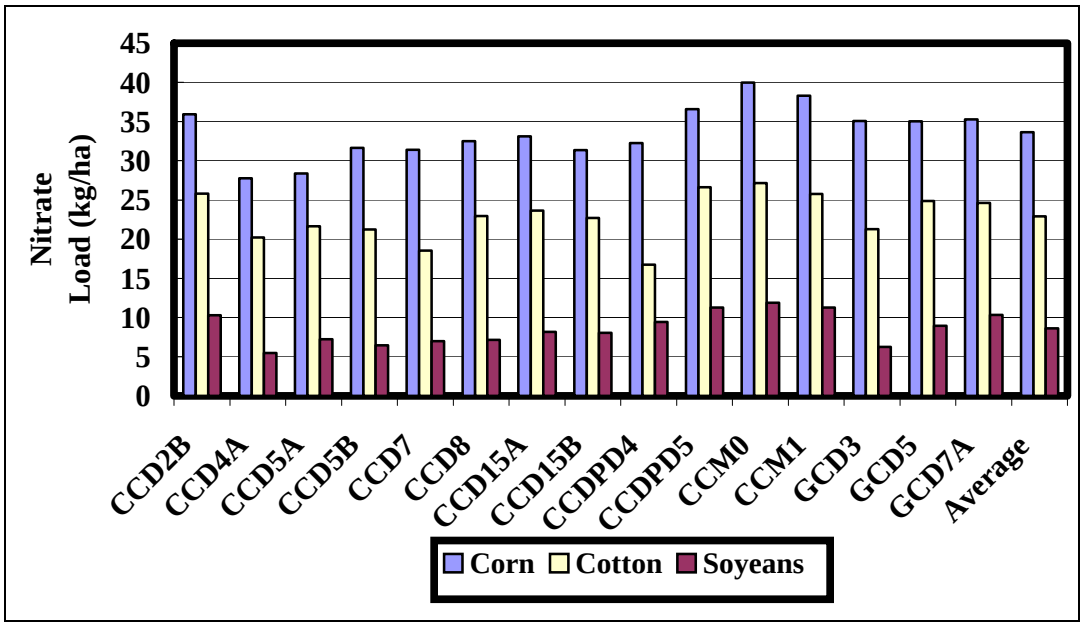


Figure 2.34 Yearly nitrate losses to drainage water for each monitoring site operating under controlled drainage and no nutrient management plan

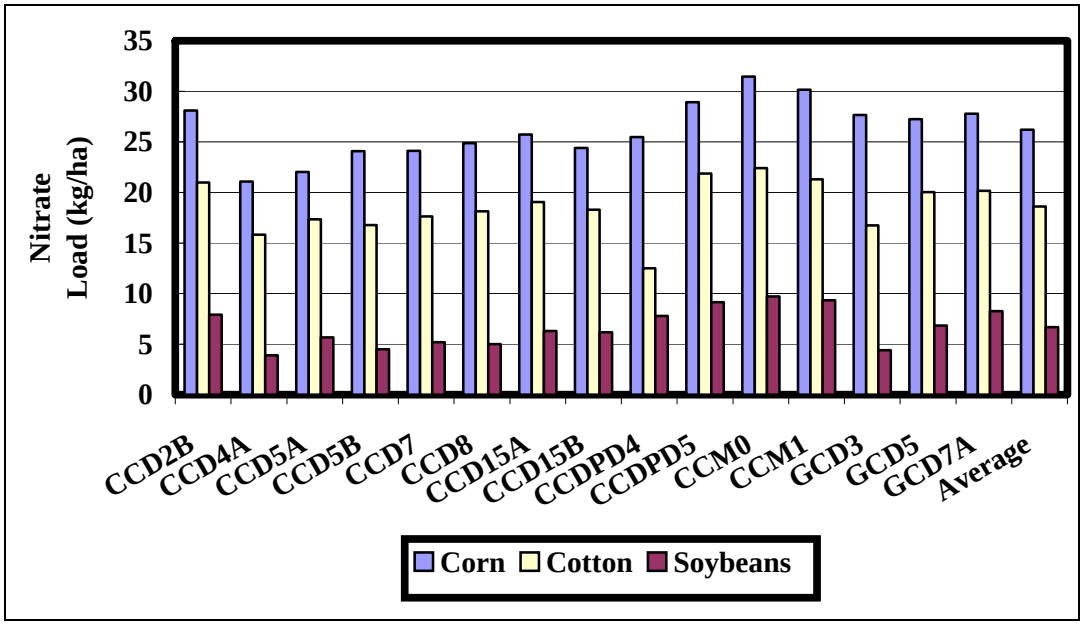


Figure 2.35 Yearly nitrate losses to drainage water for each monitoring site operating under controlled drainage and a nutrient management plan

Table 2.13 Predicted average yearly nitrate load reduction using different cropping systems in the Core Creek watershed, compared to corn [1]

BMP	Cotton	Soybeans
None (Conventional Drainage)	35.1%	74.6%
Nitrate Management Plan (NMP)	32.1%	74.4%
Controlled Drainage	31.9%	74.4%
Controlled Drainage & NMP	29.0%	74.5%

[1] % Reduction = 100 x (Corn – Crop)/Corn

Model results indicate that controlled drainage significantly lessens the yearly nitrate loss for individual crops ($\alpha = 0.05$), Table 2.14. Controlled drainage has more of an effect on nitrate loads when the field is cropped under corn than under cotton or soybeans.

Table 2.14 Average yearly nitrate load reduction using controlled drainage for different continuous cropping systems in the Core Creek watershed, in kg/ha[1]

Crop	Conventional Drainage	Controlled Drainage	% Reduction
Corn	38.3	33.6	12.3%
Cotton	24.9	22.9	7.8%
Soybeans	9.7	8.6	11.5%

[1] % Reduction = 100 x (Conventional – Controlled)/Conventional

2.6 CONCLUSIONS

The total NO_3-N load to Core Creek was reduced when BMPs such as controlled drainage and nutrient management plans were implemented. Nitrate-nitrogen reduction was most effectively accomplished when these two BMPs are used in conjunction with one another. If implemented separately, using a NMP was predicted be more effective than controlled drainage.

The cropping system also impacts the drainage rate and nitrate loss from the fields. Theoretically, a 30% and 75% nitrate reduction can be achieved growing cotton or soybeans, respectively instead of corn. This is primarily caused by the various fertilizer requirements needed by the corn, cotton, and soybeans. While cropping straight soybeans is unrealistic, the potential impact of incorporating them into a rotation can be realized.

Controlled drainage can potentially reduce the drainage outflow by an average of 23.1%, 6.8 centimeters, annually. This flow reduction accounts for the majority of NO_3-N load reduction leaving the site.

2.7 REFERENCES

Amatya, D. M., Gilliam, J. W., Skaggs, R. W., Lebo, M. E., and Campbell, R. G. (1998). "Effects of Controlled Drainage on Forest Water Quality." *Journal of Environmental Quality*, 27, 923-935.

Ambus, P., and Christensen, S. (1993). "Denitrification Variability and Control in a Riparian Fen Irrigated with Agricultural Drainage Water." *Soil Biology Biochemistry*, 25(7), 915-923.

Ambus, P., and Lowrance, R. (1991). "Comparison of Denitrification in Two Riparian Soils." *Soil Science Society of America Journal*, 55, 994-997.

Bass, K. (2004). Raleigh, NC.

Beegle, D. B., Carton, O. T., and Bailey, J. S. (2000). "Nutrient Management Planning: Justification, Theory, Practice." *Journal of Environmental Quality*, 29, 72-79.

Beeson, C. E., and Doyle, P. F. (1995). "Comparison of Bank Erosion at Vegetated and Non-Vegetated Channel Bends." *Water Resources Bulletin*, 31(6), 983-990.

Brenner, F. J., and Brenner, E. K. (1998). "A Watershed Approach to Agricultural Non-Point Source Pollution Abatement." Watershed Management: Practice, Policies, and Coordination, R. J. Reimold, ed., McGraw Hill, New York City, New York.

Brevé, M. A. (1994). "Modeling the Movement and Fate of Nitrogen in Artificially Drained Soils," Ph.D., North Carolina State University, Raleigh, NC.

Brevé, M. A., Skaggs, R. W., Gilliam, J. W., Mohammad, A. T., Chescheir, G. M., and Evans, R. O. (1997). "Field Testing of DRAINMOD-N." *Transactions of the ASAE*, 40(4), 1077-1085.

Byars, M. S., and Kelly, M. "Sediment Transport in Urban Stream Restoration Design." *Wetlands Engineering and River Restoration Conference*, 17-28.

Case, R. L., and Kauffman, J. B. (1997). "Wild Ungulate Influences on the Recovery of Willows, Black Cottonwood and Thin-leaf Alder Following Cessation of Cattle Grazing in Northeastern Oregon." *Northwest Science*, 71(2), 115-126.

Casey, R. E., and Klaine, S. J. (2001). "Nutrient Attenuation by a Riparian Wetland During Natural and Artificial Runoff Events." *Journal of Environmental Quality*, 30, 1720-1731.

Chescheir, G. M., Lebo, M. E., Amatya, D. M., Hughes, J., Gilliam, J. W., Skaggs, R. W., and Herrman, R. B. "Hydrology and Water Quality of Forested Lands in Eastern North Carolina." *ASAE Annual International Meeting*, Las Vegas, Nevada.

Cooke, J. G., and Cooper, A. B. (1988). "Sources and Sinks of Nutrients in a New Zealand Hill Pasture Catchment: III. Nitrogen." *Hydrological Processes*, 2, 135-149.

Cooper, J. R., Gilliam, J. W., Daniels, R. B., and Robarge, W. P. (1987). "Riparian Areas as Filters for Agricultural Sediment." *Soil Science Society of America Journal*, 51(2), 416-420.

Correll, D. L., and Weller, D. E. "Factors Limiting Processes in Freshwater Wetlands: An Agricultural Primary Stream Riparian Forest." *Freshwater Wetlands and Wildlife Conference - 8603101*, Oak Ridge, TN.

Daniels, R. B., and Gilliam, J. W. (1996). "Sediment and Chemical Load Reduction by Grass and Riparian Filters." *Soil Science Society of America Journal*, 60, 246-251.

Dillaha, T. A., Reneau, R. B., Mostaghimi, S., and Lee, D. (1989). "Vegetative Filter Strips for Agricultural Nonpoint Source Pollution Control." *Transactions of the ASAE*, 32(2), 513-519.

Drury, C. F., Tan, C. S., Gaynor, J. D., Oloya, T. O., and Welacky, T. W. (1996). "Influence of Controlled Drainage-Subirrigation on Surface and Tile Drainage Nitrate Loss." *Journal of Environmental Quality*, 25, 317-324.

Dukes, M. D., Evans, R. O., Gilliam, J. W., and Kunickis, S. H. (2002). "Effect of Riparian Buffer Width and Vegetation Type on Shallow Groundwater Quality in the Middle Coastal Plain of North Carolina." *Transactions of the ASAE*, 45(2), 327-336.

Dukes, M. D., Evans, R. O., Gilliam, J. W., and Kunickis, S. H. (2003). "Interactive Effects of Controlled Drainage and Riparian Buffers on Shallow Groundwater Quality." *Journal of Irrigation and Drainage Engineering*, 129(2), 82-92.

El-Sadek, A., Feyen, J., and Berlamont, J. (2001). "Comparison of Models for Computing Drainage Discharge." *Journal of Irrigation and Drainage Engineering*, 127(6), 363-369.

El-Sadek, A., Oorts, K., Sammels, L., Timmerman, A., Radwan, M., and Feyen, J. (2003). "Comparative Study of Two Nitrogen Models." *Journal of Irrigation and Drainage Engineering*, 129(1), 44-52.

Evans, R. O., Gilliam, J. W., and Skaggs, R. W. (1989). "Effects of Agricultural Water Table Management on Drainage Water Quality." *237*, North Carolina Water Resources Research Institute, Raleigh, NC.

Evans, R. O., Gilliam, J. W., and Skaggs, R. W. (1990). "Controlled Drainage Management Guidelines to Improve Drainage Water Quality." *N.C. Agricultrual Service Bulletin*, AG-443.

Evans, R. O., and Skaggs, R. W. "Development of Controlled Drainage as a BMP in North Carolina." *Drainage VIII Proceedings of the Eighth International Symposium*, Sacramento, CA, 1-15.

Evans, R. O., Skaggs, R. W., and Gilliam, J. W. (1995). "Controlled Versus Conventional Drainage Effects on Water Quality." *Journal of Irrigation and Drainage Engineering*, 121(4), 271-275.

Gambrell, R. P., Gilliam, J. W., and Weed, S. B. (1975a). "Denitrification in Subsoils of the North Carolina Coastal Plain as Affected by Soil Drainage." *Journal of Environmental Quality*, 4(3), 311-316.

Gambrell, R. P., Gilliam, J. W., and Weed, S. B. (1975b). "Nitrogen Losses from Soils of the North Carolina Coastal Plain." *Journal of Environmental Quality*, 4(3), 317-323.

Gilliam, J. W. (1994). "Riparian Wetlands and Water Quality." *Journal of Environmental Quality*, 23, 896-900.

Gilliam, J. W., and Skaggs, R. W. (1986). "Controlled Agricultural Drainage to Maintain Water Quality." *Journal of Irrigation and Drainage Engineering*, 112(3), 254-263.

Gilliam, J. W., Skaggs, R. W., and Weed, S. B. (1979). "Drainage Control to Diminish Nitrage Loss from Agricultural Fields." *Journal of Environmental Quality*, 8(1), 137-142.

Green, D. M., and Kauffman, J. B. (1995). "Succession and Livestock Grazing in a Northeastern Oregon Riparian Ecosystem." *Journal of Range Management*, 48(4), 307-313.

Groffman, P. M., Axelrod, E. A., Lemunyon, J. L., and Sullivan, W. M. (1991). "Denitrification in Grass and Forest Vegetated Filter Strips." *Journal of Environmental Quality*, 20, 671-674.

Haycock, N. E., and Burt, T. P. (1993). "The Sensitivity of Rivers to Nitrate Leaching: the Effectiveness of Near-Stream Land as a Nutrient Retention Zone." Landscape Sensitivity, D. S. G. Thomas and R. J. Allison, eds., John Wiley and Sons, Ltd.

Haycock, N. E., and Pinay, G. (1993). "Groundwater Nitrate Dynamics in Grass and Poplar Vegetated Riparian Buffer Strips During the Winter." *Journal of Environmental Quality*, 22, 273-278.

Helfield, J. M., and Diamond, M. L. (1997). "Use of a Constructed Wetland for Urban Stream Restoration: A Critical Analysis." *Environmental Management*, 21(3), 329-341.

Hunt, P. G., Stone, K. C., Humenik, F. J., Matheny, T. A., and Johnson, M. H. (1999). "In-Stream Wetland Mitigation of Nitrogen Contamination in a USA Coastal Plain Stream." *Journal of Environmental Quality*, 28(1), 249-256.

Iowa State University Forestry Extension. (2001). "Buffer Strips for Riparian Zones."

Jacobs, T. C., and Gilliam, J. W. (1985). "Riparian Losses of Nitrate from Agricultural Drainage Water." *Journal of Environmental Quality*, 14(4), 472-478.

James, B. R., Bagley, B. B., and Gallagher, P. H. "Riparian Zone Vegetation Effects on Nitrate Concentration in Shallow Groundwater." *New Perspectives in the Chesapeake System: A Research and Management Partnership*, 605-611.

Jarrett, A. R. (2001). *Land Application of Wastes*, Engineering Copy Center, University Park, PA.

Jennings, G. D., and Doll, B. A. "Natural Channel Design Applications for Restoring Incised Streams in North Carolina." *ASAE Annual International Meeting/CIGR XV World Congress*, Chicago, Illinois.

Johnson, P. A., and Brown, E. R. (2001). "Incorporating Uncertainty in the Design of Stream Channel Modifications." *Journal of the American Water Resources Association*, 37(5), 1225-1236.

Jordan, T. E., Correll, D. L., and Weller, D. E. (1993). "Nutrient Interception by a Riparian Forest Receiving Inputs from Adjacent Cropland." *Journal of Environmental Quality*, 22, 467-473.

Kadlec, R. H., and Hay, D. L. (1994). "Constructed Wetlands for River Water Quality Improvement." *Water Science Technology*, 29(4), 159-168.

Kauffman, J. B., Krueger, W. C., and Varva, M. (1983). "Impacts of Cattle on Streambanks in Northeastern Oregon." *Journal of Range Management*, 36(6), 683-685.

Kimmelshue, J. E., Gilliam, J. W., and Volk, R. J. (1995). "Water Management Effects on Mineralization of Soil Organic Matter and Corn Residue." *Soil Science Society of America Journal*, 59, 1156-1162.

Kliewer, B. A., and Gilliam, J. W. (1995). "Water Table Management Effects on Denitrification and Nitrous Oxide Evolution." *Soil Science Society of America Journal*, 59, 1694-1701.

Kralova, M., Masscheleyn, P. H., Lindau, C. W., and Patrick Jr., W. H. (1992). "Production of Dinitrogen and Nitrous Oxide in Soil Suspension as Affected by Redox Potential." *Water, Air, and Soil Pollution*, 61, 37-45.

Kuhnle, R. A., Simon, A., and Knight, S. S. "Developing Linkages Between Sediment Load and Biological Impairment for Clean Sediment TMDLs." *Wetlands Engineering and River Restoration Conference*, 1021-1030.

Lee, K., Kenhart, T. M., Schultz, R. C., and Mickelson, S. K. (2000). "Multispecies Riparian Buffer Trap Sediment and Nutrients During Rainfall." *Journal of Environmental Quality*, 29(4), 1200-1205.

Lenat, D. R., and Crawford, J. K. (1994). "Effects of Land Use on Water Quality and Aquatic Biota of Three North Carolina Piedmont Streams." *Hydrobiologia*, 294, 185-199.

Lenat, D. R., Penrose, D. L., and Eagleson, K. W. (1981). "Variable effects of Sediment Addition on Stream Benthos." *Hydrobiologia*, 79, 187-194.

Line, D. E. (2002). "Changes in Land Use/Management and Water Quality in the Long Creek Watershed." *Journal of the American Water Resources Association*, 38(6), 1691-1701.
Line, D. E. (2003). "Changes in a Stream's Physical and Biological Conditions Following Livestock Exclusion." *Transactions of the ASAE*, 46(2), 287-293.
Line, D. E., Harman, W. A., Jennings, G. D., Thompson, E. J., and Osmond, D. L. (2000). "Nonpoint-Source Pollutant Load Reductions Associated with Livestock Exclusion." *Journal of Environmental Quality*, 29(6), 1882-1890.
Line, D. E., and Jennings, G. D. (2002). "Long Creek Watershed Nonpoint Source Water Quality Monitoring Project - Final Report." North Carolina State University, Raleigh, North Carolina.
Lowrance, R. (1992a). "Groundwater Nitrate and Denitrification in a Coastal Plain Riparian Forest." *Journal of Environmental Quality*, 21, 401-405.
Lowrance, R. (1992b). "Nitrogen Outputs from a Field-Size Agricultural Watershed." *Journal of Environmental Quality*, 21, 602-607.
Lowrance, R., Leonard, R., and Sheridan, J. (1985). "Managing Riparian Ecosystems to Control Nonpoint Pollution." *Journal of Soil and Water Conservation*, 40, 87-97.
Lowrance, R., and Leonard, R. A. (1988). "Streamflow Nutrient Dynamics on Coastal Plain Watersheds." *Journal of Environmental Quality*, 17(4), 734-740.
Lowrance, R., Sharpe, J. F., and Sheridan, J. M. (1986). "Long-Term Sediment Deposition in the Riparian Zone of a Coastal Plain Watershed." *Journal of Soil and Water Conservation*, 41(4), 266-272.
Lowrance, R., Todd, R., Fail Jr., J., Hendrickson Jr., O., and Asmussen, L. (1984a). "Riparian Forests as Nutrient Filters on Agricultural Watersheds." *Bioscience*, 34(6), 374-377.
Lowrance, R., Todd, R. L., and Asmussen, L. (1984b). "Nutrient Cycling in an Agricultural Watershed: II. Streamflow and Artificial Drainage." *Journal of Environmental Quality*, 13(1), 27-32.
Lowrance, R., Todd, R. L., and Asmussen, L. E. (1984c). "Nutrient Cycling in an Agricultural Watershed: I. Phreatic Movement." *Journal of Environmental Quality*, 13(1), 22-26.
Lowrance, R., Vellidis, G., and Hubbard, R. (1995). "Denitrification in a Restored Riparian Forest Wetland." *Journal of Environmental Quality*, 24(808-815).
Marlow, C. B., Pogacnik, T. M., and Quinsey, S. D. (1987). "Streambank Stability and Cattle Grazing in Southwestern Montana." *Journal of Soil and Water Conservation*, 42(4), 291-296.
Meals, D. W. (2001). "Water Quality Response to Riparian Restoration in an Agricultural Watershed in Vermont, USA." *Water Science Technology*, 43(5), 175-182.
Meals, D. W., and Hopkin, R. B. (2002). "Phosphorus Reductions Following Riparian Restoration in Two Agricultural Watersheds in Vermont, USA." *Water Science Technology*, 45(9), 51-60.
Miller, D. E., and Skidmore, P. B. "Natural Channel Design: How Does Rosgen Classification Based Design Compare with Other Methods?" *2001 Wetlands Engineering and River Restoration Conference*, 813-822.

Miner, J. R., Humenik, F. J., and Overcash, M. R. (2000). *Managing Livestock Wastes to Preserve Environmental Quality*, Iowa State University Press, Ames, Iowa.
NC DENR. (2001). "Standard Operating Procedures for Benthic Macroinvertebrates: Biological Assessment Unit." Division of Water Quality - Water Quality Section, Environmental Sciences Branch.
NC DENR. (2003). "North Carolina Water Quality Assessment and Impaired Waters List (2002 Integrated 305(b) and 303(d))." *021RMT04Ff*, Division of Water Quality Section - Planning Branch, Raleigh, NC.
Neuse River Basin Oversight Committee. (2003). "Neuse Nutrient Sensitive Water Management Strategy: Annual Report for Year 2003 (Reported Crop Year 2002)."
Novak, J. M., Stone, K. C., Szogi, A. A., Watts, D. W., and Johnson, M. H. (2004). "Dissolved Phosphorus Retention and Release from a Coastal Plain In-Stream Wetland." *Journal of Environmental Quality*, 33, 394-401.
Osmond, D. L., Gilliam, J. W., and Evans, R. O. (2002). *Riparian Buffers and Controlled Drainage to Reduce Agricultural Nonpoint Source Pollution*, North Carolina State University, Raleigh, NC.
Owens, L. B., Edwards, W. M., and vanKeuren, R. W. (1996). "Sediment Losses from a Pastured Watershed Before and After Streambank Fencing." *Journal of Soil and Water Conservation*, 51(1), 90-95.
Owens, L. B., Edwards, W. M., and vanKeuren, R. W. (1997). "Runoff and Sediment Losses Resulting from Winter Feeding on Pastures." *Journal of Soil and Water Conservation*, 52(3), 194-198.
Paerl, H. W. (1997). "Coastal Eutrophication and Harmful Algal Blooms: Importance of Atmospheric Deposition and Groundwater as 'New' Nitrogen and Other Nutrient Sources." *Limnology Oceanography*, 45(5, part 2), 1154-1165.
Paerl, H. W., Dyble, J., Twomey, L., Pinckney, J. L., Nelson, J., and Kerkhof, L. (2002). "Characterizing Man-Made and Natural Modifications of Microbial Diversity and Activity in Coastal Ecosystems." *Antoine van Leeuwenhoek*, 81, 487-507.
Paerl, H. W., Willey, J. D., Go, M., Peierls, B. L., Pinckney, J. L., and Fogel, M. L. (1999). "Rainfall Simulation of Primary Production in Western Atlantic Ocean Waters: Roles of Different Nitrogen Sources and Co-Limiting Nutrients." *Marine Ecology Progress Series*, 176, 205-214.
Peterjohn, W. T., and Correll, D. L. (1984). "Nutrient Dynamics in an Agricultural Watershed: Observations on the Role of a Riparian Forest." *Ecology*, 65(5), 1466-1475.
Pickney, J. L., Paerl, H. W., Tester, P., and Richardson, T. L. (2001). "The Role of Nutrient Loading and Eutrophication in Estuarine Ecology." *Environmental Health Perspectives*, 109(Supplement 5), 699-706.
Piehler, M. F., Dyble, J., Moisander, P. H., Pickney, J. L., and Paerl, H. W. (2002). "Effects of Modified Nutrient Concentrations and Ratios on the Structure and Function of the Native Phytoplankton Community in the Neuse River Estuary, North Carolina, USA." *Aquatic Ecology*, 36, 371-385.

Pinay, G., Haycock, N. E., Ruffinoni, C., and Holmes, R. M. (1994). "The Role of Denitrification in Nitrogen Removal in River Corridors." Global Wetlands: Old World and New, W. J. Mitsch, ed., Elsevier Science B.V.

Pinay, G., Roques, L., and Fabre, A. (1993). "Spatial and Temporal Patterns of Denitrification in Riparian Forest." *Journal of Applied Ecology*, 30, 581-591.

Platts, W. S., and Nelson, R. L. (1985). "Stream Habitat and Fisheries Response to Livestock Grazing and In-Stream Improvement Structures, Big Creek, Utah." *Journal of Soil and Water Conservation*, 41, 374-379.

Platts, W. S., and Wagstaff, F. J. (1984). "Fencing to Control Livestock Grazing on Riparian Habitats Along Streams: Is It a Viable Alternative?" *North American Journal of Fisheries Management*, 4, 266-272.

Qui, Z., and Prato, T. (1998). "Economic Evaluation of Riparian Buffers in an Agricultural Watershed." *Journal of the American Water Resources Association*, 34(4), 877-890.

Rickland, W. H., and Cushing, C. E. (1982). "Recovery of Streamside Woody Vegetation After Exclusion of Livestock Grazing." *Journal of Range Management*, 35(3), 360-361.

Ritter, W. F. (2001). "Nonpoint Source Pollution and Livestock Manure Management." Agricultural Nonpoint Source Pollution, W. F. Ritter and A. Shirmohammadi, eds., Lewis Publishers, New York, NY, 135-168.

Rosenberg, D. M., Danks, H. V., and Lehmkuhl, D. M. (1986). "Importance of Insects in Environmental Impact Assessment." *Environmental Management*, 10(6), 773-783.

Rosgen, D. L. (1996). *Applied River Morphology*, Wildland Hydrology, Pasoga Springs, Colorado.

Rostagno, C. M., and Sosebee, R. E. (2001). "Biosolids application in the Chihuahuan Desert: Effects on Runoff Water Quality." *Journal of Environmental Quality*, 30, 160-170.

Ryther, J. H., and Dunstan, W. M. (1971). "Nitrogen, Phosphorus, and Eutrophication in the Coastal Marine Environment." *Science*, 171(3975), 1008-1013.

Scrimgeour, G. J., and Kendall, S. (2002). "Consequences of Livestock Grazing on Water Quality and Benthic Algal Biomass in a Canadian Natural Grassland Plateau." *Environmental Management*, 29(6), 824-844.

Sharpley, A. N., Daniel, T., Sims, T., Leymunyon, J., Stevens, R., and Parry, R. (1999). *Agricultural Phosphorus and Eutrophication*, National Technological Information Service, Springfield, IL.

Sherer, B. M., Miner, J. R., Moore, J. A., and Buckhouse, J. C. (1992). "Indicator Bacterial Survival in Stream Sediments." *Journal of Environmental Quality*, 21, 591-595.

Sherer, B. M., Miner, J. R., Moore, J. A., and Buckhouse, J. C. (1998). "Resuspending Organisms from a Rangeland Stream Bottom." *Transactions of the ASAE*, 31(4), 1217-1222.

Shultz, T. T., and Leininger, W. C. (1990). "Differences in Riparian Vegetation Structure Between Grazed Areas and Enclosures." *Journal of Range Management*, 43(4), 295-299.

Shuyler, L. R. (1994). "Why Nutrient Management?" *Journal of Soil and Water Conservation*, 49(2, Supplement), 3-6.

Skaggs, R. W. (1978). "A Water Management Model for Shallow Water Table Soils." *134*, North Carolina Water Resources Research Institute, Raleigh, NC.
Skaggs, R. W. (1980). " "DRAINMOD REFERENCE REPORT"; "Methods for Design and Evaluation of Drainage-Water Management Systems for Soils with High Water Tables"." North Carolina State University, Raleigh, NC.
Skaggs, R. W. (1991). "Drainage." Modeling Plant and Soil Systems, ASA-CSSA-SSA, Madison, Wisconsin, 205-243.
Skaggs, R. W. (2001). "DRAINMOD." North Carolina State University, Raleigh, NC.
Skaggs, R. W., Brevé, M. A., and Gilliam, J. W. (1994). "Hydrologic and Water Quality Impacts of Agricultural Drainage." *Critical Reviews in Environmental Science and Technology*, 24(1), 1-32.
Skidmore, P. B., Shields, F. D., Doyle, M. W., and Miller, D. E. "A categorization of approaches to natural channel design." *Wetlands Engineering and River Restoration Conference*, Reno, Nevada.
Sovell, L. A., Vondrack, B., Frost, J. A., and Mumford, K. G. (2000). "Impacts of Rotational Grazing and Riparian Buffers on Physiochemical and Biological Characteristics of Southeastern Minnesota, USA, Streams." *Environmental Management*, 26(6), 629-641.
Spruill, T. B. (2000). "Statistical Evaluation of Effects of Riparian Buffers on Nitrate and Groundwater Quality." *Journal of Environmental Quality*, 29, 1523-1538.
Sweet, W. M., and Geratz, J. W. (2003). "Bankfull Regional Curves for the Coastal Plain Physiographic Province of North Carolina." EcoScience Corporation.
Tan, C. S., Drury, C. F., Gaynor, J. D., and Welacky, T. W. (1993). "Integrated Soil, Crop, and Water Management System to Abate Herbicide and Nitrate Contamination of the Great Lakes." *Water Science Technology*, 28(3-5), 497-507.
Tan, C. S., Drury, C. F., Gaynor, J. D., and Welacky, T. W. (1996). "Influence of controlled drainage-subirrigation on surface and tile drainage nitrate loss." *Journal of Environmental Quality*, 25(2), 317-324.
Thomas, D. L., Hunt, P. G., and Gilliam, J. W. (1992). "Water Table Management for Water Quality Improvement." *Journal of Soil and Water Conservation*, 47(1), 65-70.
United States Army Corps of Engineers. (2003). "HEC Hydrologic Modeling System." Visix Software Inc., Davis, California.
US Environmental Protection Agency. (2002). "Water Quality Conditions in the United States: A Profile from the 2000 National Water Quality Inventory." *EPA-841-F-02-003*.
US Environmental Protection Agency. (2003). "Chemical/Name Index to EPA Test Methods."
Van Dam, J. C., Huygen, J., Wesseling, J. G., Feddes, R. A., Kabat, P., van Walsum, P. E. N., Groenedijk, P., and van Diepen, C. A. (1997). "SWAP version 2.0, Theory. Simulation of Water Flow, Solute Transport, and Plant Growth in the Soil-Water-Atmosphere-Plant Environment." Department of Water Resources, Wageningen University, Wageringen, The Netherlands.
Vanclooster, M., Viaene, P., Christiaens, K., and Ducheyne, S. (1996). "WAVE, A Mathematical Model for Simulating Water and Agrochemicals in the Soil and Vadose

Environment, Reference and User's Manual, Release 2.1." Institute for Land and Water Management, Katholieke Universiteit Leuven, Leuven, Belgium.
Verchot, L. V., Franklin, E. C., and Gilliam, J. W. (1997). "Nitrogen Cycling in Piedmont Vegetative Filter Zones: II. Subsurface Nitrate Removal." *Journal of Environmental Quality*, 26, 337-347.
Welsch, D. J. (1991). "Riparian Forest Buffers: Function and Design for Protection and Enhancement of Water Resources." *NA-PR-07-91*, United States Department of Agricultural Forest Service, Northeast Area, Radnor, PA.
Youssef, M. A. (2004). H.Smeltz, ed., Raleigh, NC.

Appendix A. Stream Restoration Design Process for Grape Creek Tributary

Site Survey and Characterization

A survey using a total station instrument was performed to develop a topographic map of the site. Particular attention was paid to cross-sections of the creek. Transects of the stream were taken based upon stream features. The acquired points were then plotted in SurvCADD 6.0 and a topographic map generated. This map aided in the design of the site, Figure A.1.

Figure A.1 Topographic map developed from total station survey. Darker areas are waterbodies. Contours are at 0.3-meter intervals.

The tributary to Grape Creek was characterized in terms of bank full cross sectional area, floodplain area, entrenchment ratio, width/depth ratio, streambed material, and sinuosity, as seen in Table A.1. Additional parameters and definitions are available in Appendix B. This information was used to classify the creek according to the Rosgen

Classification of Natural Rivers (Rosgen 1996). Based upon these characteristics, the existing channel was classified as an E5c. According to Rosgen (1996), this stable stream type generally has a high meander width ratio, high sinuousity, and low width/depth ratios. A riffle/pool system and channel slope of less than 2% characterize these streams. The streambank materials are generally finer than the bed materials and are generally well secured by extensive riparian vegetation. This helps maintain the high sediment transport and hydraulically stable channel (Rosgen 1996).

Table A.1 Existing and design characteristics of Grape Creek restoration site (Bass, 2004)

Parameter	Existing		Design	
	Min	Max	Min	Max
Drainage Area (mi^2)	1	1.04	1	1.04
Bankfull Cross-Sectional Area (ft^2)	66.0	127.0	-	18.0
Bankfull Width (ft)	28.0	53.0	14	14.0
Bankfull Mean Depth (ft)	2.5	3.4	1.5	2.0
Width to Depth Ratio (ft/ft)	11.2	15.6	7.0	9.3
Width of Floodprone Area (ft)	-	75.0	200	350
Entrenchment Ratio (ft/ft)		<1.4	14.0	25.0
Meander Length (ft)	-	*	160	180
Sinuosity	-	*	-	1.30
Channel Slope (ft/ft)	-	0.0016	-	0.0010
Valley Slope (ft/ft)	-	0.0021	-	0.0021

* Existing Stream has been straightened and channelized. Continued cattle access made identification of geomorphic features difficult and prevented any pattern determinations

Design Process

As Grape Creek is a sand-bed channel, a reference reach/natural channel design approach, alone, to the site is inappropriate (Bass 2004). The research supporting the NCD approach was originally done in Colorado and piedmont areas. The sediment transport dynamics and interaction is very different in these types of streams as compared to those strongly influenced by groundwater (Bass 2004). Vegetation also impacts a stream's

development, especially on small streams such as Grape Creek. On a reference reach, the vegetation contributes to the stability of the site. This stream restoration was designed for stability while vegetation is established.

For this stream, the analog approach was risky, so additional analysis was performed to support the design (Bass 2004). Design was begun using Coastal Plains regional curves to develop bankfull characteristics. In this area of the state, drainage area is difficult to determine due to flat topology and interconnectivity of ditches. The actual drainage area of a watershed may fluctuate with the size of the storm. Consequently, a range of drainage areas (2.3 square kilometers to 4 square kilometers) was used in two different regional curve equations, Table A.2.

Table A.2 Published Regional Curve Equations for the coastal plains of North Carolina

Parameter	(Doll et al 2003)			(Sweet and Geratz 2003)		
	Equation [1]	R^2	Value [2]	Equation [1]	R^2	Value [2]
Bankfull Area (ft^2)	$14.52A_w^{0.66}$	0.88	13.5, 19.0	$9.43A_w^{0.74}$	0.92	8.7, 12.7
Bankfull Discharge (cfs)	$16.56A_w^{0.72}$	0.90	15.4, 22.2	$8.79A_w^{0.76}$	0.96	8.1, 12.0
Bankfull Width (ft)	$10.97A_w^{0.36}$	0.87	10.6, 12.7	$9.64A_w^{0.38}$	0.95	9.3, 11.2
Bankfull Depth (ft)	$1.29A_w^{0.30}$	0.74	1.2, 1.5	$0.98A_w^{0.36}$	0.92	0.9, 1.1

[1] A_w – watershed area, mi^2
[2] 2.3 square kilometers, 4 square kilometers areas, respectively

To improve confidence in the values generated by the regional curve equations, the watershed runoff model HEC-Hydrologic Modeling System (HMS) (United States Army Corps of Engineers 2003) was used. This enabled the designer to match design discharges to those produced from the regional curves and to test the design under different conditions. The results from the HEC-HMS are compared to the results from the regional curves, Table A.3.

In the lower coastal plains, the fields are underlain by a highly permeable sand layer within 0.9 – 1.8 meters of the soil surface (Osmond et al. 2002). In this case, ditch drainage is predominantly subsurface flow, possibly making a groundwater model more applicable to this site. A groundwater model was not used in the design process due to time constraints.

Table A.3 Peak discharges for tributary to Grape Creek using HEC-HMS, two published regional curves for the Coastal Plains, and DRAINMOD, using a 4 square kilometer watershed

Design Storm	HEC-HMS [1]	Doll et al 2003	Sweet and Geratz 2003	DRAINMOD [2]
1-yr, 24-hr	1.6 m^3/s	0.6 m^3/s	0.3 m^3/s	1.1 m^3/s
2-yr, 24-hr	2.5 m^3/s	- -	- -	1.1 m^3/s
5-yr, 24-hr	5.3 m^3/s	- -	- -	3.5 m^3/s
10-yr, 24-hr	7.9 m^3/s	- -	- -	4.2 m^3/s

[1] Bass, personal communication, 17 August 2004
[2] Average daily discharge

The flows determined from the Coastal Plains regional curves are substantially lower than from HEC-HMS. The regional curves yield in-channel flows. HEC-HMS outputs the cumulative in- and out-of-bank flows due to surface runoff for the design storm. The DRAINMOD analysis includes surface and subsurface flows for the return period of interest. This value is an average flow over the entire day, not a peak discharge. The DRAINMOD discharge ranges from 32% to 55% of the HEC-HMS peak discharge.

The regional curves may underestimate what is actually occurring at this site. The curves were calculated based upon stable natural channels. The site designed for restoration has an unstable channel and contributing drainage ditches. It is unknown when the pasture was ditched or the watershed the ditching was designed for. Using standard ditch design equations for different watersheds (Table A.4), the peak flows determined are similar to those calculated by HEC-HMS and Doll et al (2003).

Table A.4 Ditch design flows for a 4 square kilometer watershed in pasture, forest, and agriculture

Watershed	Peak Flow [1]
Pasture	0.9 m^3/s
Forest	1.2 m^3/s
Agriculture	1.8 m^3/s

[1] Peak Flow (ft^3/s) = $Cm^{5/6}$ [C = 22.5 – pasture, 30 – forest, 45 – agriculture; m = watershed area ($miles^2$)]

The HEC-HMS findings support the testing of the stream stability during 1-year, 2-year, and 5-year storm events. Rainfall data used in the modeling is located in Appendix C. This data was used in the HEC-HMS analysis design storm calculations (Table A.3).

A stable channel design approach was used to test the channel characteristics for sediment transport. Velocity limited and shear stress limited dimensions were determined and compared to those from the hydraulic modeling. The Copeland Method was used to perform a sediment balance and determine the channel slope.

The designed pattern of the stream was based upon two reference reaches. These values are located in Appendix B. William's Equations were also used to determine an appropriate pattern. A range of values was used in the design to create the impression of a non-manmade stream.

The design called for 66 root wads to be placed on the outer side of almost every channel bend. This was to provide bank stability and habitat. These root wads were to be placed even with the bankfull channel height and partially buried in the streambed. This was to reduce flow obstruction.

Due to the lack of rocks in the coastal plains, hardwood logs were used to create cross vanes. The vanes were designed to rise approximately 20 centimeters above the streambed. The purpose is two-fold: create ripples and create small pools. An innovative feature of the

cross vanes is their placement before bends. Pools would be created in the curves by using the structures. Since the cross vanes are constantly underwater, they should not degrade (Bass 2004).

Along with the root wads and cross vanes, other safety and habitat features include erosion control fabric and a dense planting scheme on the stream banks. This includes live stakes, shrubs, and a grass wetland seed mix.

The final design resulted in an E5-E5c channel being created for this site. This sand-dominated stream type naturally occurs in coastal plains. An E5 is slightly entrenched, meanders, and has a well-developed flood plain (Rosgen 1996). The streambanks are normally composed of sandy materials (Rosgen 1996).

The out-of-bank recurrence interval was designed to be three to six times per year (Bass 2004). The culvert below the stream was designed to barely handle the bankfull flow, promoting the flooding. The streambanks were designed with a small berm on the upper edge of the cross section, as seen in Figure A.2, to encourage overflowing waters to remain in the floodplain/wetland. This will increase hydraulic retention time, improve hydrology, and water quality on the site (Bass 2004).

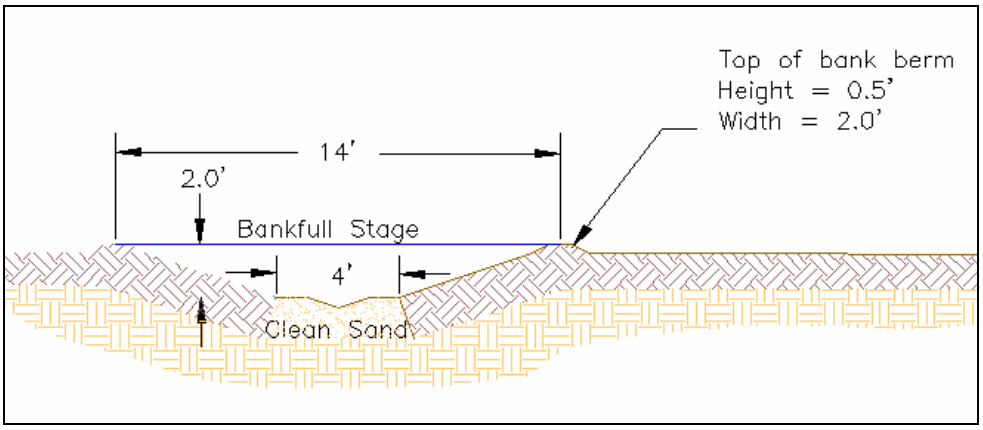


Figure A.2 Typical cross section of design stream in tributary to Grape Creek pasture (Bass, 2004)

The riparian buffer/wetland adjacent to the stream channel was designed to be planted with hardwood wetland trees.

Figure A.3 shows the plan view of the final design. Existing water is shown in blue. The design stream is indicated by red. The black road towards the top of the sketch is County Road 1237. The tan areas indicate the contours and borders of the floodplain/riparian zones of the new design.

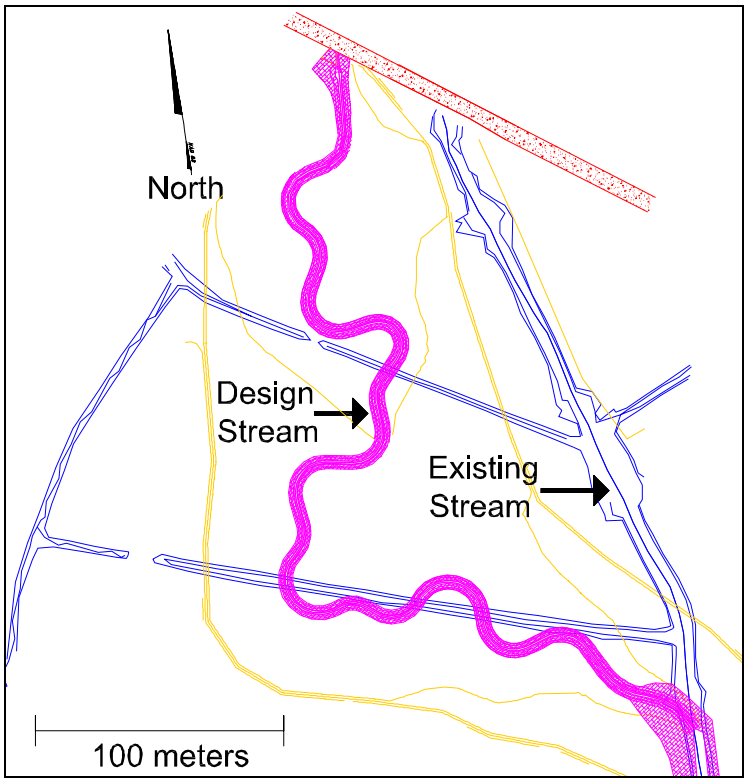


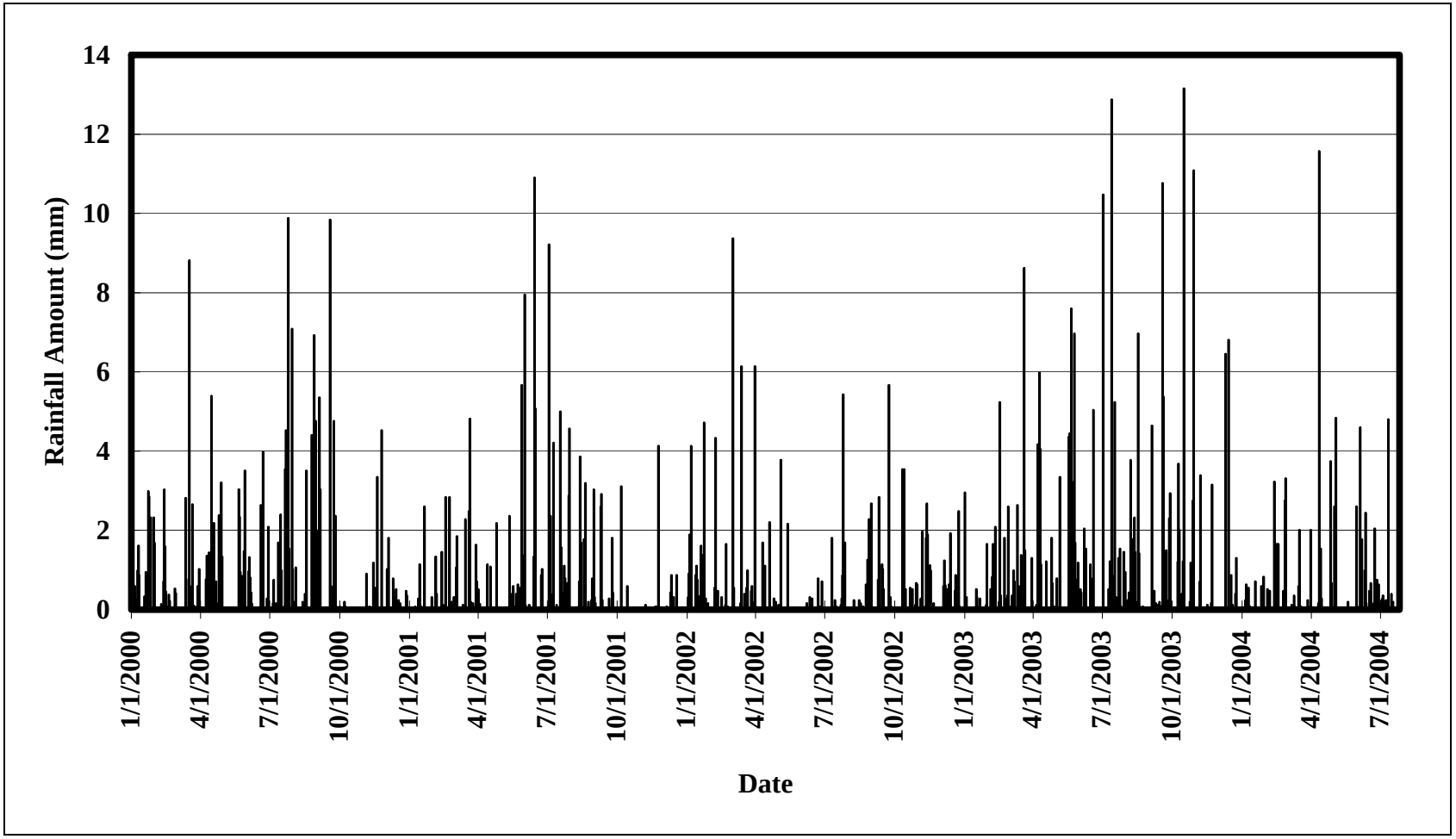
Figure A.3 Existing stream and drainage canals and design stream of tributary to Grape Creek pasture (Bass, 2004)

Appendix B. Rosgen Characteristics Used in Stream Restoration Design

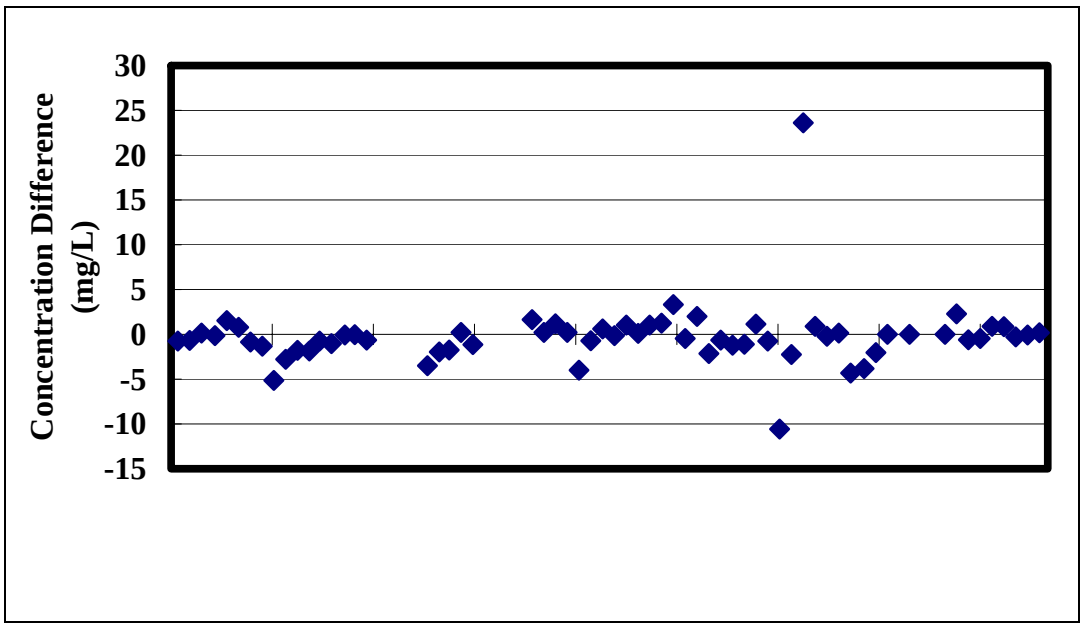
Parameter	Existing Stream*		Reference Reach Dewaynes Creek		Reference Reach UT (Carteret Co)		Design Stream	
	MIN	MAX	MIN	MAX	MIN	MAX	MIN	MAX
Drainage Area, DA (mi^2)	1	1.04	-	0.18	0.16	0.18	1	1.04
Stream Type (Rosgen)	-	G5c	-	E	-	C5-C5c	-	E5c
Bankfull XSEC Area, A_{bkf} (ft^2)	66.0	127.0	-	8.1	12.5	19.4	-	18.0
Bankfull Width, W_{bkf} (ft)	28.0	53.0	-	9.0	11.6	20.7	14	14.0
Bankfull Mean Depth, D_{bkf} (ft)	2.5	3.4	-	0.9	0.9	1.5	1.5	2.0
Width to Depth Ratio, W/D (ft/ft)	11.2	15.6	-	10.0	13.6	14.3	7.0	9.3
Width Floodprone Area, W_{fpa} (ft)	-	75.0	-	103	100.0	200.0	200	350
Entrenchment Ratio, Wfpa/Wbkf (ft/ft)		<1.4	-	11.4	8.6	9.7	14.0	25.0
Max Depth @ bkf, D_{max} (ft)	3.0	4.8	-	-			2.0	2.3
Max Depth Ratio, D_{max}/D_{bkf}	1.2	1.4	-	-			1.0	1.2
Meander Length, L_m (ft)	-	*	-	-	80	330	160	180
Meander Length Ratio, L_m/W_{bkf}	-	*	-	-	6.9	15.9	11.4	12.8
Radius of Curvature, R_c (ft)	-	*	-	-	19	70	35	50
Rc Ratio, R_c/W_{bkf}	-	*	-	-	1.6	3.4	2.5	3.6
Belt Width, Wblt (ft)	-	*	-	-	64	118	100	160
Meander Width Ratio, W_{blt}/W_{bkf} (ft)	-	*	-	-	5.5	5.7	7.1	11.4
Sinuosity, K	-	*	-	1.00	-	1.1	-	1.30
Valley Slope, S_{va}l (ft/ft)	-	0.0021	-	0.0008	-	0.0010	-	0.0021
Channel Slope, S_{chan} (ft/ft)	-	0.0016	-	0.0008	-	0.0013	-	0.0010

*Existing Stream has been straightened and channelized. Continued cattle access made identification of geomorphic features difficult and prevented any pattern determinations

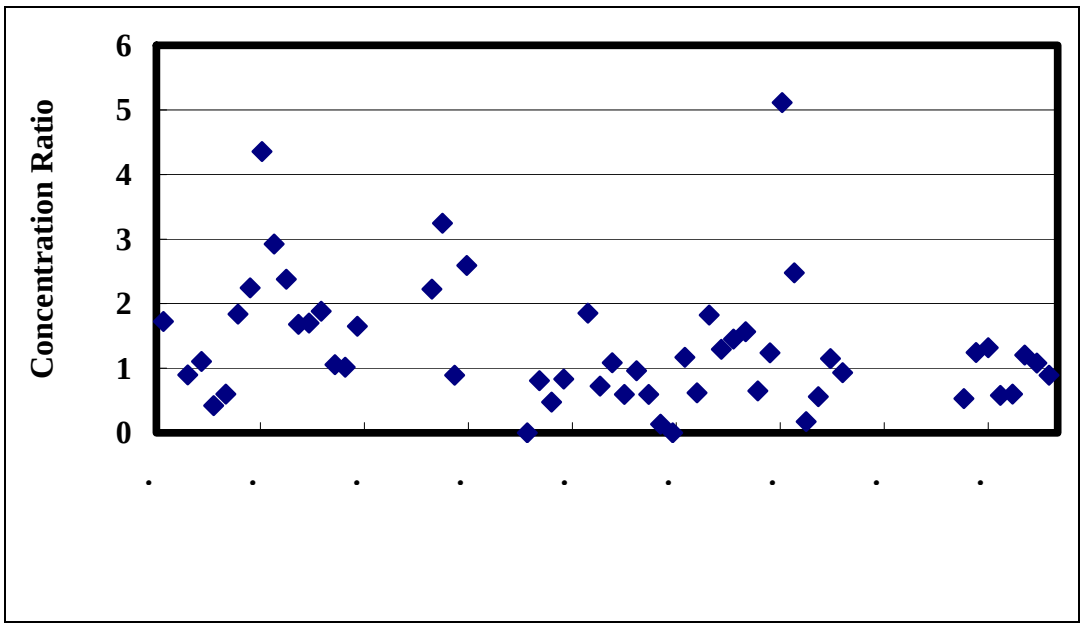
Appendix C. Rainfall Data Used in Stream Restoration Design



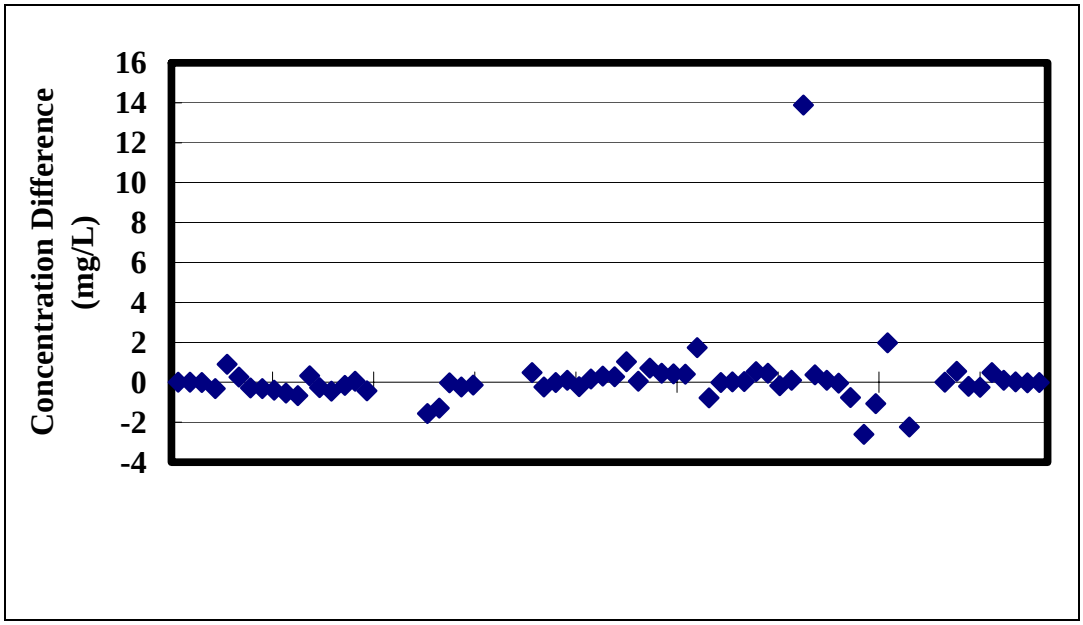
Appendix D. Nutrient Concentration Differences and Ratios from Tributary to Grape Creek



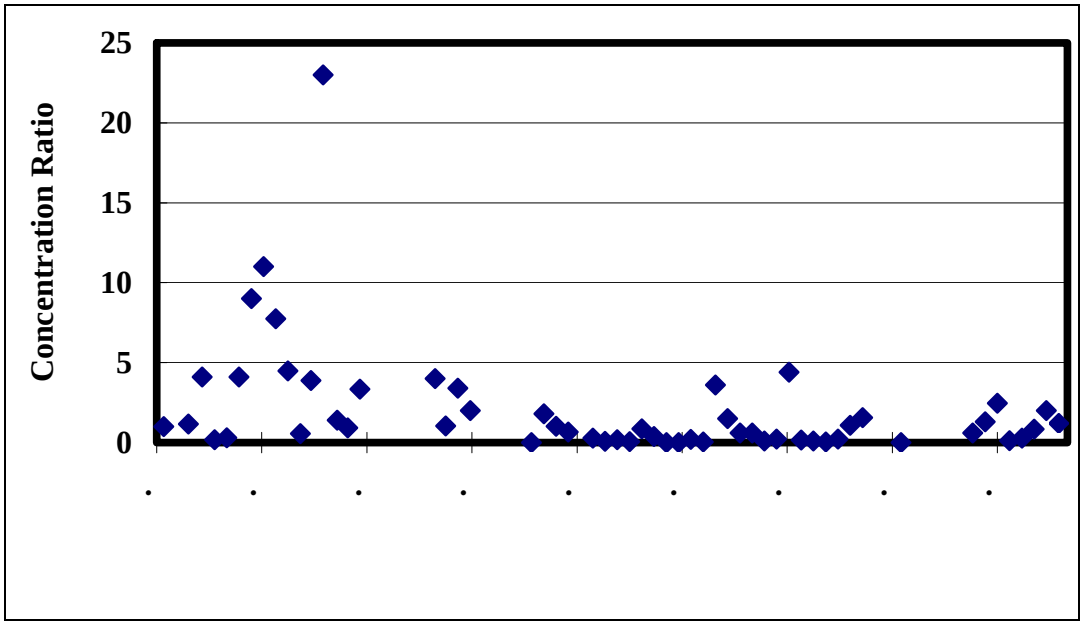
Total Kjeldahl nitrogen concentration difference (downstream-upstream) tributary to Grape Creek pasture



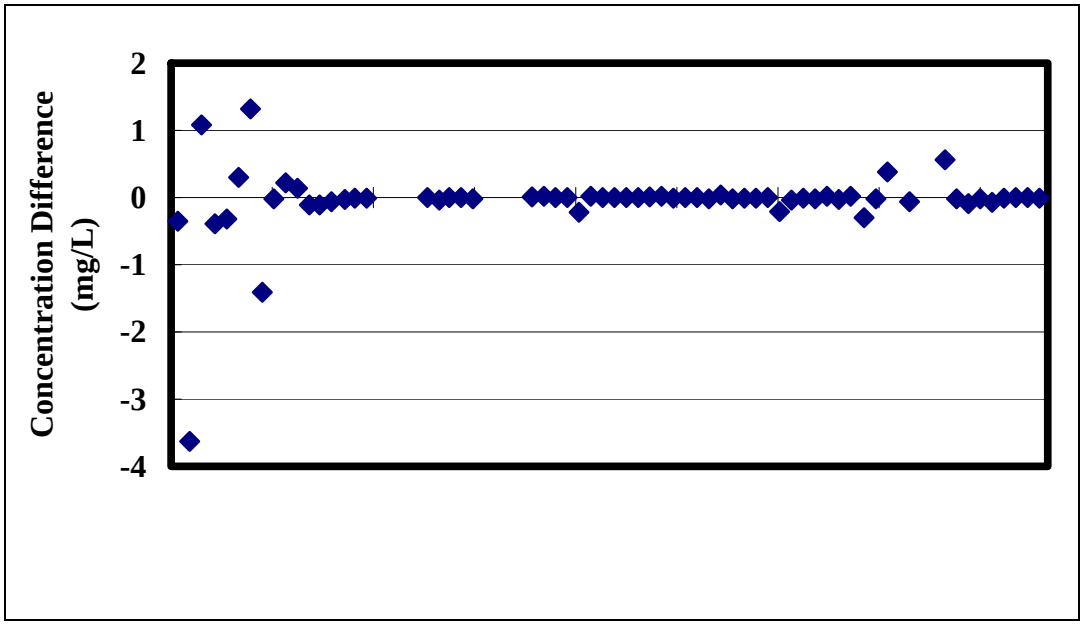
Total Kjeldahl nitrogen upstream/downstream concentration ratios for tributary to Grape Creek pasture



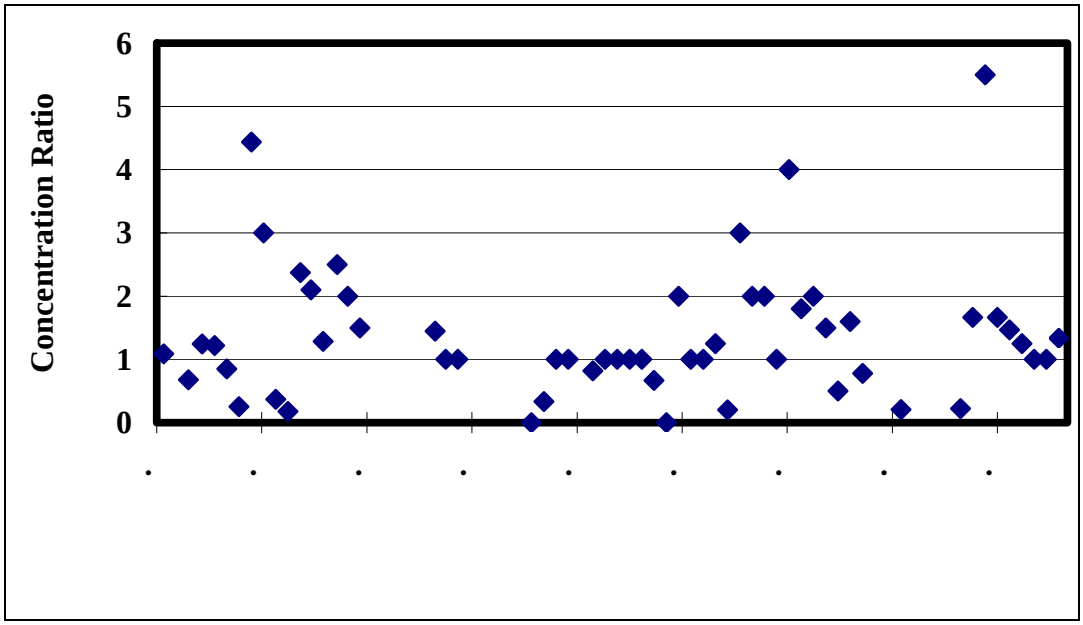
Ammonium concentration difference (downstream-upstream) tributary to Grape Creek pasture



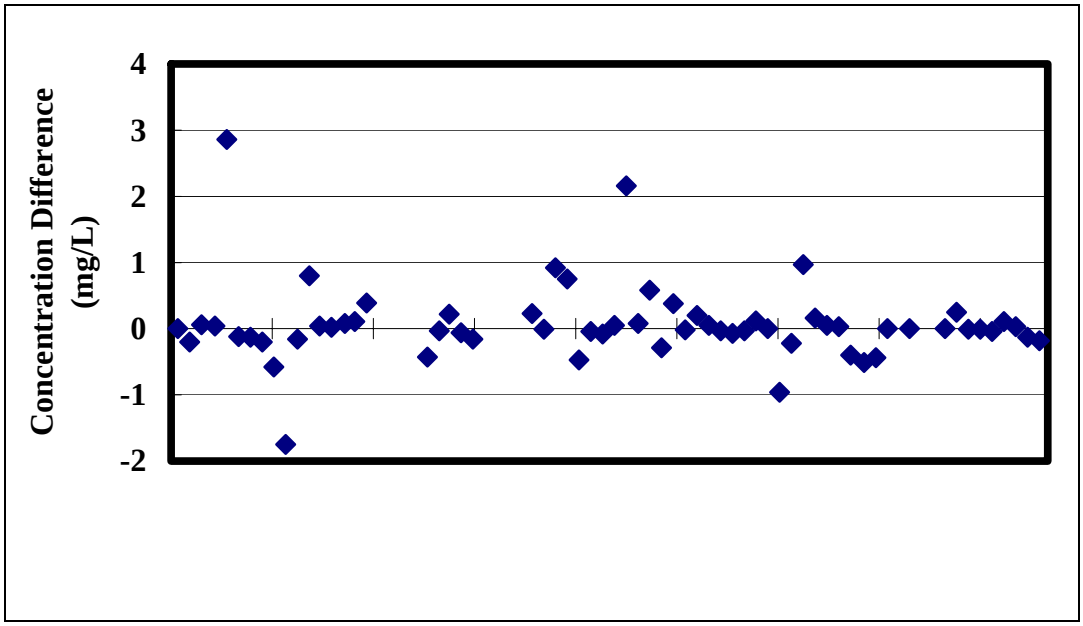
Ammonium upstream/downstream concentration ratios for tributary to Grape Creek pasture



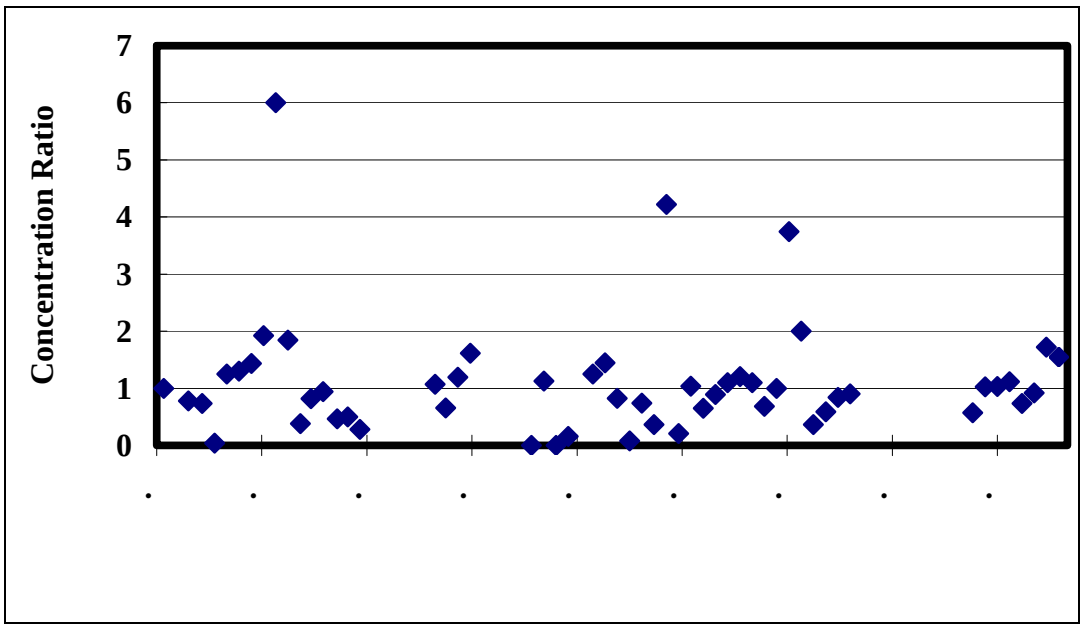
Nitrate concentration difference (downstream-upstream) tributary to Grape Creek pasture



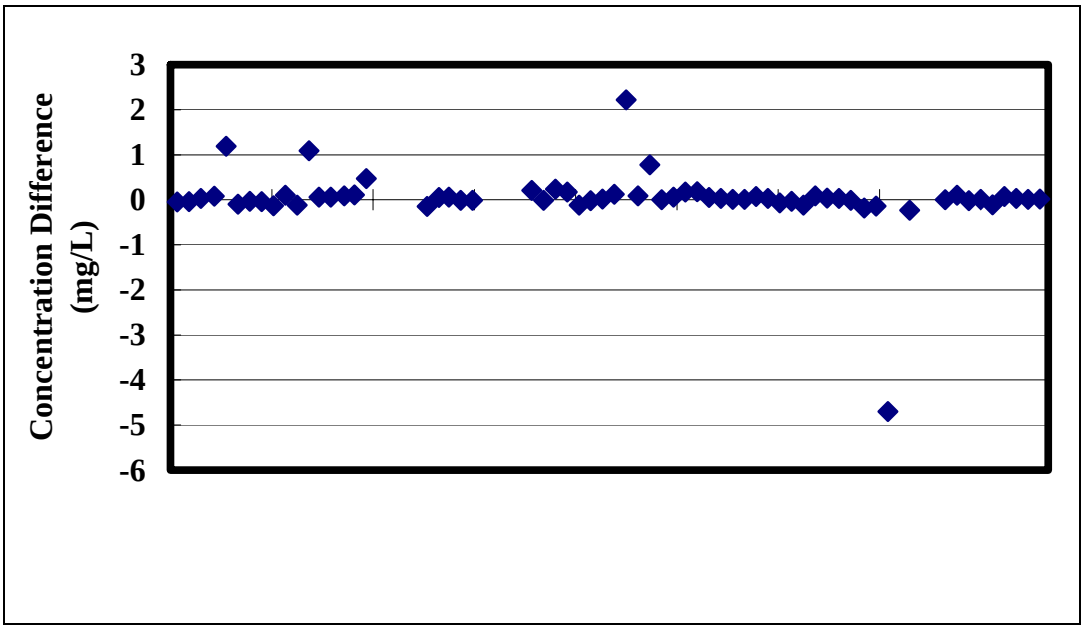
Nitrate upstream/downstream concentration ratios for tributary to Grape Creek pasture



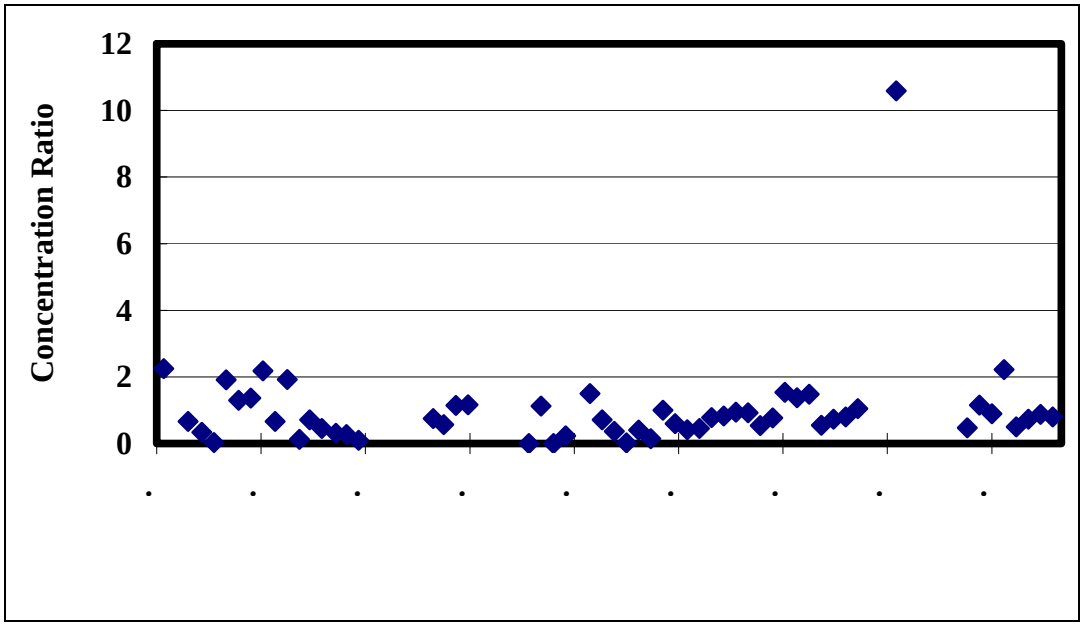
Total phosphorus concentration difference (downstream-upstream) tributary to Grape Creek pasture



Total phosphorus upstream/downstream concentration ratios for tributary to Grape Creek pasture

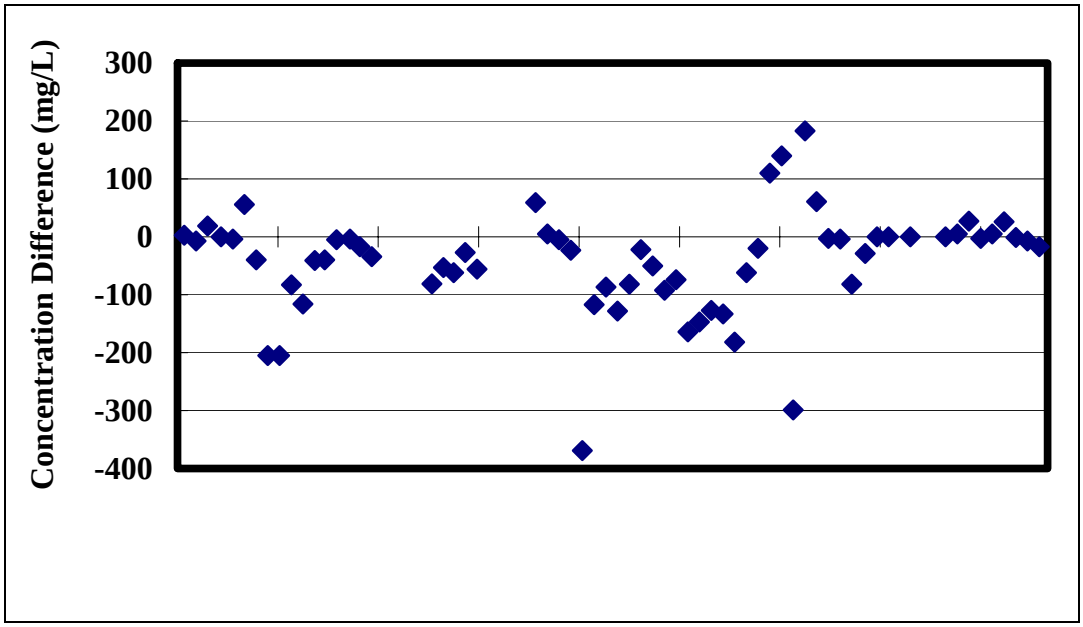


Orthophosphate concentration difference (downstream-upstream) tributary to Grape Creek pasture

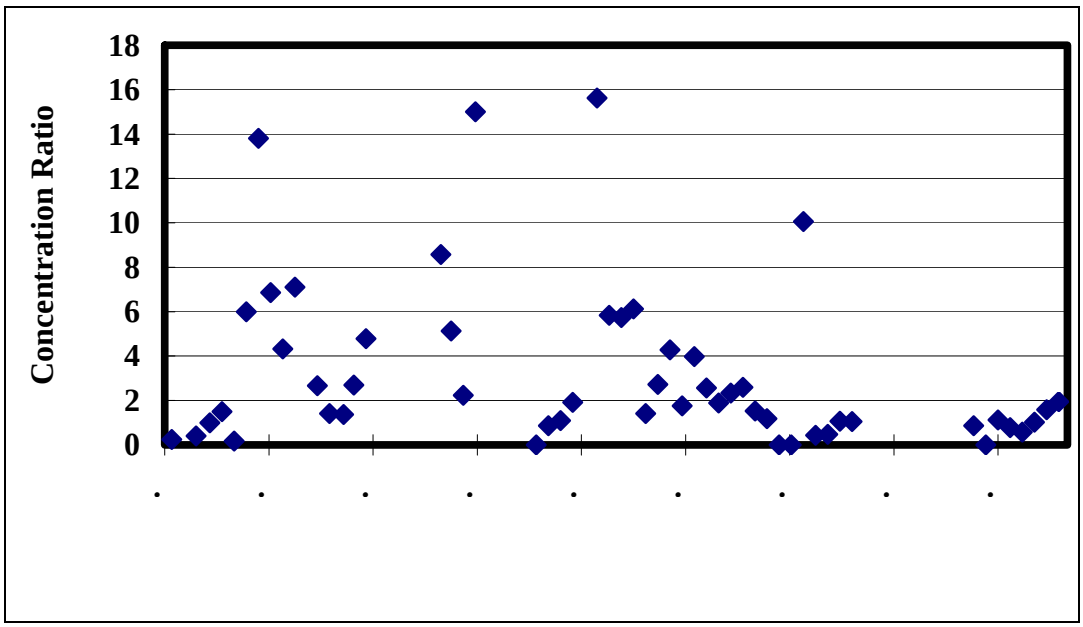


Orthophosphate upstream/downstream concentration ratios for tributary to Grape Creek pasture

Appendix E. Total Suspended Solids Concentration Differences and Ratios from Tributary to Grape Creek



Total suspended solids concentration difference (downstream-upstream) tributary to Grape Creek pasture



Total suspended solids upstream/downstream concentration ratios for tributary to Grape Creek pasture

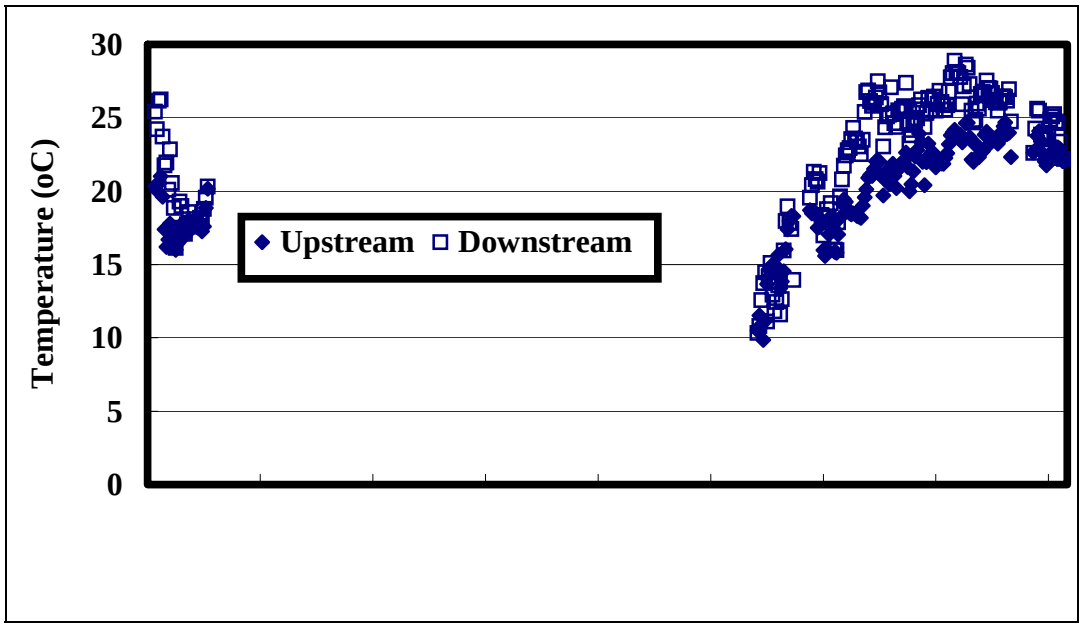
Appendix F. Nutrient Concentrations of Grab and Composite Samples, Sorted According to Flow Rate

Flow (cms)	DATE	TKN	NH_4N	NO_3N	TP	Ortho-P	TSS	Sample
0.562 [1]	9/15/2004	0.68	0	0.08	0.36	0.11	6	GRAB
0.352	5/29/03	1.94	0.37	2	0.48	0.11	68	Composite
0.220	9/15/04	1.64	0.05	0.03	0.33	0.1	18	Composite
0.163	9/24/03	1.61	0.43	0.09	0.42	0.2	7	Composite
0.153	8/18/2003	0.53	0	0.05	0.42	0.04	5	GRAB
0.152	7/16/03	1.06	0.09	0.1	0.22	0.21	24	Composite
0.145	8/18/04	2.13	0.56	0.15	0.35	0.09	22	Composite
0.106	4/14/04	2.57	0.05	0.07	0.35	0.13	140	Composite
0.103	5/5/04	2.01	0.4	0.04	0.39	0.2	115	Composite
0.090	9/8/04	0.85	0.03	0.04	0.18	0.08	12	Composite
0.081	9/1/04	1.36	0.12	0.04	0.36	0.11	37	Composite
0.072	10/15/03	0.73	0.13	0	0.26	0.06	4	Composite
0.072	2/19/04	2.69	0.51	0.11	0.58	0.29	55	Composite
0.072	3/3/04	2.61	0.3	0.08	0.46	0.23	142	Composite
0.071	7/23/03	1.19	0.02	0.21	0.35	0.11	12	Composite
0.069	6/5/03	1.04	0.09	1.77	0.43	0.1	8	Composite
0.065	12/25/03	0.82	0.22	0.11	0.16	0.04	8	Composite
0.064	7/16/2003	0.4	0	0.39	0.13	0.05	19	GRAB
0.055	4/16/2003	1.2	0	4.64	0.08	0.03	8	GRAB
0.045	8/13/03	0.97	0.18	0.02	0.54	0.52	9	Composite
0.042	4/21/04	1.53	0.13	0.05	0.22	0.08	33	Composite
0.035	2/26/04	5.22	1.8	0.06	0.57	0.33	94	Composite
0.034	5/20/2003	0.95	0.04	2.36	0.4	0.05	33	GRAB
0.033	10/1/03	0.78	0.4	0	0.64	0.14	15	Composite
0.032	7/31/03	1.28	0.38	0.02	0.15	0.13	11	Composite
0.028	8/25/04	2.17	0.14	0.04	0.41	0.14	61	Composite
0.026	1/1/04	2.14	0.34	0.02	0.18	0.07	18	Composite
0.024	2/5/04	1.43	0.45	0.02	0.09	0.09	28	Composite
0.023	4/23/03	1.05	0.02	4.06	0.21	0.04	4	Composite
0.023	6/12/03	1.07	0.04	0.41	0.46	0.11	16	Composite
0.022	5/12/04	1.52	0.14	0.04	0.31	0.15	49	Composite
0.022	2/23/2004	0.71	0	0	0.03	0.03	4	GRAB
0.022	8/18/2004	0.77	0	0.09	0.27	0.07	3	GRAB
0.021	8/6/03	1.78	0.6	0.01	0.22	0.15	10	Composite
0.021	6/26/03	1.45	0.08	0.35	0.35	0.3	25	Composite

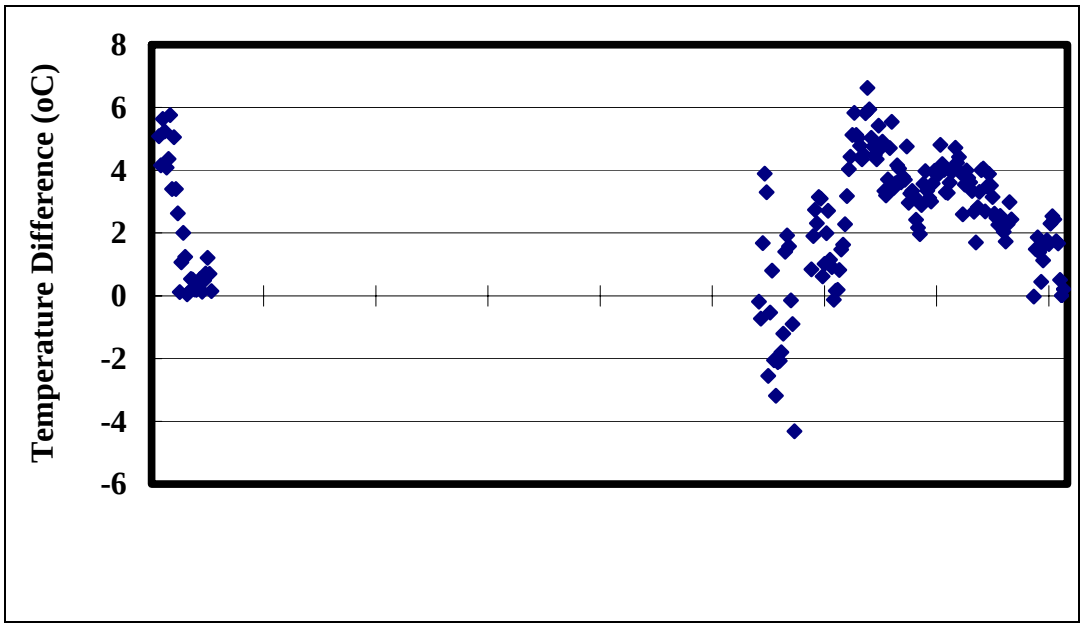
Flow (cms)	DATE	TKN	NH_4N	NO_3N	TP	Ortho-P	TSS	Sample
0.019	3/17/2004	0.59	0	1.02	0.03	0.03	3	GRAB
0.018	5/22/03	2.65	1.1	1.46	2.97	1.23	8	Composite
0.016	11/26/03	1.13	0.29	0.03	0.08	0.08	38	Composite
0.016	3/10/04	2.21	0.02	0.05	0.3	0.17	100	Composite
0.015	7/3/03	1.29	0.19	0.17	0.19	0.13	19	Composite
0.014	1/8/04	1.63	0.34	0	0.28	0.19	27	Composite
0.013	7/10/03	2.73	0.75	0.08	1.29	1.24	0	Composite
0.013	1/29/04	2.56	1.14	0.03	0.91	0.91	29	Composite
0.012	1/15/04	2.55	1.09	0	2.35	2.27	16	Composite
0.012	3/17/04	2.66	0.05	0.01	0.34	0.17	114	Composite
0.012	11/24/2003	0.32	0	0	0.04	0.04	1	GRAB
0.012	12/9/03	1.33	0.29	0.01	0.89	0.22	25	Composite
0.011	4/21/2004	0.86	0	0.01	0.11	0.04	1	GRAB
0.010	4/28/04	28.53	15.35	0.01	1.53	0.25	319	Composite
0.009	2/12/04	3.32	0.43	0.01	0.48	0.15	98	Composite
0.009	5/7/03	1.35	0.06	3.36	0.27	0.09	32	Composite
0.008	3/24/04	1.93	0.1	0.01	0.31	0.13	116	Composite
0.008	1/22/04	3.02	0.46		0.31	0.15	53	Composite
0.007	12/9/2003	0.29	0	0	0.06	0.06	0	GRAB
0.006	8/11/04	1.44	0.17	0.03	0.32	0.09	24	Composite
0.005	10/8/03	2.04	0.1	0	0.31	0.07	22	Composite
0.005	5/19/04	2.36	0.5	0.05	0.31	0.15	74	Composite
0.005	11/19/03	1.64	0.49	0.01	0.23	0.21	59	Composite
0.005	6/19/03	1.53	0.04	0.01	0.63	0.11	35	Composite
0.004	8/4/04	2.52	0.67	0.02	0.38	0.13	27	Composite
0.004	5/15/03	1.25	0.1	1.6	0.15	0.12	21	Composite
0.004	6/19/2003	1.32	0	0	0.61	0.12	25	GRAB
0.003	4/7/04	3.13	0.59	0.02	0.36	0.13	110	Composite
0.003	3/31/04	3.22	0.6	0.01	0.38	0.15	106	Composite
0.003	12/3/03	2.24	0.4	0.01	0.92	0.24	51	Composite
0.002	10/23/2003	0.79	0	0	0.18	0.04	0	GRAB
0.001	5/17/2004	1.54	0.01	0.1	0.27	0.09	26	GRAB
0.001	5/26/04		1.36	0.09		0.22		Composite
0.001	7/28/04	4.84	1.35	0.03	0.58	0.19	39	Composite
0.000	7/21/04			0.72				Composite
0.000	6/17/04		1.98	0.48		0.49		Composite

[1] 15.1 mm of rainfall observed the morning of sampling

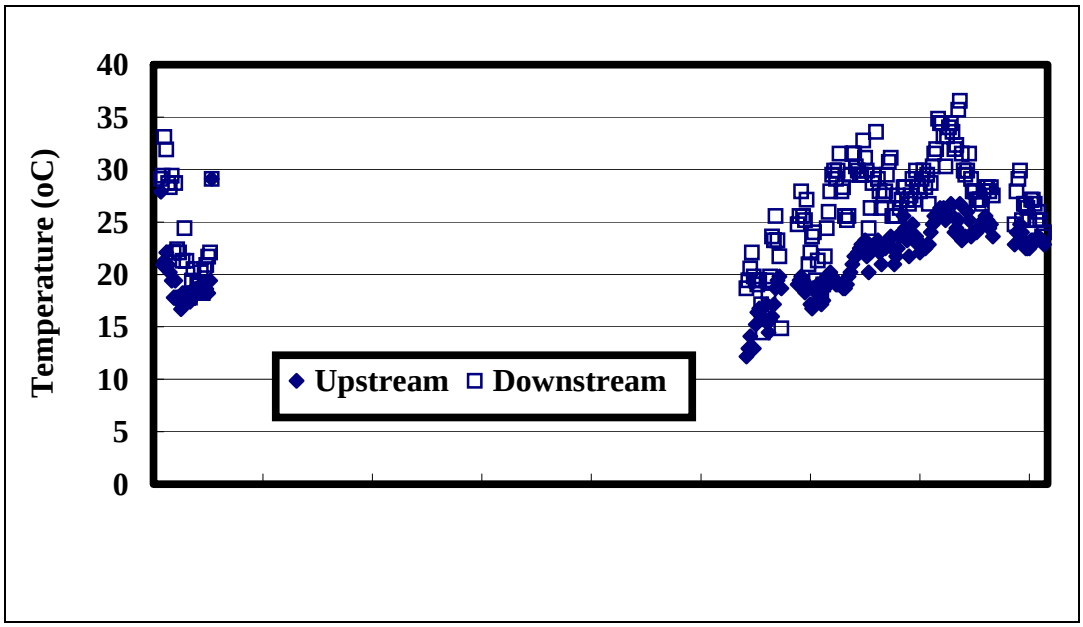
Appendix G. Additional Temperature Data from Tributary to Grape Creek



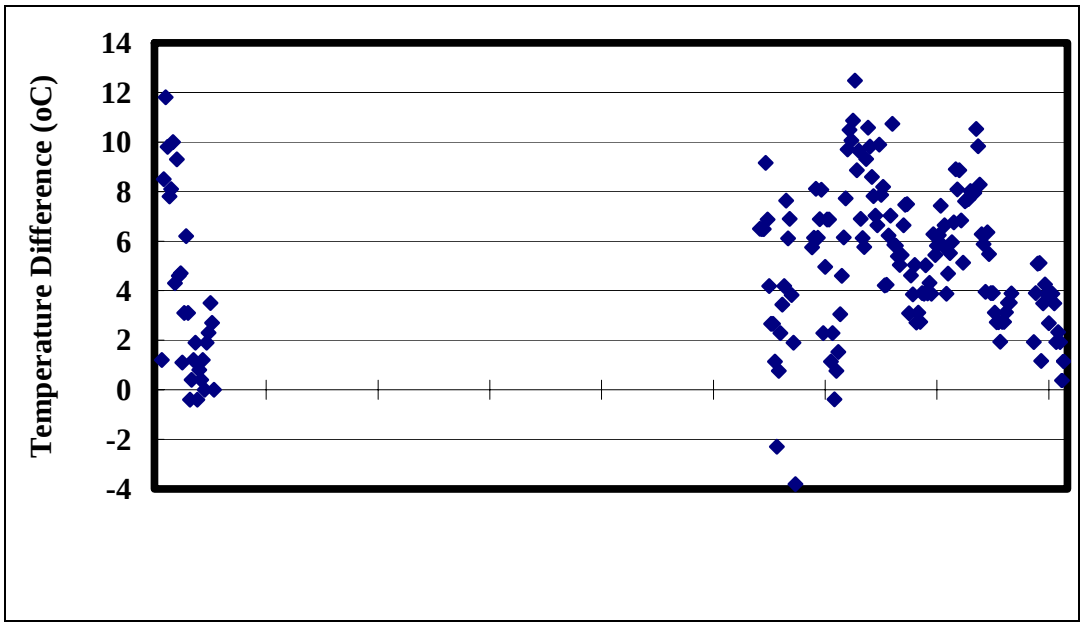
Average daily temperatures recorded above and below tributary to Core Creek cattle pasture



Average daily temperature difference (downstream-upstream) tributary to Grape Creek pasture



Maximum daily temperatures recorded above and below tributary to Core Creek cattle pasture



Temperature difference of maximum daily temperatures (downstream-upstream) tributary to Grape Creek pasture

Appendix H. Macroinvertebrates Identified From Benthic Assessment on 8 August 2003

Macrophytes, ponded areas with no flow						
Order		Family	Genus	Species	Abundance	Tolerance Value
1	Odonata	Coenagrionidae	*Ishnura*	*verticalis*	Rare	9.52
2	Odonata	Coenagrionidae	*Enallagma*	*signatum*	Rare	8.9
3	Odonata	Coenagrionidae	*Ishnura*	*ramburi*	Common	9.52
4	Odonata	Coenagrionidae	*Enallagma*	*sp1*	Rare	8.91
5	Coleoptera	Dytiscidae	*Hygrotus*	*farctus*	Rare	n/a
6	Ephemeroptera	Baetidae	*Callibaetis*	*sp*	Common	9.84
7	Hemiptera	Naucoridae	*Pelocoris*	*f. femoratus*	Rare	7.01
8	Coleoptera	Noteridae	*Hydrocanthus*	*iricolor*	Rare	7.11
9	Trichoptera	Leptoceridae	*Oecetis*	*inconspicua*	Rare	1.85
10	Coleoptera	Chrysomelidae			Rare	n/a
11	Ephemeroptera	Caenidae	*Caenis*	*sp*	Common	7.41
12	Hemiptera	Belostomatidae	*Belostoma*	*sp*	Rare	9.8
13	Ephemeroptera	Baetidae	*Baetis*	*sp*	Rare	n/a
14	Coleoptera	Dytiscidae	*Celina*	*sp*	Rare	8.04
15	Coleoptera	Hydrophilidae	*Tropisternus*	*sp*	Common	9.68
16	Coleoptera	Helodidae			Rare	n/a
17	Diptera				Rare	n/a
18	Odonata	Coenagrionidae	*Enallagma*	*sp3*	Common	8.91
19	Odonata	Coenagrionidae	*Enallagma*	*sp4*	Common	8.91
20	Odonata	Coenagrionidae	*Enallagma*	*sp5*	Rare	8.91
21	Odonata	Coenagrionidae	*Enallagma*	*sp?*	Rare	8.91
22	Isopoda	Asellidae	*Caecidotea*	*sp*	Common	9.11
23	Coleoptera	Dytiscidae	*Celina*	*sp*	Rare	8.04
24	Diptera	Culicidae			Rare	n/a
25	Odonata	Gomphidae			Rare	n/a
26	Diptera	Chironomidae	*Krenopelopia*	*hudsoni*	Rare	n/a
27	Diptera	Chironomidae	*Polypedilum*	*tritum*	Common	n/a

Detritus, Low Flow						
	Order	**Family**	**Genus**	**Species**	**Abundance**	**Tolerance Value**
1	Ephemeroptera	Baetidae	*Callibaetis*	*sp*	Rare	9.84
2	Trichoptera	Leptoceridae	*Oecetis*	*inconspicua*	Rare	1.85
3	Odonata	Coenagrionidae	*Enallagma*	*sp*	Common	8.91
4	Odonata	Coenagrionidae	*Enallagma*	*exsulans*	Rare	8.91
5	Coleoptera	Dytiscidae	*Copelatus*	*sp*	Rare	n/a
6	Oligocheata				Common	n/a
7	Diptera	Chironomidae	*Clinotanypus*	*pinguis*	Rare	8.74
8	Diptera	Chironomidae	*Polypedilum*	*tritum*	Rare	n/a
9	Diptera	Chironomidae	*Rheotanytarsus*	*exiguus* group	Rare	n/a
10	Diptera	Chironomidae	*Orthocladius*	*(S.)annectens*	Rare	n/a
11	Diptera	Chironomidae	*Cladopelma*	*sp*	Common	3.49
12	Diptera	Chironomidae	*Larsia*	*sp*	Common	9.3

Sand						
	Order	**Family**	**Genus**	**Species**	**Abundance**	**Tolerance Value**
1	Oligocheata				Rare	n/a
2	Diptera	Chironomidae	*Clinotanypus*	*pinguis*	Rare	8.74
3	Diptera	Chironomidae	*Chironomus*	*decorus* group	Rare	9.63

APPENDICES

Appendix I. Macroinvertebrates Identified From Benthic Assessment on 7 September 2004

Macrophytes, ponded areas with no flow						
Order		Family	Genus	Species	Abundance	Tolerance Value
1	Odonata	Coenagrionidae	*Ishnura*		Abundant	9.52
2	Odonata	Libellulidae	*Perithemis*	*sp*	Rare	9.9
3	Odonata	Libellulidae	*Pachydiplax*	*longipennis*	Rare	9.9
4	Coleoptera	Hydrophilidae	*Berosus*	*sp*	Rare	8.4
5	Coleoptera	Dytiscidae	*Hydroporus*	*sp*	Rare	8.6
6	Ephemeroptera	Baetidae	*Callibaetis*	*sp*	Rare	9.8
7	Ephemeroptera	Caenidae	*Caenis*	*sp*	Abundant	7.4
8	Hemiptera	Belostomatidae	*Belostoma*	*sp*	Rare	9.8
9	Trichoptera	Leptoceridae	*Oecetis*	*inconspicua*	Rare	1.9
10	Trichoptera	Hydroptilidae	*Oxyethira*	*sp*	Rare	2.2
11	Diptera	Chironomidae	*Polypedilum*	*illinoense*	Rare	9
12	Diptera	Chironomidae	*Polypedilum*	*halterale*	Rare	7.3
13	Diptera	Chironomidae	*Tanytarsus*		Rare	6.8
14	Diptera	Chironomidae	*Dicrotendipes*	*nervosus*	Common	9.8
15	Oligocheata	Lumbriculidae	*Lumbriculidae*		Rare	7
16	Oligocheata	Tubificadae	*Tubificadae*		Common	7.1
17	Oligocheata	Tubificadae	*Limnodrilus*	*hoffmeisteri*	Common	9.5

Detritus, Low Flow						
Order		Family	Genus	Species	Abundance	Tolerance Value
1	Odonata	Coenagrionidae	*Ishnura*		Rare	9.52
2	Odonata	Libellulidae	*Perithemis*	*sp*	Common	9.9
3	Odonata	Aeshnidae	*Anax*	*sp*	Rare	5.9
4	Coleoptera	Hydrophilidae	*Berosus*	*sp*	Rare	8.4
5	Ephemeroptera	Caenidae	*Caenis*	*sp*	Common	7.4
6	Diptera	Chironomidae	*Rheotanytarus*	*spp*	Rare	5.9
7	Diptera	Chironomidae	*Cryptochironomus*	*fulvus*	Common	6.4
8	Diptera	Chironomidae	*Cricotopus*	*bicinctus (C/O sp 1)*	Rare	8.5
9	Diptera	Chironomidae	*Conchapelopia*	*Group*	Rare	8.4
10	Diptera	Chironomidae	*Zavrelia*	*sp*	Rare	5.3
11	Oligocheata	Lumbriculidae	*Lumbriculidae*		Rare	7
12	Oligocheata	Tubificadae	*Tubificadae*		Common	7.1
13	Megaloptera	Sialidae	*Sialis*	*sp*	Rare	7.2
14	Crustacea		*Astacidae*		Rare	
15	Mollusca		*Sphaer*		Common	

Grass/Sand						
	Order	**Family**	**Genus**	**Species**	**Abundance**	**Tolerance Value**
1	Odonata	Coenagrionidae	*Ishnura*		Abundant	9.52
2	Odonata	Libellulidae	*Pachydiplax*	*longipennis*	Rare	9.9
3	Coleoptera	Dytiscidae	*Laccophilus*	*sp*	Rare	10
4	**Ephemeroptera**	**Baetidae**	***Callibaetis***	***sp***	**Abundant**	**9.8**
5	**Ephemeroptera**	**Caenidae**	***Caenis***	***sp***	**Abundant**	**7.4**
6	**Trichoptera**	**Leptoceridae**	***Oecetis***	***inconspicua***	**Common**	**1.9**
7	Diptera	Ceratopogonidae	*Palpomyia*	*complex*	Rare	6.9
8	Diptera	Chironomidae	*Chironomus*	*sp*	Common	9.6
9	Diptera	Chironomidae	*Polypedilum*	*illinoense*	Common	9
10	Diptera	Chironomidae	*Tanytarsus*		Rare	6.8
11	Diptera	Chironomidae	*Dicrotendipes*	*nervosus*	Abundant	9.8
12	Diptera	Chironomidae	*Nanocladius*	*sp*	Rare	7.1
13	Diptera	Chironomidae	*Cheatocladius*		Rare	
14	Oligocheata	Tubificadae	*Tubificadae*		Rare	7.1
15	Crustacea	Gammaridae	*Crangonyx*	*sp*	Rare	7.9
16	Mollusca		*Somato*		Rare	
17	Mollusca		*Physel*		Rare	

Appendix J. Water Control Structure Dimensions Used in DRAINMOD-N Modeling

Parameter	CCD15A	CCB15B	CCD8		CCM0	CCM1	CCDPD4	CCDPD5
# Weirs	1	1	2	2	2	2	1	2
Weir Width (cm)	122	104	61	61	76	104	91	76
Weir Angle (^{o})	90	120	80	0	120	90	120	90
Weir Height (cm)	20	10	20	0	10	20	10	20
Riser Diameter (cm)	132	114	130	130	163	221	99	163
Riser Cross Section (cm)	66	61	69	69	91	152	58	81
Riser Circum. (cm)	207	186	210	210	272	416	170	255
Pipe Diameter (cm)	91	76	91	91	107	152	76	76
Drainage Area (ha)	121	77	121	121	186	465	77	77

Parameter	CCD2B	CCD7	CCD4A	CCD5A	CCD5B	GCD3	GCD5	GCD7B
# Weirs	1	2	1	1	1	1	1	2
Weir Width (cm)	81	61	79	107	91	104	91	76
Weir Angle (^{o})	90	120	90	90	90	90	90	90
Weir Height (cm)	20	10	20	20	20	20	20	20
Riser Diameter (cm)	91	130	89	114	102	112	99	163
Riser Cross Section (cm)	61	65	65	66	58	66	58	81
Riser Circum. (cm)	168	203	173	194	172	192	170	255
Pipe Diameter (cm)	61	91	76	76	61	91	61	107
Drainage Area (ha)	42	121	77	40	20	121	30	121

Appendix K. Calibrated Hydrology DRAINMOD Inputs

	Drainage Design							
	System Design							
	D surface to drain (cm)	Drain Spacing (m)	Effect. Radius (cm)	surface to imperm layer (cm)	drain coeff. cm/day	D Water Table	Max Surface Storage (cm)	Kirkham's D (cm)
CCD2B	168	90	27	250	2.5	60	2	0.75
CCD4A	183	150	25	250	2.5	60	1.5	0.5
CCD5A	122	150	21	250	2.5	60	2	1
CCD5B	122	115	21	250	2.5	60	1.5	0.75
CCD7	137	100	33	250	2.5	60	1.7	1.2
CCD8	183	100	38	250	2.5	60	2	1
CCD15A	152	100	29	250	2.5	60	1.5	0.85
CCD15B	152	150	29	250	2.5	60	1.5	0.6
CCDPD4	152	140	25	250	2.5	60	1.5	1
CCDPD5	152	100	21	250	2.5	60	1.5	1
CCM0	122	89	41	250	2.5	60	1.5	1
CCM1	200	120	39	250	2.5	60	1.5	1
GCD3	190	150	38	250	2.5	60	1.5	0.75
GCD5	122	90	36	200	2.5	60	2	1
GCD7A	122	100	38	250	2.5	60	1.5	1

	Drainage Design								
	Lateral Saturated Conductivity						Weir Settings		
	Bottom Depth of Layer (cm)	k	Bottom Depth of Layer (cm)	k	Bottom Depth of Layer (cm)	k	Bottom width (cm)	side slope (H:V)	weir setting
CCD2B	30	6	100	4	250	1	122	1.25	75
CCD4A	30	6	100	4	250	1	122	1.5	70
CCD5A	30	6	100	4	250	1	122	2	65
CCD5B	30	6	100	4	250	1	122	2	75
CCD7	30	6	100	4	250	1	168	1.25	75
CCD8	30	6	100	4	250	1	182	1	80
CCD15A	30	6	100	4	250	1	122	1	60
CCD15B	30	6	100	4	250	1	122	1	60
CCDPD4	30	6	100	4	250	1	122	1.5	60
CCDPD5	30	6	100	4	250	1	122	2	90
CCM0	30	6	100	4	250	1	244	1.33	90
CCM1	30	6	100	4	250	1	305	2	160
GCD3	30	6	100	4	250	1	183	1	100
GCD5	30	6	100	4	250	1	168	1	70
GCD7A	30	6	100	4	250	1	183	1	75

Appendix L. Calibrated Nitrogen DRAINMOD-N Inputs

	Nitrogen										
	Model						CROP				
	Dispersivity	Tortuosity	Diffusion Coeff.	Net Mineral. Rate	Denitr. Rate	Days of Sat. for Denitr.	DAP	Fert. Rate	DAP	Fert. Rate	
CCD2B	5.5	0.65	1E-06	0.00008	1	3	5	22	60	88	Cotton
CCD4A	6	0.625	1E-06	0.00005	1	3	5	22	60	88	Cotton
CCD5A	9	0.675	1E-06	0.000075	1	3	0	0	0	0	Soybeans
CCD5B	7.5	0.65	1E-06	0.00005	1	3	0	0	0	0	Soybeans
CCD7	7.5	0.8	1E-06	0.00006	1	3	5	22	60	88	Cotton
CCD8	5.8	0.625	1E-06	0.00005	0.8	3	5	27	60	175	Corn
CCD15A	5	0.6	1E-06	0.000075	0.9	3	5	27	60	175	Corn
CCD15B	5.5	0.63	1E-06	0.000075	1	3	5	27	60	175	Corn
CCDPD4	8	0.68	1E-06	0.0001	0.75	3	5	27	60	175	Corn
CCDPD5	7.5	0.65	1E-06	0.0001	1	3	5	27	60	175	Corn
CCM0	5	0.6	1E-06	0.0001	1	3	5	27	60	175	Corn
CCM1	10	0.7	1E-06	0.0001	1	3	5	27	60	175	Corn
GCD3	7.5	0.65	1E-06	0.00005	1	3	5	27	60	175	Corn
GCD5	8.5	0.6	1E-06	0.00007	0.8	3	5	27	60	175	Corn
GCD7A	10	0.7	1E-06	0.00009	1	3	5	27	60	175	Corn

Appendix M. Sample DRAINMOD-N Input Files

CCD2B Hydrology File

```
*** Job Title ***
CCD2B, 1953-2003

*** Printout and Input Control ***
 1 100 c:\Program Files\Drainmod\outputs
*** Climate ***
    1 C:\PROGRAM FILES\DRAINMOD\WEATHER\NBPRECIP.RAI
    1 C:\PROGRAM FILES\DRAINMOD\WEATHER\NBTEMPC1.TEM
1953  1 2003 12 3537  76 0
 2.01 2.32 2.10 1.72 1.23 1.00  .86  .82  .92 1.05 1.22 1.44
*** Drainage System Design ***
 1    .00
   168.00     82.00   9000.00      2.00      2.50       .75      5.69     60.00
         0    0.000000E+00    0.000000E+00
         0    1000.000000     1000.000000    1.200000E-03
         0    0.000000E+00    0.000000E+00    0.000000E+00    0.000000E+00
   122.00      1.25       .00
 1150 1150 11501515015 60 1 60 1 6016150 1150 1150 1150 1150
*** Soils ***
   250.00     27.00
  30. 6.00 100. 4.00 250. 1.00   0.  .00   0.  .00
99     .00
*** Trafficability ***
 3151031 820              3.0       1.2       2.0
12311231 820              3.0       1.2       2.0
*** Crop ***
      .170
 410 930       30.00
 410 930
11
 1 1  3.00 415  3.00 5 1  4.00 515 15.00 524 25.00 612 30.00 712 30.00 821 30.00
 915  3.00 925  3.001231  3.00
*** Wastewater Irrigation ***
 0    0 0   0   0  0
 0 0       0 0       0 0       0 0
    .00000    .00000  .00  .00  .00  .00  .00  .00  .00  .00  .00  .00  .00  .00
WET *** Wetlands Information ***
 0
   1 365
 30.0  14
COM *** Combo Drainage Weir Settings ***
 0  0  0   .0
 0  0  0   .0
 0  0  0   .0
 0  0  0   .0
 0  0  0   .0
 0  0  0   .0
 0  0  0   .0
 0  0  0   .0
 0  0  0   .0
 0  0  0   .0
 0  0  0   .0
 0  0  0   .0
```

Soil *.SIN file

```
RAINS.SIN, EXAMPLE SOIL FROM EASTERN NC
1316
  .3700000       .0
  .3000000    -10.0
  .2820000    -20.0
  .2720000    -30.0
  .2660000    -40.0
  .2580000    -50.0
  .2540000    -60.0
  .2480000    -70.0
  .2440000    -80.0
  .2380000   -100.0
  .2280000   -150.0
  .2240000   -200.0
  .1500000  -2000.0
     .0000     .0000     .2000
   10.0000     .2500     .1000
   20.0000     .8000     .0800
   30.0000    1.6000     .0250
   40.0000    2.3000     .0112
   50.0000    3.0000     .0058
   60.0000    3.6000     .0031
   70.0000    4.4000     .0018
```

```
 80.0000    5.2000     .0010
100.0000    6.9000     .0004
120.0000    9.0000     .0000
150.0000   12.5000     .0000
200.0000   20.0000     .0000
300.0000   35.0000     .0000
500.0000   50.0000     .0000
1000.0000 100.0000     .0000
7
     .00      .00      .00
   50.00     1.20     1.00
  100.00     3.30     1.00
  150.00     6.00     1.00
  200.00     9.20     1.00
  500.00    25.00     1.00
 1000.00    25.00     1.00
```

Soil *.MIS file

```
  3
*TOP AND BOTTOM OF LAYER
    0.0    30.0
*NUMBER OF POINTS IN LAYER
 10
 0.365        0.0
 0.355       10.0
 0.330       25.0
 0.260       50.0
 0.250       60.0
 0.230       75.0
 0.190      200.0
 0.180      250.0
 0.162      300.0
 0.155      350.0
*TOP AND BOTTOM OF LAYER
   30.0   100.0
*NUMBER OF POINTS IN LAYER
 10
 0.365        0.0
 0.355       10.0
 0.330       25.0
 0.260       50.0
 0.250       60.0
 0.230       75.0
 0.190      200.0
 0.180      250.0
 0.162      300.0
 0.155      350.0
*TOP AND BOTTOM OF LAYER
  100.0   250.0
*NUMBER OF POINTS IN LAYER
 10
 0.365        0.0
 0.355       10.0
 0.330       25.0
 0.260       50.0
 0.250       60.0
 0.230       75.0
 0.190      200.0
 0.180      250.0
 0.162      300.0
 0.155      350.0
```

Soil *.WDV File

```
*NLAYER
  3
*TLAYER BLAYER NPTS
    0.0    30.0  201
*WATER TABLE  VOLUME DRAINED
      0      0.00000
      1      0.00050
      2      0.00200
      3      0.00450
      4      0.00800
      5      0.01250
      6      0.01800
      7      0.02450
      8      0.03200
      9      0.04050
     10      0.05000
     11      0.06083
     12      0.07333
     13      0.08750
     14      0.10333
     15      0.12083
```

16	0.14000
17	0.16083
18	0.18333
19	0.20750
20	0.23333
21	0.26083
22	0.29000
23	0.32083
24	0.35333
25	0.38750
26	0.42390
27	0.46310
28	0.50510
29	0.54990
30	0.59750
31	0.64790
32	0.70110
33	0.75710
34	0.81590
35	0.87750
36	0.94190
37	1.00910
38	1.07910
39	1.15190
40	1.22750
41	1.30590
42	1.38710
43	1.47110
44	1.55790
45	1.64750
46	1.73990
47	1.83510
48	1.93310
49	2.03390
50	2.13750
51	2.24300
52	2.34950
53	2.45700
54	2.56550
55	2.67500
56	2.78550
57	2.89700
58	3.00950
59	3.12299
60	3.23749
61	3.35316
62	3.47016
63	3.58850
64	3.70816
65	3.82916
66	3.95149
67	4.07516
68	4.20016
69	4.32649
70	4.45416
71	4.58316
72	4.71349
73	4.84516
74	4.97816
75	5.11249
76	5.24765
77	5.38313
78	5.51893
79	5.65505
80	5.79149
81	5.92825
82	6.06533
83	6.20273
84	6.34045
85	6.47849
86	6.61685
87	6.75553
88	6.89453
89	7.03385
90	7.17349
91	7.31345
92	7.45373
93	7.59433
94	7.73525
95	7.87649
96	8.01805
97	8.15993
98	8.30213
99	8.44465
100	8.58749
101	8.73065
102	8.87414

103	9.01793
104	9.16206
105	9.30649
106	9.45125
107	9.59633
108	9.74173
109	9.88745
110	10.03349
111	10.17986
112	10.32654
113	10.47354
114	10.62086
115	10.76850
116	10.91646
117	11.06474
118	11.21334
119	11.36226
120	11.51150
121	11.66106
122	11.81094
123	11.96114
124	12.11166
125	12.26250
126	12.41366
127	12.56514
128	12.71694
129	12.86906
130	13.02150
131	13.17426
132	13.32734
133	13.48074
134	13.63446
135	13.78850
136	13.94286
137	14.09754
138	14.25254
139	14.40786
140	14.56350
141	14.71946
142	14.87574
143	15.03234
144	15.18926
145	15.34650
146	15.50406
147	15.66194
148	15.82014
149	15.97866
150	16.13750
151	16.29666
152	16.45614
153	16.61594
154	16.77606
155	16.93650
156	17.09726
157	17.25834
158	17.41974
159	17.58146
160	17.74350
161	17.90586
162	18.06854
163	18.23154
164	18.39487
165	18.55851
166	18.72247
167	18.88675
168	19.05135
169	19.21627
170	19.38151
171	19.54707
172	19.71295
173	19.87915
174	20.04567
175	20.21251
176	20.37967
177	20.54715
178	20.71495
179	20.88307
180	21.05151
181	21.22027
182	21.38935
183	21.55875
184	21.72847
185	21.89851
186	22.06887
187	22.23955
188	22.41055
189	22.58187

```
   190    22.75351
   191    22.92547
   192    23.09775
   193    23.27035
   194    23.44327
   195    23.61651
   196    23.79007
   197    23.96395
   198    24.13815
   199    24.31267
   200    24.48751
*TLAYER BLAYER NPTS
  30.0  100.0  201
*WATER TABLE  VOLUME DRAINED
     0     0.00000
     1     0.00050
     2     0.00200
     3     0.00450
     4     0.00800
     5     0.01250
     6     0.01800
     7     0.02450
     8     0.03200
     9     0.04050
    10     0.05000
    11     0.06083
    12     0.07333
    13     0.08750
    14     0.10333
    15     0.12083
    16     0.14000
    17     0.16083
    18     0.18333
    19     0.20750
    20     0.23333
    21     0.26083
    22     0.29000
    23     0.32083
    24     0.35333
    25     0.38750
    26     0.42390
    27     0.46310
    28     0.50510
    29     0.54990
    30     0.59750
    31     0.64790
    32     0.70110
    33     0.75710
    34     0.81590
    35     0.87750
    36     0.94190
    37     1.00910
    38     1.07910
    39     1.15190
    40     1.22750
    41     1.30590
    42     1.38710
    43     1.47110
    44     1.55790
    45     1.64750
    46     1.73990
    47     1.83510
    48     1.93310
    49     2.03390
    50     2.13750
    51     2.24300
    52     2.34950
    53     2.45700
    54     2.56550
    55     2.67500
    56     2.78550
    57     2.89700
    58     3.00950
    59     3.12299
    60     3.23749
    61     3.35316
    62     3.47016
    63     3.58850
    64     3.70816
    65     3.82916
    66     3.95149
    67     4.07516
    68     4.20016
    69     4.32649
    70     4.45416
    71     4.58316
    72     4.71349
```

73	4.84516
74	4.97816
75	5.11249
76	5.24765
77	5.38313
78	5.51893
79	5.65505
80	5.79149
81	5.92825
82	6.06533
83	6.20273
84	6.34045
85	6.47849
86	6.61685
87	6.75553
88	6.89453
89	7.03385
90	7.17349
91	7.31345
92	7.45373
93	7.59433
94	7.73525
95	7.87649
96	8.01805
97	8.15993
98	8.30213
99	8.44465
100	8.58749
101	8.73065
102	8.87414
103	9.01793
104	9.16206
105	9.30649
106	9.45125
107	9.59633
108	9.74173
109	9.88745
110	10.03349
111	10.17986
112	10.32654
113	10.47354
114	10.62086
115	10.76850
116	10.91646
117	11.06474
118	11.21334
119	11.36226
120	11.51150
121	11.66106
122	11.81094
123	11.96114
124	12.11166
125	12.26250
126	12.41366
127	12.56514
128	12.71694
129	12.86906
130	13.02150
131	13.17426
132	13.32734
133	13.48074
134	13.63446
135	13.78850
136	13.94286
137	14.09754
138	14.25254
139	14.40786
140	14.56350
141	14.71946
142	14.87574
143	15.03234
144	15.18926
145	15.34650
146	15.50406
147	15.66194
148	15.82014
149	15.97866
150	16.13750
151	16.29666
152	16.45614
153	16.61594
154	16.77606
155	16.93650
156	17.09726
157	17.25834
158	17.41974
159	17.58146

```
   160    17.74350
   161    17.90586
   162    18.06854
   163    18.23154
   164    18.39487
   165    18.55851
   166    18.72247
   167    18.88675
   168    19.05135
   169    19.21627
   170    19.38151
   171    19.54707
   172    19.71295
   173    19.87915
   174    20.04567
   175    20.21251
   176    20.37967
   177    20.54715
   178    20.71495
   179    20.88307
   180    21.05151
   181    21.22027
   182    21.38935
   183    21.55875
   184    21.72847
   185    21.89851
   186    22.06887
   187    22.23955
   188    22.41055
   189    22.58187
   190    22.75351
   191    22.92547
   192    23.09775
   193    23.27035
   194    23.44327
   195    23.61651
   196    23.79007
   197    23.96395
   198    24.13815
   199    24.31267
   200    24.48751
*TLAYER BLAYER NPTS
 100.0  1000.0  201
*WATER TABLE  VOLUME DRAINED
     0    0.00000
     1    0.00050
     2    0.00200
     3    0.00450
     4    0.00800
     5    0.01250
     6    0.01800
     7    0.02450
     8    0.03200
     9    0.04050
    10    0.05000
    11    0.06083
    12    0.07333
    13    0.08750
    14    0.10333
    15    0.12083
    16    0.14000
    17    0.16083
    18    0.18333
    19    0.20750
    20    0.23333
    21    0.26083
    22    0.29000
    23    0.32083
    24    0.35333
    25    0.38750
    26    0.42390
    27    0.46310
    28    0.50510
    29    0.54990
    30    0.59750
    31    0.64790
    32    0.70110
    33    0.75710
    34    0.81590
    35    0.87750
    36    0.94190
    37    1.00910
    38    1.07910
    39    1.15190
    40    1.22750
    41    1.30590
    42    1.38710
```

43	1.47110
44	1.55790
45	1.64750
46	1.73990
47	1.83510
48	1.93310
49	2.03390
50	2.13750
51	2.24300
52	2.34950
53	2.45700
54	2.56550
55	2.67500
56	2.78550
57	2.89700
58	3.00950
59	3.12299
60	3.23749
61	3.35316
62	3.47016
63	3.58850
64	3.70816
65	3.82916
66	3.95149
67	4.07516
68	4.20016
69	4.32649
70	4.45416
71	4.58316
72	4.71349
73	4.84516
74	4.97816
75	5.11249
76	5.24765
77	5.38313
78	5.51893
79	5.65505
80	5.79149
81	5.92825
82	6.06533
83	6.20273
84	6.34045
85	6.47849
86	6.61685
87	6.75553
88	6.89453
89	7.03385
90	7.17349
91	7.31345
92	7.45373
93	7.59433
94	7.73525
95	7.87649
96	8.01805
97	8.15993
98	8.30213
99	8.44465
100	8.58749
101	8.73065
102	8.87414
103	9.01793
104	9.16206
105	9.30649
106	9.45125
107	9.59633
108	9.74173
109	9.88745
110	10.03349
111	10.17986
112	10.32654
113	10.47354
114	10.62086
115	10.76850
116	10.91646
117	11.06474
118	11.21334
119	11.36226
120	11.51150
121	11.66106
122	11.81094
123	11.96114
124	12.11166
125	12.26250
126	12.41366
127	12.56514
128	12.71694
129	12.86906

130	13.02150
131	13.17426
132	13.32734
133	13.48074
134	13.63446
135	13.78850
136	13.94286
137	14.09754
138	14.25254
139	14.40786
140	14.56350
141	14.71946
142	14.87574
143	15.03234
144	15.18926
145	15.34650
146	15.50406
147	15.66194
148	15.82014
149	15.97866
150	16.13750
151	16.29666
152	16.45614
153	16.61594
154	16.77606
155	16.93650
156	17.09726
157	17.25834
158	17.41974
159	17.58146
160	17.74350
161	17.90586
162	18.06854
163	18.23154
164	18.39487
165	18.55851
166	18.72247
167	18.88675
168	19.05135
169	19.21627
170	19.38151
171	19.54707
172	19.71295
173	19.87915
174	20.04567
175	20.21251
176	20.37967
177	20.54715
178	20.71495
179	20.88307
180	21.05151
181	21.22027
182	21.38935
183	21.55875
184	21.72847
185	21.89851
186	22.06887
187	22.23955
188	22.41055
189	22.58187
190	22.75351
191	22.92547
192	23.09775
193	23.27035
194	23.44327
195	23.61651
196	23.79007
197	23.96395
198	24.13815
199	24.31267
200	24.48751

Rainfall File

1 2000 1 417 3 418 3 419 3 420 5 517 3 518 3 519 3 520 6 717 0 718 0 719 0 720 3
1 2000 1 817 1 818 1 819 1 820 3 917 6 918 6 919 6 920 71017 101018 101019 101020 11
1 2000 1 1117 51118 51119 51120 71817 21818 21819 21820 31917 11918 11919 11920 1
1 2000 1 2017 62018 62019 62020 62217 02218 02219 02220 12317 192318 192319 192320 19
1 2000 1 2417 182418 182419 182420 192517 82518 82519 82520 92617 142618 142619 142620 17
1 2000 1 3017 143018 143019 143020 173117 103118 103119 103120 13
1 2000 2 417 0 418 0 419 0 420 0 917 1 918 1 919 1 920 11217 41218 41219 41220 6
1 2000 2 1317 191318 191319 191320 201417 101418 101419 101420 111517 31518 31519 31520 3
1 2000 2 1817 01818 01819 01820 21917 21918 21919 21920 32017 12018 12019 12020 2
1 2000 2 2717 32718 32719 32720 52817 22818 22819 22820 4
1 2000 3 1217 171218 171219 171220 201617 41618 41619 41620 71717 561718 561719 561720 56
1 2000 3 2017 32018 32019 32020 62117 172118 172119 172120 172217 02218 02219 02220 0
1 2000 3 2317 02318 02319 02320 32717 02718 02719 02720 22817 32818 32819 32820 6

1 2000 3 3017 63018 63019 63020 83117 03118 03119 03120 1
1 2000 4 817 4 818 4 819 4 820 7 917 8 918 8 919 8 920 101217 91218 91219 91220 10
1 2000 4 1317 81318 81319 81320 101417 51418 51419 51420 81517 341518 341519 341520 35
1 2000 4 1617 81618 81619 81620 101717 71718 71719 71720 71817 141818 141819 141820 14
1 2000 4 2117 42118 42119 42120 62217 12218 12219 12220 12417 02418 02419 02420 2
1 2000 4 2517 152518 152519 152520 162617 52618 52619 52620 52717 12718 12719 12720 2
1 2000 4 2817 202818 202819 202820 212917 82918 82919 82920 103017 03018 03019 03020 1
1 2000 5 2117 192118 192119 192120 202217 152218 152219 152220 152317 62318 62319 62320 6
1 2000 5 2417 02418 02419 02420 32517 52518 52519 52520 72617 12618 12619 12620 1
1 2000 5 2817 92818 92819 92820 112917 222918 222919 222920 233017 03018 03019 03020 1
1 2000 6 317 6 318 6 319 6 320 7 417 8 418 8 419 8 420 10 517 5 518 5 519 5 520 5
1 2000 6 2717 02718 02719 02720 32917 152918 152919 152920 17
1 2000 7 517 1 518 1 519 1 520 3 617 5 618 5 619 5 620 5 917 1 918 1 919 1 920 4
1 2000 7 1217 161218 161219 161220 191517 131518 131519 131520 141617 51618 51619 51620 5
1 2000 7 2017 02018 02019 02020 12117 242118 242119 242120 242217 252218 252219 252220 27
1 2000 7 2317 122318 122319 122320 152417 72418 72419 72420 82517 482518 482519 482520 51
1 2000 7 2617 112618 112619 112620 113017 453018 453019 453020 483117 63118 63119 63120 8
1 2000 8 117 0 118 0 119 0 120 1 317 0 318 0 319 0 320 2 417 6 418 6 419 6 420 8
1 2000 8 517 0 518 0 519 0 520 1 917 1 918 1 919 1 920 41317 01318 01319 01320 2
1 2000 8 1617 41618 41619 41620 61717 01718 01719 01720 11817 231818 231819 231820 25
1 2000 8 2517 92518 92519 92520 102617 02618 02619 02620 12717 42718 42719 42720 5
1 2000 8 2817 442818 442819 442820 472917 22918 22919 22920 53017 213018 213019 213020 21
1 2000 8 3117 133118 133119 133120 16
1 2000 9 117 7 118 7 119 7 120 7 317 7 318 7 319 7 320 10 417 32 418 32 419 32 420 32
1 2000 9 517 25 518 25 519 25 520 26 617 0 618 0 619 0 620 21817 571818 571819 571820 59
1 2000 9 2117 12118 12119 12120 32217 42218 42219 42220 42317 312318 312319 312320 34
1 2000 9 2517 112518 112519 112520 132617 02618 02619 02620 12917 02918 02919 02920 1
1 200010 117 0 118 0 119 0 120 2 617 0 618 0 619 0 620 1 717 1 718 1 719 1 720 2
1 200010 817 0 818 0 819 0 820 21917 01918 01919 01920 12417 02418 02419 02420 1
1 200010 2617 02618 02619 02620 1
1 200011 517 5 518 5 519 5 520 6 917 0 918 0 919 0 920 11417 61418 61419 61420 9
1 200011 1617 01618 01619 01620 11717 31718 31719 31720 31817 01818 01819 01820 1
1 200011 1917 191918 191919 191920 222117 02118 02119 02120 12517 282518 282519 282520 30
1 200011 2617 02618 02619 02620 12917 02918 02919 02920 1
1 200012 217 5 218 5 219 5 220 7 317 4 318 4 319 4 320 4 417 11 418 11 419 11 420 11
1 200012 517 1 518 1 519 1 520 1 617 0 618 0 619 0 620 11017 41018 41019 41020 5
1 200012 1117 01118 01119 01120 21217 11218 11219 11220 41317 01318 01319 01320 2
1 200012 1417 31418 31419 31420 31617 01618 01619 01620 31717 21718 21719 21720 2
1 200012 1917 01918 01919 01920 32717 22718 22719 22720 42817 22818 22819 22820 2
1 2001 1 817 0 818 0 819 0 820 2 917 0 918 0 919 0 920 11217 11218 11219 11220 4
1 2001 1 1417 61418 61419 61420 71617 01618 01619 01620 12017 172018 172019 172020 17
1 2001 1 2217 02218 02219 02220 12317 02318 02319 02320 33017 13018 13019 13020 3
1 2001 2 417 7 418 7 419 7 420 9 517 1 518 1 519 1 520 31217 81218 81219 81220 8
1 2001 2 1317 11318 11319 11320 11417 11418 11419 11420 21717 151718 151719 151720 17
1 2001 2 2017 02018 02019 02020 12217 172218 172219 172220 182317 02318 02319 02320 1
1 2001 2 2517 12518 12519 12520 22817 12818 12819 12820 4
1 2001 3 317 7 318 7 319 7 320 7 417 13 418 13 419 13 420 13 517 0 518 0 519 0 520 1
1 2001 3 1217 01218 01219 01220 31317 01318 01319 01320 11517 141518 141519 141520 17
1 2001 3 1717 01718 01719 01720 12017 142018 142019 142020 162117 332118 332119 332120 33
1 2001 3 2217 12218 12219 12220 22517 02518 02519 02520 32917 102918 102919 102920 10
1 2001 3 3017 33018 33019 33020 3
1 2001 4 117 3 118 3 119 3 120 3 317 1 318 1 319 1 320 11317 71318 71319 71320 9
1 2001 4 1717 71718 71719 71720 81817 01818 01819 01820 12517 142518 142519 142520 16
1 2001 5 1217 151218 151219 151220 161317 01318 01319 01320 21517 11518 11519 11520 4
1 2001 5 1617 11618 11619 11620 31717 21718 21719 21720 31817 01818 01819 01820 1
1 2001 5 1917 01918 01919 01920 12117 22118 22119 22120 22317 32318 32319 32320 4
1 2001 5 2617 22618 22619 22620 42717 02718 02719 02720 12817 282818 282819 282820 29
1 2001 5 2917 92918 92919 92920 12
1 2001 6 117 54 118 54 119 54 120 57 217 1 218 1 219 1 220 1 717 0 718 0 719 0 720 1
1 2001 6 817 0 818 0 819 0 820 11217 01218 01219 01220 11317 81318 81319 81320 8
1 2001 6 1417 481418 481419 481420 481517 291518 291519 291520 312317 52318 52319 52320 6
1 2001 6 2417 52418 52419 52420 62617 02618 02619 02620 1
1 2001 7 117 0 118 0 119 0 120 1 317 43 318 43 319 43 320 45 417 0 418 0 419 0 420 1
1 2001 7 517 10 518 10 519 10 520 13 817 1 818 1 819 1 820 3 917 13 918 13 919 13 920 16
1 2001 7 1017 01018 01019 01020 11317 01318 01319 01320 31817 351818 351819 351820 36
1 2001 7 1917 51918 51919 51920 72017 02018 02019 02020 12217 12218 12219 12220 1
1 2001 7 2317 92318 92319 92320 92417 22418 22419 22420 32617 12618 12619 12620 1
1 2001 7 2717 32718 32719 32720 42817 02818 02819 02820 12917 152918 152919 152920 15
1 2001 7 3017 163018 163019 163020 19
1 2001 8 1317 81318 81319 81320 81417 111418 111419 111420 111817 71818 71819 71820 10
1 2001 8 1917 11918 11919 11920 32017 182018 182019 182020 202217 12218 12219 12220 1
1 2001 8 2717 02718 02719 02720 12817 32818 32819 32820 42917 42918 42919 42920 4
1 2001 8 3017 03018 03019 03020 03117 203118 203119 203120 21
1 2001 9 117 1 118 1 119 1 120 3 217 2 218 2 219 2 220 4 317 0 318 0 319 0 320 0
1 2001 9 517 0 518 0 519 0 520 0 917 15 918 15 919 15 920 151017 101018 101019 101020 13
1 2001 9 1117 01118 01119 01120 31217 01218 01219 01220 02017 12018 12019 12020 2
1 2001 9 2117 02118 02119 02120 12317 02318 02319 02320 12417 82418 82419 82420 11
1 2001 9 2517 22518 22519 22520 4
1 200110 617 22 618 22 619 22 620 23 817 0 818 0 819 0 820 11417 31418 31419 31420 5
1 200110 1517 01518 01519 01520 12417 02418 02419 02420 13017 03018 03019 03020 0
1 200111 217 0 218 0 219 0 220 0 717 0 718 0 719 0 720 11817 01818 01819 01820 0
1 200111 2017 02018 02019 02020 22217 02218 02219 02220 02317 02318 02319 02320 1
1 200111 2417 222418 222419 222420 232517 02518 02519 02520 12617 02618 02619 02620 0
1 200111 2717 02718 02719 02720 02817 02818 02819 02820 12917 02918 02919 02920 1
1 200111 3017 03018 03019 03020 1
1 200112 417 0 418 0 419 0 420 0 517 0 518 0 519 0 520 1 717 0 718 0 719 0 720 1
1 200112 1017 31018 31019 31020 41117 41118 41119 41120 51217 01218 01219 01220 1

1 200112 1317 01318 01319 01320 11417 21418 21419 21420 21817 51818 51819 51820 7
1 200112 2317 02318 02319 02320 1
1 2002 1 217 2 218 2 219 2 220 4 317 6 318 6 319 6 320 9 417 10 418 10 419 10 420 13
1 2002 1 517 2 518 2 519 2 520 4 617 20 618 20 619 20 620 22 717 0 718 0 719 0 720 1
1 2002 1 1217 51218 51219 51220 71317 51318 51319 51320 71417 41418 41419 41420 5
1 2002 1 1517 11518 11519 11520 41917 101918 101919 101920 102017 12018 12019 12020 1
1 2002 1 2117 72118 72119 72120 92217 02218 02219 02220 12317 232318 232319 232320 23
1 2002 1 2517 12518 12519 12520 42717 02718 02719 02720 12817 02818 02819 02820 3
1 2002 1 3017 03018 03019 03020 1
1 2002 2 117 0 118 0 119 0 120 1 617 2 618 2 619 2 620 2 717 18 718 18 719 18 720 18
1 2002 2 817 8 818 8 819 8 820 8 917 0 918 0 919 0 920 11017 21018 21019 21020 4
1 2002 2 1117 01118 01119 01120 11517 11518 11519 11520 41617 01618 01619 01620 1
1 2002 2 2017 02018 02019 02020 22117 82118 82119 82120 112317 02318 02319 02320 2
1 2002 2 2617 02618 02619 02620 12817 02818 02819 02820 2
1 2002 3 217 13 218 13 219 13 220 16 317 30 318 30 319 30 320 30 417 1 418 1 419 1 420 1
1 2002 3 517 4 518 4 519 4 520 41217 11218 11219 11220 11317 291318 291319 291320 31
1 2002 3 1417 01418 01419 01420 11717 21718 21719 21720 31817 01818 01819 01820 1
1 2002 3 2017 52018 52019 52020 52117 52118 52119 52120 52217 02218 02219 02220 1
1 2002 3 2617 42618 42619 42620 62717 32718 32719 32720 33017 13018 13019 13020 2
1 2002 3 3117 213118 213119 213120 21
1 2002 4 117 9 118 9 119 9 120 12 317 0 318 0 319 0 320 31017 81018 81019 81020 8
1 2002 4 1317 21318 21319 21320 31417 01418 01419 01420 21517 01518 01519 01520 1
1 2002 4 1917 121918 121919 121920 142017 02018 02019 02020 22517 12518 12519 12520 2
1 2002 4 2717 12718 12719 12720 3
1 2002 5 117 1 118 1 119 1 120 1 317 0 318 0 319 0 320 1 417 19 418 19 419 19 420 22
1 2002 5 517 0 518 0 519 0 520 1 917 0 918 0 919 0 920 21317 131318 131319 131320 14
1 2002 5 1817 81818 81819 81820 101917 01918 01919 01920 13017 13018 13019 13020 2
1 2002 6 117 0 118 0 119 0 120 3 717 5 718 5 719 5 720 81417 51418 51419 51420 5
1 2002 6 1617 01618 01619 01620 11817 01818 01819 01820 12117 02118 02119 02120 2
1 2002 6 2217 132218 132219 132220 142317 02318 02319 02320 02417 02418 02419 02420 1
1 2002 6 2617 02618 02619 02620 12717 72718 72719 72720 72817 42818 42819 42820 5
1 2002 6 2917 02918 02919 02920 03017 03018 03019 03020 0
1 2002 7 217 0 218 0 219 0 220 1 517 4 518 4 519 4 520 4 617 0 618 0 619 0 620 0
1 2002 7 1017 121018 121019 121020 141117 11118 11119 11120 21217 21218 21219 21220 2
1 2002 7 1317 11318 11319 11320 11417 01418 01419 01420 31617 01618 01619 01620 1
1 2002 7 2217 02218 02219 02220 32317 12318 12319 12320 42417 52418 52419 52420 7
1 2002 7 2517 342518 342519 342520 362617 02618 02619 02620 32717 102718 102719 102720 13
1 2002 7 3117 13118 13119 13120 4
1 2002 8 817 0 818 0 819 0 820 31517 21518 21519 21520 21617 11618 11619 11620 2
1 2002 8 1717 11718 11719 11720 11817 01818 01819 01820 12017 02018 02019 02020 3
1 2002 8 2417 22418 22419 22420 42517 02518 02519 02520 02617 52618 52619 52620 5
1 2002 8 2717 12718 12719 12720 22817 122818 122819 122820 132917 42918 42919 42920 4
1 2002 8 3017 43018 43019 43020 63117 133118 133119 133120 16
1 2002 9 417 1 418 1 419 1 420 3 917 2 918 2 919 2 920 21017 191018 191019 191020 22
1 2002 9 1417 121418 121419 121420 141517 51518 51519 51520 51617 41618 41619 41620 4
1 2002 9 1717 01718 01719 01720 12217 22218 22219 22220 52317 372318 372319 372320 39
1 2002 9 2517 32518 32519 32520 32617 12618 12619 12620 32717 02718 02719 02720 1
1 200210 117 0 118 0 119 0 120 11117 241118 241119 241120 261217 01218 01219 01220 2
1 200210 1317 21318 21319 21320 51417 51418 51419 51420 81517 31518 31519 31520 3
1 200210 1617 01618 01619 01620 11717 01718 01719 01720 12117 32118 32119 32120 5
1 200210 2217 02218 02219 02220 12417 22418 22419 22420 52617 02618 02619 02620 2
1 200210 2817 12818 12819 12820 42917 32918 32919 32920 63017 43018 43019 43020 6
1 200211 417 2 418 2 419 2 420 2 517 1 518 1 519 1 520 4 617 15 618 15 619 15 620 16
1 200211 717 0 718 0 719 0 720 11017 01018 01019 01020 11117 101118 101119 101120 13
1 200211 1217 171218 171219 171220 191317 121318 121319 121320 132117 12118 12119 12120 1
1 200212 417 1 418 1 419 1 420 4 517 1 518 1 519 1 520 3 617 7 618 7 619 7 620 10
1 200212 717 3 718 3 719 3 720 3 817 6 818 6 819 6 820 7 917 0 918 0 919 0 920 3
1 200212 1017 01018 01019 01020 21117 01118 01119 01120 31217 01218 01219 01220 1
1 200212 1417 01418 01419 01420 11717 131718 131719 131720 141817 01818 01819 01820 1
1 200212 1917 21918 21919 21920 22017 42018 42019 42020 52417 162418 162419 162420 17
1 200212 2517 02518 02519 02520 2
1 2003 1 117 16 118 16 119 16 120 16 217 0 218 0 219 0 220 1 317 2 318 2 319 2 320 2
1 2003 1 1617 31618 31619 31620 41717 11718 11719 11720 42117 12118 12119 12120 3
1 2003 1 2317 02318 02319 02320 12417 02418 02419 02420 22917 02918 02919 02920 2
1 2003 1 3017 83018 83019 83020 93117 33118 33119 33120 5
1 2003 2 117 0 118 0 119 0 120 1 417 2 418 2 419 2 420 5 617 5 618 5 619 5 620 5
1 2003 2 717 11 718 11 719 11 720 121017 131018 131019 131020 151117 01118 01119 01120 1
1 2003 2 1517 11518 11519 11520 21617 331618 331619 331620 341717 21718 21719 21720 3
1 2003 2 2217 102218 102219 102220 102317 42318 42319 42320 72617 22618 22619 22620 3
1 2003 2 2717 162718 162719 162720 182817 02818 02819 02820 3
1 2003 3 217 0 218 0 219 0 220 3 417 1 418 1 419 1 420 4 517 2 518 2 519 2 520 4
1 2003 3 617 6 618 6 619 6 620 7 717 4 718 4 719 4 720 41117 151118 151119 151120 15
1 2003 3 1217 01218 01219 01220 11317 31318 31319 31320 31417 11418 11419 11420 4
1 2003 3 1517 01518 01519 01520 31617 81618 81619 81620 101717 11718 11719 11720 4
1 2003 3 1817 11818 11819 11820 11917 11918 11919 11920 22017 452018 452019 452020 45
1 2003 3 2117 82118 82119 82120 92817 12818 12819 12820 22917 02918 02919 02920 1
1 2003 3 3017 73018 73019 73020 103117 03118 03119 03120 0
1 2003 4 517 1 518 1 519 1 520 1 717 22 718 22 719 22 720 24 817 5 818 5 819 5 820 7
1 2003 4 917 34 918 34 919 34 920 351017 251018 251019 251020 271117 51118 51119 51120 8
1 2003 4 1217 01218 01219 01220 01817 51818 51819 51820 72017 02018 02019 02020 0
1 2003 4 2117 02118 02119 02120 02517 82518 82519 82520 112617 22618 22619 22620 4
1 2003 4 2717 02718 02719 02720 02817 02818 02819 02820 02917 02918 02919 02920 3
1 2003 4 3017 03018 03019 03020 0
1 2003 5 217 4 218 4 219 4 220 7 617 20 618 20 619 20 620 231517 01518 01519 01520 2
1 2003 5 1617 01618 01619 01620 01817 241818 241819 241820 261917 01918 01919 01920 3
1 2003 5 2117 442118 442119 442120 472217 222218 222219 222220 222417 162418 162419 162420 16
1 2003 5 2517 382518 382519 382520 382617 102618 102619 102620 122817 62818 62819 62820 7

1 2003 5 3017 63018 63019 63020 7
1 2003 6 217 3 218 3 219 3 220 3 317 2 318 2 319 2 320 4 717 13 718 13 719 13 720 13
1 2003 6 817 1 818 1 819 1 820 1 917 9 918 9 919 9 920 121017 01018 01019 01020 1
1 2003 6 1517 71518 71519 71520 81617 51618 51619 51620 51817 11818 11819 11820 4
1 2003 6 1917 321918 321919 321920 322017 02018 02019 02020 1
1 2003 7 217 66 218 66 219 66 220 68 317 0 318 0 319 0 320 1 917 3 918 3 919 3 920 4
1 2003 7 1017 01018 01019 01020 21117 71118 71119 71120 101217 21218 21219 21220 3
1 2003 7 1317 811318 811319 811320 841417 51418 51419 51420 71717 331718 331719 331720 34
1 2003 7 1917 21918 21919 21920 22217 82218 82219 82220 92317 42318 42319 42320 5
1 2003 7 2417 92418 92419 92420 122517 02518 02519 02520 22617 02618 02619 02620 1
1 2003 7 2717 02718 02719 02720 12917 92918 92919 92920 103017 43018 43019 43020 4
1 2003 7 3117 63118 63119 63120 6
1 2003 8 117 0 118 0 119 0 120 1 317 1 318 1 319 1 320 3 417 1 418 1 419 1 420 2
1 2003 8 517 2 518 2 519 2 520 5 617 0 618 0 619 0 620 1 717 24 718 24 719 24 720 24
1 2003 8 817 5 818 5 819 5 820 8 917 11 918 11 919 11 920 121017 31018 31019 31020 6
1 2003 8 1117 21118 21119 21120 41217 141218 141219 141220 171317 91318 91319 91320 10
1 2003 8 1617 11618 11619 11620 21717 441718 441719 441720 451817 11818 11819 11820 3
1 2003 8 1917 31918 31919 31920 52017 22018 22019 22020 42117 32118 32119 32120 4
1 2003 8 2217 102218 102219 102220 102317 112318 112319 112320 142417 02418 02419 02420 1
1 2003 8 2917 02918 02919 02920 1
1 2003 9 217 0 218 0 219 0 220 1 317 2 318 2 319 2 320 2 417 19 418 19 419 19 420 19
1 2003 9 517 4 518 4 519 4 520 6 717 3 718 3 719 3 720 3 917 0 918 0 919 0 920 2
1 2003 9 1017 01018 01019 01020 21217 11218 11219 11220 11317 01318 01319 01320 2
1 2003 9 1417 11418 11419 11420 31517 01518 01519 01520 11617 01618 01619 01620 0
1 2003 9 1717 01718 01719 01720 31817 681818 681819 681820 691917 341918 341919 341920 35
1 2003 9 2217 72218 72219 72220 72317 92318 92319 92320 112417 12418 12419 12420 3
1 2003 9 2717 142718 142719 142720 162817 182818 182819 182820 21
1 200310 717 0 718 0 719 0 720 0 817 7 818 7 819 7 820 10 917 23 918 23 919 23 920 25
1 200310 1017 121018 121019 121020 151317 01318 01319 01320 11617 01618 01619 01620 2
1 200310 1717 01718 01719 01720 11817 01818 01819 01820 12217 02218 02219 02220 1
1 200310 2317 02318 02319 02320 12817 172818 172819 172820 192917 702918 702919 702920 72
1 200311 617 4 618 4 619 4 620 6 717 21 718 21 719 21 720 231517 01518 01519 01520 1
1 200311 1617 01618 01619 01620 32117 12118 12119 12120 12217 202218 202219 202220 20
1 200311 2517 02518 02519 02520 12717 02718 02719 02720 1
1 200312 1017 411018 411019 411020 411417 431418 431419 431420 441617 01618 01619 01620 1
1 200312 1717 51718 51719 51720 71917 01918 01919 01920 32317 22318 22319 22320 4
1 200312 2417 82418 82419 82420 92717 02718 02719 02720 12817 02818 02819 02820 1
1 2004 1 117 0 118 0 119 0 120 1 517 1 518 1 519 1 520 3 617 4 618 4 619 4 620 4
1 2004 1 917 3 918 3 919 3 920 51117 01118 01119 01120 21517 01518 01519 01520 1
1 2004 1 1817 41818 41819 41820 62617 32618 32619 32620 62717 22718 22719 22720 5
1 2004 1 2817 02818 02819 02820 22917 52918 52919 52920 6
1 2004 2 317 3 318 3 319 3 320 4 417 0 418 0 419 0 420 2 617 3 618 3 619 3 620 3
1 2004 2 917 0 918 0 919 0 920 11217 201218 201219 201220 221317 01318 01319 01320 1
1 2004 2 1417 91418 91419 91420 121517 101518 101519 101520 121617 51618 51619 51620 5
1 2004 2 1717 101718 101719 101720 122417 32418 32419 32420 42617 162618 162619 162620 17
1 2004 2 2717 272718 272719 272720 28
1 2004 3 617 0 618 0 619 0 620 2 917 2 918 2 919 2 920 41017 01018 01019 01020 3
1 2004 3 1517 41518 41519 41520 71617 131618 131619 131620 131817 01818 01819 01820 2
1 2004 3 1917 01918 01919 01920 12717 12718 12719 12720 32817 02818 02819 02820 1
1 2004 3 3017 03018 03019 03020 33117 133118 133119 133120 16
1 2004 4 117 0 118 0 119 0 120 1 217 0 218 0 219 0 220 11017 01018 01019 01020 3
1 2004 4 1117 621118 621119 621120 651217 11218 11219 11220 21317 101318 101319 101320 11
1 2004 4 1417 21418 21419 21420 22617 252618 252619 252620 272717 52718 52719 52720 5
1 2004 5 117 12 118 12 119 12 120 15 217 8 218 8 219 8 220 8 317 5 318 5 319 5 320 6
1 2004 5 417 0 418 0 419 0 420 21917 11918 11919 11920 12317 02318 02319 02320 1
1 2004 5 3017 113018 113019 113020 143117 13118 13119 13120 1
1 2004 6 117 0 118 0 119 0 120 1 417 32 418 32 419 32 420 33 617 7 618 7 619 7 620 10
1 2004 6 717 0 718 0 719 0 720 11017 31018 31019 31020 61117 141118 141119 141120 14
1 2004 6 1617 11618 11619 11620 31717 01718 01719 01720 11817 81818 81819 81820 11
1 2004 6 2217 02218 02219 02220 22317 132318 132319 132320 142417 12418 12419 12420 1
1 2004 6 2517 12518 12519 12520 22617 82618 82619 82620 92717 12718 12719 12720 4
1 2004 6 2817 22818 22819 22820 42917 12918 12919 12920 13017 13018 13019 13020 4
1 2004 7 117 4 118 4 119 4 120 5 217 1 218 1 219 1 220 2 317 0 318 0 319 0 320 2
1 2004 7 417 1 418 1 419 1 420 1 817 1 818 1 819 1 820 41017 31018 31019 31020 4
1 2004 7 1117 341118 341119 341120 361517 11518 11519 11520 21717 01718 01719 01720 3
1 2004 7 1817 01818 01819 01820 11917 541918 541919 541920 562317 492318 492319 492320 51
1 2004 7 2817****2818****2819****2820****3017 13018 13019 13020 13117 83118 83119 83120 11
1 2004 8 117 3 118 3 119 3 120 3 217 23 218 23 219 23 220 23 317 7 318 7 319 7 320 9
1 2004 8 417**** 418**** 419**** 420**** 617 13 618 13 619 13 620 13 717**** 718**** 719**** 720****
1 2004 8 917**** 918**** 919**** 920****1117****1118****1119****1120****1317 391318 391319 391320 42
1 2004 8 1417 491418 491419 491420 521517 71518 71519 71520 101617****1618****1619****1620****
1 2004 8 1817****1818****1819****1820****2017****2018****2019****2020****2217 02218 02219 02220 3
1 2004 8 2317****2318****2319****2320****2517****2518****2519****2520****2717 52718 52719 52720 5
1 2004 8 2817****2818****2819****2820****3017 03018 03019 03020 13117 13118 13119 13120 2
1 2004 9 117 29 118 29 119 29 120 32 217**** 218**** 219**** 220**** 417**** 418**** 419**** 420****
1 2004 9 617 7 618 7 619 7 620 8 717 1 718 1 719 1 720 1 817 4 818 4 819 4 820 7
1 2004 9 917 24 918 24 919 24 920 261017****1018****1019****1020****1217****1218****1219****1220****
1 2004 9 1417 41418 41419 41420 61517 151518 151519 151520 16

Temperature File

1 2000 1 65 37 71 35 75 46 76 50 66 39 53 31 54 35 57 29 58 37 64 51 68 45 65 34 66 37 57 29
42 21 52 28 58 33 36 23 36 25 46 32 44 24 36 19 38 26 39 34 39 30 34 24 33 19 34 16 37 18 48 28 50 31
1 2000 2 45 27 45 26 51 23 58 31 51 31 50 29 55 30 56 29 52 38 62 36 68 39 59 39 50 34 66 45
62 39 60 34 61 37 57 39 72 45 66 37 53 33 55 31 63 36 69 39 74 43 76 46 74 47 71 47 64 35
1 2000 3 59 34 71 39 57 27 61 32 58 31 69 37 71 39 80 52 83 54 84 57 82 59 74 51 58 35 59 33
68 38 76 47 76 49 60 36 56 38 63 48 61 50 55 42 57 42 66 36 73 42 75 48 75 47 72 50 70 40 64 47 64 46

1 2000 4 67 37 73 41 78 58 79 59 67 42 70 41 82 50 82 48 70 42 67 41 76 45 78 54 65 47 59 48
69 56 73 60 76 57 76 54 62 49 69 47 76 54 72 52 66 48 71 50 66 52 59 48 63 44 61 46 64 50 72 47
1 2000 5 78 47 81 57 79 56 78 50 81 50 86 56 89 61 89 62 88 64 88 67 85 58 87 58 94 65 88 66
79 56 76 49 79 53 82 62 89 66 94 69 91 68 85 66 83 63 86 67 91 72 88 65 86 62 88 67 78 59 66 54 70 56
1 2000 6 83 57 91 66 93 68 84 64 76 66 76 66 77 57 78 53 82 57 86 61 87 61 90 66 90 71 94 71
92 69 91 73 91 74 92 74 92 72 87 71 86 68 90 72 91 69 90 69 90 70 90 72 91 72 91 73 89 73 84 68
1 2000 7 85 65 86 62 88 62 90 67 92 71 88 72 85 68 84 65 83 65 89 72 93 76 88 72 82 69 84 69
85 69 89 66 90 68 90 68 91 71 88 71 80 67 82 69 85 70 84 70 80 67 79 70 85 72 88 69 88 70 88 71 86 73
1 2000 8 88 74 91 71 89 73 85 72 84 69 87 69 90 73 93 74 94 74 92 72 90 71 87 69 83 65 81 63
86 65 90 67 90 67 89 67 88 68 82 63 80 62 81 59 84 63 88 70 86 70 83 67 85 65 84 68 84 69 85 71 84 71
1 2000 9 86 73 88 74 88 72 83 72 78 69 74 65 76 64 82 64 83 64 84 62 85 64 86 67 88 68 89 69
87 68 79 54 73 52 73 58 78 65 85 65 86 69 84 69 80 71 82 69 88 70 83 57 68 55 72 51 75 55 76 60
1 200010 76 61 75 59 82 56 85 58 85 59 87 64 80 58 66 49 56 42 61 35 69 36 73 37 76 40 79 40
81 43 82 45 79 50 74 56 73 51 74 44 76 45 79 47 78 50 75 48 74 47 74 50 75 55 79 53 72 41 66 37 66 36
1 200011 67 36 69 35 73 35 77 39 70 43 64 36 67 40 74 55 77 60 77 59 69 44 62 41 64 37 66 39
56 34 58 30 58 39 56 33 47 36 47 34 47 28 45 22 46 26 50 31 57 37 66 49 61 42 63 38 63 36 61 33
1 200012 53 29 51 29 41 30 41 25 47 21 49 24 48 28 58 31 56 32 50 39 53 40 62 40 57 32 64 40
60 43 61 43 72 39 60 28 52 28 46 24 42 21 47 24 40 21 42 19 42 21 37 18 40 23 41 30 41 25 41 23 38 21
1 2001 1 40 22 40 23 40 18 42 16 49 18 53 25 55 25 55 32 45 32 47 27 58 26 60 35 58 43 60 41
63 46 63 46 57 40 54 41 66 47 74 46 52 29 46 24 50 29 51 31 50 31 46 25 53 29 56 24 62 26 66 37 71 51
1 2001 2 65 44 54 41 50 28 49 29 51 37 57 29 60 31 68 33 72 36 72 44 60 35 51 34 49 36 60 42
68 49 77 52 75 45 50 28 49 24 63 31 73 42 60 35 46 31 58 31 67 36 71 46 66 36 57 34
1 2001 3 56 34 66 42 62 49 59 47 62 44 48 29 46 31 55 30 57 36 57 30 60 28 68 37 75 53 77 47
70 49 64 49 69 45 62 42 56 33 58 40 61 47 62 47 66 42 70 38 68 42 51 34 52 30 51 28 62 38 70 49 72 49
1 2001 4 64 46 59 39 61 41 60 46 62 38 73 41 85 53 90 65 91 64 90 61 88 59 86 61 87 65 79 56
79 57 74 51 64 36 54 32 59 31 70 38 77 50 81 52 82 54 83 60 75 50 60 41 70 38 77 49 74 44 74 41
1 2001 5 77 47 80 50 81 50 83 52 86 56 80 56 76 50 74 53 77 47 81 52 86 57 89 62 82 56 75 46
74 49 73 56 66 54 72 56 90 63 91 64 86 66 87 72 82 63 81 57 84 57 85 61 85 58 83 64 76 61 79 56 80 62
1 2001 6 80 64 85 67 86 65 85 66 90 69 91 69 89 72 84 71 80 67 84 65 87 66 89 70 89 73 84 73
77 73 83 71 85 68 86 63 88 63 86 66 87 69 88 67 87 71 83 70 83 67 85 68 88 69 90 71 91 71 91 71
1 2001 7 91 73 87 71 86 68 85 68 86 71 85 69 84 63 84 61 85 68 90 71 92 74 90 71 82 66 80 60
85 60 88 61 87 64 89 64 87 71 83 66 83 62 84 65 86 68 87 74 89 76 88 75 82 72 78 66 82 68 82 67 80 64
1 2001 8 81 62 84 64 85 64 87 65 89 67 89 69 92 72 94 74 95 75 94 77 92 76 91 72 91 72 87 73
85 69 87 66 89 65 92 69 89 70 86 71 86 69 85 68 86 65 84 67 83 67 85 62 87 62 91 68 85 71 81 69 85 70
1 2001 9 85 71 82 70 83 67 80 68 83 68 85 66 84 63 86 63 85 67 87 67 86 66 83 58 82 59 81 60
78 58 78 58 78 52 80 51 81 52 81 58 84 62 85 65 86 67 86 66 79 62 71 50 73 48 75 49 71 50 69 51
1 200110 70 46 75 46 81 48 83 54 84 56 83 55 72 46 64 41 66 42 73 43 78 49 79 50 78 51 81 54
80 54 78 48 73 44 65 37 69 42 77 49 81 55 83 55 83 54 86 59 87 64 76 44 61 37 56 34 59 30 66 31 73 37
1 200111 75 45 79 48 82 52 77 49 68 39 62 37 68 31 76 35 74 37 70 32 71 39 64 38 62 32 69 38
71 44 74 48 74 43 71 45 71 42 73 46 61 34 59 27 64 36 69 53 71 62 74 60 74 58 78 53 78 53 79 57
1 200112 79 62 73 54 65 43 66 41 70 37 75 41 76 46 76 52 71 50 62 43 61 49 60 54 64 55 67 58
70 51 61 38 65 41 71 39 65 32 60 35 54 29 52 26 57 24 64 33 53 28 49 29 49 25 51 29 59 36 53 27 45 24
1 2002 1 45 29 41 27 35 27 33 23 42 21 53 24 52 34 45 26 52 27 63 36 66 39 60 26 55 28 56 27
60 33 57 31 57 33 59 38 62 38 55 37 50 37 55 35 61 40 68 51 69 45 61 30 66 33 72 39 74 44 79 50 80 60
1 2002 2 80 63 74 42 51 34 52 33 48 26 45 28 56 36 60 38 64 32 68 36 66 37 60 28 60 35 56 34
59 29 65 37 61 41 53 31 58 24 67 36 71 47 67 39 57 41 51 38 62 30 71 35 67 37 47 25
1 2002 3 50 21 60 32 69 51 65 35 46 26 56 27 66 31 72 37 75 45 71 49 60 37 65 41 66 52 69 50
77 51 83 57 75 53 62 49 63 42 71 50 73 50 53 34 52 26 64 33 77 45 78 51 73 52 62 39 66 37 76 57 76 59
1 2002 4 71 52 73 46 81 55 69 47 59 41 57 37 58 32 67 34 78 50 76 57 72 50 76 53 76 55 78 56
82 62 87 63 90 63 90 66 91 65 88 65 87 67 88 64 75 52 69 47 73 56 73 51 69 52 79 59 85 62 78 51
1 2002 5 76 53 84 63 84 67 70 56 61 52 71 48 82 59 85 66 89 68 90 69 83 65 82 61 87 66 79 54
73 46 78 50 83 55 85 59 72 51 64 48 68 43 68 46 72 44 82 48 88 57 88 57 87 56 85 58 83 66 84 66 87 65
1 2002 6 92 68 95 68 92 71 88 64 90 67 91 68 86 67 77 60 82 53 86 53 89 58 91 65 96 73 97 71
92 69 88 62 87 64 84 66 83 67 81 69 83 68 83 68 87 69 88 67 90 71 89 71 86 73 88 71 89 70 88 69
1 2002 7 87 64 89 67 91 70 93 72 95 71 92 69 87 64 87 60 90 66 93 72 86 71 79 65 81 67 84 69
86 71 90 73 94 72 94 72 95 77 96 74 92 70 87 70 87 72 87 73 86 73 89 72 91 73 93 73 95 77 96 78 95 75
1 2002 8 93 72 89 70 89 70 89 72 88 70 89 67 84 63 83 59 84 57 84 59 88 58 92 62 94 67 92 67
90 70 90 75 92 74 93 73 94 71 93 72 92 71 91 67 95 72 98 75 96 73 88 72 85 74 78 72 80 72 80 73 80 72
1 2002 9 80 70 80 66 84 65 90 69 90 69 87 63 84 64 86 67 85 70 83 72 88 68 86 61 82 59 85 67
85 69 86 68 86 71 84 65 84 66 86 65 87 62 88 63 87 67 82 67 80 66 83 69 86 72 89 72 84 67 84 66
1 200210 84 60 86 61 90 65 90 65 92 65 87 67 84 62 81 63 76 62 77 64 79 68 78 66 80 60 76 58
68 55 70 57 72 51 69 45 74 41 75 49 72 53 70 53 68 48 67 52 66 58 72 59 74 56 75 58 68 58 60 49 59 43
1 200211 60 36 59 36 59 39 59 44 64 45 73 44 65 37 63 34 71 37 77 57 82 65 81 58 66 46 58 36
66 35 69 47 65 51 59 36 61 31 63 35 64 43 65 45 58 33 60 34 69 36 66 36 56 36 49 26 51 24 58 37
1 200212 55 26 51 23 54 29 47 27 39 31 42 29 46 22 51 23 50 34 47 38 46 39 50 38 62 41 60 43
54 33 59 34 56 31 55 31 62 35 69 46 64 35 62 35 64 36 57 36 50 41 49 30 49 24 50 24 57 33 68 31 69 38
1 2003 1 68 51 64 47 62 46 53 32 51 26 55 29 50 28 52 33 65 45 67 41 56 26 44 24 43 24 48 29
46 26 46 20 41 22 40 18 38 19 52 28 56 31 42 25 36 18 31 14 41 12 48 21 43 22 41 15 57 28 57 42 43 36
1 2003 2 48 37 54 33 66 35 70 42 61 30 52 29 45 34 45 29 50 28 50 33 48 28 57 36 57 23 57 25
66 38 56 40 42 31 41 31 55 27 58 33 61 32 71 46 74 42 64 29 62 37 53 33 44 39 46 37
1 2003 3 51 38 60 45 60 36 59 34 67 44 66 50 56 37 49 32 68 41 66 39 56 34 61 38 74 45 68 42
58 38 67 48 71 56 69 56 66 50 67 54 73 60 77 50 72 47 73 47 73 45 77 46 72 51 72 49 79 57 75 47 60 35
1 2003 4 60 32 75 50 83 54 82 55 83 59 75 50 66 48 52 45 51 45 54 45 55 42 60 45 73 46 74 45
76 44 80 49 80 49 76 51 66 51 68 46 72 45 77 56 74 46 72 41 72 52 74 58 73 55 76 49 81 52 85 59
1 2003 5 83 58 82 65 78 59 68 50 67 45 77 58 84 66 88 68 89 68 91 70 91 74 85 64 79 55 79 47
76 56 77 59 76 59 70 56 70 54 72 54 80 55 80 60 70 63 69 60 77 56 84 65 77 61 74 56 80 57 80 57 78 59
1 2003 6 75 58 77 52 79 55 80 67 83 68 82 59 83 65 82 73 86 72 87 70 89 71 89 74 88 72 90 74
89 73 87 71 83 71 84 71 87 71 86 68 80 64 79 58 84 62 90 62 93 64 93 68 93 70 91 71 88 70 90 71
1 2003 7 86 71 81 69 84 70 88 69 91 73 91 76 91 76 93 75 94 74 93 72 92 71 90 71 86 69 85 68
84 69 89 71 89 71 89 71 85 70 85 66 88 71 89 75 86 72 84 71 83 70 87 72 89 71 89 74 91 74 91 73 87 72
1 2003 8 87 73 88 74 86 71 86 73 86 69 88 72 85 74 85 73 83 72 84 72 84 73 85 70 87 71 89 71
90 72 91 72 89 71 87 68 86 70 88 72 89 70 90 71 90 72 88 68 86 65 90 72 94 73 94 73 93 74 92 74 92 73
1 2003 9 91 70 91 70 91 69 90 70 87 69 79 64 75 65 79 68 81 67 80 64 78 59 77 64 75 63 80 61
86 65 85 65 81 61 79 65 83 60 87 59 86 63 85 65 80 66 82 59 83 58 82 57 83 62 83 65 76 52 71 49
1 200310 72 48 73 49 68 44 73 46 76 53 78 50 77 55 74 63 77 63 75 67 67 63 76 60 80 57 77 59
72 51 72 42 75 43 70 45 67 42 75 44 79 49 76 52 67 39 63 41 66 46 74 58 77 62 73 59 67 51 70 45 74 46
1 200311 77 47 80 47 81 50 83 63 85 64 83 67 78 63 67 56 57 45 60 42 69 45 77 55 74 52 62 34

```
 59 34 68 46 74 50 75 54 75 57 69 41 70 37 75 43 75 41 75 43 72 42 59 41 60 41 73 45 64 34 55 29
    1 200312      65 35 59 29 48 26 47 34 51 39 45 35 47 28 48 25 54 27 66 36 67 44 55 30 49 31 50 37
 49 33 57 29 65 34 57 30 46 30 44 30 46 23 54 29 65 33 67 43 58 31 49 28 55 27 60 26 63 32 65 39 62 29
    1 2004 1      60 30 65 32 71 45 76 55 79 60 73 40 44 22 40 22 41 27 34 23 33 15 47 20 61 29 55 29
 52 30 49 26 48 22 62 33 61 34 40 22 41 20 49 22 50 26 48 29 48 28 34 28 34 29 36 28 46 27 54 30 47 23
    1 2004 2      40 20 48 24 60 33 55 29 55 29 65 35 71 47 52 28 48 25 53 40 56 43 52 39 49 35 53 38
 49 38 44 29 41 30 43 31 57 29 67 33 70 40 65 31 57 33 53 39 50 37 46 36 41 32 50 31 62 26
    1 2004 3      70 32 77 45 78 52 80 51 81 56 82 63 73 47 65 41 57 30 52 36 57 32 66 37 63 39 60 32
 68 46 65 53 58 40 54 33 63 39 66 33 70 42 60 32 52 26 58 26 70 34 75 43 78 44 73 52 63 44 61 43 65 47
    1 2004 4      66 43 61 43 59 39 63 43 62 37 60 29 70 41 80 50 78 51 75 45 77 55 77 51 72 57 73 49
 59 42 69 38 75 44 83 57 83 58 83 60 84 60 83 61 84 60 82 60 79 57 80 60 77 52 69 43 71 44 77 51
    1 2004 5      75 59 76 65 74 56 67 47 71 48 79 56 86 59 86 62 86 61 87 58 86 59 86 61 86 62 84 60
 84 59 83 58 85 59 84 60 85 64 88 52 90 68 92 71 92 70 89 69 90 71 93 72 92 71 91 71 87 67 81 65 82 70
    1 2004 6      89 68 87 66 88 68 90 68 86 67 88 66 84 71 84 68 87 68 87 69 90 70 86 67 81 65 83 66
 85 69 83 69 84 71 90 73 91 72 87 68 83 67 87 71 88 74 90 70 90 74 84 65 84 69 86 71 87 68 85 70
    1 2004 7      86 70 85 68 88 72 93 75 90 73 91 71 95 70 94 72 93 70 93 72 89 71 89 74 93 73 94 71
 89 66***199-99-99 87 70 89 65***203-99-99 86 71 86 72 87 72 86 72 89 70 87 72 80 74 86 72 89 67 88 75
    1 2004 8      90 77 84 76 85 74 92 71 93 72 78 62 79 56 82 58 84 60 85 63 85 64 85 65 80 71 78 67
 75 68 83 68 84 65 85 65 90 71 89 73 91 74 78 71 82 67 84 64 85 67 84 71 87 73 89 71 87 72 85 74 88 72
```

Crop File

```
*** First Possible and last possible dates for crop ***
265  72
*** Weir Control ***
 1
 1160 1160 1160 1160 1160 1160 1160 1160 1160 1160 1160 1160
*** Trafficability ***
 915 1 1 820              3.9      1.2      2.0
12311231 820              3.9      1.2      2.0
*** Crop ***
 928 2 3       30.00
 928 2 3
*** Root Depths ***
11
 1 1 30.00 125 30.00 210 10.00 3 1  3.00 915  3.00 921  3.0010 1  7.001016 15.00
1031 25.001116 30.001231 30.00
*** Yield Inputs ***
 1
  276  130   1.00000   1.00000   2.00000  27.00000
24 7       11.16000  -1.17000    .05800   -.00050 100.00000   1.00000
100.0000  7.2000100.0000   .6500 271 130   1
  0 24 .19 25 54 .13 55 74 .19 75 94 .26 95109 .25110129 .01130130 .00
 .01 .01 .01 .01 .01 .03 .03 .03 .03 .03 .03 .03 .03 .05 .05 .10 .10 .15 .15 .20
 .20 .10 .05 .02
*** Salinity Modifications ***
Threshold     Slope
    4000.000000    2.500000E-02
*** Irrigation Water Salinity ***
 12
  1  1     400.0
  2  1     400.0
  3  1     400.0
  4  1     400.0
  5  1     400.0
  6 15     400.0
  7 23     400.0
  8  3     400.0
  9  3     400.0
 10  4     400.0
 11  5     400.0
 12 31     400.0
```

Nitrogen File

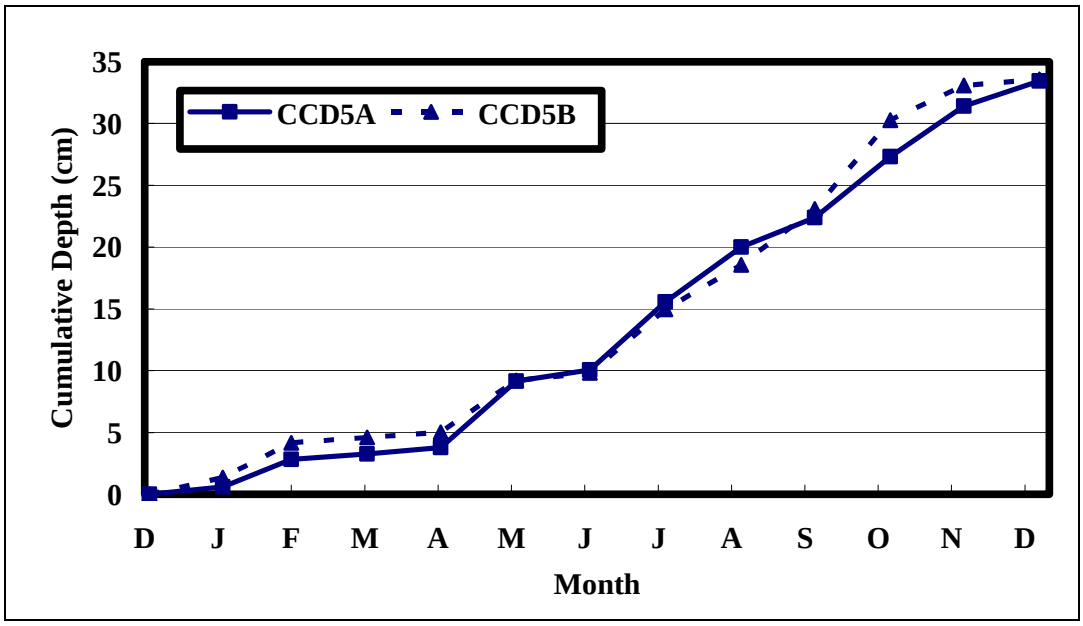
```
*General
&ROTYR NCROP ISYLD ISTMP OPFLG OPATH
    3     1     1     1     1                                          c:\Program Files\Drainmod\outputs
&LMBDA         TAU        DMOL       ERMAX
   7.5 6.50000E-01 1.00000E-06 1.00000E-04
& TOPC  CINI ONMAX       RKMIN      RKDEN  NDAY
    .8  20.0  1000 1.00000E-04 1.00000E+00     3

*Field
&TPADJ AVGTC   AMP  DAMP PHASE QRATE TBASE
     1 15.61  9.93  50.0  16.0   3.0  20.0
&WILPT  PCNT   RHO ADPTH IDTWT  IDDZ
  .170  .218 1.600   250    60     0
&SOILFILES
C:\Program Files\Drainmod\SOILS\goldsboro.MIS
C:\Program Files\Drainmod\SOILS\goldsboro.WDV

*Crops.....Levels
&C CN PDATE LGROW  PRCN PTYLD  LF LR LU
C1  1   100   130  1.55 10000   1  1  1

*Initial Conditions
```

```
&I  NDEP  CNO3
 1     0  15.0
 1   250    .0

*Fertilization
&F FDAYP FEAMT DEPIN
 1     5  .270  10.0
 1    60 1.750  10.0

*Uptake
&U FGROW  FNUP
 1  .000  .000
 1  .100  .010
 1  .200  .070
 1  .300  .190
 1  .400  .330
 1  .500  .470
 1  .600  .650
 1  .700  .800
 1  .800  .920
 1  .900  .990
 1 1.000 1.000

*Rooting Depths
&R RDAYP       RTDEP
 1     5        3.00
 1    21        4.00
 1    35       15.00
 1    44       25.00
 1    63       30.00
 1    93       30.00
 1   127       30.00
```

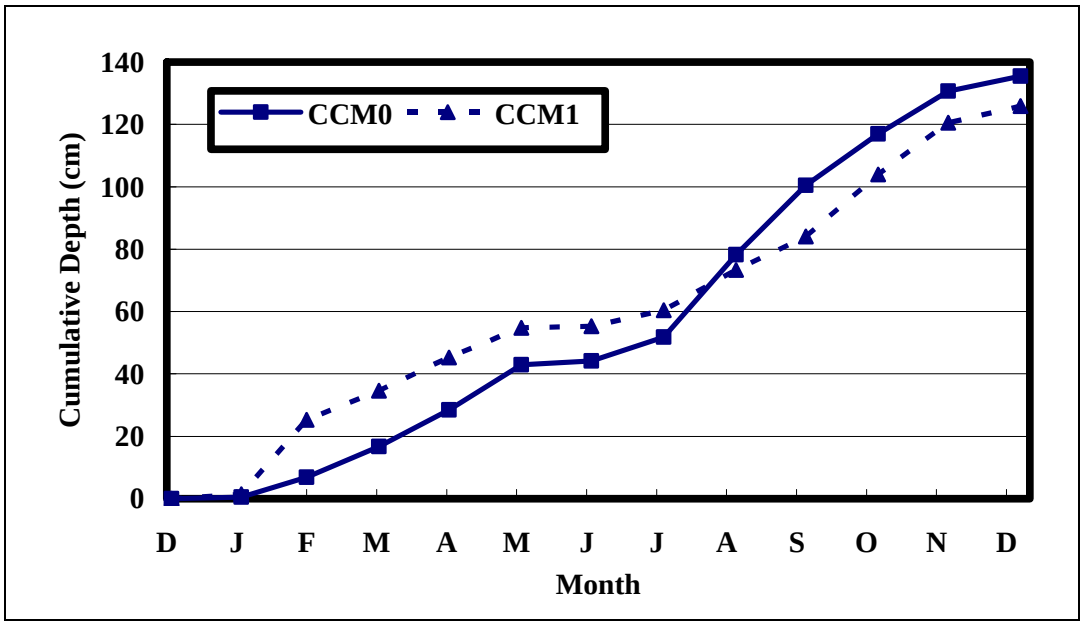
Appendix N. DRAINMOD-N Predicted Flows and Loads for Monitoring Sites in Core Creek Watershed

Site	DA (m^2)	Control		NMP		C.D.		C.D.+ NMP	
		Flow	NO_3	Flow	NO_3	Flow	NO_3	Flow	NO_3
CCD2B	424916	39.5	28.2	39.5	23.1	32.0	25.8	32.0	21.0
CCD4A	647492	30.4	21.6	30.4	17.0	23.2	20.2	23.2	15.8
CCD5A	1011706	30.8	7.9	30.8	6.2	24.4	7.2	24.4	5.7
CCD5B	222575	31.7	7.2	31.7	5.1	26.4	6.4	26.4	4.5
CCD7	809365	30.7	23.1	30.7	22.1	24.0	18.5	24.0	17.6
CCD8	3642143	38.6	38.4	38.6	29.4	29.7	32.5	29.7	24.9
CCD15A	1214048	31.7	40.1	31.7	31.1	20.0	33.1	20.0	25.7
CCD15B	384448	28.4	38.2	28.4	29.6	20.9	31.4	20.9	24.4
CCDPD4	708194	25.2	39.1	25.2	30.9	16.3	32.2	16.3	25.5
CCDPD5	809365	32.0	40.4	32.0	31.9	25.2	36.6	25.2	28.9
CCM0	2023413	32.8	42.0	32.8	33.2	28.7	40.0	28.7	31.4
CCM1	5260873	30.3	38.8	30.3	30.6	28.1	38.3	28.1	30.2
GCD3	1214048	28.5	39.2	28.5	30.8	23.2	35.1	23.2	27.7
GCD5	1424493	37.3	39.7	37.3	30.8	29.8	35.0	29.8	27.2
GCD7A	2848987	30.1	40.0	30.1	31.4	24.2	35.3	24.2	27.8
Average		31.9	32.3	31.9	25.6	25.1	28.5	25.1	22.6

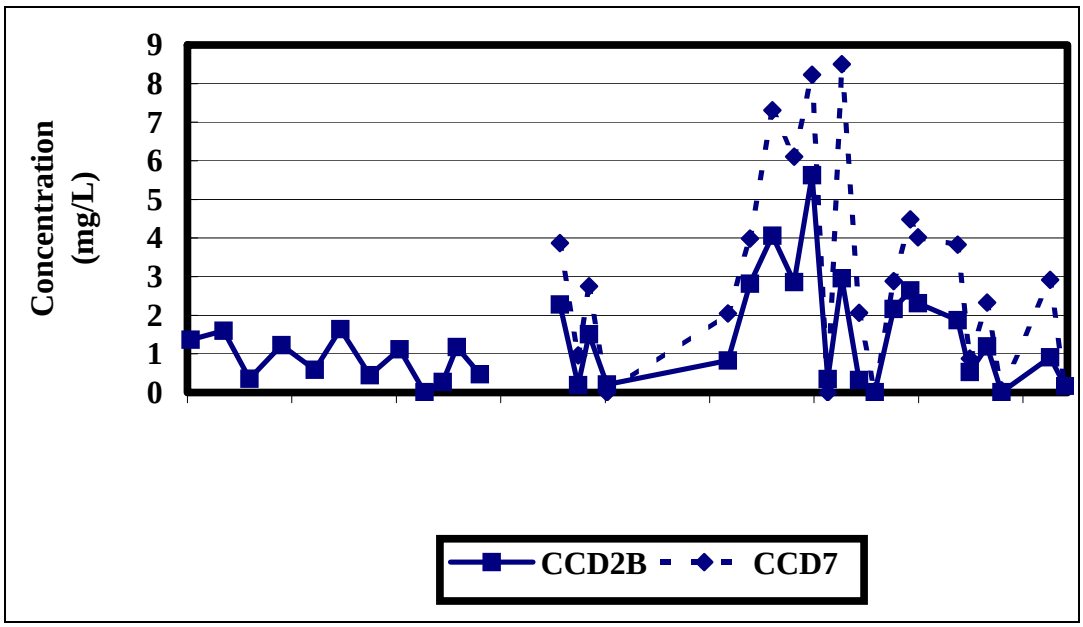
Appendix O. Observed Cumulative Monthly Drainage Depths and Nitrate Concentrations in Drainage Waters for Core Creek Water Control Structure Monitoring Sites, 2003



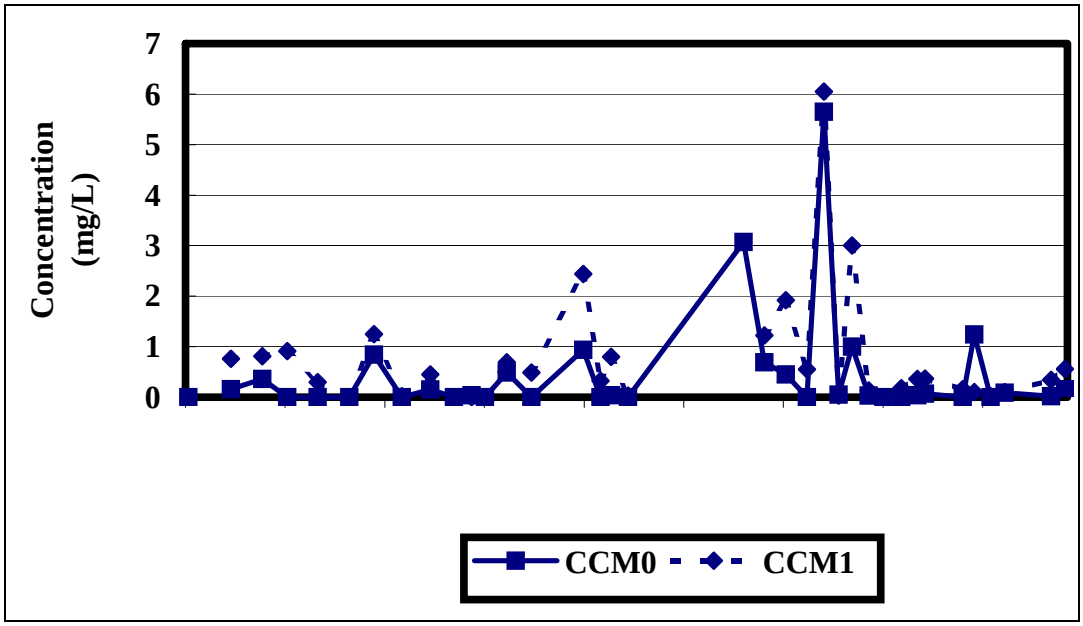
2003 Monthly cumulative drainage depths for CCD5A and CCD5B, cropped in soybeans



2003 Monthly cumulative drainage depths for CCM0 and CCM1, cropped in corn

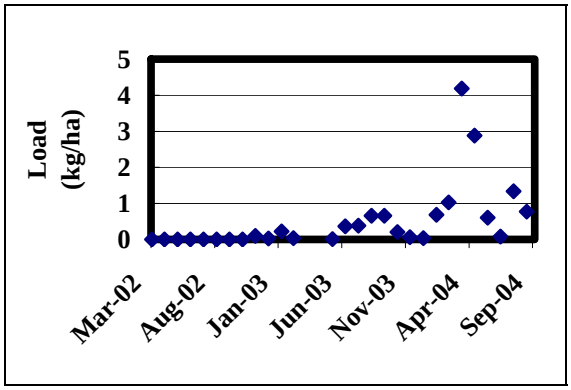


Observed drainage nitrate-N concentrations for CCD2B and CCD7, cropped in cotton

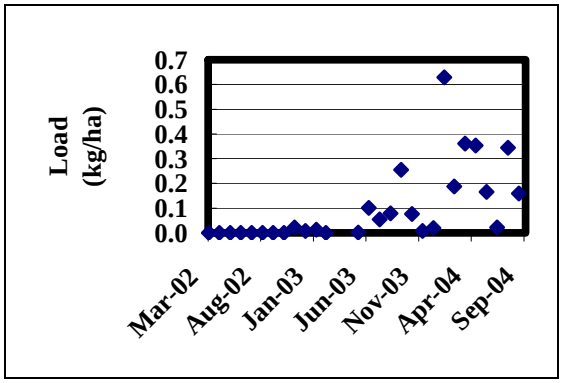


Observed drainage nitrate-N concentrations for CCM0 and CCM1, cropped in corn

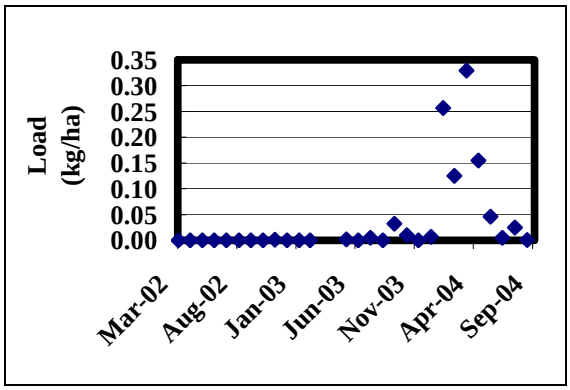
Appendix P. Monthly Nutrient Loadings for Core Creek Water Control Structure Monitoring Sites



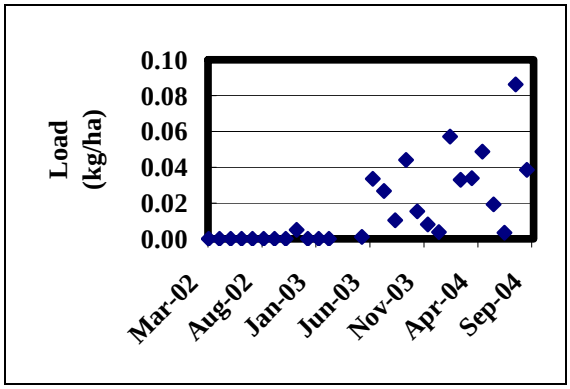
CCD2B monthly total Kjeldahl nitrogen loadings



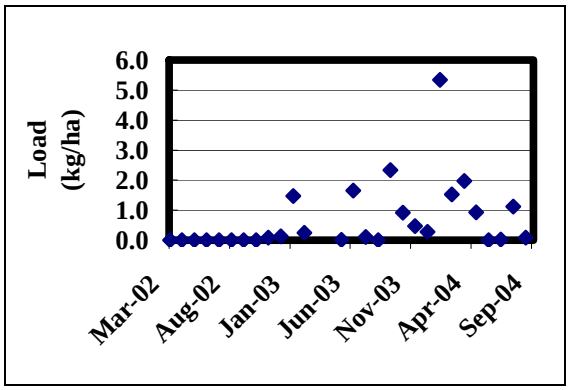
CCD2B monthly total phosphorus loadings



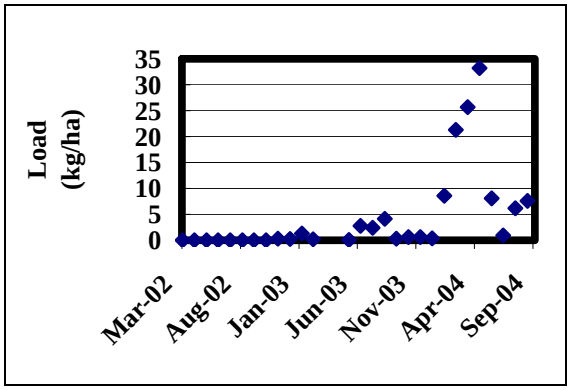
CCD2B monthly ammonium loadings



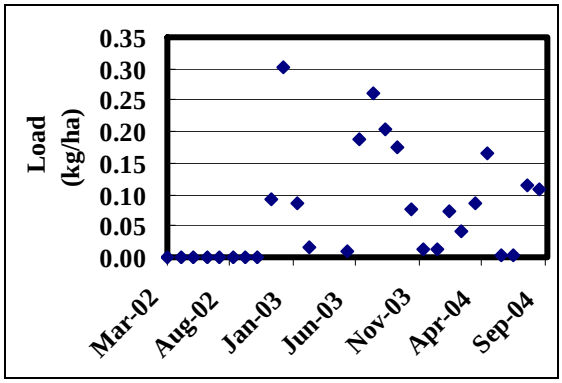
CCD2B monthly orthophosphate loadings



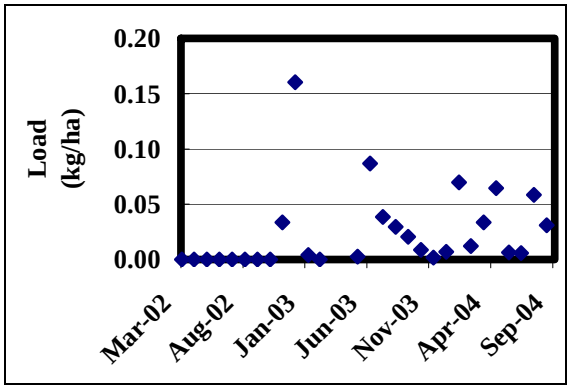
CCD2B monthly nitrate loadings



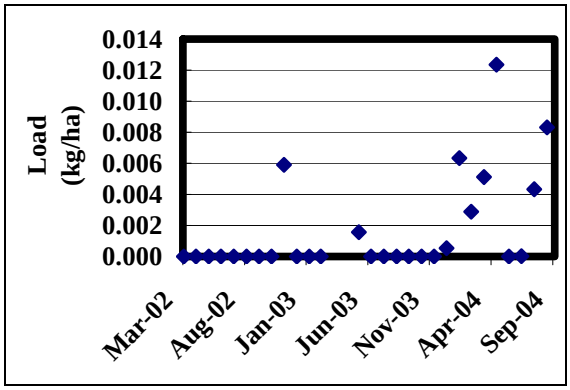
CCD2B monthly total suspended solids loadings



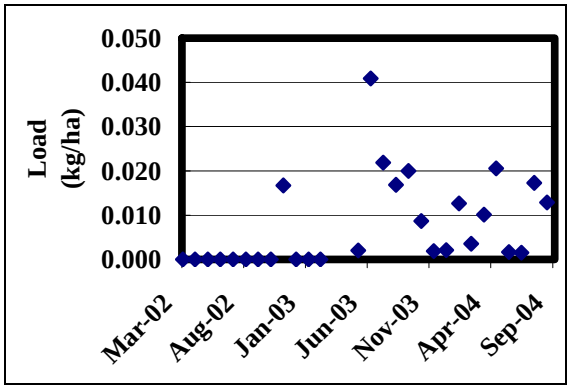
CCD4A monthly total Kjeldahl nitrogen loadings



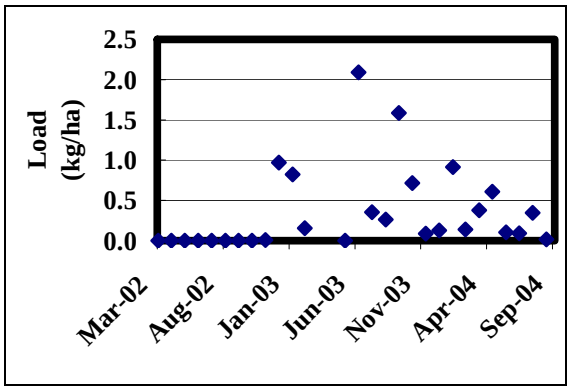
CCD4A monthly total phosphorus loadings



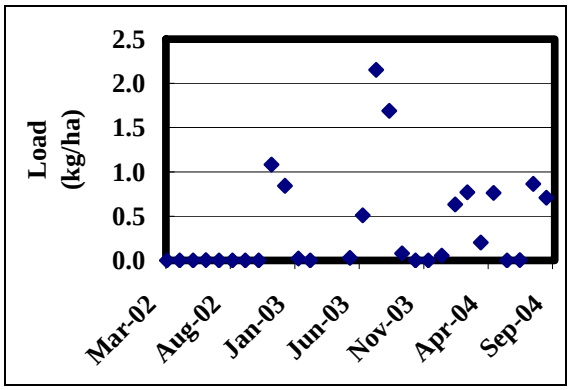
CCD4A monthly ammonium loadings



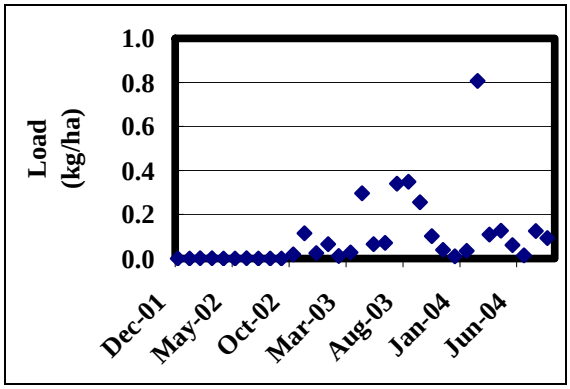
CCD4A monthly orthophosphate loadings



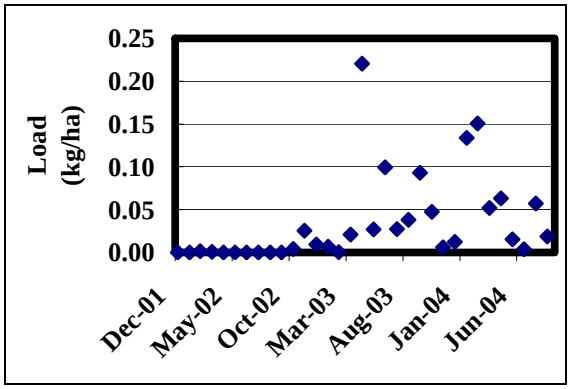
CCD4A monthly nitrate loadings



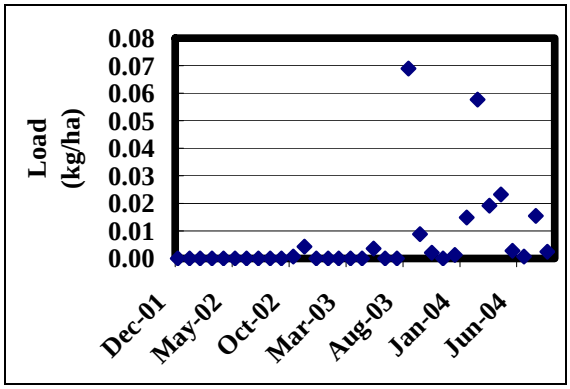
CCD4A monthly total suspended solids loadings



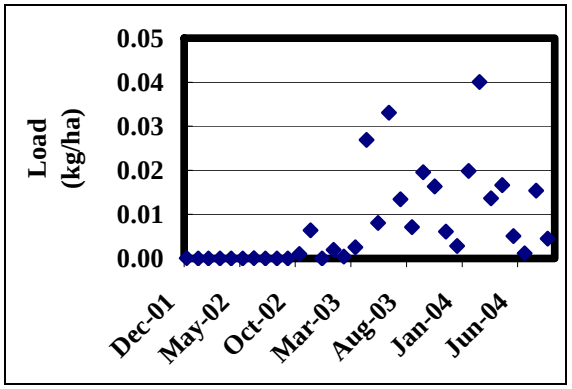
CCD5A monthly total Kjeldahl nitrogen loadings



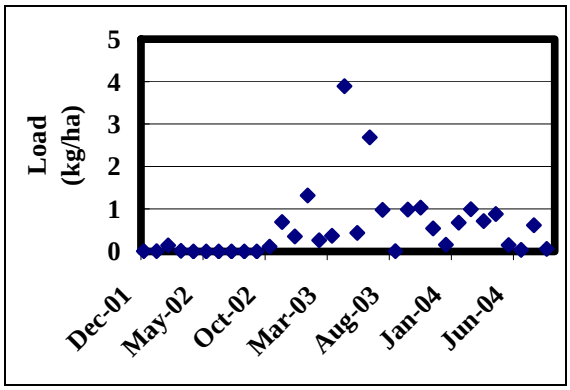
CCD5A monthly total phosphorus loadings



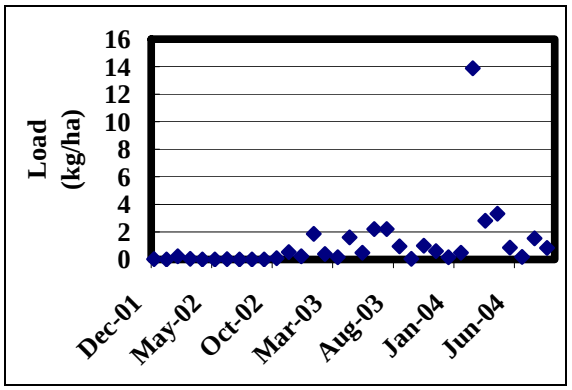
CCD5A monthly ammonium loadings



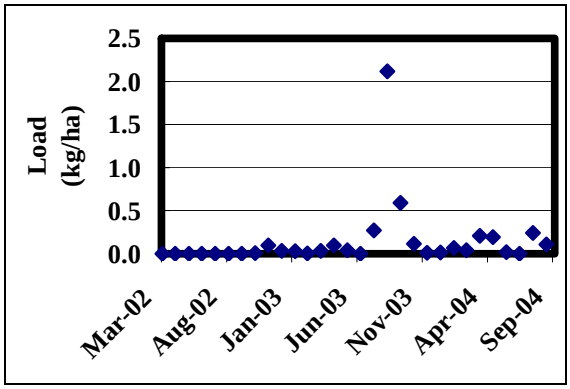
CCD5A monthly orthophosphate loadings



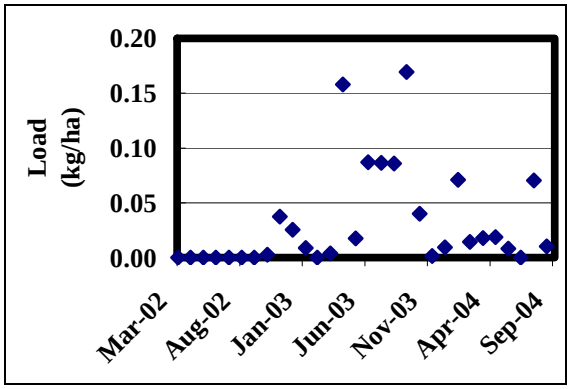
CCD5A monthly nitrate loadings



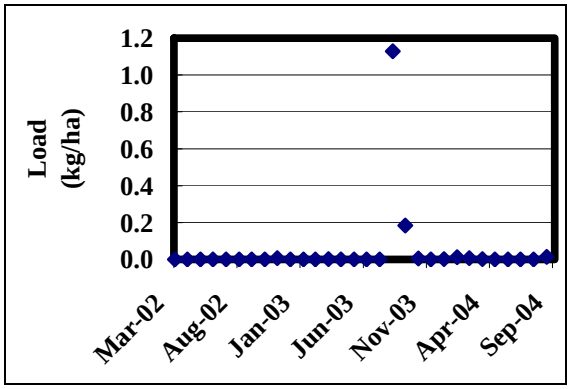
CCD5A monthly total suspended solids loadings



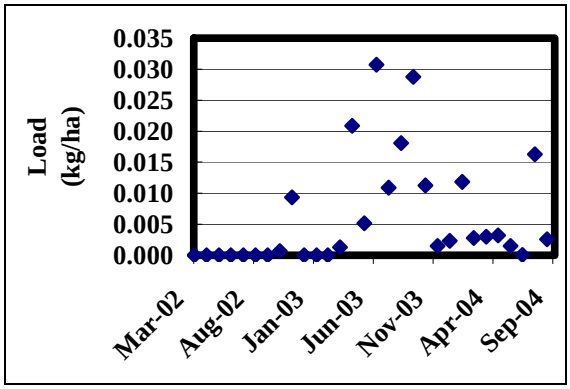
CCD5B monthly total Kjeldahl nitrogen loadings



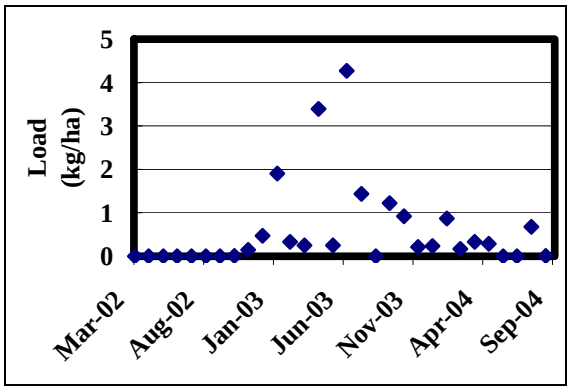
CCD5B monthly total phosphorus loadings



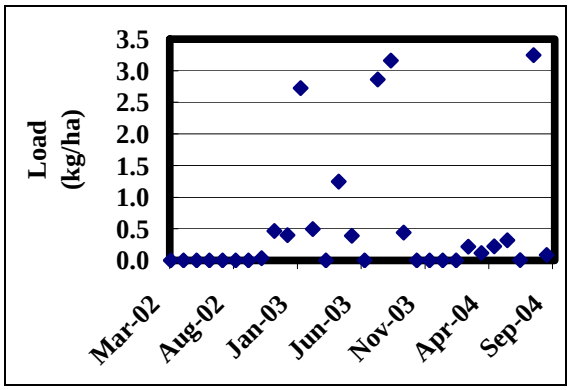
CCD5B monthly ammonium loadings



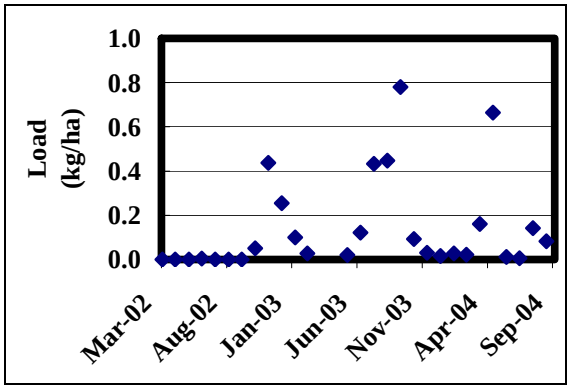
CCD5B monthly orthophosphate loadings



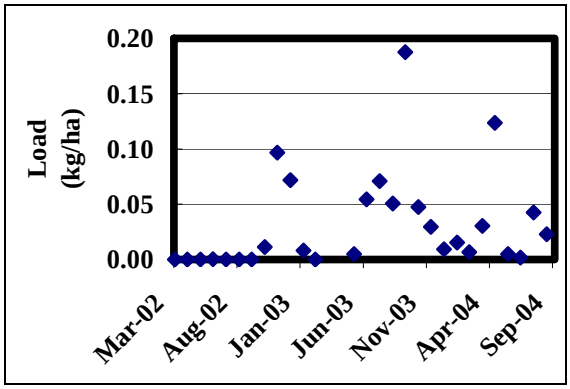
CCD5B monthly nitrate loadings



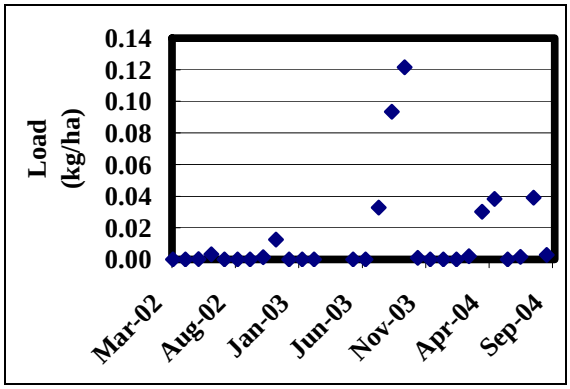
CCD5B monthly total suspended solids loadings



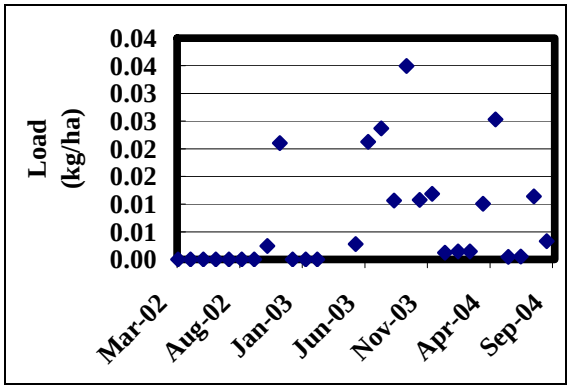
CCD7 monthly total Kjeldahl nitrogen loadings



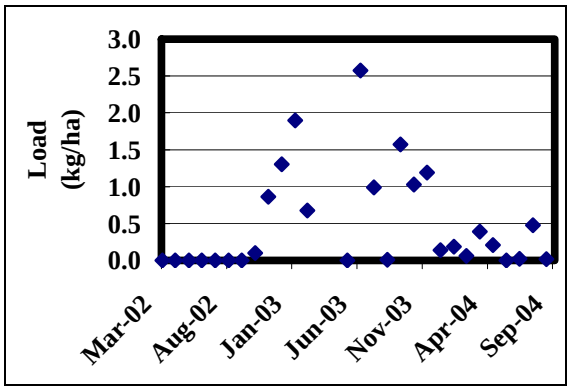
CCD7 monthly total phosphorus loadings



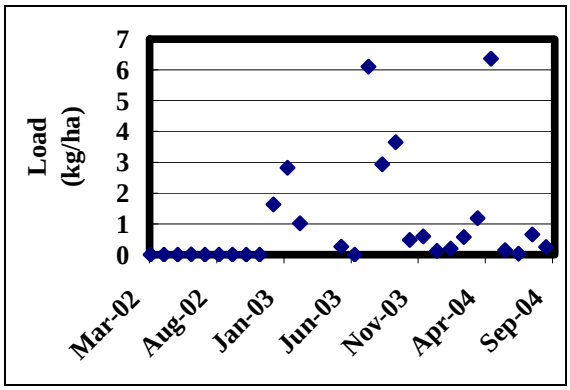
CCD7 monthly ammonium loadings



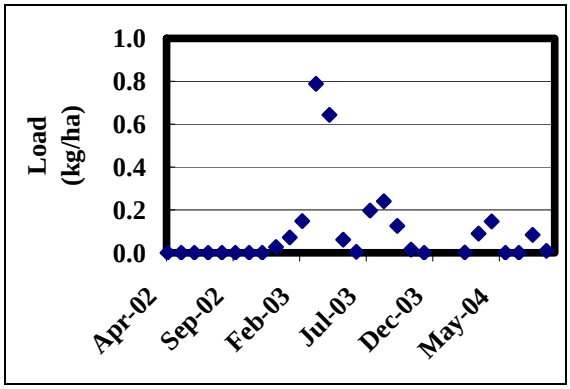
CCD7 monthly orthophosphate loadings



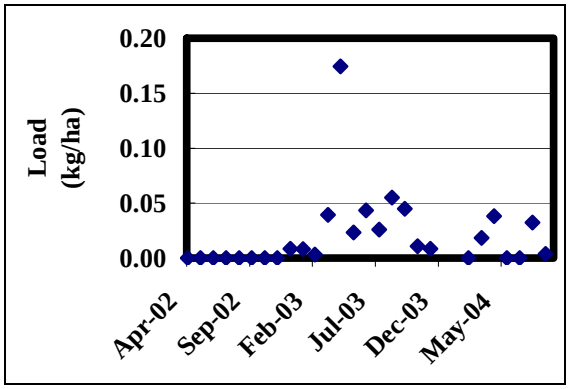
CCD7 monthly nitrate loadings



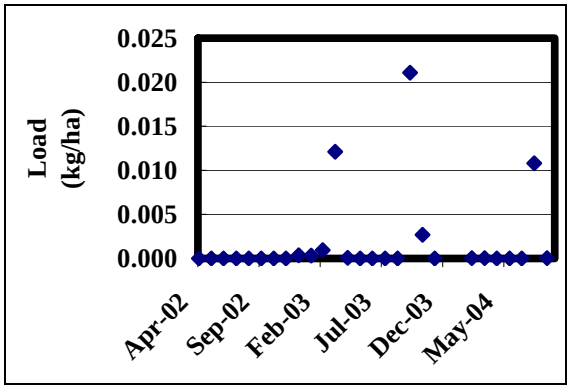
CCD7 monthly total suspended solids loadings



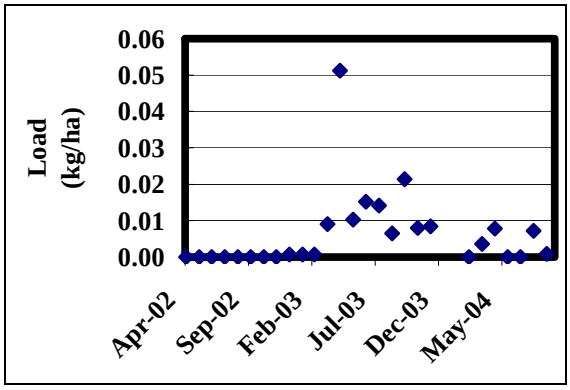
CCD15A monthly total Kjeldahl nitrogen loadings



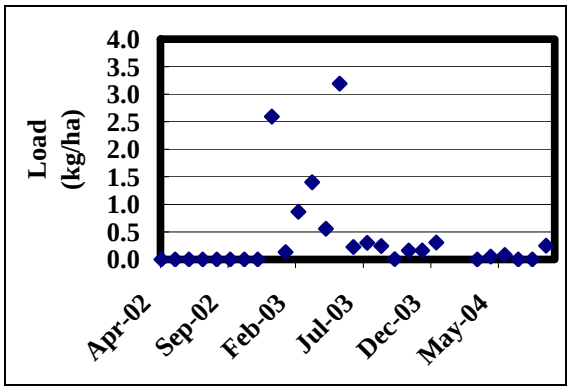
CCD15A monthly total phosphorus loadings



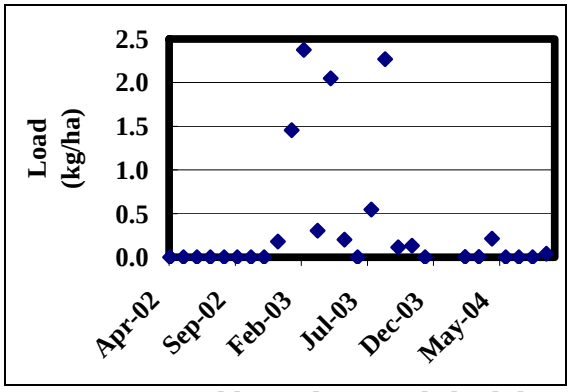
CCD15A monthly ammonium loadings



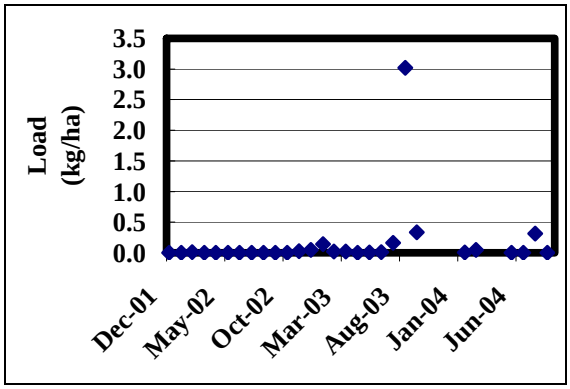
CCD15A monthly orthophosphate loadings



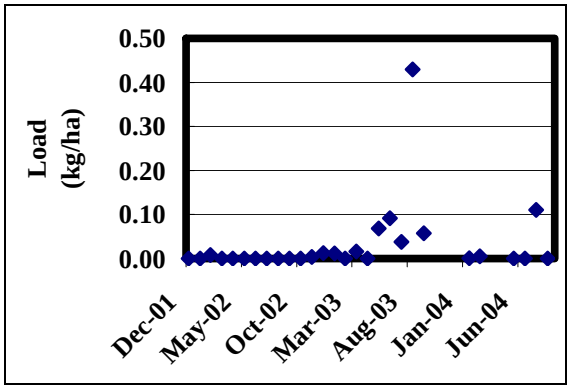
CCD15A monthly nitrate loadings



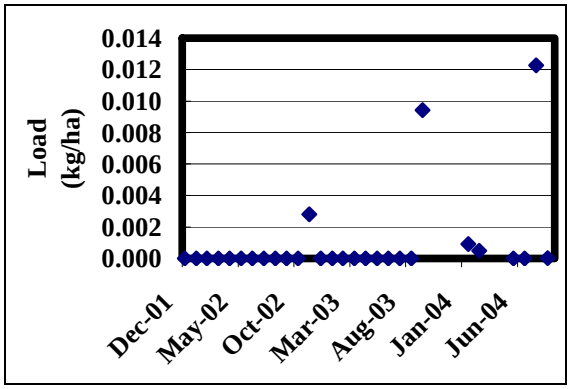
CCD15A monthly total suspended solids loadings



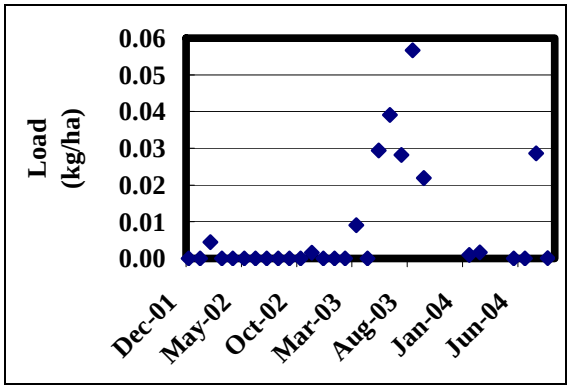
CCD15B monthly total Kjeldahl nitrogen loadings



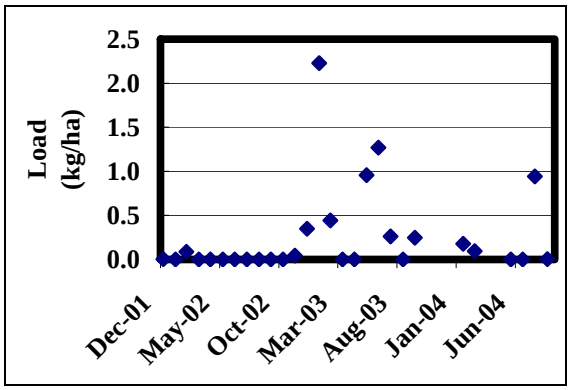
CCD15B monthly total phosphorus loadings



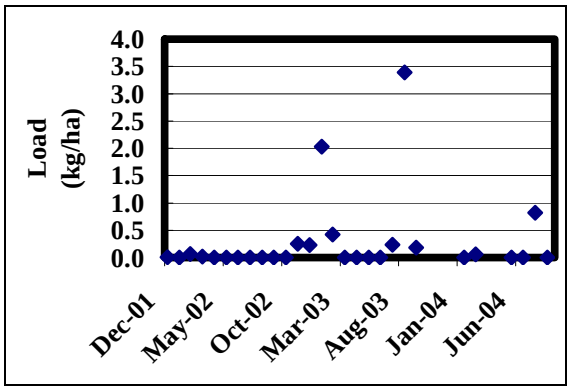
CCD15B monthly ammonium loadings



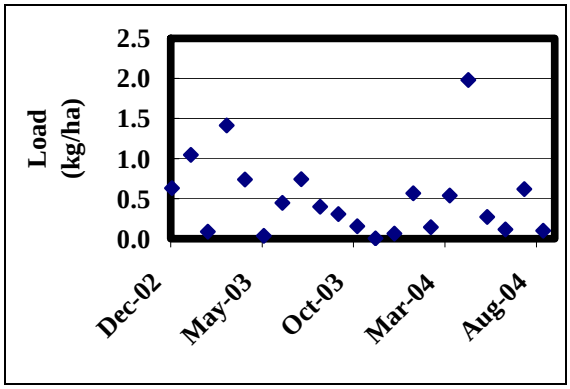
CCD15B monthly orthophosphate loadings



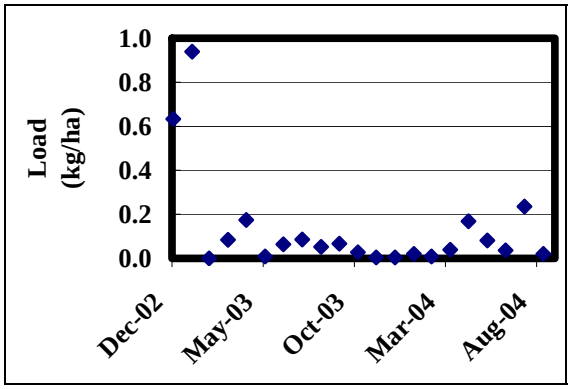
CCD15B monthly nitrate loadings



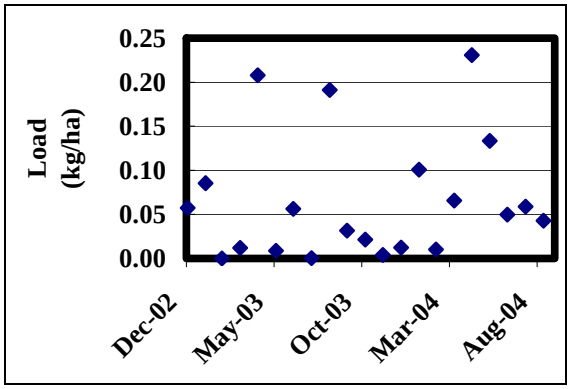
CCD15B monthly total suspended solids loadings



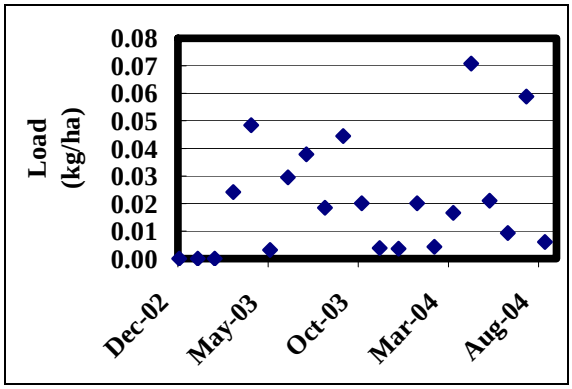
CCDPD4 monthly total Kjeldahl nitrogen loadings



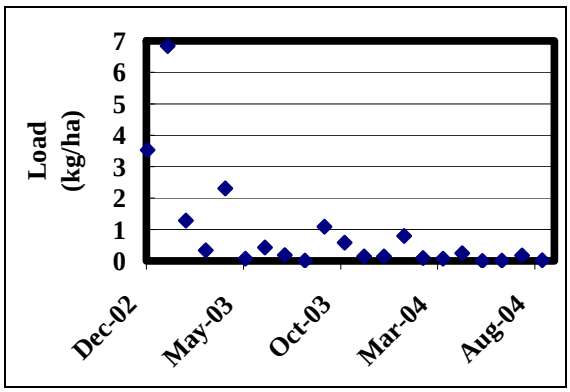
CCDPD4 monthly total phosphorus loadings



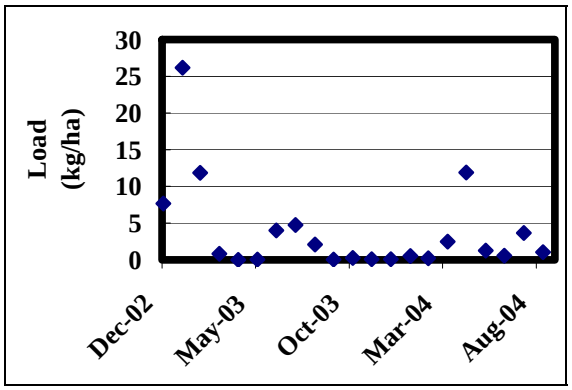
CCDPD4 monthly ammonium loadings



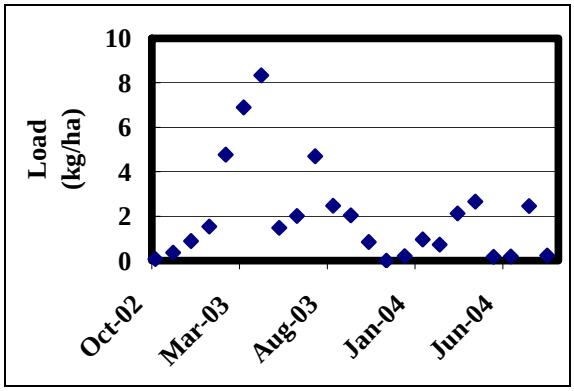
CCDPD4 monthly orthophosphate loadings



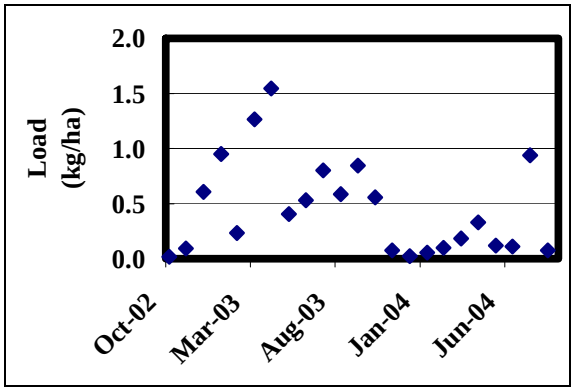
CCDPD4 monthly nitrate loadings



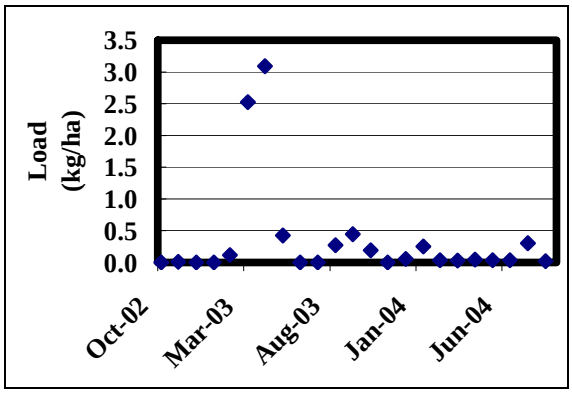
CCDPD4 monthly suspended sediment loadings



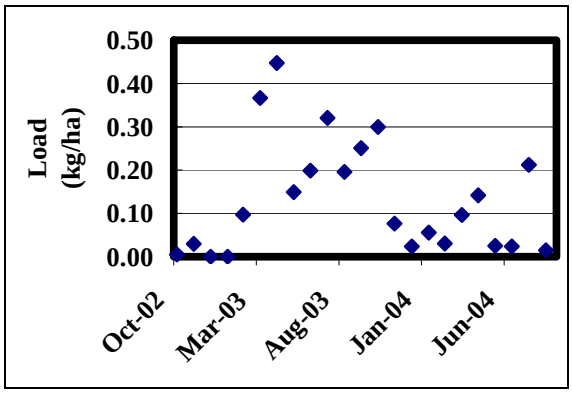
CCDPD5 monthly total Kjeldahl nitrogen loadings



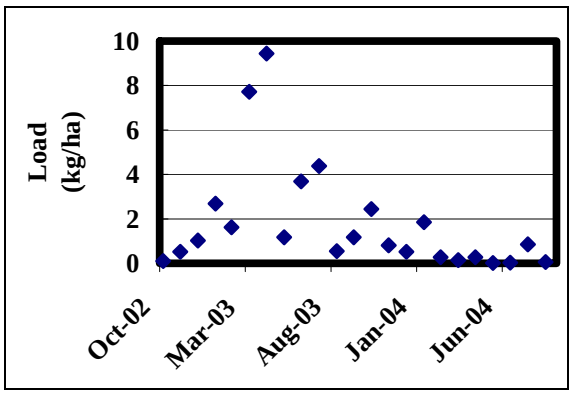
CCDPD5 monthly total phosphorus loadings



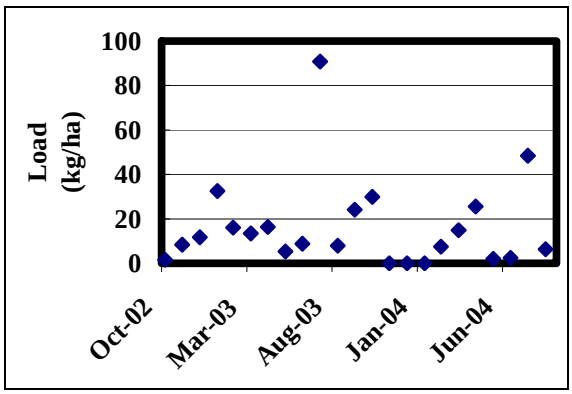
CCDPD5 monthly ammonium loadings



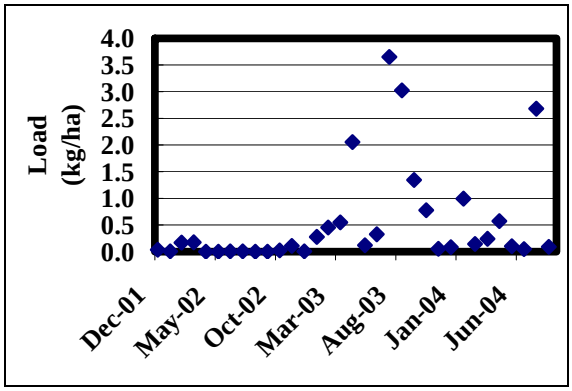
CCDPD5 monthly orthophosphate loadings



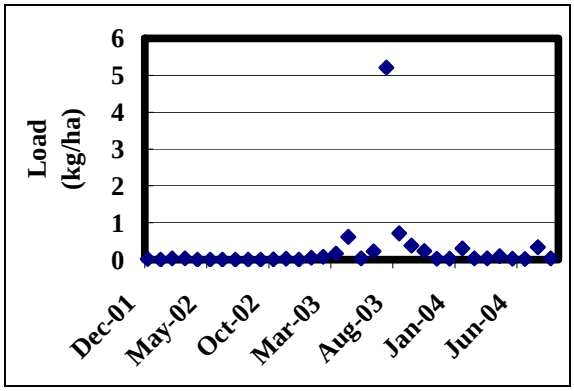
CCDPD5 monthly nitrate loadings



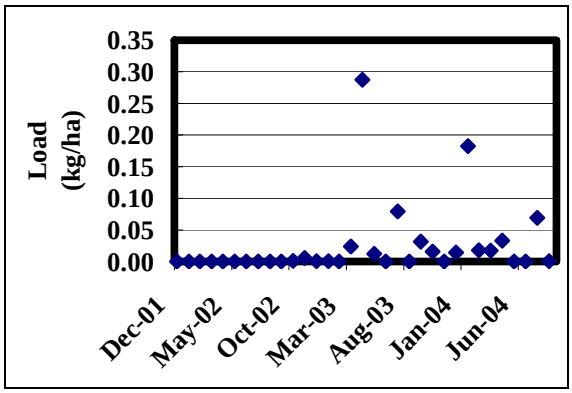
CCDPD5 monthly total suspended solids loadings



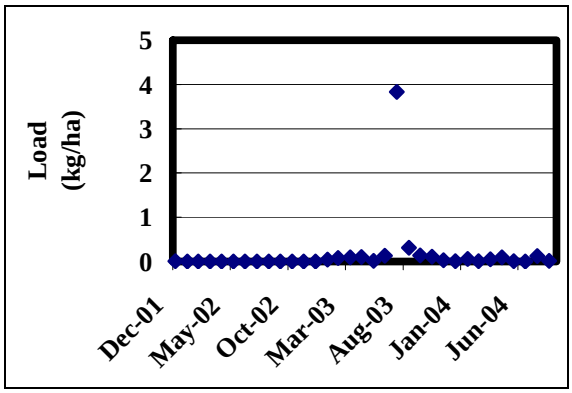
CCM0 monthly total Kjeldahl nitrogen loadings



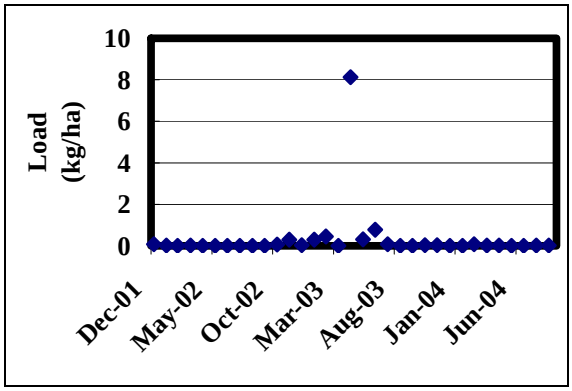
CCM0 monthly total phosphorus loadings



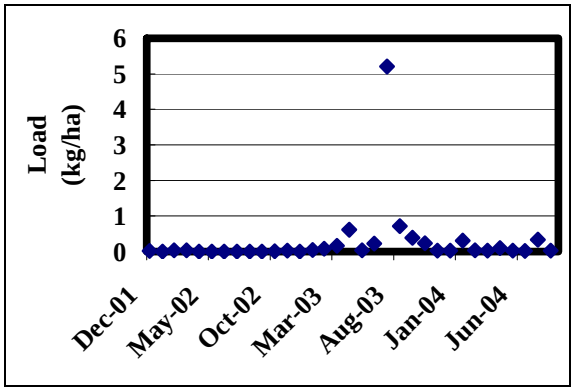
CCM0 monthly ammonium loadings



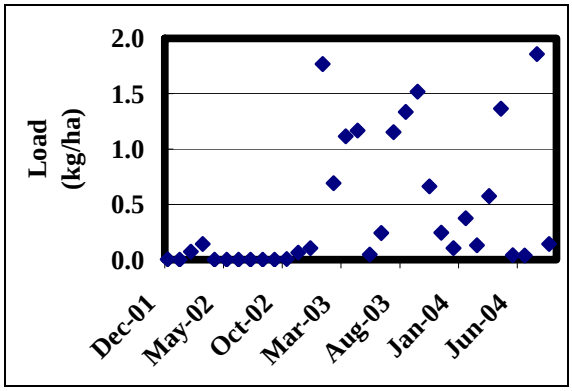
CCM0 monthly orthophosphate loadings



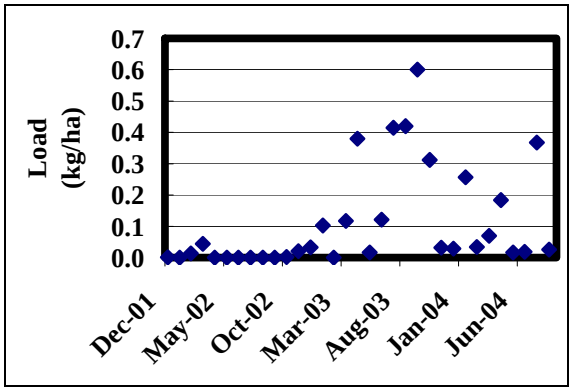
CCM0 monthly nitrate loadings



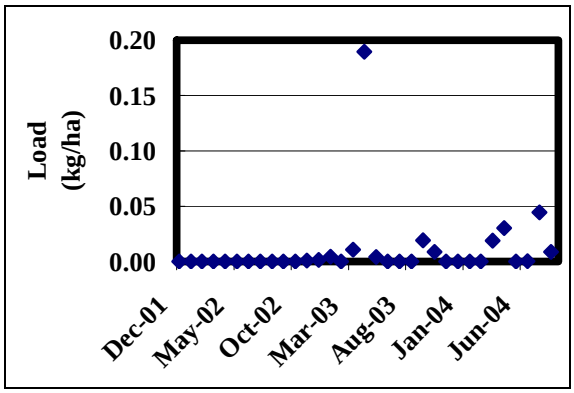
CCM0 monthly total suspended solids loadings



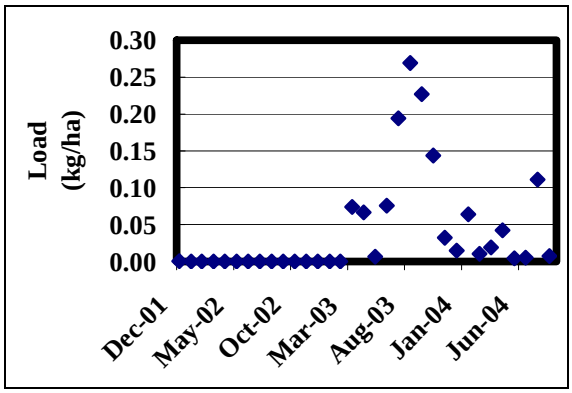
CCM1 monthly total Kjeldahl nitrogen loadings



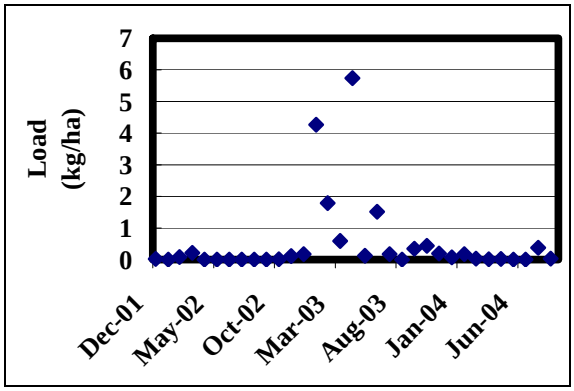
CCM1 monthly total phosphorus loadings



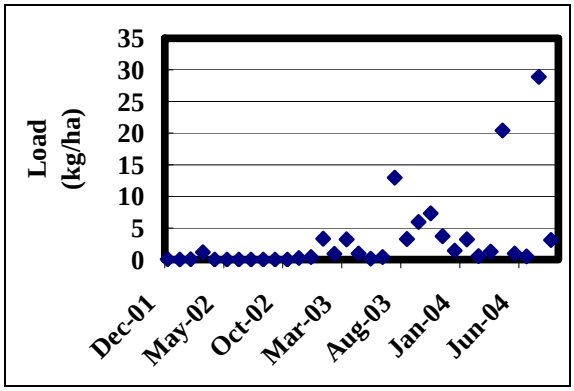
CCM1 monthly ammonium loadings



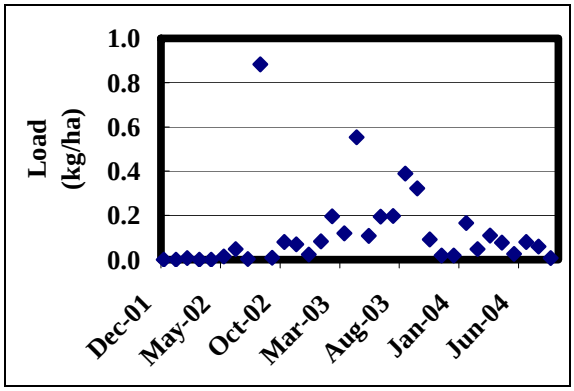
CCM1 monthly orthophosphate loadings



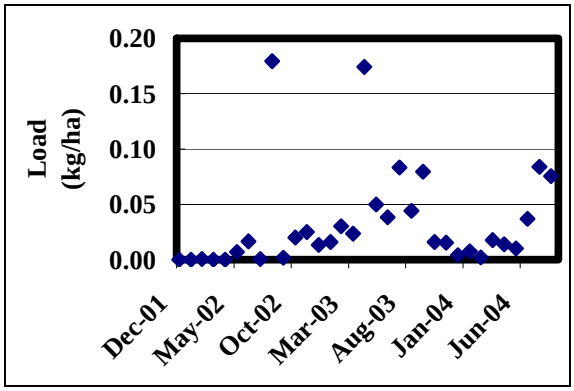
CCM1 monthly nitrate loadings



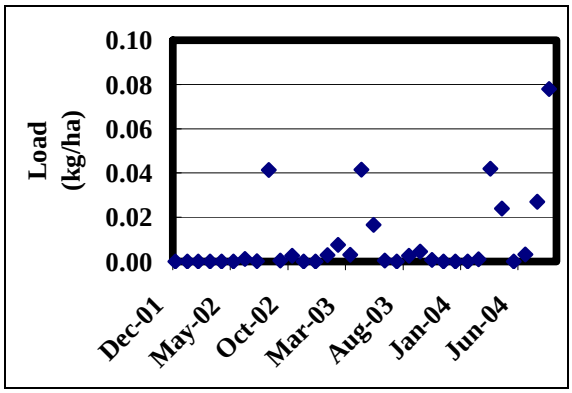
CCM1 monthly total suspended solids loadings



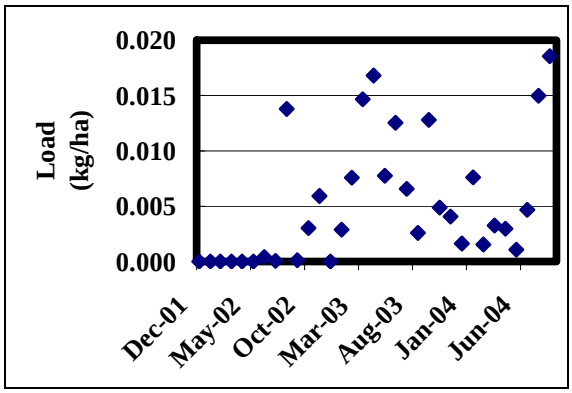
GCD3 monthly total Kjeldahl nitrogen loadings



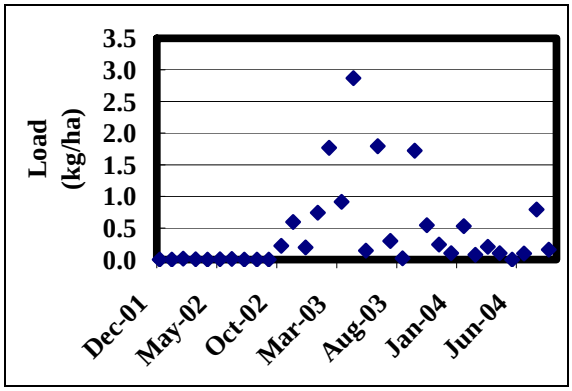
GCD3 monthly total phosphorus loadings



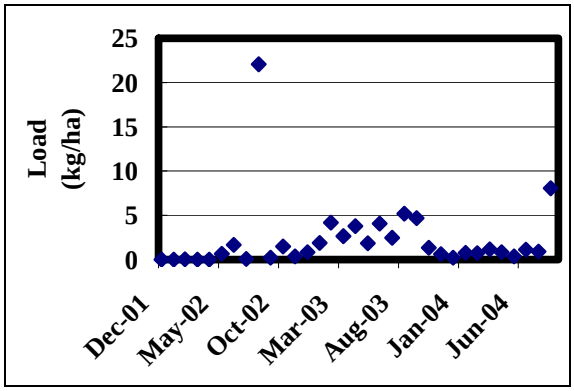
GCD3 monthly ammonium loadings



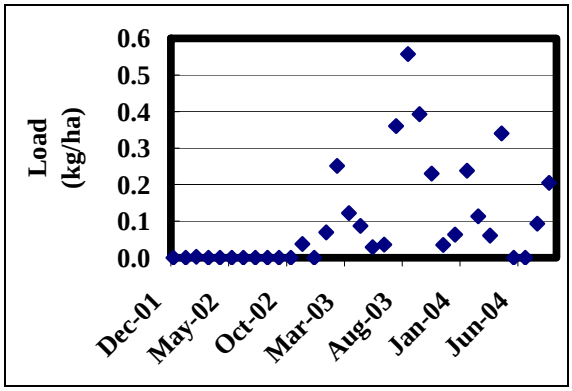
GCD3 monthly orthophosphate loadings



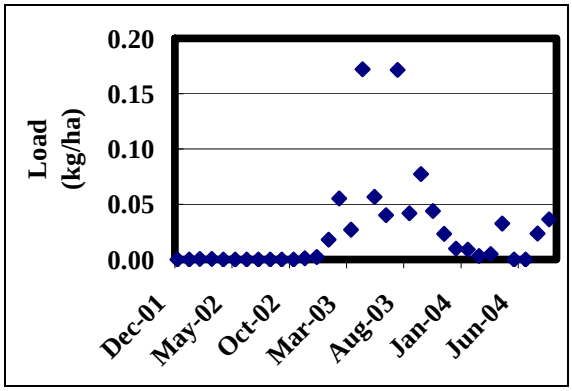
GCD3 monthly nitrate loadings



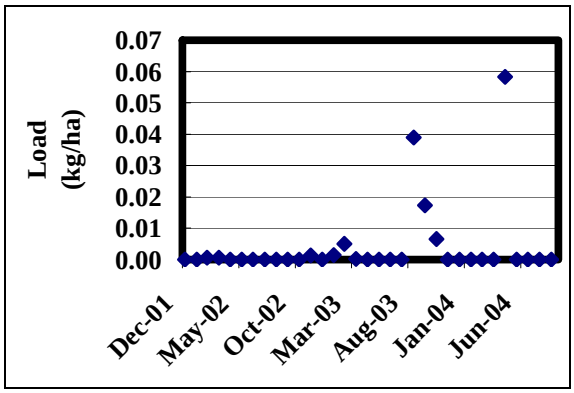
GCD3 monthly total suspended solids loadings



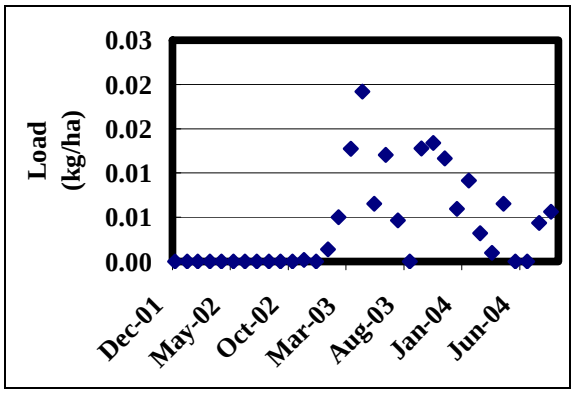
GCD5 monthly total Kjeldahl nitrogen loadings



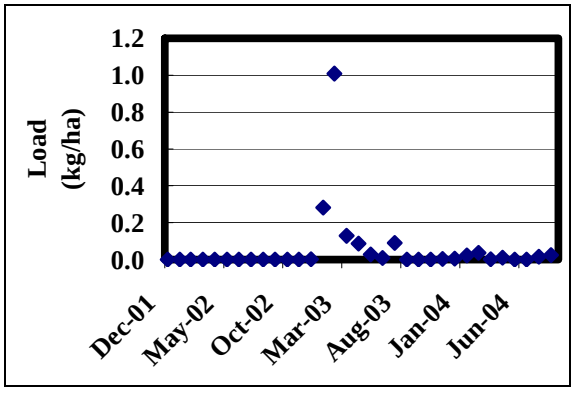
GCD5 monthly total phosphorus loadings



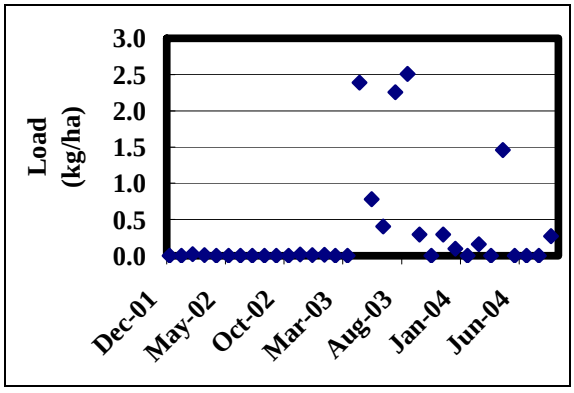
GCD5 monthly ammonium loadings



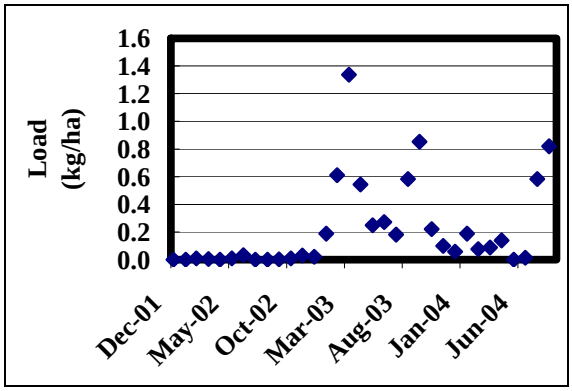
GCD5 monthly orthophosphate loadings



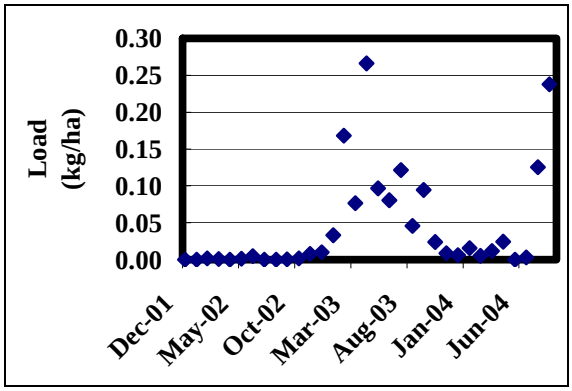
GCD5 monthly nitrate loadings



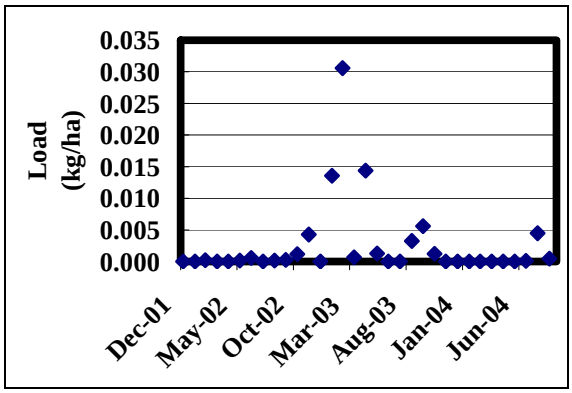
GCD5 monthly total suspended solids loadings



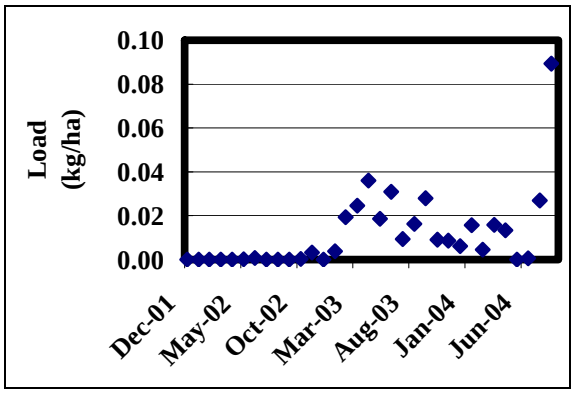
GCD7A monthly total Kjeldahl nitrogen loadings



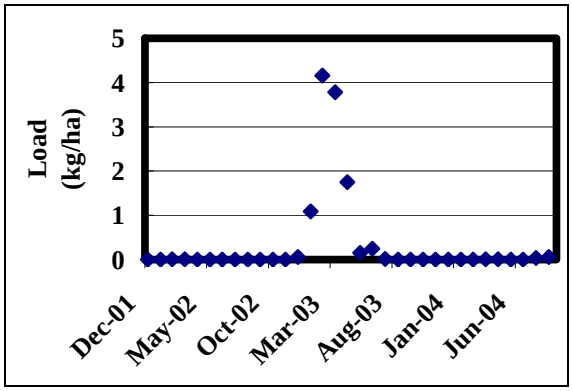
GCD7A monthly total phosphorus loadings



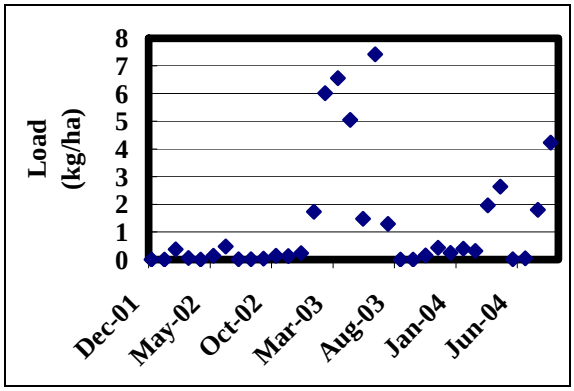
GCD7A monthly ammonium loadings



GCD7A monthly orthophosphate loadings

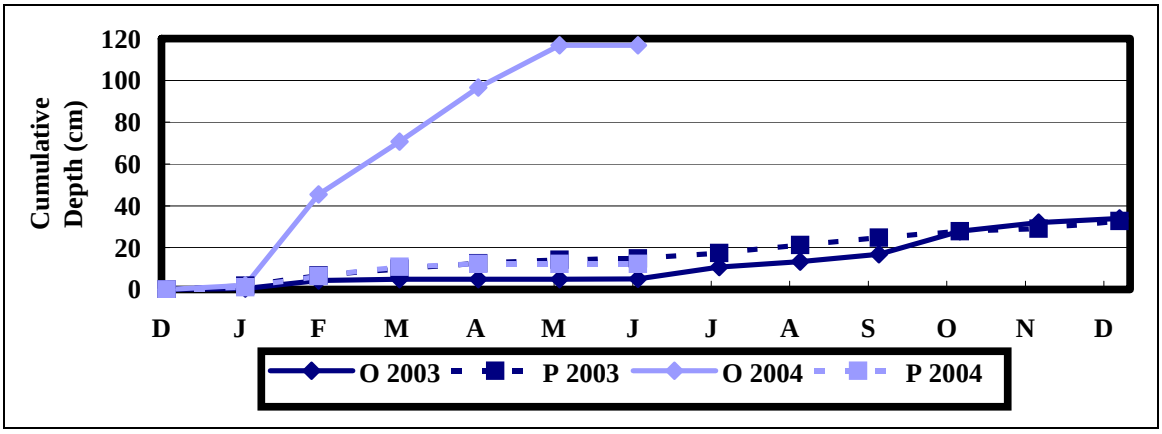


GCD7A monthly nitrate loadings

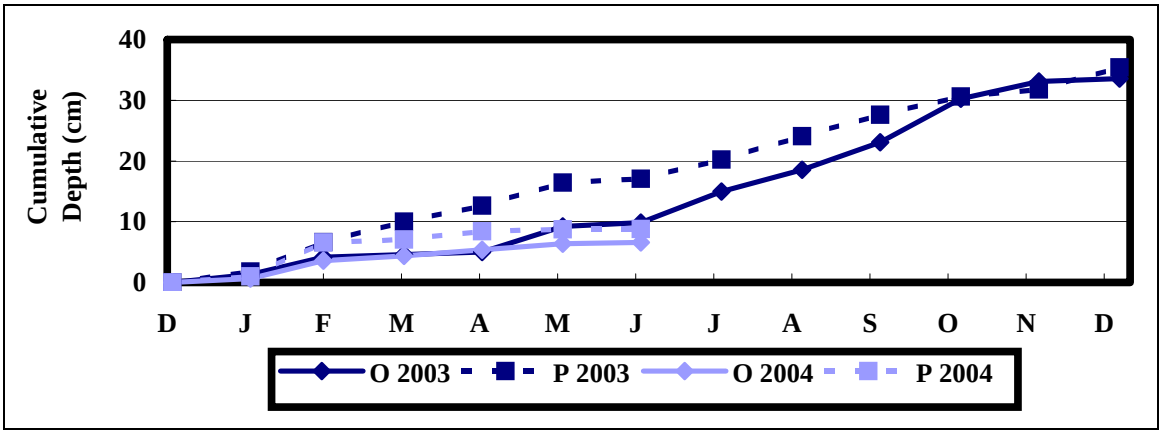


GCD7A monthly total suspended solids loadings

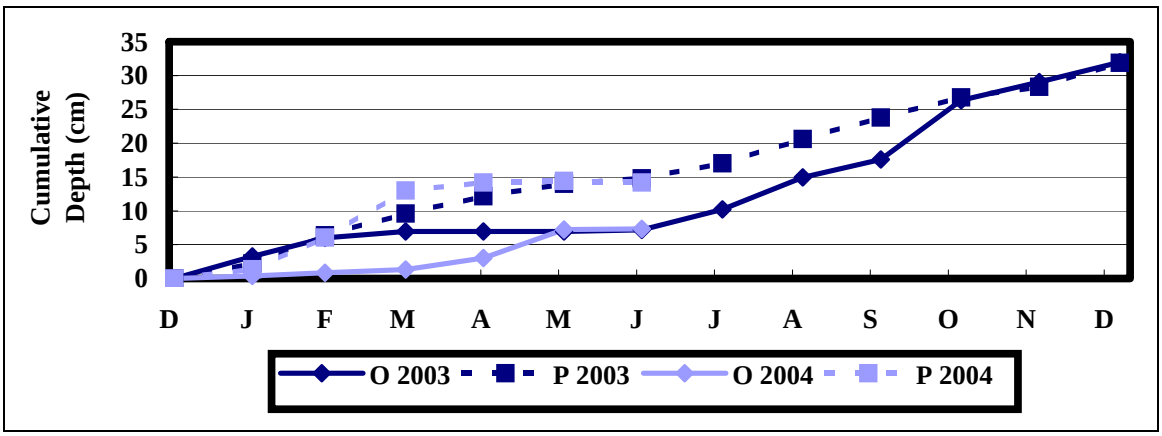
Appendix Q. Predicted and Observed Cumulative Monthly Drainage Depths for Core Creek Water Control Structure Monitoring Sites, 2003 and 2004



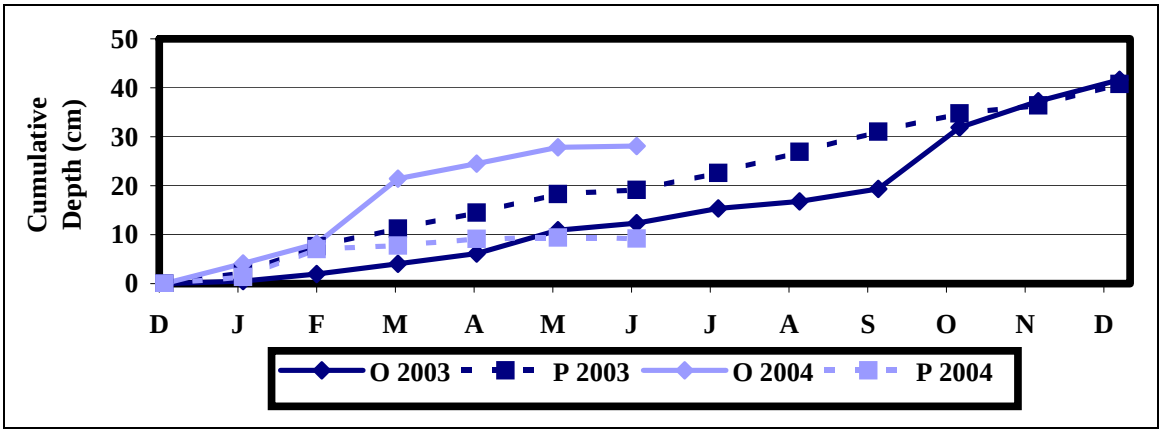
CCD2B cumulative monthly predicted and observed drainage depths for 2003 and 2004



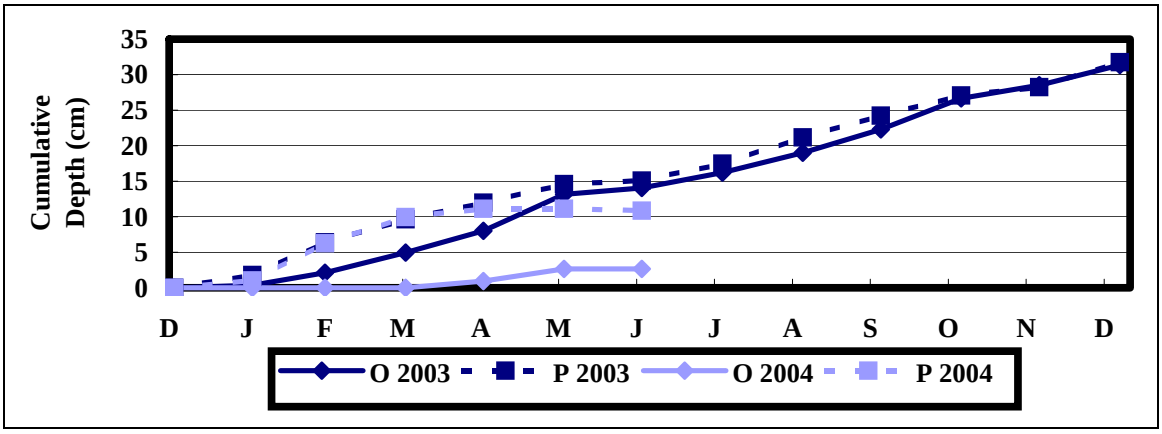
CCD5B cumulative monthly predicted and observed drainage depths for 2003 and 2004



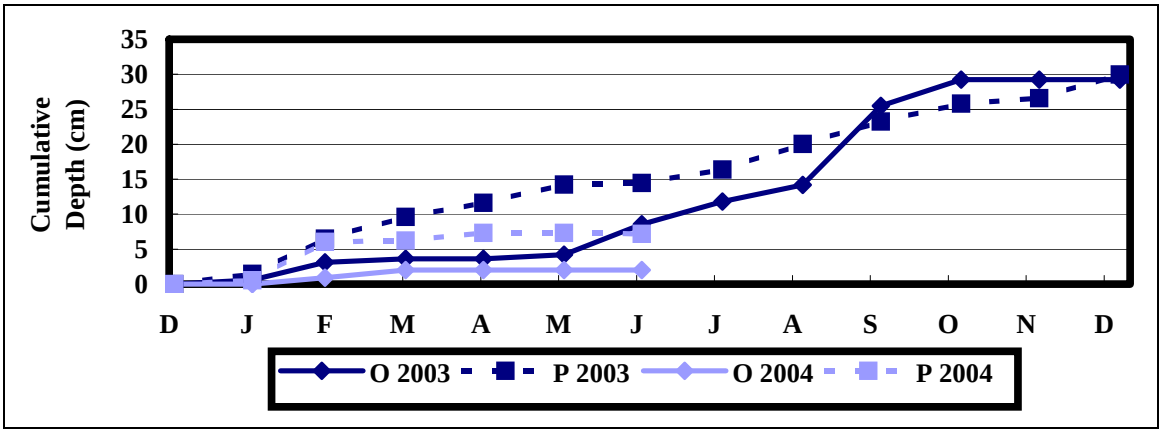
CCD7 cumulative monthly predicted and observed drainage depths for 2003 and 2004



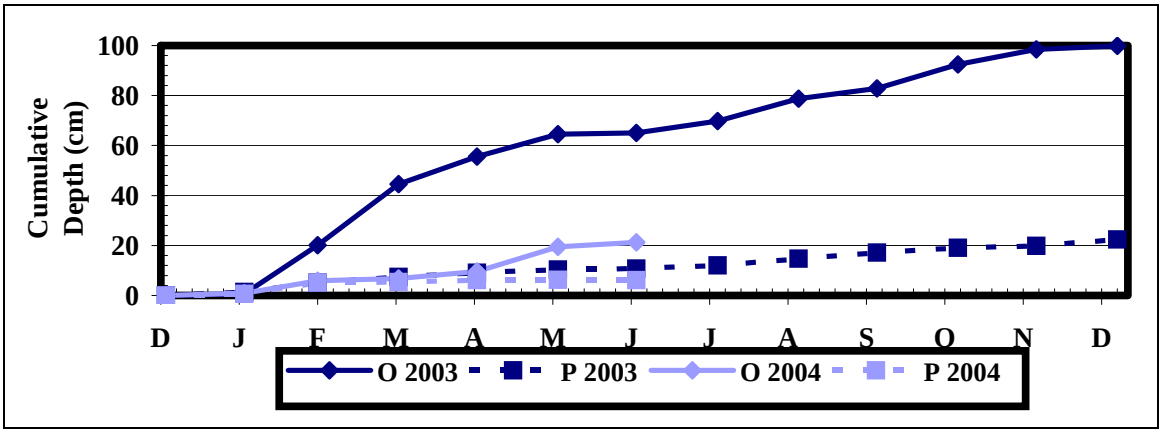
CCD8 cumulative monthly predicted and observed drainage depths for 2003 and 2004



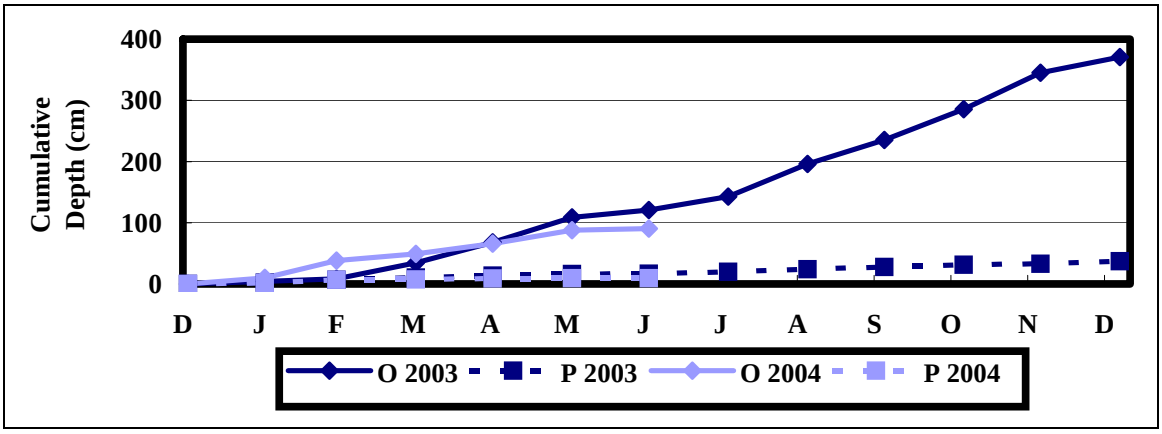
CCD15A cumulative monthly predicted and observed drainage depths for 2003 and 2004



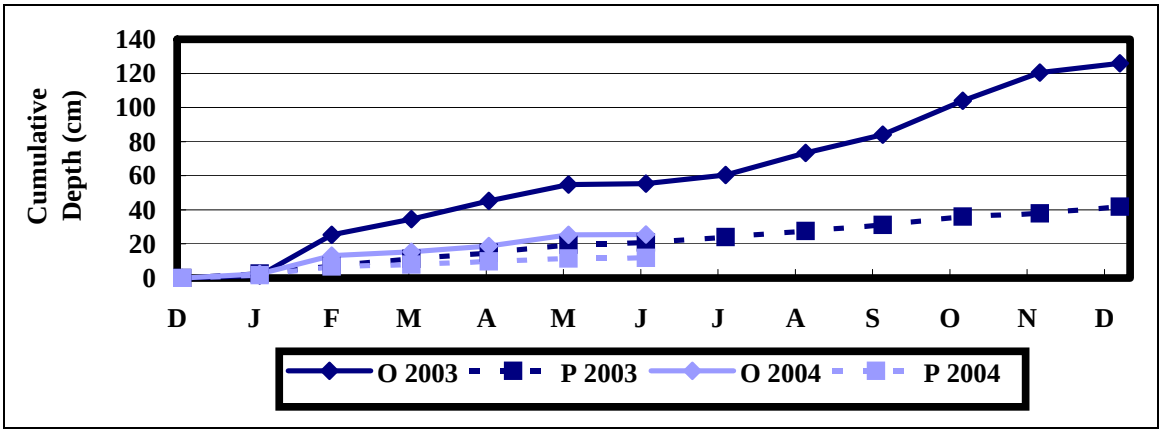
CCD15B cumulative monthly predicted and observed drainage depths for 2003 and 2004



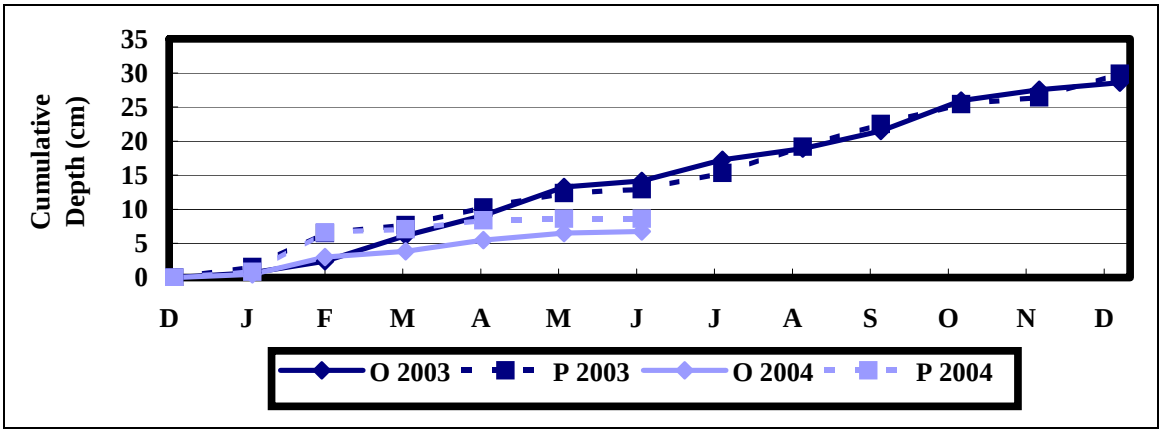
CCDPD4 cumulative monthly predicted and observed drainage depths for 2003 and 2004



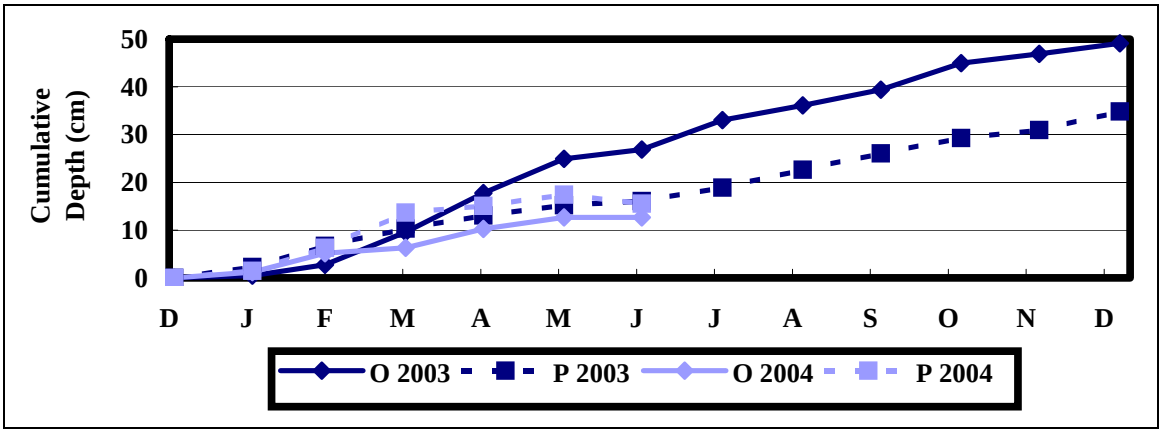
CCDPD5 cumulative monthly predicted and observed drainage depths for 2003 and 2004



CCM1 cumulative monthly predicted and observed drainage depths for 2003 and 2004

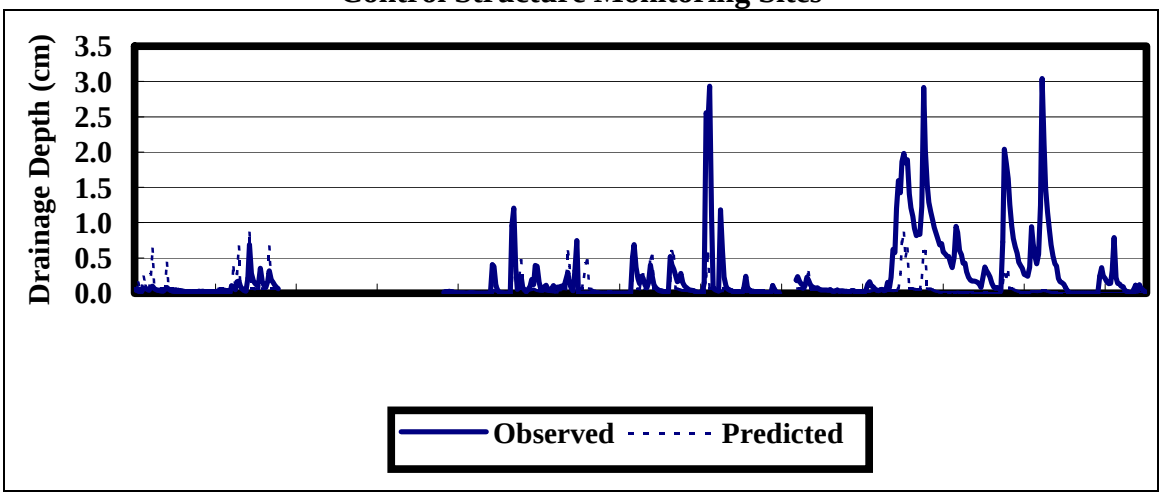


GCD3 cumulative monthly predicted and observed drainage depths for 2003 and 2004

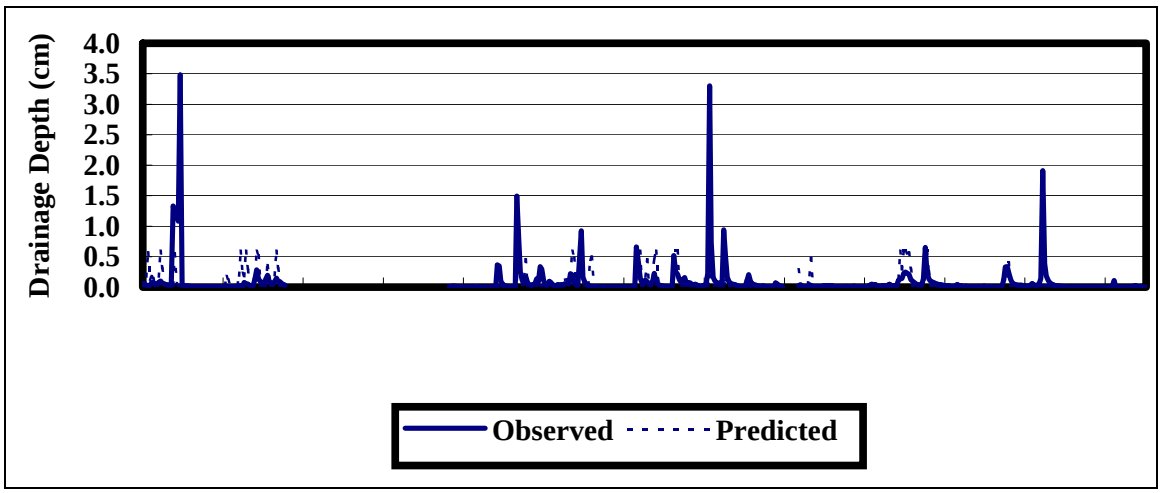


GCD7A cumulative monthly predicted and observed drainage depths for 2003 and 2004

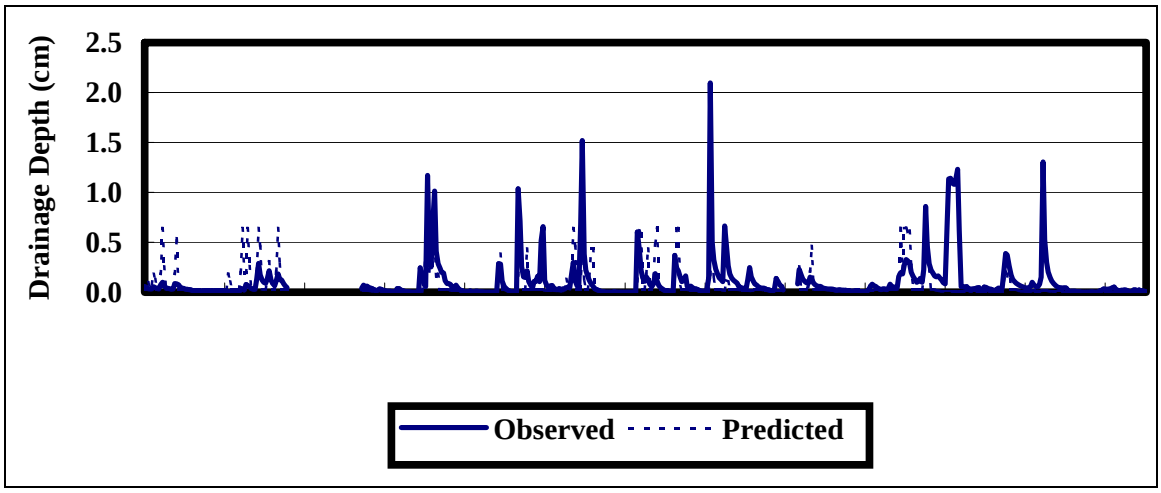
Appendix R. Predicted and Observed Daily Drainage Depths for Core Creek Water Control Structure Monitoring Sites



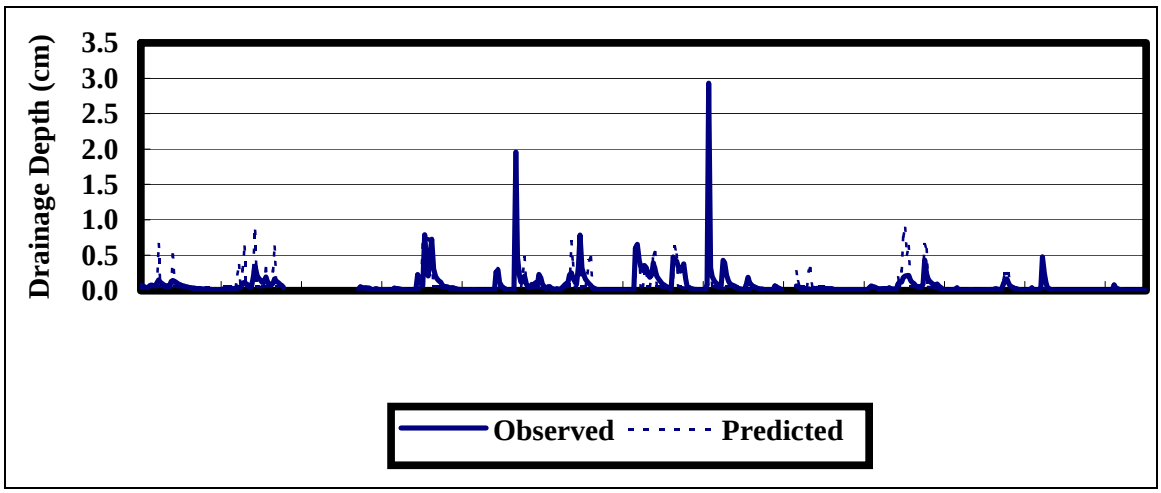
CCD2B daily observed and predicted drainage depths



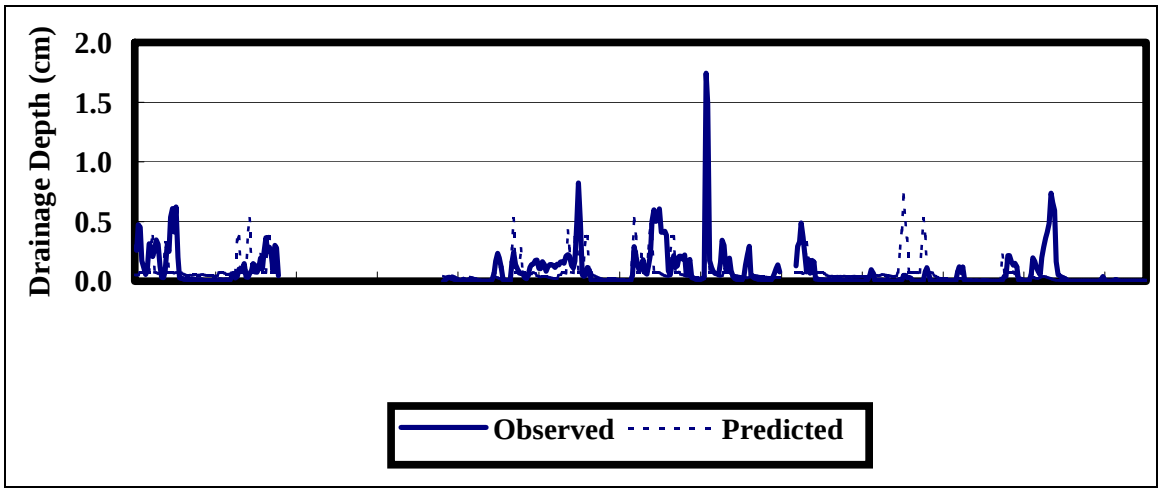
CCD4A daily observed and predicted drainage depths



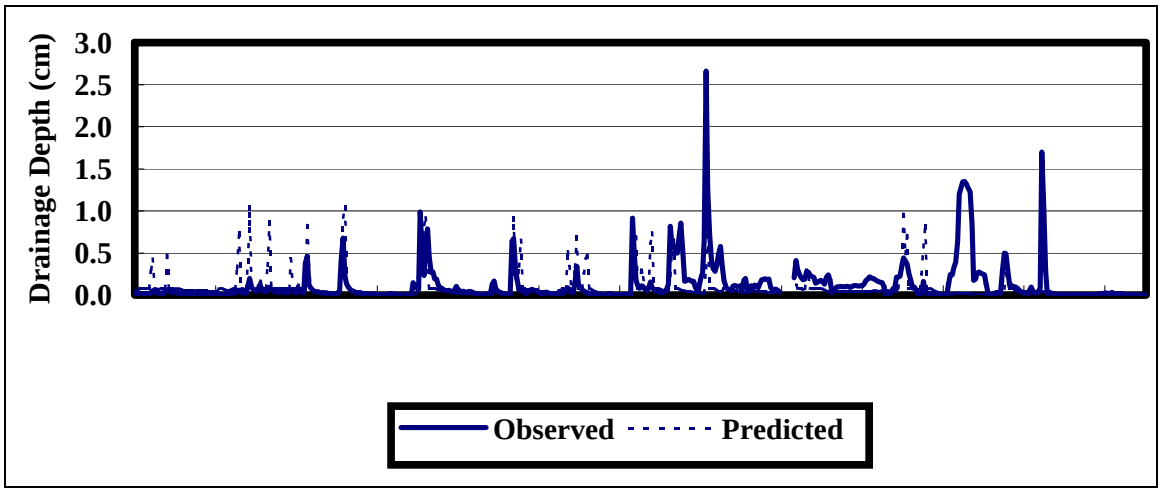
CCD5A daily observed and predicted drainage depths



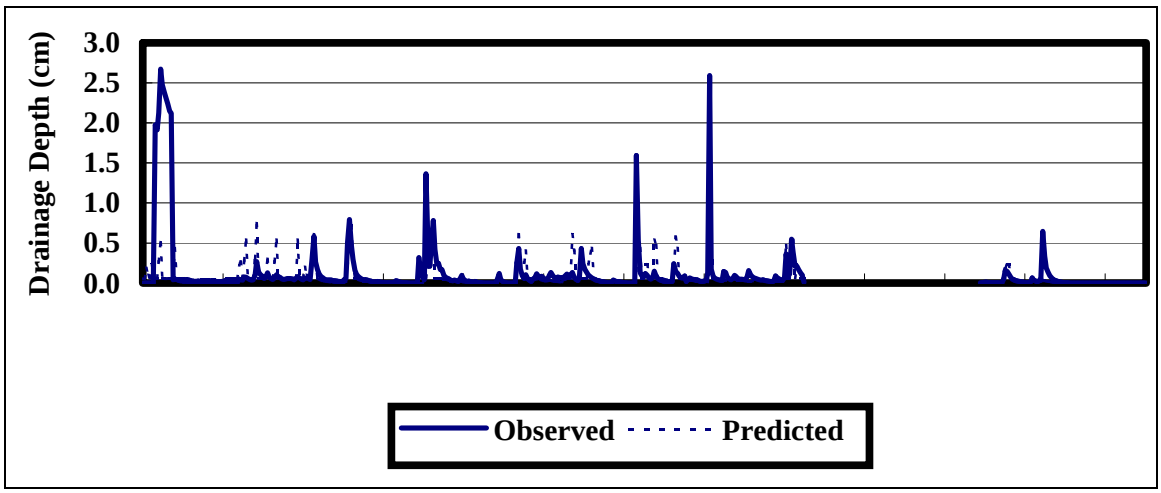
CCD5B daily observed and predicted drainage depths



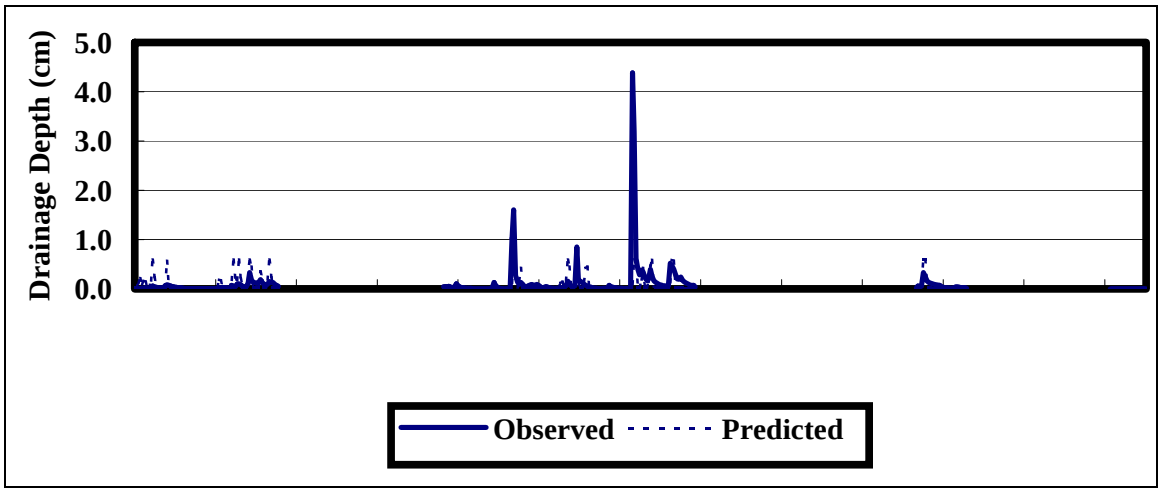
CCD7 daily observed and predicted drainage depths



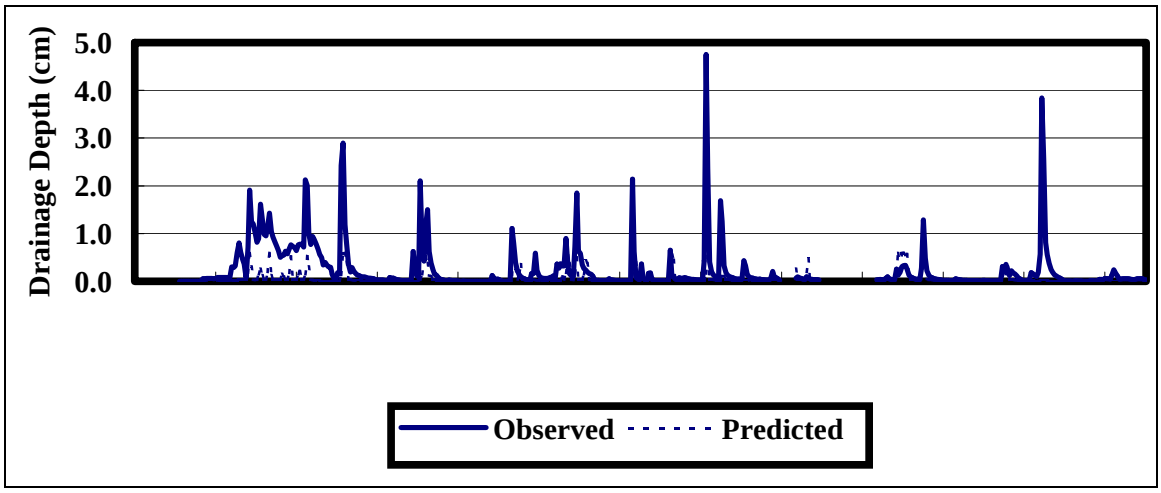
CCD8 daily observed and predicted drainage depths



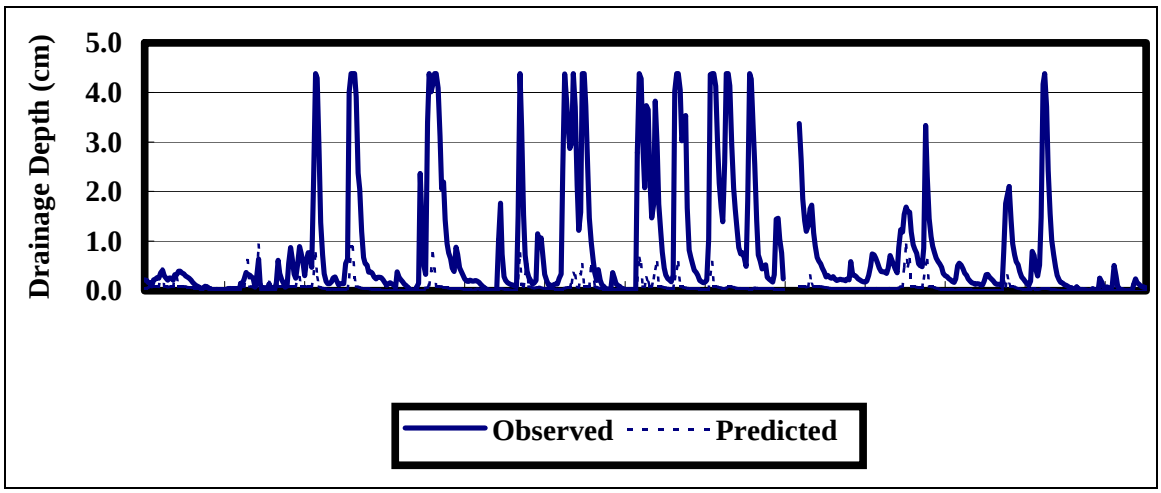
CCD15A daily observed and predicted drainage depths



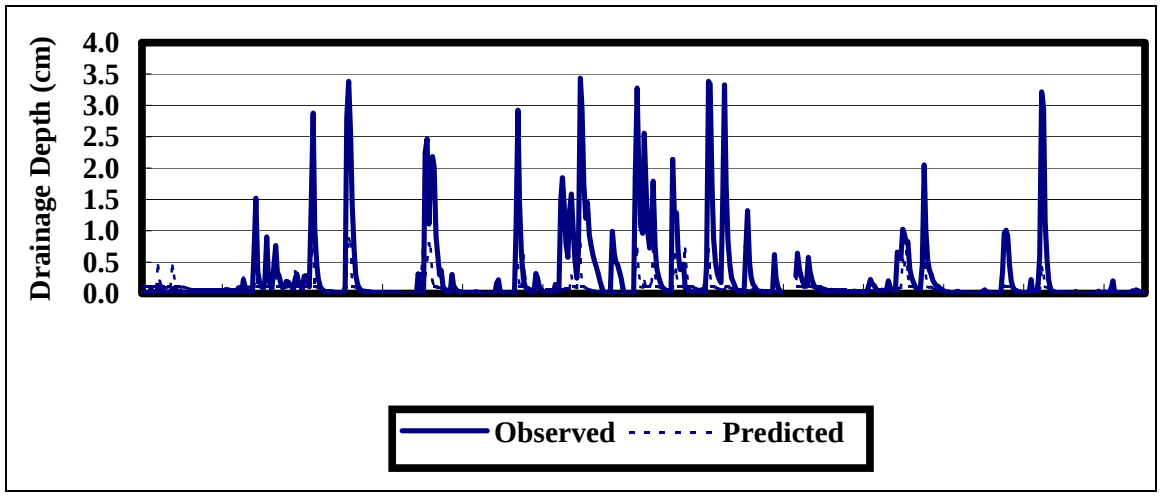
CCD15B daily observed and predicted drainage depths



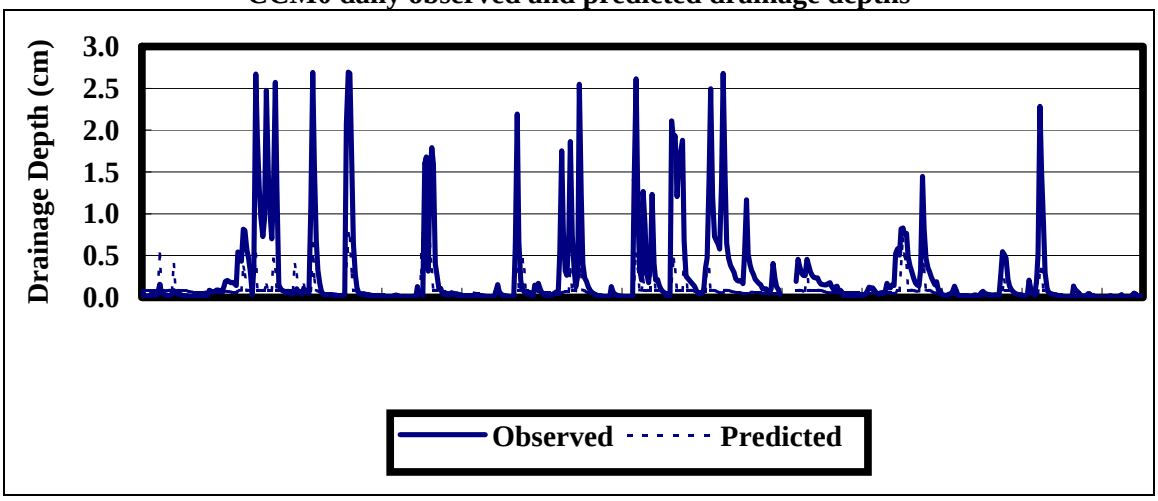
CCDPD4 daily observed and predicted drainage depths



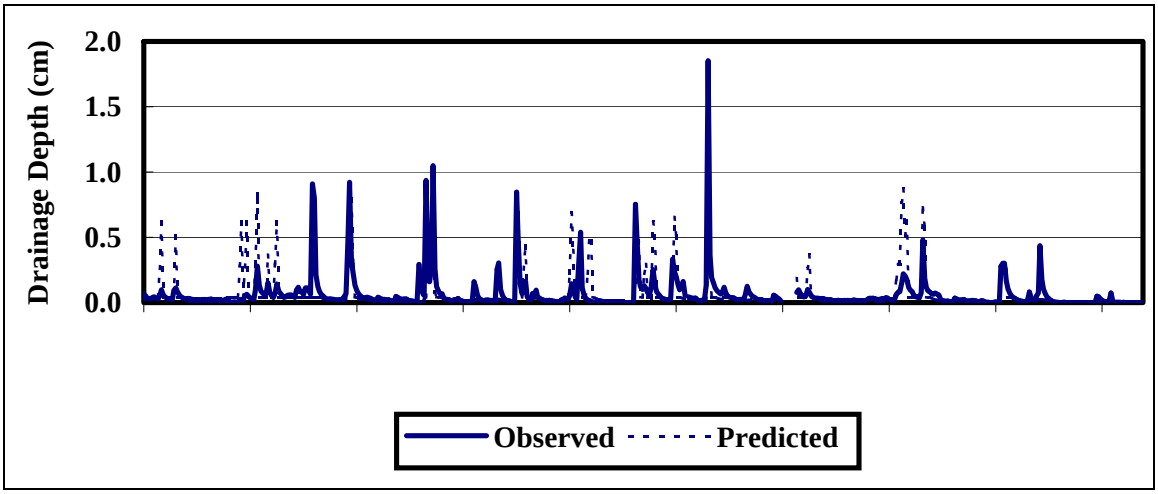
CCDPD5 daily observed and predicted drainage depths



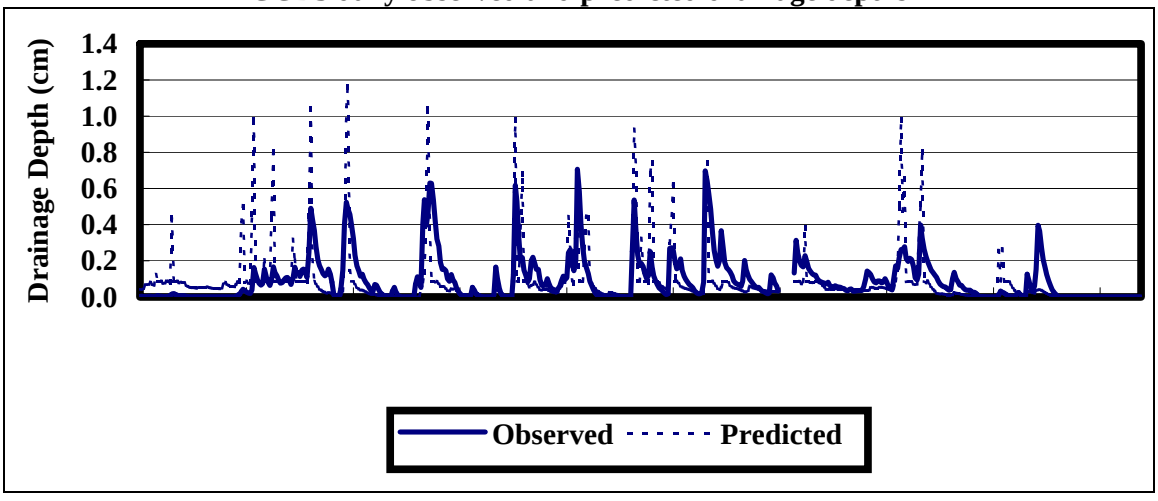
CCM0 daily observed and predicted drainage depths



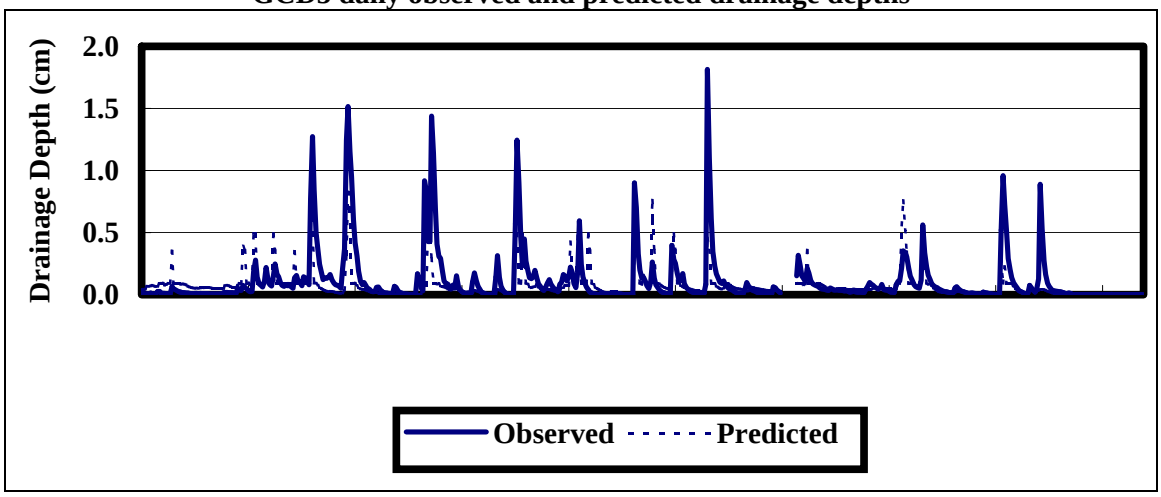
CCM1 daily observed and predicted drainage depths



GCD3 daily observed and predicted drainage depths

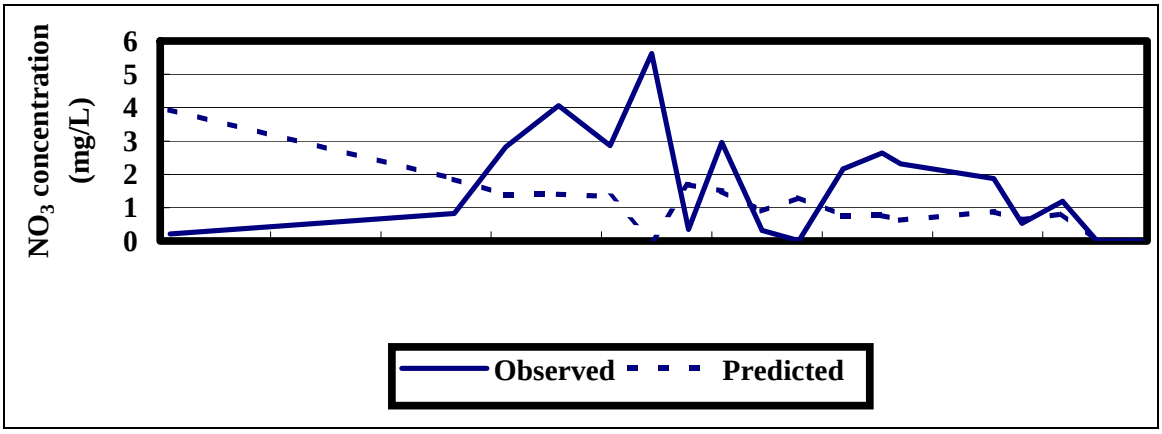


GCD5 daily observed and predicted drainage depths

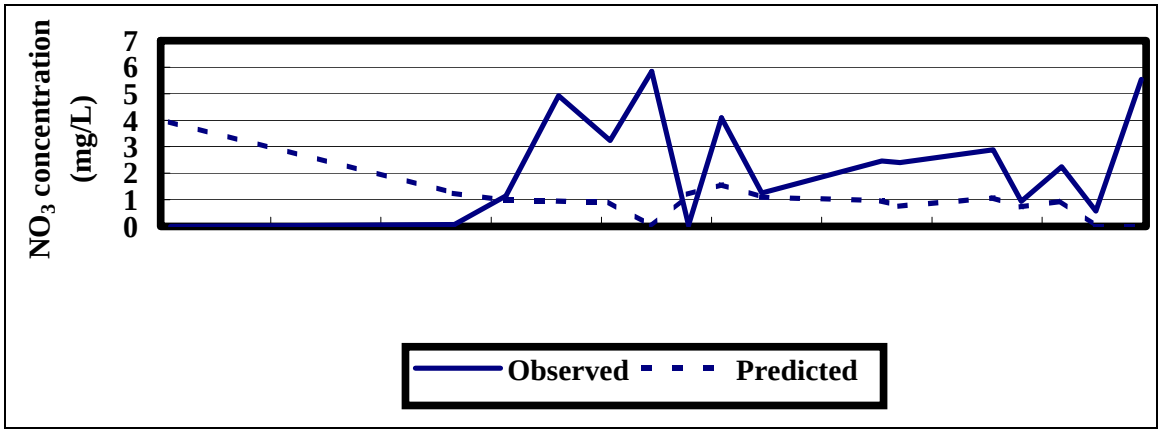


GCD7A daily observed and predicted drainage depths

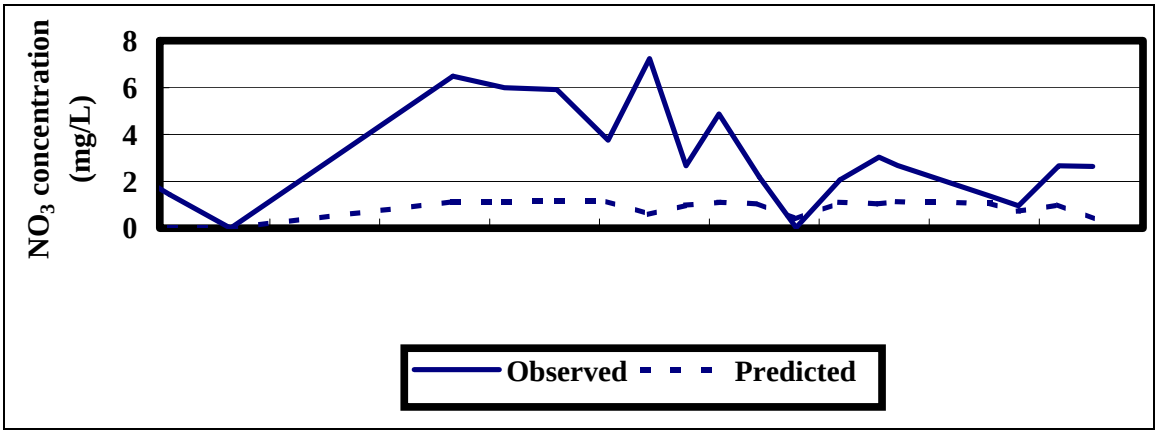
Appendix S. Predicted and Observed Daily Nitrate Concentrations in Drainage Waters for Core Creek Water Control Structure Monitoring Sites



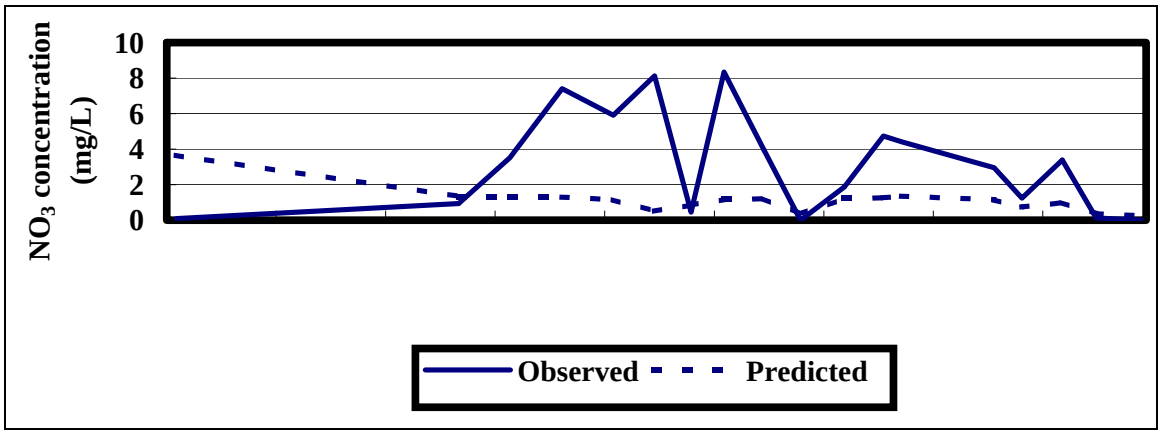
CCD2B daily observed and predicted nitrate concentrations



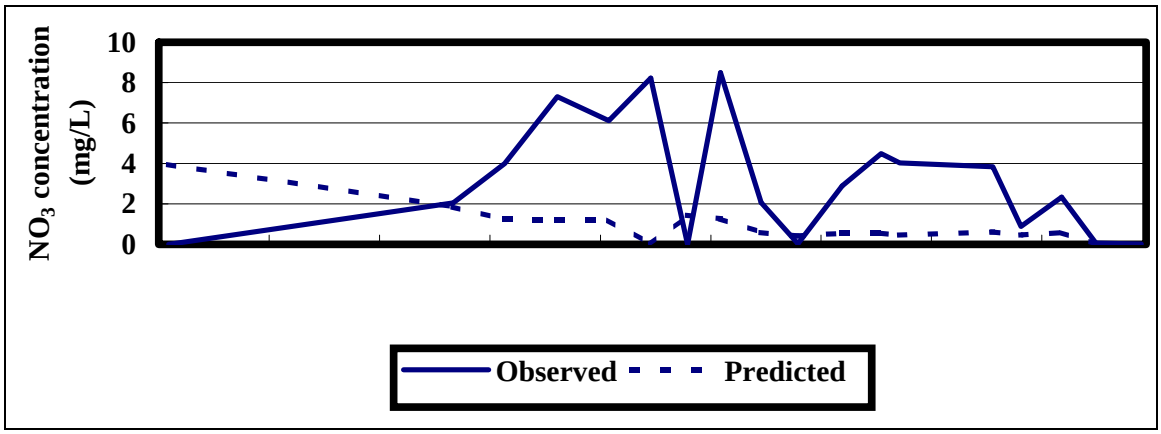
CCD4A daily observed and predicted nitrate concentrations



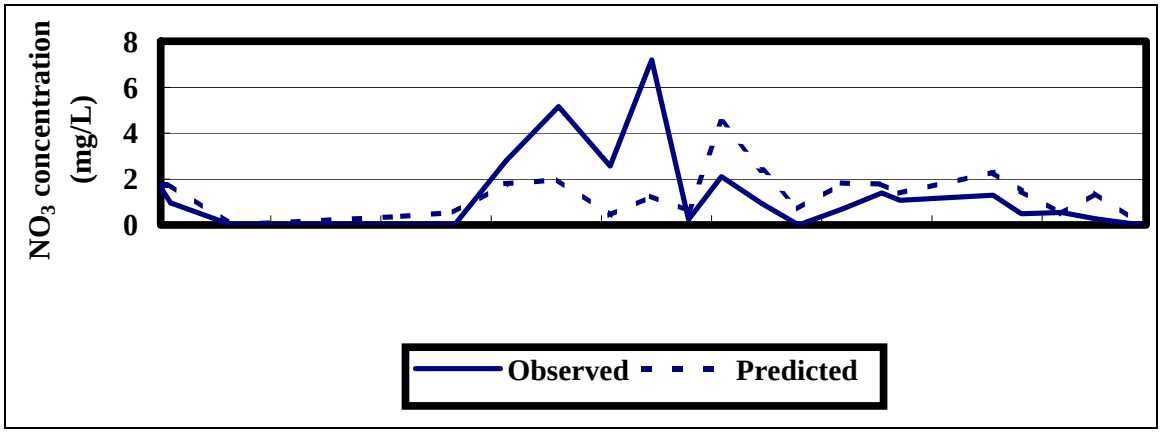
CCD5A daily observed and predicted nitrate concentrations



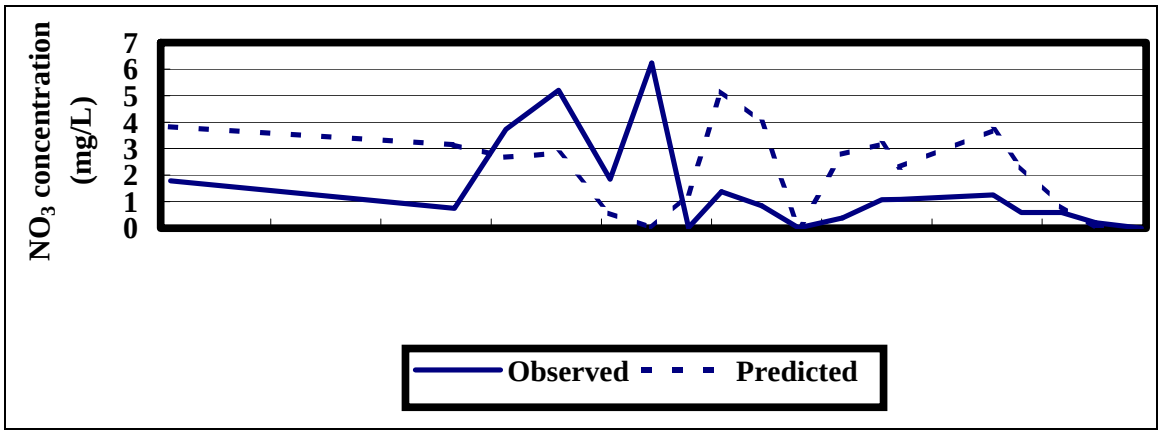
CCD5B daily observed and predicted nitrate concentrations



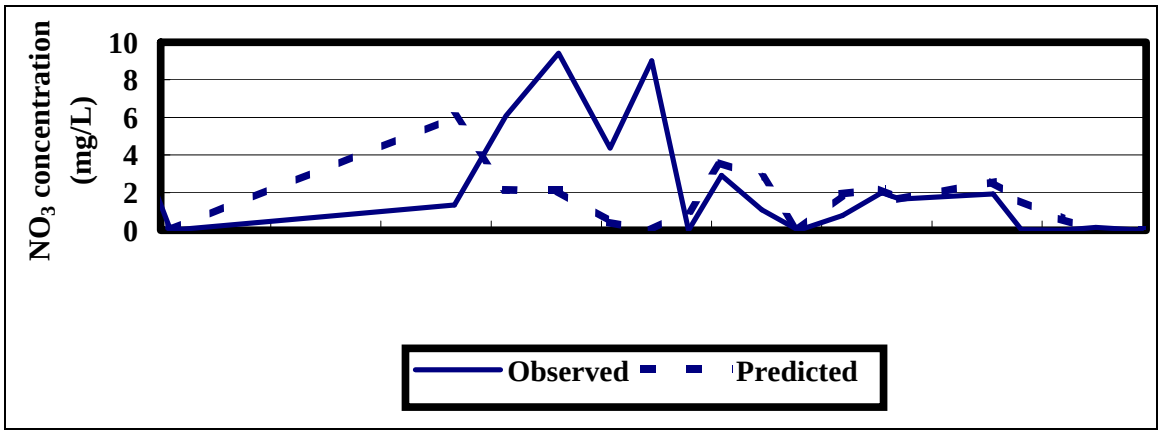
CCD7 daily observed and predicted nitrate concentrations



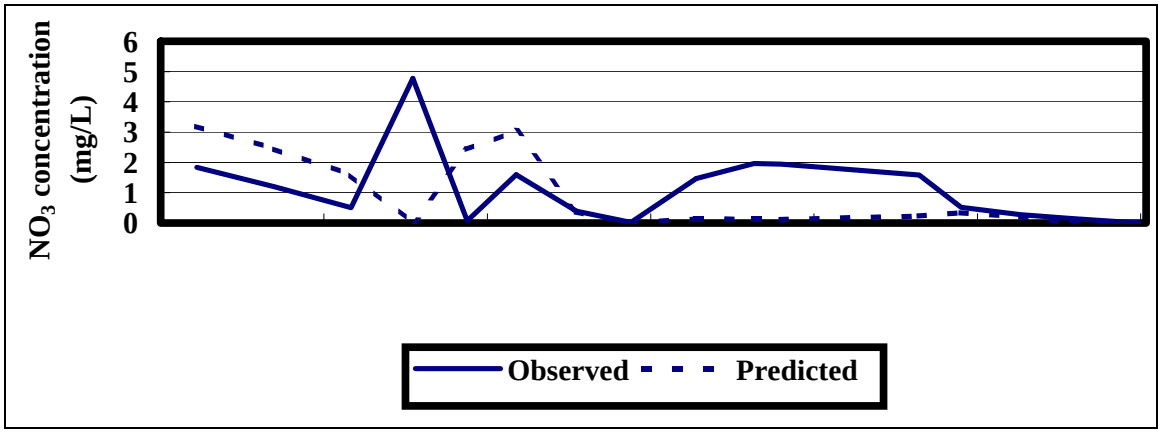
CCD8 daily observed and predicted nitrate concentrations



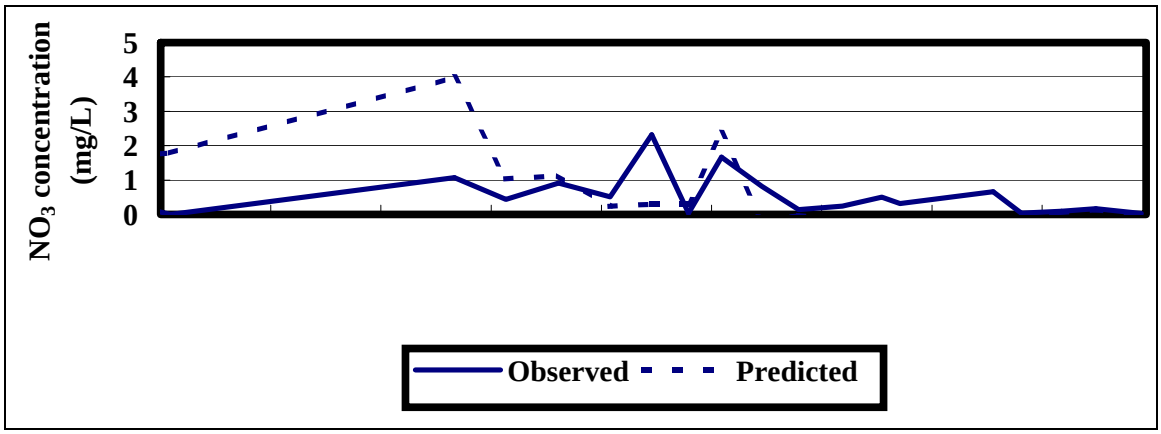
CCD15A daily observed and predicted nitrate concentrations



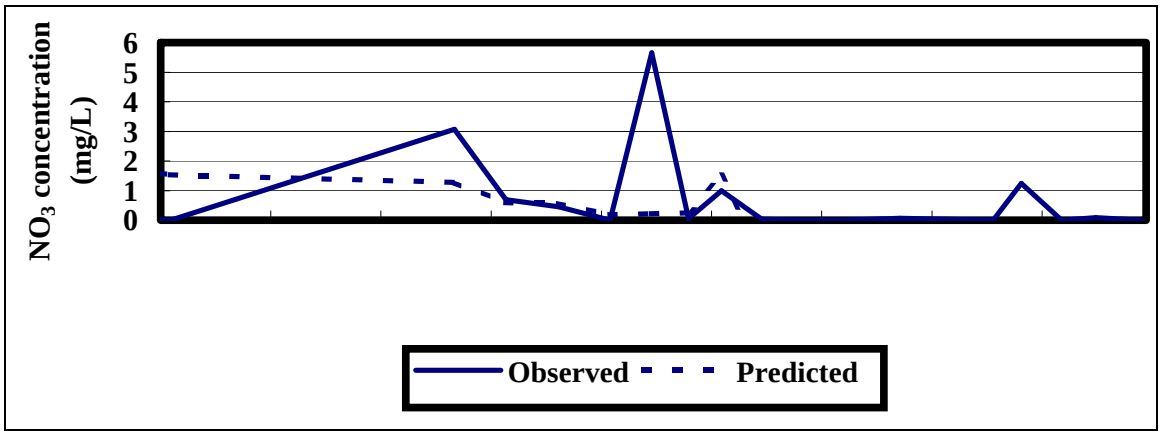
CCD15B daily observed and predicted nitrate concentrations



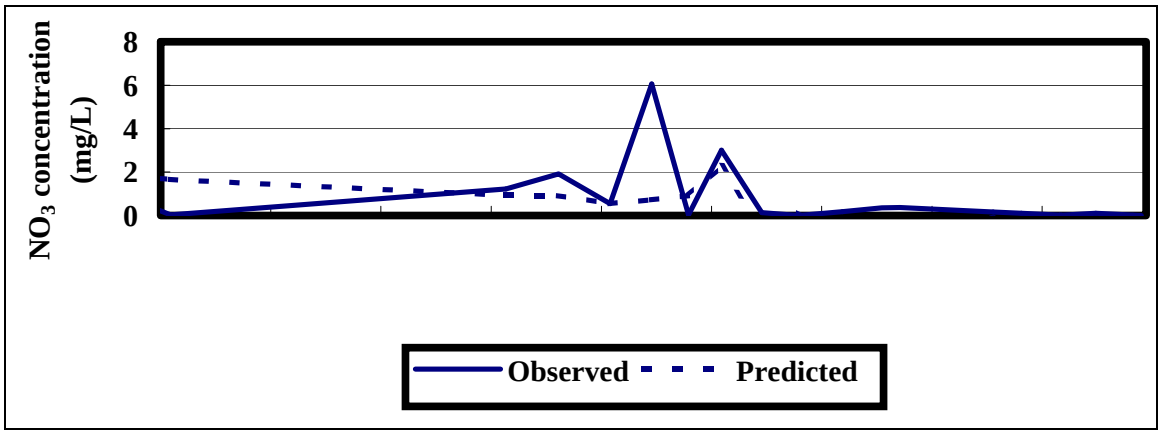
CCDPD4 daily observed and predicted nitrate concentrations



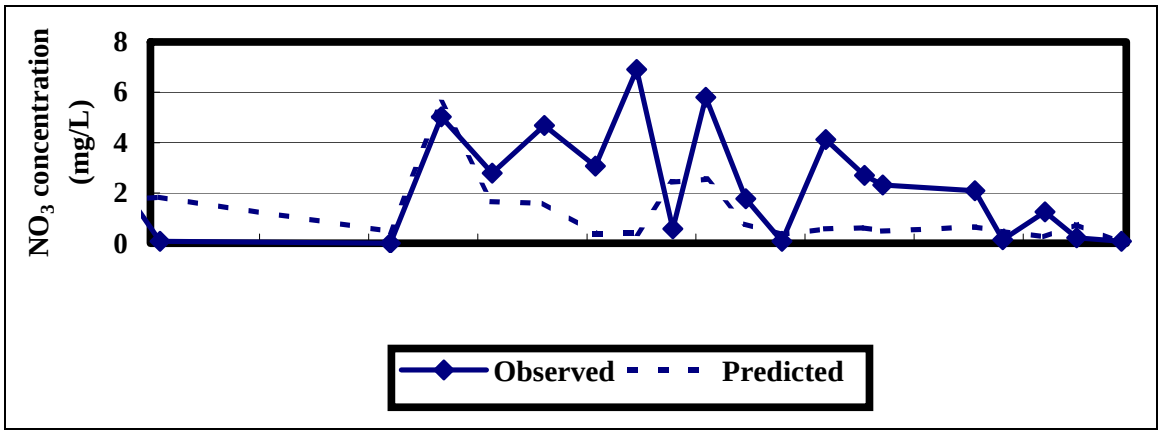
CCDPD5 daily observed and predicted nitrate concentrations



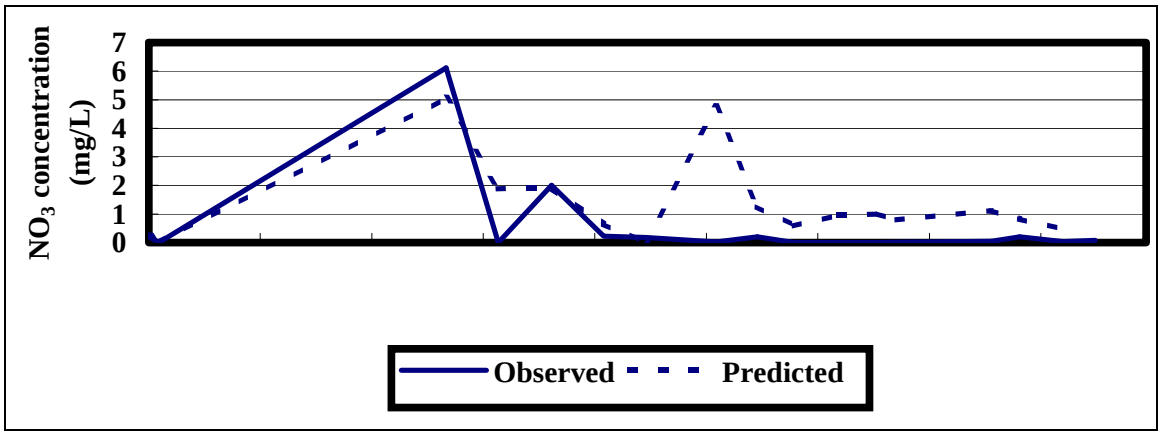
CCM0 daily observed and predicted nitrate concentrations



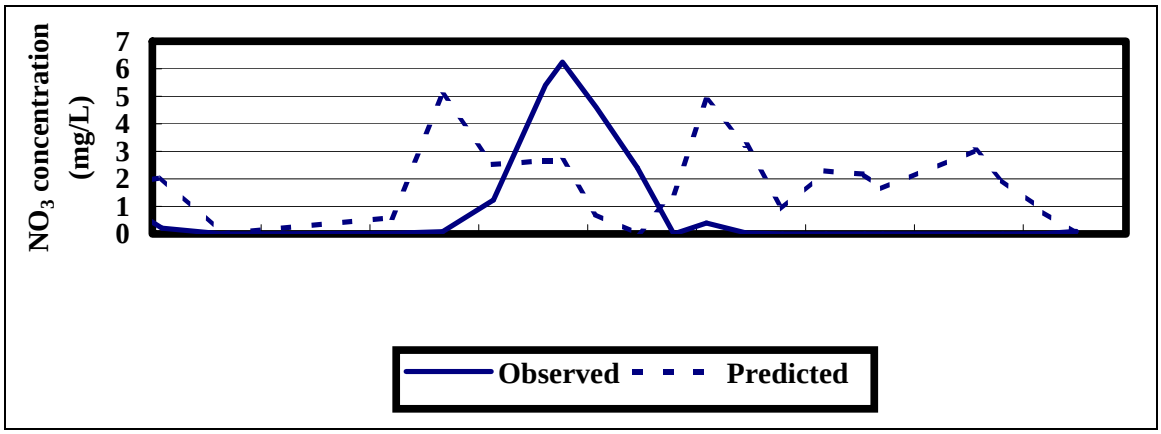
CCM1 daily observed and predicted nitrate concentrations



GCD3 daily observed and predicted nitrate concentrations

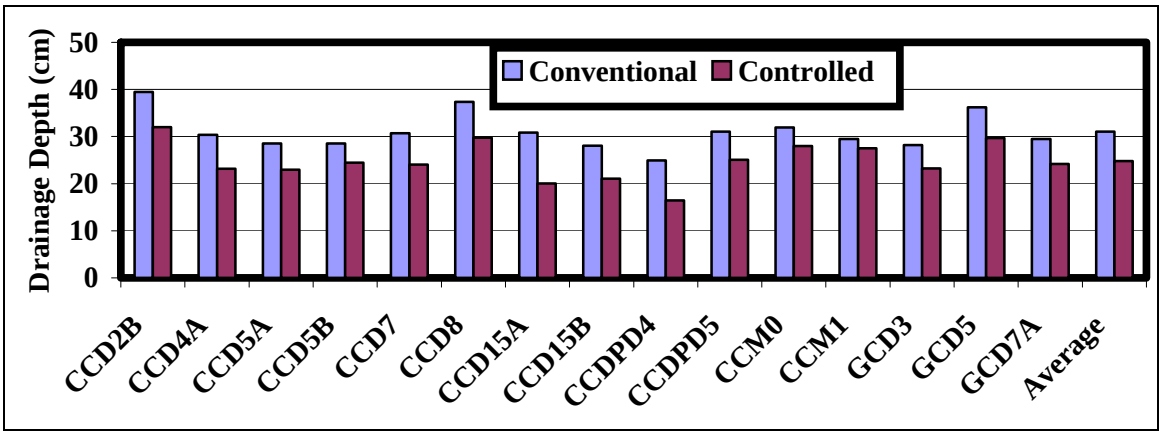


GCD5 daily observed and predicted nitrate concentrations

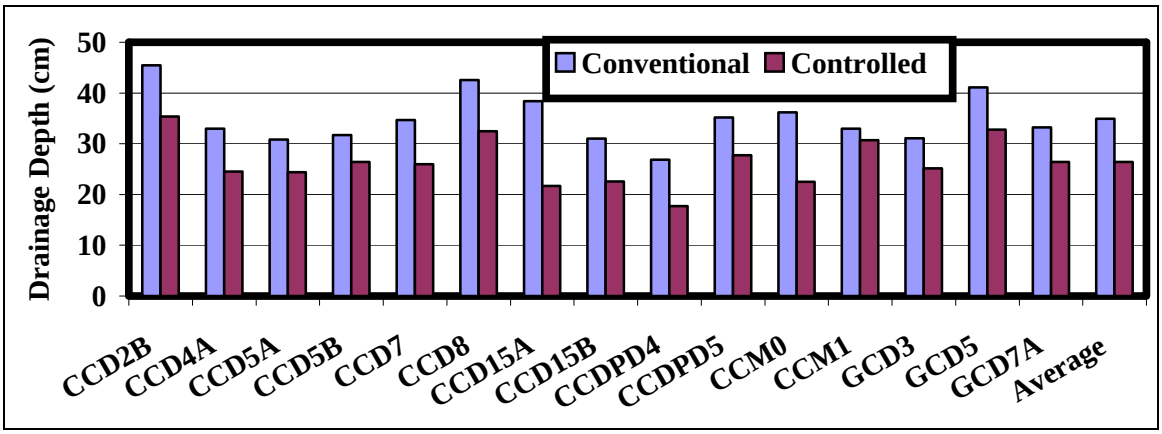


GCD7A daily observed and predicted nitrate concentrations

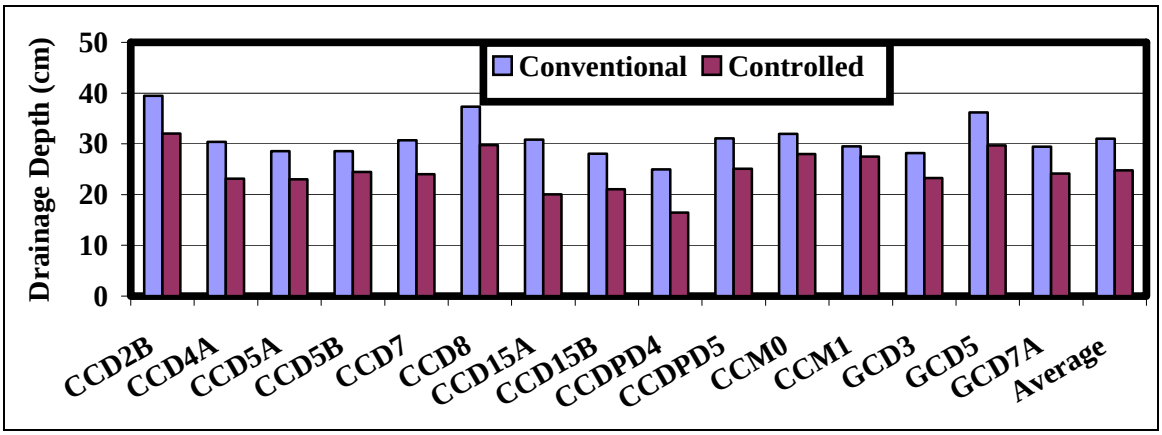
Appendix T. Yearly Drainage Depths for Core Creek Monitoring Sites in Different Crops



Controlled and conventional drainage depths for monitoring stations in the Core Creek watershed cropped under corn



Controlled and conventional drainage depths for monitoring stations in the Core Creek watershed cropped under soybeans



Controlled and conventional drainage depths for monitoring stations in the Core Creek watershed cropped under cotton