AN EVALUATION OF PRE- AND POST-TIMBER HARVEST WATER QUALITY IN LOW-ORDER STREAMS IN THE MISSOURI OZARKS

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…………Dedicated to my Late Father, Dhurba B. Koirala

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TABLE OF CONTENTS

CHAPTER 1 INTRODUCTION

CHAPTER 2 LITERATURE REVIEW

CHAPTER 3 MATERIALS AND METHODS

CHAPTER 4 ESTABLISHING METHODS FOR DEFINING BACKGROUND FOR WATER QUALITY PARAMETERS IN FORESTED EPHEMERAL WATERSHEDS IN THE MISSOURI OZARKS

CHAPTER 5 COMPARISON OF PRE- AND POST- HARVEST WATER QUALITY IN THE LOW ORDER STREAMS OF MISSOURI OZARKS

CHAPTER 6 ANALYSIS AND COMPARISON OF PRE-AND POST-HARVEST WATER QUALITY USING OTHER STATISTICAL METHODS IN THE MISSOURI OZARKS

CHAPTER 7 CONCLUSIONS AND RECOMMENDATIONS

LIST OF TABLES

LIST OF FIGURES

AN EVALUATION OF PRE- AND POST-TIMBER HARVEST WATER QUALITY IN LOW-ORDER STREAMS IN THE MISSOURI OZARKS

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ABSTRACT

Missouri Department of Conservation's (MDC) best management practices (BMPs) for Regenerative Oak Clear Cutting (ROCC) practice was evaluated on effectiveness to preserve downstream water quality. Fifteen sites, located on MDC lands in Shannon and Reynolds counties in Missouri Ozarks, ranging from 5-50 acres were instrumented with in-stream and hill-slope water samplers. Samples were collected for approximately three years prior to harvest and two to three years after harvest.

The comparison of pre-and post-harvest samples showed that six of the twelve water quality parameters (TSS, TVSS, Ca, K, NO_3^- and SRP) had probabilities that the post-harvest concentration would exceed the pre-harvest concentration, after taking climatic factors into account. However, the probability of exceedance (PoE) were less than 15 percent. Total Suspended Solids (TSS) showed a 4% PoE which was deemed low in a natural system, whereas the maximum PoE, found for TVSS, was about 13%.

Overall, the impact of timber harvest on water quality in the Ozarks was minimal comparing using PoE or discrete analysis of histograms. The US EPA only sets parameter limits for impaired or threatened streams, so there was no regulatory limit in effect for the ephemeral streams. However, the method of determining PoE closely followed USEPA's total maximum daily load (TMDL) method. Owners, contractors and monitoring organizations can use this procedure to compare the PoE of various water quality parameters with regulatory agency limits should they be established.

CHAPTER 1: INTRODUCTION

1.1 Background

Public perception that timber harvesting negatively impacts water quality by eroding sediments and leaching out nutrients has driven research to investigate whether Missouri Department of Conservation's (MDC) best management practices (BMPs) are effective (Hollabaugh, 2006). Missouri Department of Natural Resources (MDNR), Missouri Department of Conservation, United Stated Department of Agriculture Forest Service (USDA FS) and the Institute for Interdisciplinary Geotechnics (I2G) at the University of Missouri are collaborating to qualitatively and quantitatively determine the impact of timber harvesting on water quality in the Missouri Ozark Highlands. I2G was charged with the task of monitoring sedimentation and water quality changes by installing water samplers and weather stations to collect water samples before and after timber harvesting over a seven year period (Bunger, 2005).

Harvesting of trees in the Missouri Ozarks is a regular silviculture practice to manage state-owned forests for sustained, healthy, multi-use areas, to generate revenue for MDC and the employment for people in the vicinity. MDC' conducts timber harvests under the supervision of a forester who implements BMPs (Roadside Management Zone (RMZ) and Streamside Management Zone (SMZ)) to reduce impact, if any, on downstream water quality (MDC, 1987).

Woodlands are managed for a variety of objectives, including sustaining healthy and diverse forests, periodic income from the sale of timber, recreational uses, aesthetics and other considerations. Healthy forests and watersheds are critically important commodities for a sustainable ecosystem. Managing healthy forest resources for human as well as environmental sustainability is a challenge for resource managers in the 21st century (MDC, 1997). Missouri Department of Conservation conducts timber harvesting on state lands surrounding the Current and Jack's Fork Rivers to maintain a diverse selection of the tree and plant species, preserve wildlife habitat, and to produce commercial products. The forest product industry makes a significant contribution to the Missouri economy. Harvesting timber, the most common silviculture practice in the State of Missouri, has been conducted to maintain a diverse forestry system, modify wildlife habitat and produce commercial products to reach the objectives of the landowner and farmers. Commercial forests in the state of Missouri account for 13.3 million acres (29%) of 44.3 million acres of total land, of which 83% are privately owned (MDC, 1997). The value of wholesale forest products in Missouri is estimated to be approximately $ 2.7 billion annually (1997 dollars) (MDC, 1997).

Potential pollution from silviculture practice is referred to as a non-point pollution source and must follow the statutes of the Clean Water Act (CWA) of 1977 and Clean Water Act of 1987 (EPA, 2008). The CWA dictates that silviculture activities cannot adversely affect the water that leaves forested watersheds, as they may in turn negatively impact larger bodies of water (Smith, 2006). In order to ensure that the effluent from timber harvest sites is not degraded, MDC implements BMP of leaving a riparian buffer zone (RBZ), also referred to as a streamside management zone (SMZ), to negate detrimental effects. BMPs are actions implemented by MDC during harvesting to minimize detrimental environmental impacts. The SMZ consists of a strip of vegetation that is preserved in order to improve water quality through various processes, depending on the pathway of the flow of water through the buffer. In the case of surface flow, the vegetative cover impedes flow, causing suspended solids to sediment, and acts as a sink for nutrients (Smith, 2006). The riparian buffer zones are placed alongside perennial and ephemeral drainage ways as these are main pathways for the movement of water (MDC, 1978). The SMZ is the area of planted and preserved forest, maintained along each side of the stream between the harvest area and stream. It is intended to be effective in filtering sediment, nutrients and organic matter from surface and ground water flows (Ducros and Joyce, 2003; Martin and Hornbeck, 1994). Various buffer zones from 3-200 meters have been used to protect the streams and wetlands; however, the relative effectiveness of the SMZ to filter the nutrients and minerals from surface runoff differs according to its width, length and plant composition and density in the watershed (Jorgenson et. al., 2000).

Timber harvest activities have the potential to increase sediment loading to streams from harvest site erosion and to cause direct physical disturbance of stream channels and riparian zones. Minimizing sediment-related effects on water quality and aquatic habitat is a primary focus of water quality protection efforts in areas managed for commercial timber production. Management practices intended to prevent or control non-point water pollution are referred to as best management practices, a term that has regulatory connotation under Federal Clean Water Act and state water quality laws (Brown et al., 1993). These BMP's are usually defined in state regulations or voluntary guidelines for forest management activities, and specific practices vary widely among deferent state programs (Ice et al., 2004; Lee et al., 2004).

To control the impact of logging on soil erosion and the stream water quality, forestry best management practices (BMPs) have been developed and implemented in many places (Aust & Blinn, 2004; NFA, 2004). The BMPs provide guidelines and emphasize the importance of pre-harvest planning, ameliorating the severe traffic associated with the temporary and permanent road construction and site preparation, designing the activities to minimize soil disturbance and bare soil exposure, maintaining a SMZ and rapid revegetation after harvesting.

The state of Missouri has been facing conflicts between forest management activities (especially clear-cut timber harvesting) and adjacent stream quality. The concept that normal harvesting treatment is accompanied by negative consequences, including degradation of water resources, is a public concern that in some cases resulted in litigation. Often this concern stems from the belief that present-day logging is just as abusive and exploitive as logging was at the turn of 20th century (Stuart, 2006). While it is generally believed that forest harvesting adversely impacts stream water quality, the impacts are highly variable and much of this variability is attributable to differences in site conditions, including soils and topography, as well as differences in harvesting methods and post-harvest procedures to manage leftover biomass on the site. This suggests that the effects of harvesting on stream water quality are more commonly region and/or site-specific and thus cannot be generalized as a whole (MDC, 1997).

Therefore, the focus of this research study is to produce a before and after harvest water quality database and analyze it to identify any post-harvest effects of timber clear-cutting on streams within forested watershed. The MDC's current ROCC procedure for timber harvest leaves the branches, tree tops and other biomass in the ground after harvest (Figure 1.1).

Figure 1.1 - Water quality study site after clear cut timber harvest (Reynolds County) with tree tops, branches and other biomass on the ground in Current River CA in the Missouri Ozarks

Without the proper implementation of BMPs, timber harvest could negatively affect site quality and streams and water bodies downstream (MDC, 1997). Terrestrially, the soil profile can be altered through erosion and compaction. Nutrient mineralization and vitalization rates can be changed. Aquatically, stream water temperature, turbidity, sedimentation, and nutrient loading generally increase during and after a logging operation. However, with the proper selection of silviculture practices and through the use of BMPs, all of these adverse effects can be attenuated (Corbett et al., 1978).

Timber harvest inevitably causes some measure of downstream effects but that impact may or may not be significant over time. Changes in evapotranspiration accompanying timber harvest will generally result in change to the water balance and the distribution of water between base flow and runoff. Changes in biomass uptakes and soil conditions will interrupt nutrient cycles. Any disruptions of the ground surface by skid trails, roads, or other traffic (horse trail, bike trail, hikers trail) will disrupt hydrological pathways and provide opportunity for soil erosion at greater than natural rates. The combination of these changes can alter water yield, peak flows, water quality and sediment yield (Jacobson, 2004).

To successfully implement BMPs on private land in Missouri, resource professionals must demonstrate their effectiveness in a manner easily understood by the public, which owns most of the forested land in Missouri. Quantifying the amount of sediment transported off-site with and without BMPs will provide landowners the quantitative information they need to begin changing their land use practices. MDC lacked a verifiable database to determine if its current BMPs effectively protected surface water quality during clear-cut timber operations (Bunger, 2005).

The goals of this research therefore, are to test the efficacy of MDC's current BMPs during Regenerative Oak Clear Cutting (ROCC) in the southern Ozarks region of state of Missouri and to provide an understanding of the processes in ephemeral streams adjacent to harvested areas. These data are critical to MDC in developing timber harvest management guidelines that provide protection for the stream ecosystem and the environment in those areas where regular periodic timber management activities are performed.

1.2 Limitations of Existing State of Knowledge

University of Missouri, School of Forestry began a water quality study on water yields from four experimental watersheds at its university forest facility in the southwest Missouri Ozarks in 1973. The study objectives were to compare the flux of specific nutrients between the several experimental watersheds and to examine the relationship between the nutrient inflow from precipitation and outflow from runoff as a function of total stream flow and discharge rate, in order to determine the impacts of certain land use practices on water quality. The nutrient flux study conducted in the Missouri Ozarks merely considered the precipitation inputs and the runoff losses (Settergren et al., 1978).

Although there is considerable published information from the far west and northwest on the effect of certain timber harvest practices and associated harvesting techniques on erosion and stream sediment yield, very little data is available for the central US hardwood region. Even the available research results have been variable (Settergren et al., 1978). The majority of the published work conducted in the Pacific Northwest and southern United States focuses on public lands (Corbett, 1978).

Very few research studies in the mid-west on Regenerative Oak Clear Cut (ROCC) hardwood forests have lasted the duration necessary for understanding the effect of clear-cutting on downstream water quality and the surrounding environment. The research that had been done to address timber harvesting water quality were of short term with a small sample frequency as well as variation in species and treatments often conducted under different geo-environmental conditions. Water quality in terms of leaching of nutrients and erosion of sediments off of the clear-cut site might differ from location to location because of variation in topography, slope, soil and geological formation, species and root systems, stream characteristics, soil and air moistures and amount as well as intensity of the rainfall. So, to qualitatively and quantitatively determine the harvesting effects on water quality, a multi-year research study in the desired location is important to determine localized effects of harvesting operation on down-stream rivers and water bodies as well as upland loss of nutrients and minerals necessary for the health of the forests.

Review of the literature on timber water studies suggest that there is not much known about how streams in many parts of the midcontinent United States would respond to the hydrological, water quality and sediment stresses of timber harvest. Sustainable forestry strives to plan timber harvest so that it imposes minimal and acceptable levels of environmental degradation downstream (Aplet et. al., 1993). Sustainability cannot be claimed, of course, unless the downstream effects are measured. Noss, 1993 observed that forest management involves considerable uncertainty, and given the uncertainty it is necessary to monitor ecological effects, evaluate their magnitude and manage adaptively. Uncertainty in forecasting downstream cumulative effects are especially severe. Improved understanding of downstream effects of timber harvest in the Ozarks will require an investment in a long-term, detailed, quantitative assessment of responses at the drainage basin scale (Jacobson, 2004).

1.3 Hypothesis

There are no measurable or significant impacts of Regenerative Oak Clear Cutting (ROCC) on water quality in low-order ephemeral streams in upland forested watersheds in the Missouri Ozarks.

1.4 Research Objectives

The objectives are to describe our current understanding of how timber harvest affects downstream areas and to synthesize recent studies that indicate how Ozark streams have responded to historical and present-day land use disturbances. The Ozarks lack any long-term, instrumental record of hydrologic, water quality responses at scales relevant to timber harvest. Therefore, a long-term, comprehensive study focused on a micro-scale around the ephemeral streams in the Ozark highland must be done over a wide area to observe variation in water quality as a result of differences in seasons and precipitation, topography, channels and other physical disturbances

The objective of this study is to evaluate and quantify the effects of timber harvesting treatment in oak regenerative forest to the downstream river water systems. The main goal is to determine the efficacy of Missouri Department of Conservation's BMP practices as they pertain to protecting water quality in an ephemeral drainage way. The Ozarks stream systems are fed by first- and second-order streams from the harvested watersheds. So, the foremost objective of this project is to quantitatively determine if MDC's best management practices for Oak Regenerative Clear-Cutting (ROCC) is effectively preventing sediment, nutrients and minerals washing out of harvested hillslopes from entering into ephemeral stream channels. This would be accompanied by capturing pre- and post-harvest water samples and analyzing them for sediment, nutrients and their surrogate water quality parameters.

Evaluating the effectiveness of timber management practices is a critical part of an interactive adaptive management process whereby BMP's are initially established using best available information on water quality protection measures and operational feasibility. This is followed by an evaluation of the practices to determine whether they are achieving the desired level of water quality protection mandated by the current state and federal laws and regulations.

Tasks of the research described are herein included:

- Develop, utilize and evaluate equipment for pre- and post-harvest water sampling; analyze the water samples in the laboratory using standard analytical methods.
- Document background (pre-harvest) water quality parameters as well as post – harvest effects (database) on water quality in low-order streams in the state of Missouri Ozarks.
- Compare pre- and post-harvest water quality to quantify the impact of harvest
- Make a final assessment of current BMPs in terms of effectiveness and suggest improvements to MDC to further consider the outcome for management considerations

1.5 Research Scope

Water quality samples were obtained from fifteen sites scattered around 500 square miles of MDC forested land in Angeline and Current River Conservation Areas (Reynolds and Shannon County) in the southeastern Ozarks highlands of state of Missouri. The aerial size of a site varies anywhere from 10 to 46 acres.

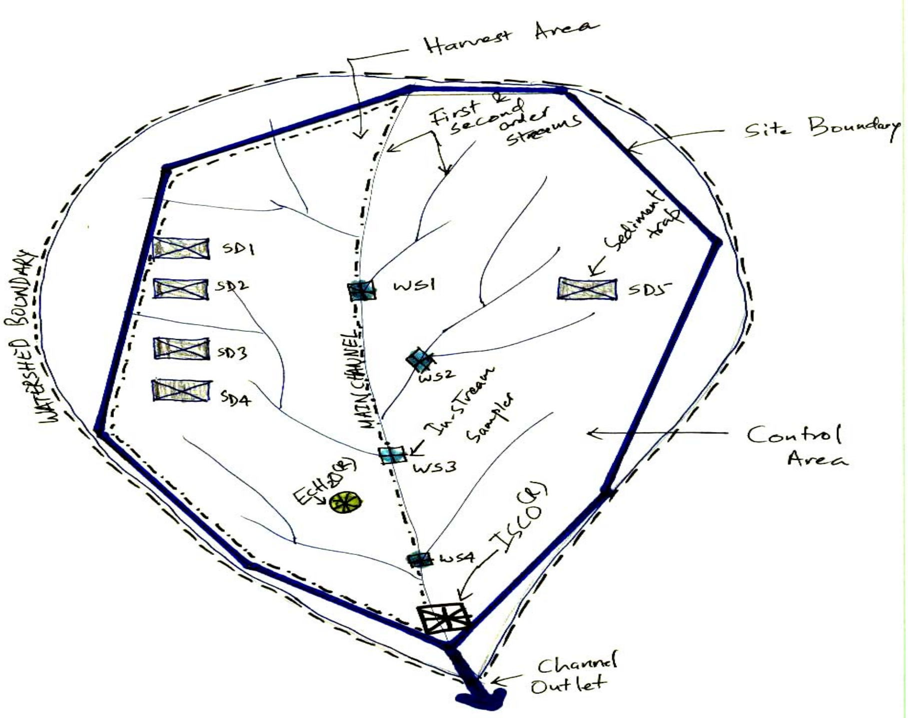

Figure 1.2- Schematic of a typical Ozarks watershed and instrument layout for timber water study

Each site consisted of at least one first-order ephemeral stream and its corresponding drainage basin. Criteria were developed to determine which sites would be most suitable for instrumentation and harvesting. Of the fifteen sites, four are "intensive" sites that are heavily instrumented by both manual and automated samplers and weather stations; eleven sites are "extensive" that are instrumented by only manual samplers on the slope of the hills as well as in the stream channel. Of these fifteen sites, eight sites are cut sites where adequate post-harvest samples were collected. Among the four "intensive" sites, three sites were harvested whereas the remaining one acts as a "control" site and it was left unharvested throughout the project duration. Some sites will be harvested on one aspect of the thalweg of the first-order ephemeral stream to the ridgetop and others will be harvested both sides of the hills.

1.6 Outline of Contents of the Dissertation

A review of the relevant literature is summarized in Chapter 2. Methods and materials are discussed in Chapter 3. Results of the research are presented in three separate and complete journal papers. Chapter 4 (Paper #1) outlines and evaluates statistical methods with respect to determination of appropriate background concentration whereas Chapter 5 (paper #2) includes Probability of Exceedance (PoE) analyses. Chapter 6 (Paper #3) includes pre- and post-harvest water quality comparisons and results of the research using PoE and other methods taking consideration of control sites as well. Conclusions, recommendations, and the future research direction are included in Chapter 7. Appendices of data and charts relevant to support the results and conclusions of this research conclude the document. A note on format is that the references used in each chapter are listed at the end of the chapter.

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CHAPTER 2: LITERATURE REVIEW

2.1 Introduction

The need for knowledge to guide water resources planning on forested land in the US is embedded in several state and federal legislative mandates and environmental statutes. Specifically, information on effects of silviculture prescription on the quality, quantity and timing of stream flow is at the forefront of planning needs. Watershed ecosystem analysis provides a scientific tool for quantifying forest resource responses to management and subsequent communication of findings to planners and practitioners (Hornbeck and Swank, 1992). Catchment scale analyses are also useful in addressing the emerging paradigm of ecosystem management in federal resource management agencies (Meyer and Swank, 1996) and issues of sustainability.

The focus of silvicultural Best Management Practices (BMPs) guidelines has often been the protection of water quality for streams, both ephemeral and perennial, and lakes. The main issues have centered on sediments, fertilizer, and natural nutrients loads, pesticides, fuels and lubricants, organic matter, and thermal impacts (Blinn and Kilgore, 2001). In forest stands where harvesting is conducted to promote natural regeneration, water quality concerns have focused on erosion (sediment transport), fluctuation in natural nutrient loads and thermal impacts.

Section 208 of Clean Water Act, 1972 states the need for all states to assess the damage caused by non-point source pollution (USEPA, 2007). The BMP is the result of this act which pertains to forestry activities and should be followed and reviewed because of their importance in the field. The result of not using BMPs to effectively reduce non-point source pollution is a direct violation of this Act (Wang and Goff, 2007). The applications of best management practice (BMP) are becoming increasingly important to preventing or minimizing the adverse impacts of timber harvesting activities on water quality. All states have developed forestry BMP guidelines or regulations, which include the use of some form of riparian buffer strip for perennial streams and their proper implementations (Phillips et al., 2000). Many forestry agencies periodically assess the extent of BMP implementation and approximately 40% of the states monitor BMP effectiveness (Edwards and Straut, 2002).

Forest managements, however, are not currently subject to the total maximum daily load (TMDL) regulations covered under section 303(d) of the Clean Water Act (33 USC 1313; 40CFR 130.7). But logging and log transports are considered by the Environmental Protection Agency (EPA) to be contributors to non-point source pollution (Corbett et al. 1978). Thus the impacts in forest management are neither easily identifiable nor enforceable (Endreny, 2002). For this reason, along with an EPA mandate, each state must develop a program of Best Management Practices (BMPs) to control such non-point source of pollution (Shostak, 2008).

The MDC has established guidelines for reducing non-point source water pollution from silviculture activities (MDC, 1997). While required for managing state conservation areas, these guidelines are voluntary for non-industrial private forest (NIPF) lands. Since Missouri's landowners own about 85% of the 14 million forested acres in the state (MDC, 1997), these stakeholders need to be made aware of the impacts their land-use management decisions can have on the larger landscape. Information about non-point source impacts of forest management and the associated BMPs for protecting water and soil resources must be gathered and subsequently disseminated to raise the level of awareness (Shostak, 2008). Forest management activities that create the potential for erosion can reduce site quality by the mass wasting of soil and the removal of nutrients through surface runoff. These same management activities can also reduce site quality through soil compaction.

To control the impact of logging on soil erosion and stream water quality, forestry best management practices have been developed in many places (NFA, 2004). The BMPs provide guidelines and emphasize the importance of pre-harvest planning, ameliorating severe trafficking associated with road construction and site preparation, designing the activities to minimize soil disturbance and exposure, maintaining SMZ, and ensuring rapid re-vegetation after harvesting. The SMZ is the planted or preserved forest patch, maintained along each side of stream between the harvest area and the stream. It is intended to be effective at filtering sediment, nutrients and organic matter from surface and ground water flows (Martin & Hornbeck, 1994). However, the relative effectiveness of SMZ to filter the nutrients and minerals from surface runoff differs according to its width, length and plant composition in the watershed (Vaidya et al., 2008).

2.2 Water Quality Parameters

Several water quality parameters analyzed before and after timber harvests provide a useful look at immediate and long-term impacts. With this information, management options can be prioritized to control loss and degradation on- and off-site and to address particular problems. Some of the important parameters for water quality (Table 2.1) are reviewed thoroughly in the following sections.

2.2.1 Sediments (or Solids)

2.2.1.1 Total Suspended Solid Sediments (TSS)

Water volume entering in the perennial stream may increase as does the sediments after the timber harvest because of reduced evapotranspiration and increased runoff in the ridges and hills but decreases sediment yield after re-growth of stabilizing vegetation (Doisy, 2002). Organic sediment serves to enhance invertebrate biodiversity by adding additional energy stores to the stream system whereas non-organic sediment serves as a stressor to the invertebrate community by altering the stream geomorphology in perennial and ephemeral streams by reducing temperature, day light exposure and pH altercation. Moreover, the logging and skidder trail road are *thought to have* catastrophic consequences by increasing the sediments and solids flow washout to the downstream (Henderson et al., 1989)

With respect to sedimentation, forest roads and log landing have been found to produce up to 90% of the off-site sedimentation (Corbett et al., 1997; Grace III, 2001). Properly implemented BMPs can mitigate sedimentation problems. Moore et al., 1995 found that the sediment reduction was 84% on forest roads when tire pressure of logging trucks was reduced. Grace III 1999 found that the concentration in runoff was reduced to 93% in comparison to bare soil controls when erosion control ground techniques, such as the planting of native or exotic groundcover species, were practiced. The magnitude of the positive result has been driving widespread development of erosion and sediment control BMPs.

The loss and accumulation downstream of nutrients and sediments off of the hill slope increases turbidity, which negatively impacts water quality. Turbid water blocks light transmission, thereby reducing both the primary production of aquatic plants and the visual feeding range of fish (Corbett, 1978). The fine sediment that causes this turbidity can also fill the interstitial spaces of gravel in spawning beds, reduce available oxygen needed by fish embryos, and can cause gill inflammation and eventual death to young and susceptible fish. Organic sediment may deplete oxygen needed by fish and impact all primary production capabilities thus breaking down the stream's food web. Sedimentation may also reduce reservoir storage and channel water carrying capacities, increase the cost of potable water treatment, and reduce hydrologic amenities (Shostak, 2004)

Sediment losses from a study in some Arkansas Ozark Plateau catchments (Rogerson, 1976) have been found small, averaging only 19.7 lbs/acre a year during 1966-1974 periods. In contrast, annual sediment losses of 200 lbs/acre/year were reported for hardwood watersheds in northern Mississippi (Ursic, 1970); in North Carolina, losses were 154 lbs per acre when the watershed supported hardwoods and 1 ton/acre when it was farmed (Dils, 1953). Average annual losses ranged from 64.4 lbs in 1973 to 1.9 lbs per acre in 1972. This large range might have been attributed to storm frequencies, size and intensity that influence water content and runoff discharge rate. Large storms periodically flush out drainage channels and produce larger-than-normal sediment losses. Discharge rates greater than 0.50 ft^3/s occurred in only 24 percent of the runoff-producing storms, but these storms accounted for 91% of the sediment losses.

Sediments are probably the most important parameter because they not only harm the stream with increasing turbidity and reduced dissolved oxygen, but they also denude fertile slopes, stunting vegetative growth.

2.2.1.2 Total Volatile Suspended Solids (TVSS)

Volatile solids are the organic matter fraction in the stream systems that are being carried away after the precipitation event. If volatile suspended solids increase in the stream and channels, the downstream water will increase in turbidity. The volatility of those organic matters and their chemistry as well as duration into the system are important for fish and other aquatic animals as well as plant life in the water system.

2.2.2 Nutrient Parameters

2.2.2.1 Nitrogen and Nitrogen Associates

Ammonia (NH_3), nitrate (NO_3), ammonium (NH_4), nitrogen gas (N_2) and nitrite (NO_2) are the forms of nitrogen that exist in the soil and atmosphere. Ammonium and nitrate are the intermediate forms that are not ready to be used forms (needed to further degrade to be used). Nitrogen should come from either fixation or from the decaying of the organic materials that had some form of nitrogen (Johnson, 2002). Nitrogen and ammonia are used by plants and microbes as an energy source using the two main processes of changing nitrogen, nitrification and de-nitrification.

Nitrification occurs when NH_3 is taken in by plants and soil heterotrophs and then converted into nitrate, which is used to construct proteins for growth in an oxidative process (Table 2.1). Denitrification is the reduction of nitrate to nitrogen gas. If the nitrogen supply is greater than demands of soil heterotrophs and vegetation, then nitrate leaches into the watershed (Henderson, 2002).

Table 2.1- List of source pool and limiting factors of some nutrients and minerals selected for water quality study in Ozarks (Brinkley, 2000)

Nutrients	Major Pool	Long Term Source	Biochemical Roles	Limiting Situations
Nitrogen	Nitrate, Ammonium, N2 fixing species	Organic matter, N2 fixing species	Proteins, enzyme, nucleic acid	Most temperate forests
Phosphorous	Soluble phosphorous	Organic matter, mineral phosphate	Nucleic acids, lipids, energy flow	Soils high in aluminum and iron
Potassium	Soluble K+	Organic matter, mineral potassium	Enzyme cofactor, ionic buffer	Soils if no fertilization of N, P
Calcium	Soluble Ca2+	Organic matter, mineral calcium	Call walls	Rarely limiting
Magnesium	Soluble Mg2+	Organic matter, mineral magnesium	Enzyme cofactor	Rarely limiting

Nitrogen and nitrogen associates are important elements for plants because they, more than any other nutrients, are primarily responsible for limiting the growth of vegetation. In some timber harvest operations, trees' green canopies are left on the ground after harvesting to make sure that the soil develops a pool of nitrogen. This also prevents rapid leaching nutrients from the soil (Stone, 1975; Binkley, 2000).

2.2.2.2 Total and Soluble Reactive Phosphorous (TP and SRP)

Phosphorous is an important nutrient material for plants; large concentrations of aluminum and iron are the sources of phosphorous in the Ozark system that come from the weathered rock. Phosphorous can be taken in by plants, precipitates in the presence of calcium, iron and aluminum, or may be leached from the root system (Fisher, 2000). Soil containing calcium phosphate has pH and soluble but the soil containing aluminum phosphate is least soluble. In the Ozarks, it was found that phosphorous was distributed with regard to landforms and soil depth. Most phosphorous was in the A-horizon and decreased with depth due to high levels of aluminum and iron within the C-horizon

(Nien-Tzu, 1997). The phosphorus in the A-horizon is considered soluble, and is obtained through long-decomposed organic materials (Binkley, 2000). This form of phosphorous can easily be measured by measuring for soluble reactive phosphorous in the watershed effluent (Fisher, 2000). Timber harvest was not shown to have a big impact on phosphorous because those are formed by the geological weathering process from the parent materials prevalent in the site. However, erosion and mass washing of soils are found to be a detriment to soil stores. Nien-Tzu, 1997 noted that the Ozarks will have a scarcity of phosphorus if the soils are not managed properly.

2.2.3 Minerals: Calcium (Ca), Magnesium (Mg) and Potassium (K)

Measurement of calcium, magnesium and potassium are important since they are formed from the rock that has undergone physical and chemical weathering. Ozarks areas have these cations since the major geologic formations; are dolomite limestone principally comprised of calcium and magnesium. The constituents also have important relations to hydrological characteristics of the stream itself such as armoring of the channel and other channel characteristics. Calcium and magnesium also serve several limnogical uses such as buffering of water and enhancing bacterial and plant growth.

Potassium, like phosphorous, is also limited in the system by the availability of old soils is released by the decomposition beneath the leaf litter layer. It is the most mobile nutrient but could be sequestered by clays resulting in limited use by the plants. The nutrients are not only a pH buffer but are also used in plants for enzyme activation, protein synthesis and photosynthesis (Binkley, 2000).

2.2.4 Index Parameters: pH and Electrical Conductivity

The electrical conductivity (EC) of water depends on the concentration of ions in solution, their ability to dissociate, their charges and speed of diffusion. The pH specifically tells the concentration of one particular ion, H^+. In environmental systems, particularly in soil and water, pH is a main indicator of the presence of nutrients and minerals. In other words, in certain circumstances, if pH is too high or too low then other factors involved that could lead to the precipitation of the constituents or leaching of the constituents. EC is also used as an index test to validate the amount of calcium and magnesium present; however, EC is a measure of cations. If there is a high conductivity but low calcium and magnesium present, then there are other constituents that are adding to conductivity in the sample and should therefore be further explored (Smith, 2006).

2.3 Nutrient Flux Study in the Missouri Ozarks (Settergren et al., 1978)

A nutrient budget approach was used to investigate the flux of nitrogen, phosphorous, calcium, magnesium, potassium, sodium and silica from four different forested watersheds in the southeast Missouri Ozarks (Table 2.2). The objective of the study was to compare the flux of specific nutrients between the watersheds, and examine the relationship of nutrients inflow from precipitation and outflow from runoff as a function of total stream flow and discharge rate (Settergren et al., 1978).

Table 2.2- Inflows and outflows of nutrients and its cycle in a watershed (Settergren et .al., 1978)

Inflows	Watershed nutrient pool	Outflows
1.Atmospheric fixation solution in precipitation	⇨ ⇨ ↻ Internal ↻	1. Stream flows
2. Weathering of geologic parent material	Cycling ⇦ Nutrient	2. Volatilization to atmosphere
3. Hydrologic Import	(chemical and biological process)	3. Losses to deep seepage-hydrologic export
4. Fertilization		4. Nutrient harvest

Four forested watersheds were used in the flux study; the area of the watersheds ranged from 9-18 acres, the catchment had an even-aged predominantly oak and hickory forest that was left undisturbed. The soils of the research area were weathered residuum of the underplaying dolomitic limestone and sandstone geology, primarily the Roubidoux formation series. A Bausch ad Lamb Spectronic 70 spectrophotometer with a 19 mm light path was used for all the colorimetric analyses after sample collection and filtration in the lab. Calcium and magnesium concentration were determined by atomic absorption spectroscopy using a Perkin-Elmer 290-B unit. Primarily, precipitation input and the quantity loss of nutrients to stream flow were monitored for about two years.

The flux study showed net losses of calcium, magnesium, potassium, sodium and silica but net gain of total phosphorous, ammonia and nitrate nitrogen (Table 2.3). High yields of ammonia, phosphorous, potassium and calcium occur most frequently in the summer and early fall as these nutrients are picked up by rainfall from the tree foliage and decomposing leaf litter. Phosphorous and potassium yield were closely correlated with the stream turbidity, and indication that these nutrients probably are removed with flushes of organic and inorganic particulate matter. Under the higher moisture regime these soluble ions are flushed from the watershed to the extent that the flux becomes negative. High yields of silica, calcium and magnesium are associated with the winter and spring seasons when increased soil moisture levels probably facilitate the geologic weathering, solution and movement of these minerals. The high outflow and negative flux from Watershed #4 for calcium, magnesium and silicon probably indicate local solution of the dolomitic geology and weathered residuum (Table 2.3).

Table 2.3- Result of a nutrient flux study conducted in the Missouri Ozarks (Settergren et al., 1978)

1973-74 Water Year					
	Precipitation (total 79.52 inches)	Watershed 1 (runoff 24.20 inches)		Watershed 4 (runoff 30.50 inches)	
Nutrient ion	Nutrient inflow (kg/ha)	Nutrient outflow (kg/ha)	Flux (kg/ha)	Nutrient outflow (kg/ha)	Flux (kg/ha)
Ca	7.86	10.21	-2.35	107.48	-99.62
Mg	1.07	5.78	-4.71	73.91	-72.84
K	5.17	5.51	-0.34	6.41	-1.24
Na	4.44	5.04	-0.60	6.25	-1.81
NH3-N	9.89	3.15	6.74	1.70	8.28
No3-N	2.71	0.39	2.32	0.38	2.33
T-Phosphorous	0.68	0.25	0.43	0.06	0.62
SiO2	0.68	5.21	-4.53	44.47	-43.79
1974-75 Water Year					
	Precipitation (total 52.84 inches)	Watershed 1 (runoff 9.47 inches)		Watershed 4 (runoff 13.45 inches)	
Nutrient ion	Nutrient inflow (kg/Ha)	Nutrient outflow (kg/ha)	Flux (kg/ha)	Nutrient outflow (kg/ha)	Flux (kg/ha)
Ca	4.79	4.00	-0.79	44.91	-40.12
Mg	0.64	2.29	-1.65	29.25	-28.61
K	3.09	2.22	0.87	2.90	0.19
Na	2.81	2.28	0.53	2.73	0.08
NH3-N	5.90	1.01	4.89	0.79	5.11
NO3-N	1.75	0.14	1.61	0.18	1.57
T-Phosphorous	0.38	0.05	0.33	0.05	0.33
SiO2	0.53	2.01	-1.48	18.34	-17.81

Settergren et al., 1978 further carried out a study on one of those four watersheds to quantify the contributions from several of the internal sources, i.e., precipitation, throughfall and forest floor leachate, runoff etc to the nutrient flux and also to discuss these pathways in relation to stream flow quality.

The result suggested that the Throughfall potassium concentration increased during the growing season because of the increased availability in leaf tissue to leaching (Table 2.4). The high magnesium concentration in Throughfall in the spring coincides with the emergence of young leaves and reproductive structures. A relationship of antecedent moisture and calcium and magnesium leachate concentration may also be due to timing of storm events. With deficient quantities of precipitation, the forest floor produces less calcium and magnesium in the leachate (Settergren et al., 1978).

Table 2.4- Nutrient concentration and flux from the internal source in the Ozarks flux study

Nutrient concentration year 1975-76	Source(kg/ha)	K	Na	Ca	Mg
	Precipitation	0.76	1.46	3.61	0.29
	Throughfall	6.68	1.85	6.94	1.33
	Forest floor leachate	13.15	1.97	15.02	3.05
Nutrient flux year 1975-76	Flux(kg/ha)	K	Na	Ca	Mg
	Precipitation	2.611	1.824	5.438	1.194
	Runoff	0.915	0.798	2.486	1.244
	Flux	1.696	1.026	2.952	-0.05
Nutrient flux three storms year 1975-76	Source (kg/ha)	K	Na	Ca	Mg
	Precipitation	0.206	0.61	0.882	0.088
	Throughfall	0.701	0.834	1.316	0.212
	Forest floor leachate	2.839	0.827	1.956	0.416
	Runoff	0.203	0.058	0.268	0.242
	Flux	0.003	0.55	0.614	-0.154

A similar research study by Henderson et al., 1980 in the Missouri Ozarks for control and harvested watershed resulted in NH_4^+-N concentration increase in surface runoff (Table 2.5). Parameters including calcium, magnesium, potassium and sodium increased after harvest in the watershed. Similarly, NH_4^+-N (mg/L), NH3-N (mg/L) and dissolved organic N (mg/L) all were seen increasing in concentration after harvesting of the watershed hardwoods in the catchments (Table 2.5).

Table 2.5- Results of a study on seven water quality parameters in the Missouri Ozarks (1979-82) (Henderson et al., 1980)

	Calcium (mg/L)		Magnesium (mg/L)		Potassium (mg/L)	
Collection location	Control watershed	Harvested watershed	Control watershed	Harvested watershed	Control watershed	Harvested watershed
Runoff						
Uncut	6.07	6.31	1.26	1.1	4.33	4.36
Cut		8.48		1.79		5.59
Subcatchments						
With buffer		1.97		1.3		0.75
Without buffer		3.43		1.68		1.59
Entire watershed (main Flumes)	2.41	2.83	1.12	1.38	0.51	0.46

	NH4^+-N(mg/L)		NH3-N(mg/L)		Dissolved organic N(mg/L)	
Collection location	Control watershed	Harvested watershed	Control watershed	Harvested watershed	Control watershed	Harvested watershed
Runoff						
Uncut	2.33	2.24	0.44	0.41	2.77	2.65
Cut		3.29		0.71		4
Subcatchments						
With buffer		0.72		0.4		1.12
Without buffer		0.29		0.83		1.12
Entire watershed (main Flumes)	0.05	0.03	0.06	0.12	0.11	0.15

2.4 MU, Agro-Forestry Research at Knox County Missouri

A paired watershed comparison for agro-forestry practices, runoff and nutrient loss, by Udawatta et al., 2002 in the University of Missouri-Greenley Memorial Research center in Knox County, MO, found that agro-forestry and contour strip resulted in reduction of up to 10% runoff in the watershed. The difference between observed and predicted sediment loss averaged 18 and 230 m3/ha annually for agro-forestry and contour strip treatments, during the three years of treatments. The total runoff during the treatment was only about 90% of the runoff produced by the control watersheds. During the two initial years, the sediment was higher than predicted because of soil disturbance during tree planting and crop establishment. But, sediment loss did decline over the reminder of the treatment period. As the grass strip and permanent vegetation became established and started to transpire and infiltration improved, runoff loss was reduced and associated losses declined (Udawatta et. al., 2002).

The contour strip vegetation method showed about 19% reduction in runoff during a year. Total phosphorous loss was about 8 and 17% for contour and agro-forestry watersheds respectively. The reduction did not begin until a year or so after the treatment was applied to the watersheds. Similarly, during the treatment period, the control, agro-forestry, and contour strip watersheds lost 3.77, 3.37 and 3.24 kg/ha of total nitrogen per year.

Compared to the loss of total nitrogen predicted, no reduction was obtained during the first two years but a very small reduction occurred during the third year after the treatment applied to the watersheds. Similarly for ammonia and nitrate loss, the control strip treatment reduced the former to about 32% during the treatment period whereas the contour strip reduced the loss to about 40% whereas the agro-forestry treatment showed more than that in the watershed. The control, agro-forestry and contour strip treatments lost 4.35, 4.43 and 3.17 kg/ha per year nitrate N respectively in 1998. The contour strip treatment had a 0.15 kg/ha reduction in nitrate loss while the agro-forestry treatment lost 1.92 kg/ha more than the predicted losses. The reduction of the nitrate N loss in the contour strip accounts for 4% of the predicted loss (Udawatta et. al., 2002).

Overall, the research found that the extreme precipitation events contributed significantly to the export of the nutrients and runoff.

2.5 Walker Branch Study (1967) Oak Ridge, Tennessee

The Walker Branch study (1967) area is located on the Oak Ridge Reservation in Anderson County, Tennessee near Oak Ridge National Laboratory. The watersheds can be best described as a mixed hardwood forest that includes various oaks and hickory lower in the landscape and pine located higher in the landscape (Harris, 1977). The study area lies within a humid continental climate zone; drains eventually into the Tennessee Valley Reservoir. The study area covers 98 hectares and consists of two smaller watersheds – the west catchment and the east catchment

The climate supports a wet winter and dry spring, followed by a wet summer and a dry autumn. July is not only the wettest month with a mean rainfall of 4.4 inches but also the hottest month with an average temperature of 85 degrees F (Curlin and Nelson, 1968). Walker Branch's geology is mainly comprised of a 1200 ft thick sequence of siliceous dolomite (Henderson et al., 1971).The water quality data collected and analyzed from 1970 to 1974 in the Walker Branch Study is shown in Figure 2.1.

The Walker Branch study highlighted many facets of the watershed, i.e., measuring the hydrologic characteristics of a watershed ranging from subsurface flow, variable source area flow, transport across the plant-soil interface, and outflow, the measuring of the chemical composition of wet and dry deposition above ground and biomass located below ground, and the interaction of flow and the pooling of biomass with regard to underlying geology, topography, soils, as well as understory and overstory vegetation.

The research study had three objectives: 1) provide data for unpolluted forested areas, 2) contribute to the knowledge of cycling and loss of chemical elements in natural systems, and 3) to enable the construction of models to better predict societal impacts on natural environments (Henderson et al., 1989).

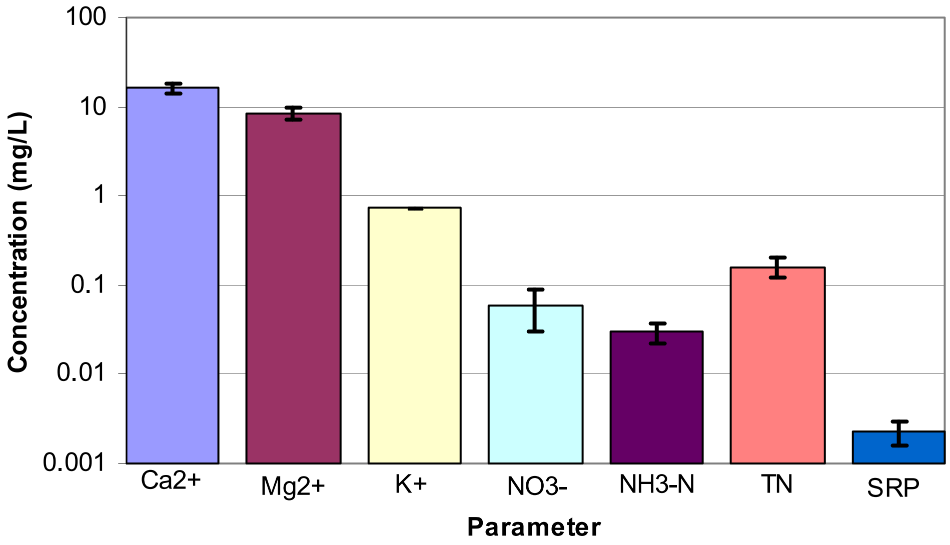

Figure 2.1- An average and range of concentration of various water quality parameters in the Walker Branch Watershed Project for the years 1970-74 (Henderson et. al., 1989)

The following observations were made in the Walker Brach Watershed Study:

- Nitrate, ammonia-nitrogen and soluble reactive phosphorous concentration in the water are relatively small and typical of streams draining second-growth forested watersheds in the southeastern United States (Messer et al., 1987).
- Calcium and magnesium concentrations showed a dilution effect whereas total nitrogen and soluble reactive phosphorous show a concentration effect.
- Potassium levels increased in the watershed’s effluent during fall months attributed to the leaching of potassium from fallen leaves and debris from ephemeral channels and intermittent streams in early to late Fall.

- Soluble reactive phosphorous variation is due to leaching of phosphorous associated with soil and litter in the upper horizons. The landscape had larger amounts of phosphorous in the A-horizon and decreases in the B-horizon (Johnson et al., 1981). Fragipans that inhibit vertical flow, thus increasing lateral flow, could move more water over debris and increase soluble reactive phosphorous in the effluent (Elwood and Turner, 1989).
- Nitrate concentration in water samples is highest in the winter and lowest in the summer (Elwood and Turner, 1989).

2.6 Boston Mountain Study (1974) in Arkansas

The Boston Mountain study site is located in northwest Arkansas on the Ozark National Forest southwest of Fayetteville, Arkansas. Water quality from four forested watersheds located was monitored for about eight years (Lawson et al., 1985). The samples collected were analyzed for multiple parameters including: potassium, total phosphorous, calcium, iron, sodium, ammonia-nitrogen, magnesium, manganese, nitrate, and carbonic acid. Soils at the site were infertile, highly acidic, and moderate in permeability whereas overstory vegetation was classified as mixed hardwoods and consists of white oak, red oak, various hickories, black oak, and red maple.

All laboratory analyses were performed at the University of Arkansas, using standard methods (American Public Health Association, 1980). Analyses were made on unfiltered samples and consisted of the following parameters: pH, iron, manganese, total phosphorous, potassium, calcium, magnesium, sodium, total hardness, ammonia nitrogen, nitrate, bicarbonate, specific conductance, and turbidity. A mean concentration of some water quality parameters is shown in Figure 2.2.

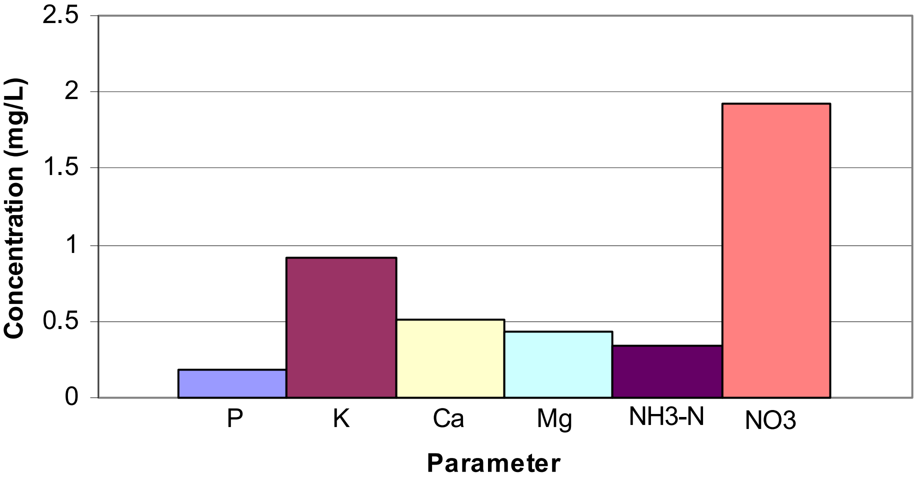

Figure 2.2- Mean concentration of selected parameters for watershed study in the Boston Mountains 1974-81 (Lawson et al., 1985)

Summary of findings from the Boston Mountain Study are as follows:

- Average concentrations of calcium and potassium varied seasonally. In the summer and early fall months, these concentrations increased dramatically whereas the average concentrations of phosphorous and calcium did not differ greatly across the watersheds.
- Nitrate was found to be highest in sampling months of July and August. Ammonia-nitrate was also found to be the highest in August. Increased nutrient precipitation input is thought to be the reason for the increased concentrations.
- Monthly pH readings ranged from 5.8 in June to 6.3 in January, but did not show any seasonal trends. The pH of precipitation and soil pH levels have been reported to show seasonal trends (Keogh and Maples, 1972) and changes in atmospheric deposition are thought to lower the yearly mean over the eight year study changing the pH from 6.1 to 5.6.

- Electrical conductivity levels varied with regard to season and other nutrients. Conductivity was highest in summer and early fall, the same time of the year that coincided with the higher concentrations of most nutrients.

2.7 Other Relevant Timber Harvest Water Quality Studies

Forested areas not only provide some control over the rate of water discharge, but they also protect the watershed and thus, the water quality, against the effects of erosion, sedimentation, leaching of nutrients, and overland flow (Pope, 1977). The forested watersheds of the Ozark region provide an array of resources to the human, plant, and the animal populations of the southern region of the State of Missouri. These watersheds help sustain water quality for the growing human population and they provide a host of recreational opportunities. They provide timber which provides an important economic resource for the region. Additionally, forested watersheds provide significant and, in some instances, vital habitat to plant and animal species of conservation concern (Chaberd and Abt, 2004).

Forestry activities such as road building, harvesting and site preparation can affect the quality and quantity of water flowing though a watershed. Some indicators of water quality include suspended and deposited sediment, nutrients and temperature and other surrogate parameters. Undisturbed forested watersheds are generally recognized as a primary source of high-quality water. The physical and chemical nature of these waters fluctuate constantly in response to natural stresses but are most influenced by man's activities.

A study in the Ozarks highlands in the state of Missouri by Jacobson (2004) concluded that the water yield enhanced base flow that had significant potential to increase sediment yield through direct soil disturbance and stream flow erosion of stream beds and banks. In general, the most important factor in increasing stream flow and sediment yield was the design and density of trails and haul roads. The cyclic timber harvest could have fewer downstream effects than alternative agriculture land use. Whereas, there is very little knowledge about the importance of spatial scale and pattern to down-stream cumulative effects and the degree to which low order Ozarks stream have recovered from historical disturbance. Importance of transient fine sediment impacts and threshold of stream biota as well as quantitative understanding of sources of rates of sediment yield associated with timber harvest roads are little known in the Missouri Ozarks watersheds.

Timber harvesting, one of the major forestland management options, may have an adverse affect on water quality. A 20 year long study in water yield, storm hydrograph, stream inorganic chemistry and sediment yield were analyzed for a 150 acre mixed hardwood covered catchment in a southern Appalachian mountains following clearcutting and logging. The study conducted by Swank et. al., 2001 concluded that the year after cutting, stream flow increased at 28% of the flow expected in an uncut site. Analysis of stream solute concentration and catchment nutrients fluxes showed a small increase in nutrient losses following clearcutting and logging. Responses were largest the third year after treatment with annual values of 1.3, 2.4, 2.7, 3.2, 1.4, 0.39, and 2.1 kg/ha for NO3-N, K, Na, Ca, Mg, S, and Cl, respectively. In general, research results indicated that nutrient losses, particularly nitrogen, following forest clearcutting were small to negligible.

In subsequent years, the discharge decreased at a rate of 5-7 cm per year until the fifth year and changes returned to the baseline value. Intra- annual analyses showed that proportionally larger increases, 48% in flow occurred in the low flow months of August – October. Storm hydrograph analyses showed that on an average, initial flow rate and peak flow rate increased 14-15% and steam flow increased about 10% (Swank et. al., 2001). The largest water yield increase occurred the first year after cutting when evapo-transpiration (Et) was most reduced due to minimal leaf area index (LIA). As sprout and seedlings regrew, LAI and Et increased and stream flow and water yield decreased logarithmically over time.

Swank et. al., 2001 also concluded that the analysis of stream solute concentrations and catchment nutrient fluxes showed a small increased in nutrient losses following clear cutting and logging. A large increase in sediment yield was measured immediately after road construction due to two major storm events. Subsequently, sediments yield from roads immediately after road construction was greatly reduced and insignificant when logging activities were completed. In contrast, cumulative increase in sediment yield were observed downstream over the next 15 years, which illustrates the lag between pulsed sediments inputs to a stream and the routing of sediments through a stream system.

Rashin et al., 2006 in another study concluded that during the first year following harvest, the extent of disturbed soil at sites with stream buffers ranged from less than 1 percent to 19 percent of the survey area, compared to 6 to 50 percent soil disturbance at harvest site without stream buffers. Average levels of disturbed soil were three times lower at sites where streams were buffered than where streams were not buffered. The soil disturbance was higher in total and partial clear cut in the second year of treatment. The average level of disturbed soil was three times less in buffered streams than non buffered streams. The volume of sediment delivered to the streams was estimated 24 % of those erosion features found to deliver sediment to streams during the second year following timber harvest. The 21% erosion features in this subsample had a median exposed soil area of 22 m^2, and maximum volume of sediment delivered was 0.5 m^3 per year. Linear regression of the log-transformed data showed a significant positive correlation between the exposed soil area and the estimated volume of sediment delivered to streams.

Forest harvesting has the potential to increase nutrient inputs into aquatic systems, which can have an eventual impact on surface water quality and biotic response. Increased nitrogen movement from the terrestrial portion of the watershed is of critical importance as it influences productivity and nutrient cycling in aquatic system. Whether there will be an increased export of nitrogen to aquatic systems after harvesting depends on the coincidental occurrence of increased production and/or decreased uptake by plants and microorganisms within the terrestrial ecosystem and the ability to transfer these nutrients to adjacent receiving waters (Putz et. al., 2003).

A review of research conducted in the southeastern US Coastal Plain shows that specific water quality trends can be anticipated after clearcutting activities. Responses of stream temperature, dissolved oxygen, suspended solids and some nutrients to logging activities have been replicated by overall studies (Binkley and Brown, 1993). Sedimentation has been cited the most important water quality parameter concern related to forestry practice in the United States. Similarly, a review of eastern forestry practices concluded that timber harvesting leads to minor changes in stream nutrient concentration (Corbett et al., 1978). These changes in stream water chemistry have been attributed to alterations of biogeochemical cycles in the harvested watersheds (Lynch and Corbett, 1990). The nutrient input in the Blackwater stream in North Carolina ended up blooming phytoplankton species due to light and nutrient changes (Mallin et al., 1997)

Harvesting of the forest canopy disrupts the annual circulation of nutrients and sediments. The harvest can take away some or all of the many years accumulation of aboveground vegetative stand (Stone, 1975). Such removal of crown allows for mass movement of soil sediment and nutrients more readily, and with the addition of skidder trails this movement is compounded (Doisy, 2000). A clear cutting can increase storm water flow and allow overland sheet flow leading to increases in annual water yields and peak discharge rates. A review by Sheppard (1994) of logging in wetlands concluded that silviculture practices has temporary effects on water quality, with water quality parameters returning to pre-harvest levels within periods of months to several years.

Messina et al., 1997 conducted a study on initial responses of woody vegetation, water quality and soils to harvesting intensity in the Texas hardwood ecosystem which looked at the effects of clearcutting and partial cutting on woody vegetation regeneration dynamics, surface and groundwater quality, soil physical properties, and soil respiration were tested in a bottomless hardwood ecosystem with non-cut control sites. The study concluded that there were few significant differences in groundwater properties when harvesting treatments were compared with control areas during a 17 month period following harvest. Turbidity, temperature, electrical conductivity, dissolved O, NH_4-N, NO_3-N and PO_4-P of stream water did not vary very significantly among treatments. No significant differences in treatments in measured soil physical properties were observed at 5-10 cm depth. Overall, most of the variables showed only slight responses to harvesting, thereby indicating that these specific harvesting practices in that setting can be conducted with minimal initial impacts on measured variables.

Ensign & Mallin (2001) studied water quality changes after clearcutting of timber in Backwaters river in North Carolina and concluded that the temperature and pH did not differ much before and after the timber harvest. Total suspended solids showed a significant difference between creeks after clear cutting but not before. Overall, the study concluded that the clearcutting lowered dissolved oxygen, increased TN, TP, TSS and they were significantly elevated for 15 months after timber harvest began.

The research conducted by Ensign & Mallin (2001) was in line with most short-term water quality impacts on most physical and nutrient parameters reported in previous research on clearcutting in the southern coastal plains. The increase in nutrients input increased chlorophyll and prompted an algae bloom. The research also concludes that the clear-cut landscape may not have been able to assimilate the watershed-derived nutrients load after periods of intense rainfall. The vegetative buffer left along the streamside was not sufficient to protect stream water quality from the short term impacts and long term impacts of algae blooms.

Skid trails used by tracked hydraulic grappling equipment referred to as a “shovel” trails collectively made up to 29 percent of all erosion features identified at harvest sites but accounted for 54% of the exposed soil associated with sediment delivery, due to the large size of the features. The dominance of skid trails in terms of exposed soil area is partly a reflection of the fact that the total sample included more than twice as many ground-based yarding sites at cable sites. Among skid and shovel trails, 26 % were found to deliver sediment to streams during on or both survey years, compared to 44% delivery for falling and yarding features. Virtually all skid and shovel trails associated with chronic sediment delivery were trails that crossed streams (Rashin et al., 2006).

However, today's responsible forestry and logging operations bear little resemblance to historical logging in environmental consequences and effect on downstream water quality especially after using methods to lower the sedimentation as well as trap them before hitting the channels by using buffer strips of vegetation. Today, BMPs generally are used to protect resources and are critical for controlling erosion and sedimentation (Edwards and Stuart 2002). Erosion occurs and sediment is delivered proximally from roads, trails and log landings on which the mineral soil has been exposed, compaction has occurred and water has been concentrated.

Best management practices reduce erosion and in-stream sedimentation through careful planning and location of roads, trails, and landings; a) minimizing their length and surface area as well as the number of stream crossings within the road system; b) using road crossing systems like culverts and bridges that are appropriate for the areas' physical conditions and drainages; c) using proper road surfacing techniques and material at stream crossings and water control areas; d) providing sufficient numbers and sizes of water control features like cross drainage culverts and broad based dips to divert water from roads in small quantities so that erosion is controlled; and e) retaining forest filter strips between roads and strips and landing to trap soil eroded from those areas and prohibiting machine operation where soils are wet and vulnerable to compaction and erosion (Stuart and Edwards, 2006).

Lockaby et al., (1997b) in a review of silvicultural activities in flood plain forests of the southeastern United States, concluded that clear cutting followed by the natural regeneration and accompanied by best management practices has a small and brief effect on water quality. A review of timber harvest in the southern coastal plain concludes that the short term effects of forestry activities on water quality can negatively impact the coastal environment (Herz, 1996). These studies and others cite that the cumulative water quality impacts from forestry activities is slight and transient compared with other land uses, because timber harvest in those lands are performed infrequently at 25-50 year intervals (Herz, 1996).

Clear cutting and land cover change can alter the nutrient retention mechanisms in soil that subsequently affect the quality of water in streams and lakes in the watershed (Lynch & Corbett, 1990). Swank et al., (2001) reported that, following clearcutting of mixed hardwood on a southern Appalachian catchment, the on-site impacts were soil and nutrient losses and offsite impacts were on stream water quality, attributed to the altered chemistry and flow rates, sedimentation, and impacts on invertebrate habitat and community structure.

Increase in nutrient concentrations and loadings often are observed during the first year or for several years after harvesting, although rarely to levels that adversely affect water quality (Stednick, 2000). Public concern often is that the nitrogen and phosphorous level may increase from forestry operations. But it was found that the nitrogen concentration often remains below the 10 mg/L standard for public water supplies, and the phosphorous generally remains unchanged by harvesting. There can be a wide variation of nutrient changes among the sites during forest operations. Concentrations and/or loadings of some constituents increase, whereas others decrease or do not change, but in all cases where logging, including clearcutting, and related activities are conducted carefully, changes in stream water chemistry are small or of short duration (Stuart and Edwards, 2006).

A study conducted in Central Nova Scotia, Canada on best management practice applied while harvesting trees at the Pockwock Lake and Five miles Lake watersheds for two years before and two years after harvesting, found that the natural background concentration of nutrients and minerals in stream water is influenced by marine aerosols, long range transport of air pollutants, landscape geology and land cover. The natural background concentrations established before timber harvesting were used as the baseline water quality to investigate the impact of timber harvesting on stream waters (Vaidya et al., 2008). Three types of streamside management zones, a 20 m no cut, 20 m select cut, and a 30 m select cut, were applied and their efficacy was evaluated for protecting the stream water quality.

Non-parametric test in the study on stream water quality showed that there was significant change in the concentration of potassium in six streams, manganese in five streams, zinc in two streams, and total nitrogen in one stream after harvesting. There was no significant change in the quality of water in two streams used as controls sites in the neighboring watershed of similar size and hydrology characteristics. The result showed that the forest management practices were most favorable in streams maintained width 30 m select cut followed by 20 m no cut and 20 m select cut SMZ. The vegetation may have decreased the flow velocity and increased residence time and thus increased filtration and retention of minerals in the riparian soil (Vaidya et al., 2008). The stream chemistry concentrations of potassium, manganese, calcium, zinc and total nitrogen were influenced in several streams by these operations.

Vegetation responds rapidly to stabilize exposed soil. Long-term studies conducted on managed forest land show that soil erosion occurs at about the same rate as naturally occurring geologic erosion (Miller et al., 1978). To some extent, silviculture practices do affect water quality. However, the effects are of short duration and return to a pre-harvest condition occurs within a three to seven year period depending upon the source of contamination. Timber harvesting water quality poses little threat to water quality when care is taken to prevent or minimize soil exposure thereby erosion (MDC, 1997

2.8 Summary of the Literature Review

Twelve water quality parameters selected for evaluation include: a) sediments: total suspended solids, total volatile suspended solids; b) index or surrogate parameters: pH, electrical conductivity; c) minerals: calcium, magnesium and potassium and d) nutrients: nitrate, total nitrogen, ammonia-nitrogen, total phosphorous, and soluble reactive phosphorous. These parameters have been selected because of their importance or indicate specific cycling attributes to the forest or their potential to degrade downstream water quality. Observations from previous studies can be used to further the understanding of the water samples in the present study.

The nutrient flux (Settergren et. al., 1978) study in the Missouri Ozarks showed net loss of calcium, magnesium, potassium, sodium and silica but net gain of total phosphorous, ammonia and nitrate nitrogen. High yields of ammonia, phosphorous, potassium and calcium occur most frequently in the summer and early fall as these nutrients are picked up by rainfall from the tree foliage and decomposing leaf litter. Phosphorous and potassium yield were closely correlated with the stream turbidity, indicating that these nutrients are probably removed with flushes of organic and inorganic particular matter. The study was taken done virtually in the same sites in the southeast Missouri Ozarks. The result is a primary indication of the constituent properties of water quality. The study provided essential information about seasonal trends in the same setting as this Timber Harvest Project for many of the same parameters. In addition, the study gives information about the hydrology of sites similar to the Timber Harvest sites. Settergren et al., (1978) indicates yearly precipitation and the amount of effluent that came off of the four watersheds. The data indicates that on average from 20 to 30 percent of the water that falls on the sites leaves the sites as surface flow.

The Walker Branch Watershed (Harris, 1977; Henderson et. al., 1971) research was fundamental to understanding the processes of a mixed hardwood forest watershed. The study area was in a similar climate regime to the Ozarks and shares similar geologic features. Water samples collected were analyzed for multiple constituents including: calcium, magnesium, potassium, nitrate and ammonia-nitrogen, and soluble reactive phosphorous. The corresponding baseline values for the years of 1970 to 1974 were found to be 16 mg/L, 8.4 mg/L, 0.73 mg/L, 0.03 mg/L, 0.06 mg/L. The research led to conclusions on how multiple variables could affect the effluent of their study areas.

The research conducted in the Boston Mountains (Lawson et. al., 1985; Koegh and Maples, 1972) in Arkansas shares similar importance. The Boston Mountain study also focused on ephemeral streams and the concentrations of various parameters in water samples that originated from four watersheds over an eight year period. The parameters measured were total phosphorus with an average concentration of 0.18 mg/L, potassium with an average value of 0.92 mg/L, calcium and magnesium with values of 0.51 and 0.43 mg/L respectively, and ammonia-nitrogen with 0.34 mg/L and nitrate with an average of 1.93 mg/L. The study sites were located in the Ozark National Forest and were characterized as mixed hardwood forests.

There are a multitude of additional forestry projects on the topic of water quality timber harvesting and agro-forestry practices and treatments (MDC, 1997; Swank et al., 2001; Mullein et al., 1997; Brinkley and Brown, 1993; Herz, 1996; Lockably et al., 1997b; Doisy, 2000; Stone, 1975; Putz et al., 2003; Roshin et al., 2006; Messina et al., 1997; Ensign and Mallin, 2001; Stewart and Edwards, 2006; Goff, 1997). However, most of these projects are located in different climatic regimes or are coniferous forests and as such were not selected for review.

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CHAPTER 3: MATERIALS AND METHODS

3.1 Site Selection and Characteristics

Fifteen forested sites owned by Missouri Department of Conservation (MDC) in southeast Missouri Ozarks were selected to be instrumented and monitored for water quality samples for a period of seven years. All watersheds in the sites had an even-aged, predominantly oak and hickory forests cover that were undisturbed since establishment of about 50-70 years ago. The MDC authorizes local loggers by auction sale to harvest timber lots each year by clear cutting the regenerative oak hardwood forests as their regular timber management options in the Ozarks highlands of the state of Missouri. The study sites consist of delineated area of harvest; harvested areas were either one or both sides of the channel based on size, slope, aspect and other considerations.

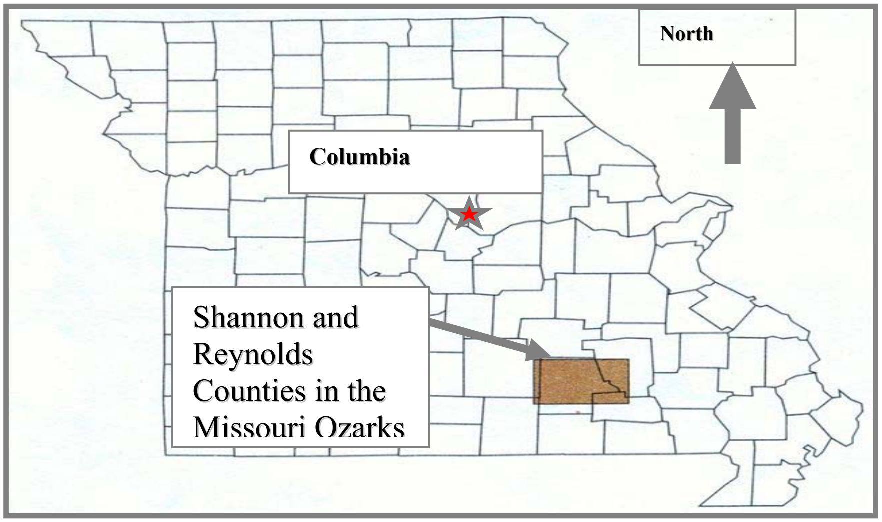

Figure 3.1 - Location of the research site in southeast Missouri Ozarks highlands

The sites were located in the Angeline and Current river conservation areas of MDC; about 150 miles Southeast of the University of Missouri-Columbia (Figure 3.1). The sites were selected in all aspects and various slopes and included three different orders of streams (first to third). The area of the sites ranged from 6 acres to about 60 acres. The biggest site, A 34-1 is located off of Hwy 19, had about 60 acres area and the smallest being CR7-5B, had about 10 acres (Table 3.1) located off of Route HH in the Current river CA.

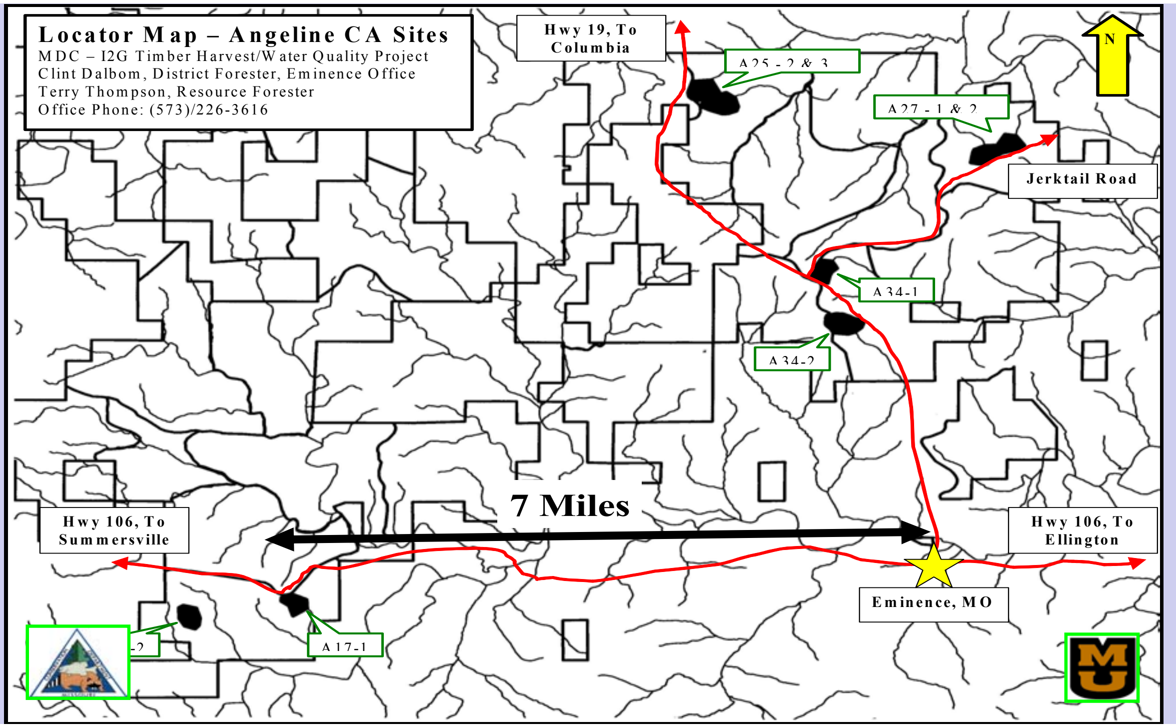

Figure 3.2- Angeline Conservation site with eight sites off of Hwy 19 and 106

The fifteen forested sites in MDC's Angeline (Figure 3.2) and Current River CA (Figure 3.3) were scattered over 500 sq. miles and were typically either isolated or in combination of twos. The sites were selected for optimum variability and differences in micro-climatic conditions in physio-geographic conditions. Slopes and aspects varied from site to site as well as order of streams (first to third) in the sites. Site CR7-2 was located closest to the Current River which is one of the important river for recreational activities which generates substantial revenue in the area.

Table 3.1 – Timber harvest-water quality monitored sites and site details including timber harvesting dates as of July 2008

Site Name	MDC Name	Treatment	Total area (ac)	Area of cut (ac)	Harvest Aspect	Ave. slope%	Harvest started	Harvest completed	Instrumentation	BMP
A34-1	Angeline CA	Cut	30	29	Entire Site	20-30	10/12/06	6/12/07	WS, SD, ECH20(moved) ISCO	yes
A34-2		Cut	44.3	13	E-NE	20-30	08/22/06	3/09/07	WS, SD, ECH20	yes
A27-1		Control	31.2	N/A	N/A	20-30	N/A	N/A	WS, SD	N/A
A27-2		Control	26	N/A	N/A	20-30	N/A	N/A	WS, SD	N/A
A17-1		Cut	24.8	13	NE	10-20	09/28/06	06/14/07	WS, SD	Yes
A17-2		Cut	29.2	8	E-NE	10-20	02/28/07	05/21/07	WS, SD	Yes
A25-2		Control	36.7	N/A	N/A	20-30	N/A	N/A	WS, SD	N/A
A25-3		Control	41.2	N/A	N/A	10-20	N/A	N/A	WS, SD	N/A
CR7-5B	Current River CA	Cut	10.2	10.2	Entire Site	20-30	3/1/07	5/1/07	WS, SD	No
CR7-5C		Cut	12.4	12.4	Entire Site	20-30	3/1/07	5/1/07	WS, SD, ECH20	No
CR7-2		Control	40.4	N/A	N/A	20-30	N/A	N/A	WS, SD	N/A
CR7-6		Control	45.6	N/A	N/A	20-30	N/A	N/A	WS, SD	N/A
CR11-1		Cut	35.8	35.8	Entire Site	10-20	3/1/07	8/1/07	WS, SD	No
CR11-3		Cut	14.2	14.2	Entire Site	20-30	3/1/07	8/1/07	WS, SD	No
CR11-9		Control	14.4	N/A	N/A	10-20	N/A	N/A	WS, SD	N/A

Seven sites were selected in Missouri Department Conservation's Current River CA (Figure 3.3) near Ellington, Missouri and eight sites were selected in Angeline CA near Eminence, Missouri (Figure 3.2). The aerial size of the eight harvest sites range from 6 to 60 acres (Table 3.1). All aspects were represented among the sites. The goal was to collect as much pre-harvest water quality data as practicable before the timber harvest and then collect approximately three years of post-harvest data for comparison. Harvest was completed at eight sites in 2007 and seven sites were remained unharvested (control). Both pre-harvest and post-harvest water samples were collected for up to six years starting in late 2004 to mid of 2009.

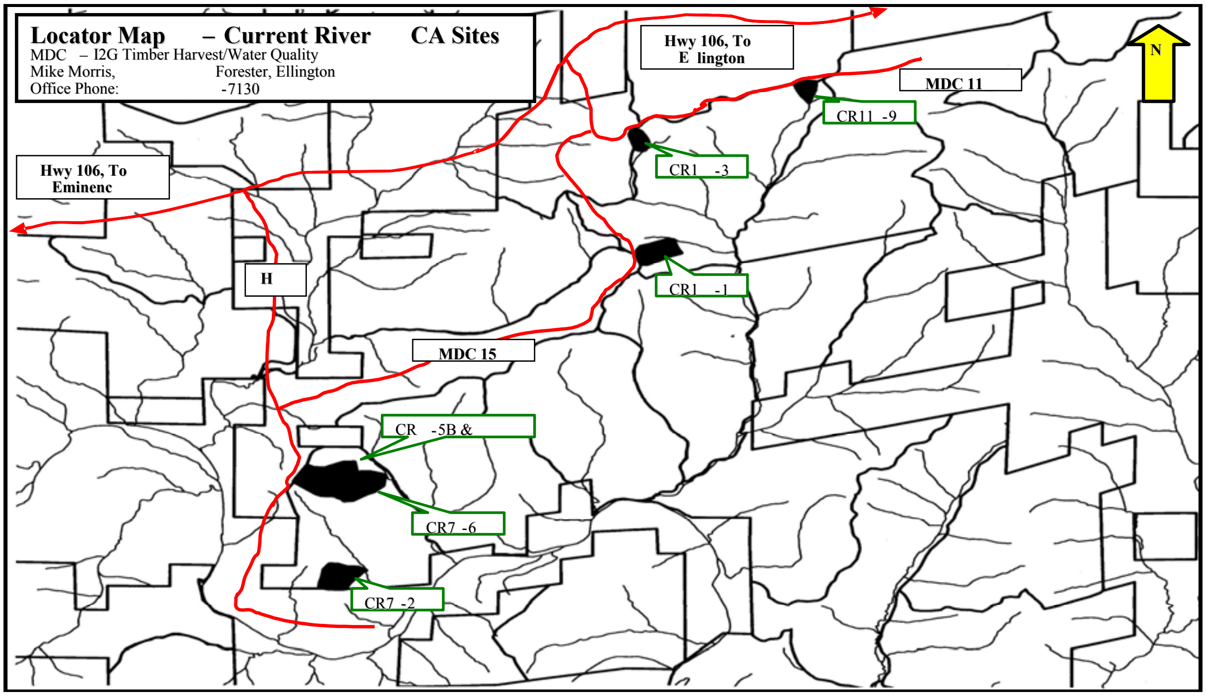

Figure 3.3- Current river conservation site with eight sites off of Hwy 19 and 106

3.2 Site Geology and Climate

The soils in the sites are derived from the weathered residuum of the underlying dolomitic limestone and sandstone geology, primarily of the Roubidoux formation series. Locally this mantle of residuum varies form 50 ft thick on the interbasin divide to somewhat less on the slopes and lower portions of the drainages. The soils are classified Carksville stony loam (Meinert et. al., 1997). These soils typically are chert silt loam and strongly acid at the surface. They tended to increase in density, percent clay and cherty with depth. In spite of the density, subsoil drainage is relatively good in comparison to most other Ozark soils and they are frequently drought during the summer time. Some soils of local alluvial origin can be found in a very limited extent in the extreme lower portions of these drainages in the site.

The ability of the Ozarks to grow trees, the history of land use changes, and the inherent sensitivity of the Ozarks to disturbance from timber harvest have been determined largely by climatic and geologic characteristics. The Ozarks Plateaus of

Missouri (known locally as the Ozarks) are in an area of humid, temperate climate. Average annual rainfall is 40-48 inches and average annual temperature is 59 to 65 ^{o}F. Ozark uplands have gently rolling topography with slopes of typically 0 -12^{o} and local ridge-to-valley relief of hundreds of feet. Adjacent to major river valleys, vertical bluffs and steep slopes are common and local relief is 250 to 650 ft (Jacobson, 2004). The Ozarks are underlain by newly flat-laying sedimentary rocks with small areas of metaigneous rocks. Lithologically, most of the rock is dolomite and cherty dolomite, with lesser contributions of limestone, sandstone, shale and metavolcanics (Koenig, 1961). The chert-rich bedrock of the Ozarks has contributed to abundant chert gravel to the bedload of streams. Residual soils range in thickness from 0 – 30 ft. More details about the geology and soils can be found in Meinert et al., 1997.

Geology of the Missouri Ozarks is made up of steep sideslopes, narrow ridges and floodplains. The formation has incised channels and structural benches with karst features with sink holes. Four distinct geological formations have surface expression among the sites. These formations include: Rd = Roubidoux (sandstone and dolomite), UG = Upper Gasconade (cherty dolomite), LG = Lower Gasconade (dolomite), and the EM = Eminence (dolomite). The Upper Gasconade occurs at all of the sites; and, the sites located in Angeline conservation area have a visible exposure of Roubidoux as they tend to have higher elevation in the landscape. The sites in the Current River conservation area, are lower in elevation, and may have a thin cap of Roubidoux formation overlying the Gasconade dolomite. Dolomite of the Eminence formation is exposed in deeply dissected sites nearest the Current River.

Much of the area is cavernous and supports a karst drainage system. The karst drainage system has resulted in some streams that are dry most of the time, whereas other streams with similar surface drainage areas have springs that provide substantial, relatively constant base flow. Because much of the residual subsoil is relatively impermeable, intense rainstorms that fill A-horizon storage can produce runoff that bypasses the karst drainage system (Jacobson, 2004).

3.3 Water Sampling

Water quality samples were obtained manually and automatically from the water samplers for each storm event using multi-stage collectors in the stream channel as well as sediment traps that were placed on both sides of the watershed on the hillslopes. Water sampling was performed since the start of the project dated December, 2004 to April 2008 and continued through June, 2009. The samplers only recovered a water sample when the hydrograph rose. About 1150 pre- and post-harvest samples were collected from all fifteen sites. Post-harvest samples started coming in as early as January 2007; after the harvest of one of the largest sites, A34-1 in the Angeline CA.

Numerous grab samples were also taken in and around the sites before and after the timber harvest. Precipitation was measured in the site as well as downloaded from Remote Automated Weather Stations (RAWS) (http://www.fs.fed.us/raws/) located near Eminence, Missouri. Timber harvest operation started gradually since late 2006 and post harvest water samples are being collected since January 2007. Hydrological and weather related (soil moisture, air temperature, precipitation) data were collected from automated instruments and weather stations. Water sampling was performed following a standard sampling procedure. A portable cooler was used to transport the water samples to the

University of Missouri, Soil Characterization Lab (SCL) for analysis. Water samples were kept in the refrigerator at 4^0C while processing in the lab and then they were preserved permanently by freezing in case there was some need to reprocess the sample for some reasons.

3.4 Instrumentation of Sites

For each site, most ephemeral streams leading to the main channel in the site were instrumented with downstream water samplers. There were also upstream water samplers on the main channel and on some of the side channels (Figure 3.4). Most sites had between 6 and 10 in-stream water samplers depending on the size, shape and length of the site. Each water sampler was a "rising-gage" multi-staged water sampler, i.e., capable of capturing a water sample from three different flow depths (ground surface or 0-, 3- and 6-inches). Automated samplers (ISCO®) and weather stations (ECH$_2$O®) were also installed at some sites for automated data collection including hydrological and weather information relevant to water quality analysis and interpretation.

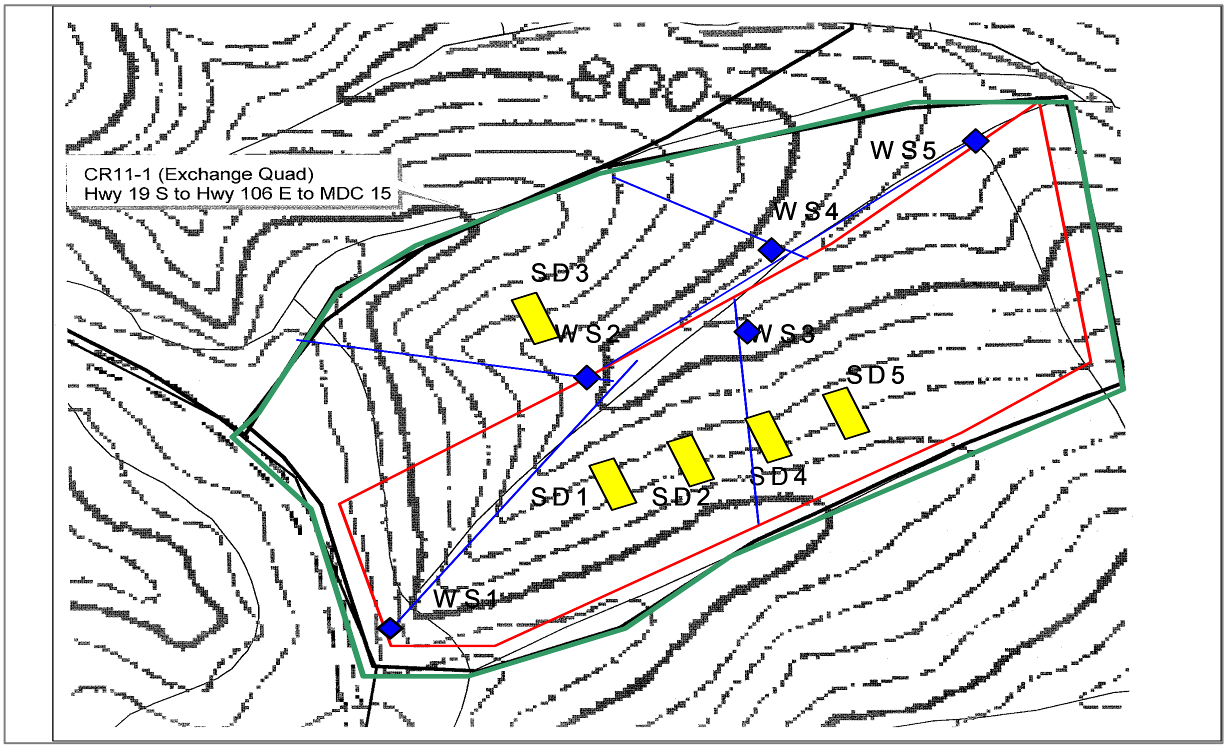

Figure 3.4- A typical water quality research site and instrumentation layout (CR11-1)

Until July, 2008 more than 185 instruments were installed (24 in 2008) including in-stream water samplers, hillslope samplers, rain gages, silt fence, and in-stream crest gages. Some of the hillslope samplers were removed to facilitate harvesting in eight of the fifteen sites that were slated for harvest during 2006-2008, and were reinstalled in same or nearby location after harvesting and slashing. A typical site instrumentation layout is depicted in Figure 3.4 shows total acreage of the site along with the cut acreage and instruments location.

During the pre-harvest period, there were typically four hillslope samplers on the side of the site designated for clear cutting and one hillslope sampler on the side of the site that was not harvested. Subsequent considerations determined that when desirable (according to the District Forester) both sides of the channel could be harvested. In the Angeline CA, the hillslope samplers were in relatively close “clusters” while being placed in various micro-relief features such as concavities and convexities. The hillslope samplers were placed to gather as much information as possible about the impact of micro-relief features on the movement of sediment before and after timber harvest. In the Current River CA, the hillslope samplers were equally spaced along a traverse parallel to the main ephemeral channel. In these cases, the hillslope samplers provided an indication of the spatial variability within a site.

3.4.1 In-stream and Hillslope Samplers

Equipments (hillslope samplers (Figure 3.5a) and in-stream samplers (Figure 3.5b)) were designed to trap water with sediments and nutrients transported downslope. Out of fifteen sites, eight sites were cut sites and seven were controlled sites. The hillslope samplers at both the Angeline and Current River CA amounted to at least four in each sites. There were 6 to10 in-stream samplers in the main and side channels of the ephemeral streams in each site.

The equipment was designed to obtain water samples to quantify the sediment load and water quality. Water samples were collected during precipitation events that created surface flow on sideslopes and in the ephemeral stream channels. Hillslope samplers were designed to collect sediment samples from hill slopes. Rising-stage water samplers were used to collect water and sediment samples in first and second-order ephemeral streams.

(3.5a) **(3.5b)**

Figure 3.5- Hill slope (3.5a) and in-stream (3.5b) water quality sampling instruments installed throughout the sites

3.4.2 Automated Water Sampler

In addition to the rising-stage water samplers, an automated flow monitoring system with water sampler was installed in one site (A34-1) in March 2006 to supplement the data from the manual samplers and gather additional information regarding discharge from the ephemeral channel. The automated sampler (Figure 3.6) was an ISCO® model 6712 water sampler, model 4150 flow logger and model 674 rain gauge.

Figure 3.6- ISCO ® automated water sampler installed in A34-1 at the Angeline Conservation Area

The ISCO® water sampler was capable of collecting 24 water samples and storing them internally until retrieved. The sampler rests at the base of the channel and a tube and a sensor rest on a platform placed on the channel bed. A peristaltic pump operated by a programmable controller provided the suction necessary to collect samples. The ESCO® sampler was programmed to collect water samples based on flow depth since the flow was not regular in the channel. Flow depths were chosen to match the sampling heights of the manual in-stream water samplers (1", 2" and 6" depth).

This ISCO® sampler (Figure 3.6) was capable of measuring and recording water depth, flow velocity, and flow quantity in the ephemeral channel during flow, and was equipped with an additional tipping bucket rain gauge. The capability to collect samples at different times during and after precipitation events, and throughout the duration of flow provided data about the variation of water quality as a function of parameters including flow depth and velocity. The information gathered from this device also enabled the creation of hydrographs for the ephemeral drainage basin, which were used to calculate water balances (water input, output, and overland flow) for the site.

3.4.3 Weather Stations

ECH$_2$O® EC-20 soil moisture sensors are installed with the tipping bucket rain gauges in two sites A34-1 and CR7-5C. One of the ECH$_2$O® was latter moved to A34-2 to facilitate harvesting. The devices (Figure 3.7) measure the dielectric constant of the soil. Because the dielectric constant depends on the moisture content of the soil, the rate of change of voltage across the buried probe can be converted to the volumetric water content of the soil (Decagon, 2006). The probe is programmed to collect data every 60 seconds and record the hourly averages to the memory. The data were used to estimate antecedent surface soil moisture to help predict surface flow volumes for various size precipitation events and provide insight into the limiting conditions of threshold events; air temperature and precipitation with the help of tipping bucket rain gauge.

Figure 3.7- ECH$_2$O® weather station located one each in both Angeline and Current River CA

The ECH$_2$O® temperature sensors were attached to the data logger as the rain gauge and soil moisture sensors. The temperature is monitored once per minute and the hourly average was recorded.

The data from these stations were correlated with: precipitation event magnitude, antecedent soil moisture content, water sample volume collected, and other parameters in an effort to quantify a threshold precipitation event. Precipitation data from two weather stations: USGS gauging station of the Jacks Fork river (http://waterdata.usgs.gov/mo/nwis/rt) (Eminence at the Route 19 bridge across the Current River) and RAWS Carr Creek weather station (http://www.wrcc.dri.edu/cgi-bin/rawMAIN.pl?ndMCAR) (Route 106/HH junction) were also collected to verify the data obtained by the data logger installed on the sites.

3.5 Analysis of Water Samples

The water quality analyses in the laboratory began with the incoming water samples collected in a HDPE Nalgene® 500 ml bottles with the number, date, site, type and sampler stage clearly written on outside the bottle with permanent marker for identification. The samples were transported to the University of Missouri-Columbia Soil Characterization Laboratory (SCL) in a cooler at 4^{o}C. The samples were then kept in the freezer at -10^{o}C until they could be processed for analysis.

All water samples collected were analyzed for the following constituents; pH, conductivity (μs/cm), total suspended solids (TSS), total volatile solid (TVSS), calcium (Ca), magnesium (Mg), potassium (K), nitrate (NO3), ammonia nitrate (NH3-N), Soluble reactive phosphorous (SRP), total phosphorous (TP), and total nitrogen (TN) among others that could be analyzed (Table 3.2).The preferences were given to the parameters (Table 3.2) that are easy to operate as well as a larger quantity in the lab.

The first step to process a group of water samples was to thaw them for about 2 hours at room temperature and later isolating a portion of the sample by pouring into two smaller, 60 and 100 mL, plastic bottles for future analysis (Figure 3.8). After the sample separation, the steps included testing pH and electrical conductivity and further to dissolve separation of well mixed samples in which 100 ml of the sample was filtered through 0.45μm reweighed Whiteman 934-AH glass microfiber filter which had previously been leached for 24 hours in two changes of deionized water using a vacuum pump to estimate total suspended sediment (TSS) and volatile sediment concentrations (APHA, 1994). The filter was retained for solids analysis and the filtrate was retained for dissolved analysis. The filters were dried in 105^{o}C to a constant weight and their dry weights were recorded. The differences between two dry weights were recorded. Again, the oven dried filters with sediments were heated using a high temperature furnace at 500^{o}C to calculate the total volatile suspended sediments (TVSS).

The pH and electrical conductivity (EC) were measured from filtered samples whereas the dissolved nutrients in the samples were then analyzed using the method listed in Table 3.4. A digestion procedure in an autoclave was required to breakdown the suspended matter of the sample so that the various unanalyzable nutrients forms could be released or separated. The digestion step was used for total nitrogen and total phosphorous tests to breakdown the suspended matter of the samples so that the various unanalyzable nutrients forms could be released and analyzed for specific parameters (Smith, 2006). About 10 ml samples were used for analysis for TN, TP, SRP, NO_3-, and NH_3-N. The details are discussed later in the chapter.

Table 3.2- Possible water quality parameters considered for timber harvest water quality study

Total Volatile Suspended solids	Total Phosphorous	Soluble Reactive Phosphorous
Total Nitrogen	Ammonia Nitrate	Nitrate
Iron	Sulfur	Total organic carbon
Total organic carbon	Biological oxygen demand	Ammonia
Manganese	Aluminum	Florescence Spectra
pH	Electric Conductivity	Total Suspended Solids
Calcium	Potassium	Hardness
Fecal coliform bacteria	Turbidity	Specific conductance
Total dissolved solids	Arsenic	Aluminum

Table 3.3- Water quality parameters selected for timber harvest water quality study

pH	Electric Conductivity	Total Suspended Solids(g/L)
Total Volatile Suspended solids(g/L)	Total Phosphorous(mg/L)	Soluble Reactive Phosphorous(mg/L)
Total Nitrogen(mg/L)	Ammonia Nitrate(mg/L)	Nitrate(mg/L)
Calcium(mg/L)	Potassium(mg/L)	Magnesium(mg/L)

Physio-chemical analyses of composite water samples were performed in the SCL at the University of Missouri-Columbia following sample collection (date of the trip made to all 15 sites are assumed a batch of samples). Colorimetric procedures (Table 3.4) with Hach® chemicals and standards were used to determine the nutrients concentrations including nitrate (NO_3-), ammonia nitrate (NH_3-N), total and soluble reactive phosphorous (TP and SRP) as well as total nitrogen (TN). Minerals like calcium (Ca), magnesium (Mg) and potassium (K) were analyzed using a Varian 240FF Fast Sequential Atomic Absorption Spectrometer (Figure 3.13). A Spectronic D20$^+$ colorimeter (Figure 3.12a) with variable white and red light spectrum were used to determine the concentration of the water quality nutrients. Various colors present in the sample using chemicals and standards were recognized by the colorimeter in terms of absorbance values which later used to obtain concentrations of various parameters.

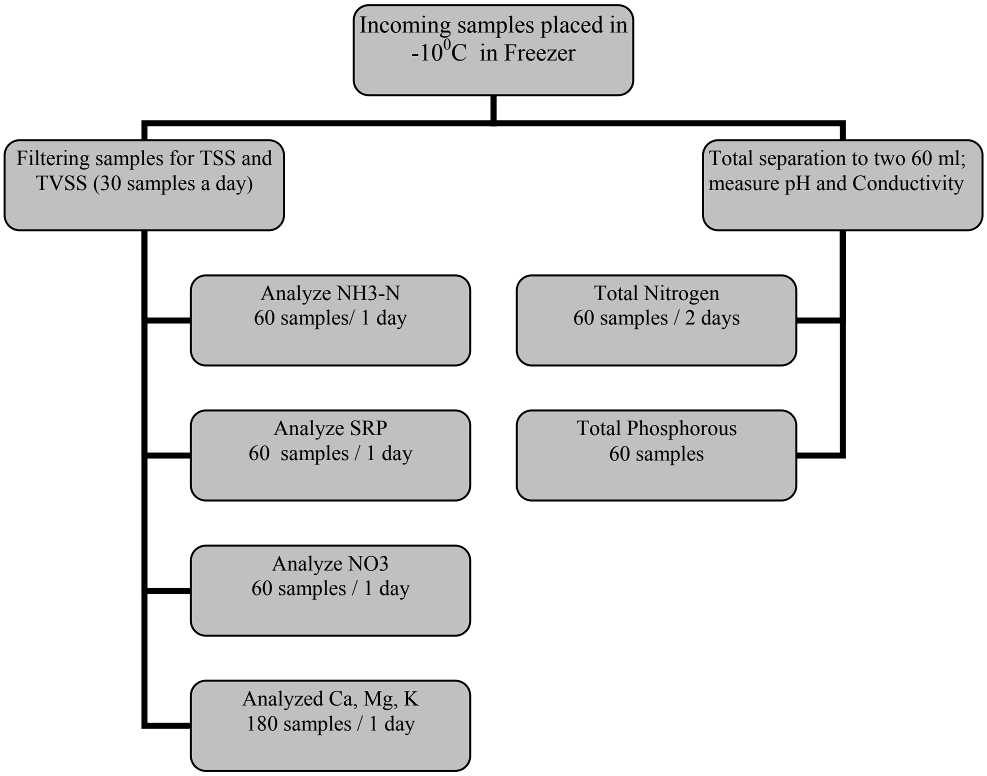

Figure 3.8- Flow diagram depicting lab activities and associated durations (Smith, 2006)

Several parameters (Table 3.2) could have been selected for water quality analysis. The preference was given to the parameters chosen for this study because of the following advantages:

- Applicable to the wide range of parameter concentrations
- Effective method for the water quality concentration
- Method detection limit ≤ 0.01 mg/L
- Large number of samples could be analyzed at a time (good production rate)
- The method is relatively easy to understand and use
- The method is reproducible/verifiable

Table 3.4- A breakdown of the analyses for all the water quality parameters employed and their detection limits.

Water Quality Parameter	Abbreviation	Detection Limit	**Test Procedure**
Total suspended solids	TSS	0.001g/L	**APHA[§] 2540D**
Total volatile suspended solids	TVSS	0.001g/L	**APHA 2540E**
pH	pH	Range 2-13	**OakTron pHTestr3+[§§]**
Electrical Conductivity	EC	0.01 µs/cm	**Corning 441***
Total Nitrogen	TN	0.01mg/L	**APHA 4500-NO3 E**
Nitrate	NO3	0.01mg/L	**APHA 4500-NO3 E**
Ammonia Nitrate	HN3-N	0.01mg/L	**MCWW 351.2****
Total Phosphorous	TP	0.01mg/L	**APHA 4500-P.E**
Total soluble reactive Phosphorous	SRP	0.01mg/L	**APHA 4500-P.E**
Calcium	Ca2+	0.01mg/L	**Varian 240ff**
Magnesium	Mg2+	0.01mg/L	**Varian 240ff**
Potassium	K+	0.01mg/L	**Varian 240ff**

§ A OakTran company pH probe located in the Soil Characterization lab
§§ A conductivity probe located in the Soil Characterization Lab
* American public Health Association
** Method for chemical analysis of water and wastes

Both Hach® standards and powder pillow regents as well as the standard made by the powdery chemicals and liquids from Fisher Scientific® were used for analyses (Appendix A). Some of the standards and regents that were used for water quality analysis are as follows:

A) Standards Solutions (500ml) (Hach® Company)

1. Nitrate Nitrogen Standard Solution (10.0 ± 0.1 mg/L as N or 44.3 ± 0.4 mg/L as NO3) ……...Cat No 307.49
2. Nitrogen, Ammonia standard solution (1.0 mg/L as NH3-N) ……Cat No 1891.49
3. Phosphate Standard Solution (1 mg/L as PO4) ………Cat No 2569.49

B) Standards Hach® powder pillows (Permachem® reagents) per 10ml sample

1. PhosVer®3 powder pillows……… ………..(Cat No 21060-69)
2. NitriVer®3 powder pillows……… ………..(Cat No 21071-69)
3. NitriVer®6 powder pillows……… ………..(Cat No 21072-49)
4. Ammonia Salicylate powder pillows……… (Cat No 26532-99)
5. Ammonia Cyanurate powder pillows………(Cat No 26531-99)

C) Chemicals and Regents

1. Potassium Antimony Tartrate 0.27% APHA (for phosphorous) (Cat No LC 18720-1) LabChem Inc, PA; Fisher chemicals
2. Potassium Phosphate ($KH_2 PO_4$) (NF/FCC/EP/BP)
3. Ascorbic Acid USP Powders
4. Sulfuric acid
5. Ammonia Molybdate

Both pre- and post-harvest water samples were analyzed in the laboratory using American Public Health Association (APHA), 1994 standards (updated 1998). Total nitrogen was determined using cadmium reduction on filtered samples following potassium persulfate digestion. Total phosphorous (TP) was determined by ascorbic acid molybladate procedure on unfiltered samples following ammonium peroxi disulfate digestion. Total phosphorous, total nitrogen, Nitrate N (cadmium reduction), and ammonia (phenolate) were determined as outlined by APHA, Water and Wastewater Works Association. The details of methods used to analyze water quality parameters according to standard procedures (Table 3.4) will be discussed later in this chapter. Testing procedures are available in the Appendix A.

Quality control for the analyzer equipment was maintained by randomly positioning three control standards with differing concentrations, four duplicate samples, and one quality control sample in each tray (60 samples). All samples with suspect concentrations and or strong color and trays with unacceptable concentrations were normally diluted further and reanalyzed to obtain reliable concentrations. The data were compiled in an Excel ® spread sheet. Pre-and post-harvest samples were collected throughout the project period to compare sediments, minerals and nutrients changes from the sites.

(3.9a) **(3.9b)**

Figure 3.9- Chemicals and regents (3.9a) as well as Hach powders pillows used for water quality analysis and samples kept in freezer (3.9b) the MU, Soil Characterization Lab

3.6 Water Sample Testing Procedure

3.6.1 Total Suspended Solids and Total Volatile Suspended Solids

Total suspended solids and volatile suspended solids were analyzed by using APHA Standard Methods (APHA, 1998). Total suspended solids were analyzed by pouring a hundred milliliters of sample through a 0.45 μm micro-fiber glass filter. A high suction vacuum pump was used to filter out the sediments in the environmental laboratory. The scale had the capacity to read 0.0001 g. Deionized water was used to wash the filtering apparatus after every sample. A blank filter sample was used every five samples. The standard operating procedures (SOP) for TSS is shown in the Appendix A.

(3.10a) **(3.10b)**

Figure 3.10- Dried filter laden with sediments (3.10a) and fisher scientific oven (3.10b) to dry samples for about 105^{0}C

The filter was then dried at 105^{o}C for 16 hours and weighed to get total suspended solids in gram per liter. Volatile suspended solids were analyzed by placing the already dried filter into another high temperature furnace to burn out volatile ingredients at 550^{o}C for 16 hours and then re-weighing the filter thus ridding the filter of all organics. The SOP for total volatile suspended solids is in the Appendix A.

3.6.2 Electrical Conductivity and pH

Electrical conductivity (EC) was measured using a Corning conductivity meter 441 (Figure 3.11a). The filtered samples were poured into a glass beaker and conductivity probes were inserted into the sample to measure electrical conductivity. The probes were rinsed thoroughly each time; after measuring five samples in a row, one blank sample was used to zero the instrument as a quality assurance measure. Similarly, a pH meter

(Figure 3.11b) was used to measure pH of all the samples in the glass beaker. The pH meter was rinsed with deionized water each time a sample was measured.

(3.11a) **(3.11b)**

Figure 3.11- Corning conductivity meter 441 (3.11a) and pHTestr 3+ double junction pH meter (3.11b)

3.6.3 Nutrients

Five nutrients parameters (total nitrogen, nitrate and ammonia nitrogen, total phosphorous and soluble reactive phosphorous) were analyzed in the laboratory for water quality using regents, chemicals and Hach® standards and powder pillows to generate colors. The Spectronic 20D+ Colorimeter (Figure 3.12a) was used to analyze these parameters.

(3.12a) **(3.12b)**

Figure 3.12- Spectronic $20D^+$ Colorimeter (3.12a) and Hach® powder pillows (3.12b) standards

3.6.3.1 Total Phosphorous and Soluble Reactive Phosphorous

Total phosphorous and soluble reactive phosphorous share the same examination technique but had different sample preparations. The first stage for Total Phosphorous (TP) is digestion that utilized potassium persulfate digestion (APHA, 1998). Soluble reactive phosphorous did not require any steps before analysis. The Ascorbic Acid technique; APHA Method 4500 P.E (APHA, 1998) was used to analyze both parameters. The samples were analyzed on a Spectron 20D+ spectrophotometer housed in the Soil Characterization Laboratory (SCL). Total phosphorous and SRP was quality controlled by the use of standards and blanks. A quality control digestion standard was not needed for total phosphorous (Solorzano, 1980). An overview of the Ascorbic Acid method follows in the section 3.6.3.2 and an SOP for the Ascorbic Method is shown in the Appendix A.

3.6.3.2 Ascorbic Acid Method Overview

Ammonium molybdate and potassium antimonyl tartrate react with orthophosphate in an acidic state and is then reduced by ascorbic acid to turn the sample's color to blue if orthophosphate is present. The degree to which this blue color is formed is read by the Spectron 20D+ at a wavelength of 660 nm or 880 nm. A summary of the potassium persulfate digestion technique is described in Section 3.6.3.3.

3.6.3.3 Potassium Persulfate Digestion Overview

Potassium persulfate digestion, method APHA Method 4500-N C, is required for digestion of total phosphorous and total nitrogen. The samples are digested together as outlined by Ebina, Tsutsui, and Shirai (1983). This technique of digestion oxidizes all nitrogenous compounds to nitrate at 100^{o}C. The method is important for phosphorous because phosphorous may occur in combination with organic matter; and, digestion releases the phosphorous in its orthophosphate form. A 10 ml sample is mixed with 2.2 ml of persulfate digestion mixture. The mixture was placed in an autoclave for 30 minutes at 98 – 137 kPa.

3.6.3.4 Total Nitrogen and Nitrate

Total nitrogen was digested via the potassium persulfate digestion technique and measured using the cadmium reduction method (APHA, 1998). Nitrate was also analyzed via the cadmium reduction method. As with total phosphorous, the samples were analyzed on the Spectron 20D+ located in the SCL. Chemical pillows, manufactured by Hach®, that contain a set amount of chemical per sample amount were used according to Hach® Method 8192 (Hach, 2004). The use of chemical pillows rather than cadmium column is preferred because the cadmium column requires 75 ml of sample and its efficiency of turning nitrate to nitrite decreases with the amount of sample that pours through the column (Smith, 2006). The cadmium reduction method is outlined in Section 3.6.3.5.

3.6.3.5 Cadmium Reduction Method Overview

Nitrate was reduced to nitrite by a copper-cadmium reduction column. The nitrite reacts with sulfanilamide in an acidic medium and forms a diazo compound which couples with N-1 napthylethylendiamine dihydrochloride (NED) to form a reddish color. The solution is then colorimetrically measured at 543 nm.

3.6.3.6 Ammonia

The salicylate method (APHA, 1988; Hach, 2004) was employed to analyze ammonia. As with the Nitrate and TN, pillows manufactured by Hach were used along with Hach's Method 8155. Samples were analyzed on the Spectron 20D+ at a wavelength of 655nm. The SOP for the salicylate method is listed in the Appendix. An overview of the Ammonia Salicylate method is in Section 3.6.3.7.

3.6.3.7 Ammonia Salicylate Method Overview

In solution, ammonia combines with chlorine to form monochloramine which then reacts with salicylate to form 5-amoinosalicylate. This chemical is oxidized by sodium nitroprusside to form a blue color which is masked by the yellow color of excess reagent to form a green color which is then analyzed colorimetrically by the Spectron 20D+.

3.6.4 Minerals: Calcium, Magnesium and Potassium

Three methods were used to analyze the samples for minerals: calcium, magnesium and potassium. Initially, the samples were analyzed using the AA-Spectroscopy methods (APHA, 1998), on a Perkin-Elmer Model 1100 AA Spectrophotometer located in the Soil Characterization Lab. The sample was combusted in an oxyacetylene flame. The machine either reads the concentration via emission of the constituent in the flame, or by the absorption of energy of the sample by a special lamp. Samples were analyzed using both the AA-Spectrophotometer and an ICP (Inductively Coupled Plasma-Mass Spectrometry (ICP-MS)).

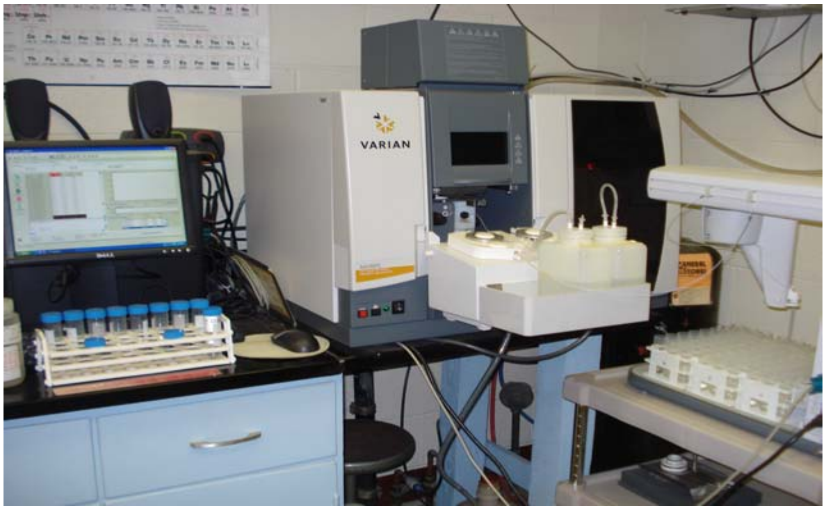

Figure 3.13- Varian 240FF Fast Sequential Atomic Absorption Spectrometer used to analyze Ca, Mg, K in the Soil Characterization Laboratory

The ICP was a powerful technique for multi-element analysis. In a single scan in the semi-quantitative mode the analyst is able to acquire estimates on practically every element in the periodic table. In the quantitative mode, accuracy and precision was comparable to existing techniques for every calibrated element. In one instrument, the ICP-MS combines the fast throughput capability of the ICP-AES (Inductively Coupled Plasma - Atomic Emission Spectroscopy). Quality control is ensured by the use of standards and blanks.

For most of the post-harvest samples and some pre-harvest sample latter in the year 2007 and 2008, the Varian 240FF Fast Sequential Atomic Absorption Spectrometer (Figure 3.13) was used to measure minerals. The instrument was automated that produced the mineral concentrations directly in a output file. This was a very efficient and fast way to measure calcium, magnesium and potassium concentrations in the water samples.

3.7 Sample Preservation

Sample preservation methods must take into account field collection time and lab holding time necessary to perform the analyses for all constituents of interest.

Temperature was maintained at 4°C during transportation and kept in the freezer at -10°C for further analysis. This temperature has been shown to preserve the constituents of interest for eight years with degradation less than 3% (Avanzino, 1993).

A sample degradation study was conducted by Smith (2006) to document the degradation of phosphorous (P), nitrate (NO_3), and ammonia (NH_3) in water samples. In the "high" sample for the four days of testing, phosphorous ranged from 0.32 mg/L to 0.34 mg/L, or suffered no degradation: whereas, NH_3-N ranged from 1.0 mg/L on the first day of the study to undetectable concentrations by the fourth day. Similarly, NO_3 ranged from 1 mg/L on the first day of the study to 0.40 mg/L on the last day of the study. The "low" sample had similar trends. Phosphorous ranged from 0.03 mg/L on the first day of the study to 0.01 mg/L on the last day of the study. Both components of nitrogen, however, degraded more extensively. Ammonia degraded from 0.10 mg/L to concentrations below 0.01 mg/L by the fourth day. Nitrate degraded from 0.10 mg/L on the first day to a concentration below 0.02 mg/L on day 2, before rebounding to a concentration of 0.04 mg/L (Figure 3.14).

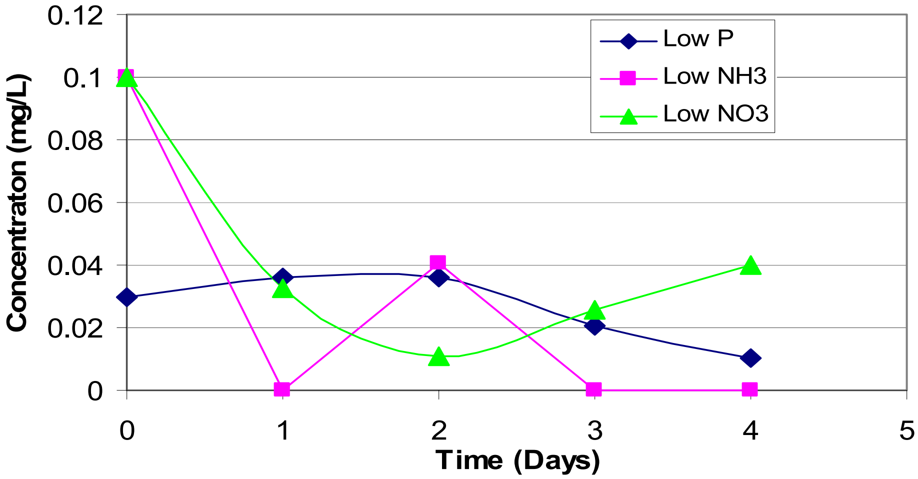

Figure 3.14- Nutrient concentrations vs. degradation rate for some nutrients (Smith, 2006)

The results showed that the samples should be collected after the precip event and they should be analyzed in the laboratory as soon as possible to preserve the natural concentration of the sample and to not let the degradation process follow.

3.8 Problems in Laboratory Testing

Staining of collected water samples forced the use of two machines to analyze for NO_3, NH_3-N, TN, SRP, and TP. The first device was the AA-Technicon located at the USGS's Columbia Environmental Research Center (CERC), and the second device, the Spectron 20D+ colorimeter located at the Soil Characterization Lab. Only the pre-harvest samples were taken to the CERC to test for the nutrient parameters. All post-harvest samples were analyzed using spectrophotometer at the SCL.

3.9 Statistical Analysis of Data

3.9.1 Normal Distribution (Background Concentration)

The quantitative baseline concentration for all parameters was defined using "the three sigma method" (Duncan, 2000). The three sigma method was used for most of the pre-harvest samples earlier because many parameters within a forested watershed have been shown to vary by 100-1000 fold at a given level of stream flow.

The so called "three sigma method" was used to quantify the baseline concentration that covers concentration bounded by the area under the curve formed by the distribution would amount 99.73% or twenty seven out of ten thousand samples would have possibility to cross the cutoff or baseline (Duncan, 2000). The major steps included finding mean (μ) and standard deviation (σ) and establish a "cutoff" at the three times the standard deviation added to the mean ($\mu+3\sigma$).

The three sigma method was used to establish background (pre-harvest) for TSS as an example (Figure 3.15). The pre-harvest background suspended solids, TSS concentration was found to be about 0.5 g/L in the Missouri Ozark (Smith, 2006). However, because of the large variation of concentrations for each parameter, only pH pre-and post-harvest samples followed the normal distribution and the "three sigma method" to determine background concentration were not applicable and/or justifiable for lognormal behavior of the parameters. The details follow in Chapter 4 (Paper #1).

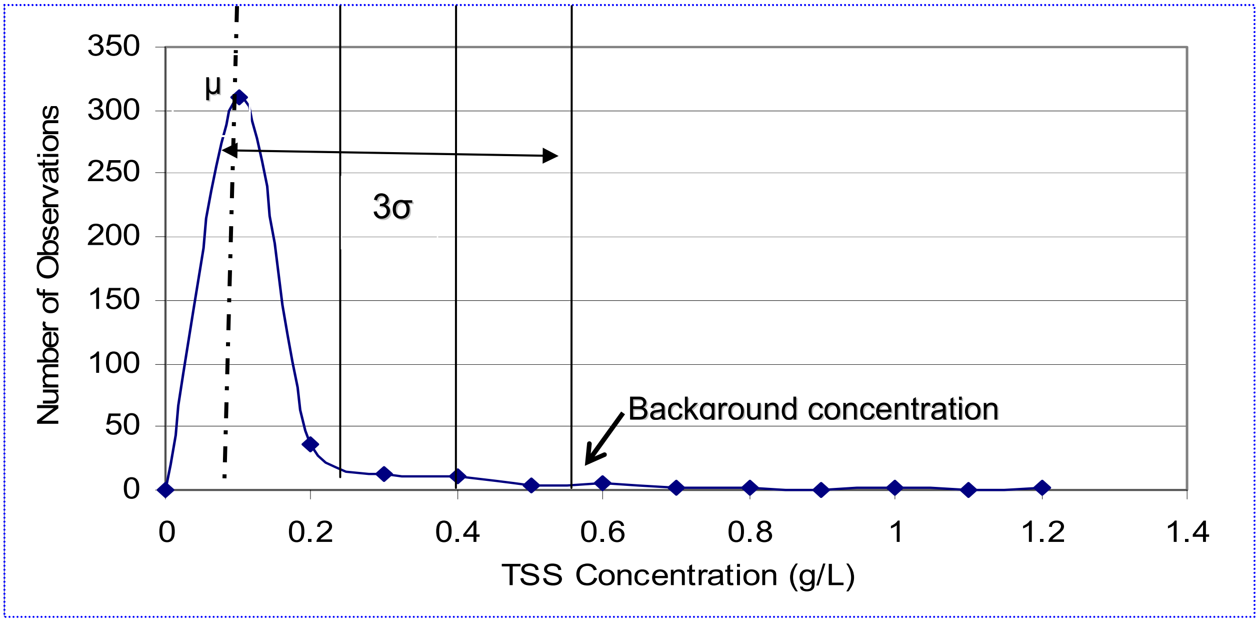

Figure 3.15- Schematic of "three sigma method" for TSS (Duncan, 2000)

3.9.2 Lognormal Distribution

Numerous factors act to cause variation in the concentration of water quality parameters including: season, frequency and duration of precipitation event, soil moisture at time of precipitation, aspect of site, geology, vegetation type and density, among many other things. The large variations in concentrations for a given parameter make it difficult to establish a background level. For example, total suspended solids (TSS) concentrations ranged from 0 to 5.4 g/L for all water samples.

Therefore, lognormal distributions were looked at to differentiate pre-harvest and post harvest water quality parameters. Data on each parameter were plotted against using log normal distribution to ascertain overlap each other or differ significantly. The mean and standard deviation for log normal distribution (λ and ξ) were calculated and differentiated. The individual post-harvest data points were also plotted against pre-harvest log normal distributions to see if the individual data points fall above or below the baseline concentration. This method also proved to be helpful on comparing the pre- and post-harvest sample concentrations.

3.9.3 Probability of Exceedance

Significance of post-harvest data while using background data is important in establishing a background concentration; thought it is not the only criteria that could be considered. Area exceedance using log normal distribution for both pre-and post-harvest water samples were called "Probability of exceedance". Even when studying how TMDL (total daily maximum load) limitations are established, there are many parameters that are taken into consideration, including sediments or nutrients parameters that could contaminate the stream. While timber harvesting could affect the water quality of the stream, these effects may or may not have a significant negative impact on the stream's water quality overall. It is possible that the concentrations on the post timber harvest data may be greater than those of the pre-harvest data; however, the EPA may not consider it a threatened or impaired stream until there is concrete evidence of deterioration of that ecosystem and its associated components. It is possible then to use the post harvest data that was gathered to determine what effects might exist by comparing pre- and post-harvest water quality and whether or not the after harvest water quality is still acceptable.

An illustration of the comparison between the pre harvest Probability distribution function (PDF) and the post harvest PDF is shown graphically in Figure 3.16. The first curve represents the log normal statistical distribution of pre- harvest concentration and the second curve represents post- harvest concentration. The shaded area represents the probability of exceedance of post harvest to pre harvest concentrations. The probability of exceedance can be defined as the "probability that the post harvest parameter concentration will be greater than the pre-harvest concentration. The probability of exceedance can range in between zero and one (0 ≤ 1.0).

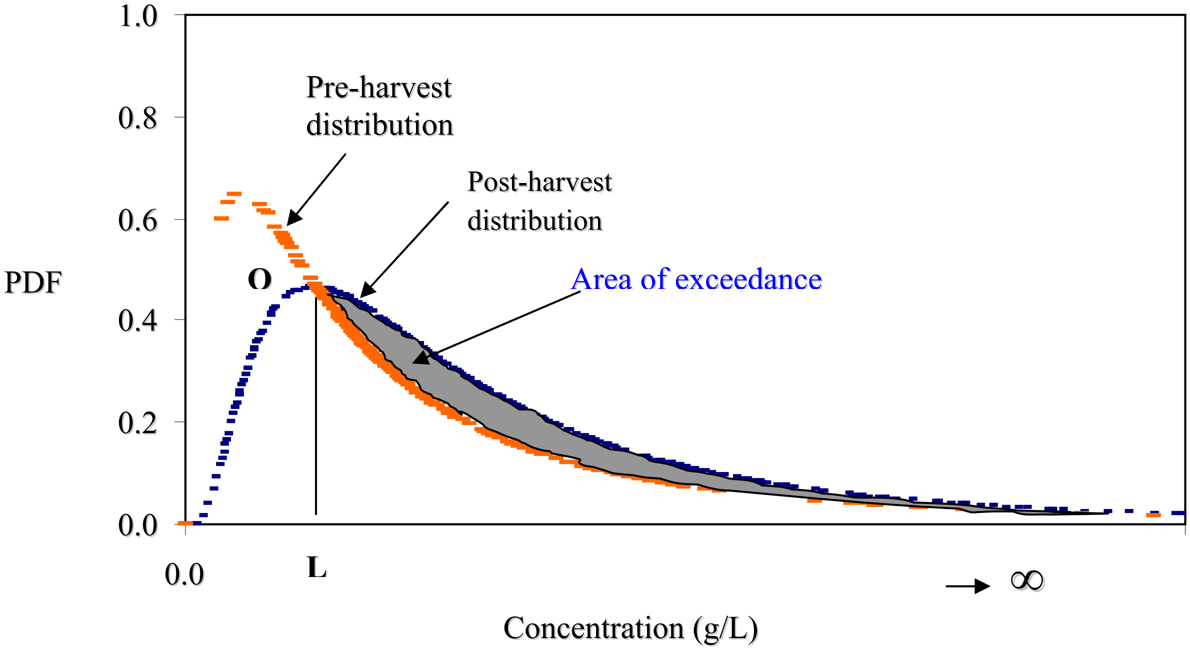

Figure 3.16- Determination of Area of Exceedance by comparing pre-harvest and post-harvest samples

The probability of exceedance can be calculated by solving for the dotted area beyond intercept O in Fig. 19 as shown below in equation (1).

Probability of Exceedance (PoE) =

$$\int_{L}^{\infty} f(C)_{post}\, dc - \int_{L}^{\infty} f(C)_{pre}\, dc \quad \ldots\ldots (1)$$

= (post harvest cum area) - (pre-harvest cum area)*100

= Probability of exceedance ($0 \leq PoE \leq 1.0$)

Where,

L = Intersection of Pre- post harvest distribution

$f(C)_{post}$ = Post harvest log normal distribution of concentration

$f(C)_{pre}$ = Pre harvest log normal distribution of concentration

Equation 1 uses an integration to find area exceedance of pre-and post-harvest distribution curves from point L to ∞ from beyond the intersection at O. The PoE was then calculated by subtracting the integrating pre-and post harvest areas under the curve to obtain residual area. The PoE was calculated for all parameters and compared for water quality effects from timber harvesting operations.

3.10 Summary

Both pre-and post-harvest water quality samples were collected from fifteen sites located in southeast Missouri Ozarks owned by Missouri Department of Conservation. About 1150 water samples along with 250 post-harvest samples were collected through July of 2009. Samples were brought to the University of Missouri, Columbia and further processing of samples was accomplished according to the American Public Health Association standards. Twelve water quality parameters i.e. pH, conductivity (µs/cm), total suspended solids (TSS), total volatile solid (TVSS), Calcium (Ca), magnesium (Mg), potassium (K), nitrate (NO3), ammonia nitrate (NH3-N), soluble reactive phosphorous (SRP), total phosphorous (TP), and total nitrogen (TN) were chosen for this study. Sediments were obtained by filtering samples and drying in both high and low temperature ovens. Minerals and nutrients concentrations were obtained using standard methods. A digestion procedure in an autoclave is required to breakdown the suspended matter of the sample so that the various unanalyzable nutrients form can be released or separated. The data were compiled using an Excel® spread sheet

Pre-harvest and post-harvest water samples were compared using log normal distribution since the variation in concentration fitted log normal distribution correctly. All twelve parameters were evaluated by dividing the harvest and non-harvest areas into appropriate subgroups and categories and integrating areas of pre-and post-harvest lognormal distributions from the point of intersection to the infinity. The area beyond the intercept of pre-harvest and post-harvest distributions was obtained and called "probability of exceedance (PoE)". Positive exceedance showed the post-harvest sample concentrations are higher than pre-harvest and may have some detrimental effects on downstream water quality.

3.11 References

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CHAPTER 4

Establishing Methods for Defining Background for Water Quality Parameters in Forested Ephemeral Watersheds in the Missouri Ozarks

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Abstract: It is generally believed that forest harvesting negatively impacts stream water quality and that the severity of the impact is proportional to harvest intensity that is highly variable within and among forest systems. Much of this variability is attributable to differences in site conditions such as soils, topography, and harvesting methods; as the later methods may include clear cutting or selection cutting or using other silvicultural methods with or without the best management practice (BMP) that is to prevent nutrients and sediments loss from the cut sites. The purpose of this paper is to establish methods for background concentration from pre-harvest water quality samples for all parameters so that post-harvest samples could be compared on that basis to determine the extent of impact of the harvesting practice in the Missouri Ozarks.

The "three sigma method" was initially used for all parameters by applying normal distributions. It was determined though, that method using normal distribution was not appropriate for water quality parameters because of large variations in concentration involved in each parameter. Therefore, a method based on "exceedance limit" with a range from 80-100% was obtained while compared against calculated backgrounds. This paper includes the some background determination methods and further sets up a basis to use "Probability of Exceedance " to compare pre-and post-harvest water quality samples using area exceedance from lognormal distributions. PoE was chosen in part because it compares favorably with EPA's Total Daily Maximum Load (TMDL) methods although TMDL is primarily used for threatened or impaired perennial streams.

4.1 Introduction

The Missouri Department of Conservation (MDC) conducts clear cutting timber harvest operations using best management practices (BMPs) in the Missouri Ozarks. There have been environmental concerns about the impacts of the clear cuts especially on down stream water quality. The waters feed nearby Jacks Fork and Current Rivers in

Southwest Missouri both of which have intensive recreational uses. The development of a method for establishing background water quality concentration (pre-harvest) that allows for the comparison of pre-and post-harvest water quality is documented in this paper. The pre-and post harvest water quality analyses will eventually be able to answer MDC's best management practice for regenerative oak clear cuttings (ROCC) are effective in the preservation of the water quality of Missouri Ozark's ephemeral streams. BMPs include, but are not limited to, a slope-derived stream-management zone (SMZ) and logging roads with a proper placement of landings and stream crossings (MDC, 2005). In order to evaluate the BMPs, approximately seven years of water samples in MDC lands located in Shannon and Reynolds counties in southern Missouri have been collected and analyzed. Between these two counties, there are fifteen watersheds of varying sizes, slopes and aspects with low-order ephemeral streams selected for monitoring to obtain quality water samples in both MDC's Current River and Angeline Conservation areas.

The "monitoring" is in reference to the investigation of the concentration of different water quality parameters including: pH, Electric Conductivity, Total Suspended Solids (TSS), Total Volatile Suspended Solids (TVSS), Calcium (Ca), Magnesium (Mg), Potassium (K), Nitrates (NO_3^-), Ammonium Nitrates (NH_4 -N), Total Nitrogen (TN), Soluble Reactive Phosphorus (SRP), and Total Phosphorus (TP). Of the fifteen sample sites, eight sites were harvested while the other seven sites were unharvested sites. The background, however, is derived from the control sites throughout the years and water samples from harvest sites prior to the harvest.

The primary objective of the work reported in this article was to establish and quantify the background (or baseline) water quality levels and to outline methods of comparison for each water quality parameters and to compare those methods with the United States Environmental Protection Agency's (USEPA) Total Maximum Daily Load (TMDL) methods. US EPA has drinking and surface water standards. TMDL methods were used for the perennial streams and waterways that are impaired or threatened by the human and environmental consequences, however, the PoE was compared for similarities. To effectively design a water quality parameter of concern requires an established method of setting reliable, meaningful background concentrations and comparing them with the post-harvest water samples.

This paper, therefore, focuses on the background concentration used with the lognormal probability density function (PDF). For simplicity, only Total Suspended Solids (TSS), one of the twelve water quality parameters were evaluated. The data pool (master data set) which contained all samples collected from sites prior to harvest as well as control sites were used for this purpose. An outline of the proposed "Probability of Exceedance (PoE)" method were discussed for all water quality parameters. Finally, EPA's TMDL method were compared with the Probability of Exceedance (PoE) method proposed for the ephemeral Ozarks streams.

4.2 Methodology

4.2.1 Timber Water Database

The water quality database used throughout this timber water quality research is the result of 32 water sampling events beginning in late 2004. Each set of water samples was analyzed for the twelve specific water quality parameters and grouped based on whether the samples were taken prior to or after timber harvest. They were also grouped by the individual sites and by conservation area. A majority of the samples collected came from sites prior to harvest. In all, eight harvested sites produced a total of about 250 TSS samples, whereas the eight sites to harvest accounted for 464 TSS samples. The seven control sites never harvested yielded a total of 436 TSS samples.

4.2.2 Water Quality Analysis

Every water quality parameter (pool of concentrations) underwent a test to see which probability density function best represented the distribution of the concentration values. The concentration matched either a normal distribution or a lognormal distribution.

4.2.2.1 Normal Distribution

Normal distributions were commonly used to represent data trends. The normal distribution was given by:

$$f(x) = 1/(\sigma\sqrt{2\pi})e - 1/2((\chi - \mu)/\sigma))\text{^}2 \ldots\ldots\ldots(1)$$

The population corresponding to the distribution had a mean, μ, as well as a standard deviation, σ. The original attempt to establish background concentrations used the mean and three standard deviation (μ +3σ)(Arnold and Milton, 2003). The area under the function +/- 3σ accounted for 99.87% of all values in the population and could be used to estimate the expected number of post-harvest concentration “outliers” from the post-harvest data concentration pool.

4.2.2.2 Lognormal Distribution

Lognormal PDF’s required a different method for determining background concentrations. The function’s asymmetrical properties were a direct result of the samples considered “outliers.” The “outliers” for a lognormal PDF were significantly larger concentrations than the normal PDF’s “outliers”. Therefore, a transformation was essential to be able to analyze a lognormal distribution function. The conversion transformed μ and σ, into λ and ζ respectively using the functions shown in equations 2 and 3 (Khisty and Mohammadi, 2001).

$$\lambda = \ln(\mu)-(\xi^2/2) \qquad \text{.........................}(2)$$

$$\xi = \sqrt{(\ln(1+(\sigma 2/\mu 2)))} \qquad \text{.....................}(3)$$

The transformation (Equation 2 and 3) allowed for standardizing the lognormal PDF which enabled comparison with the normal distribution PDF. Lambda and Xi are the parameters for the lognormal distribution equation:

$$f(x) = (1/\xi\sqrt{2\pi})\mathrm{e}^{-(1/2)\{(\ln x-\lambda)/\xi\}^{\wedge}2} \qquad \text{........ ...}(4)$$

4.3 Selecting an Appropriate Distribution

Recognizing a representative histogram must first be done to be able to assign a distribution to a population of data. A histogram of pre-harvest TSS is shown in Figure 4.1. The histogram accounted for about 900 samples with mean (μ), standard deviation (σ), coefficient of variation (δ) as well as range (R) of the concentrations. Note the shape and that a high number (510) of concentrations between 0.025-0.74 g/L. The shape has a logarithm decay. The shape of the histogram is useful to decide which distribution best fits the dataset.

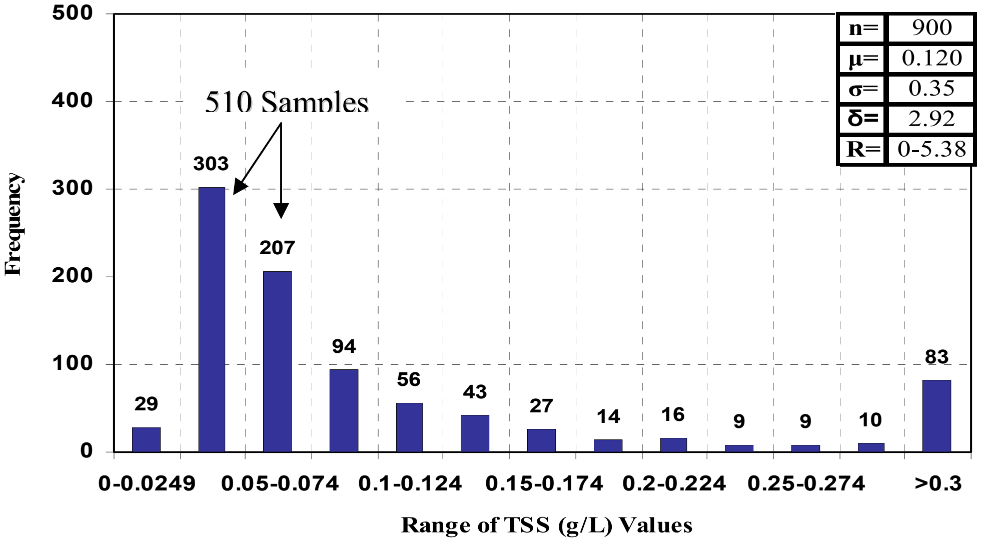

Figure 4.1- Frequency histogram of pre-harvest total suspended solids (TSS)(g/L)

4.3.1 Normal Distribution

Once the histogram was completed, it was tested for the best-fit distribution. The initial check is for the normal distribution. If the histogram resembled a "bell-shaped" curve, it would most probably be a normal distribution and analyzed as such. An ideal normal distribution was demonstrated using pH (Figure 4.2). However, when a normal distribution was applied to TSS, the function was not symmetrical as slopes were unequal in magnitude on either side of the peak. The plot also implied the potentiality for large percentage of negative concentrations which were not possible. Thus, the normal distribution is not appropriate for eleven of the twelve parameters including TSS.

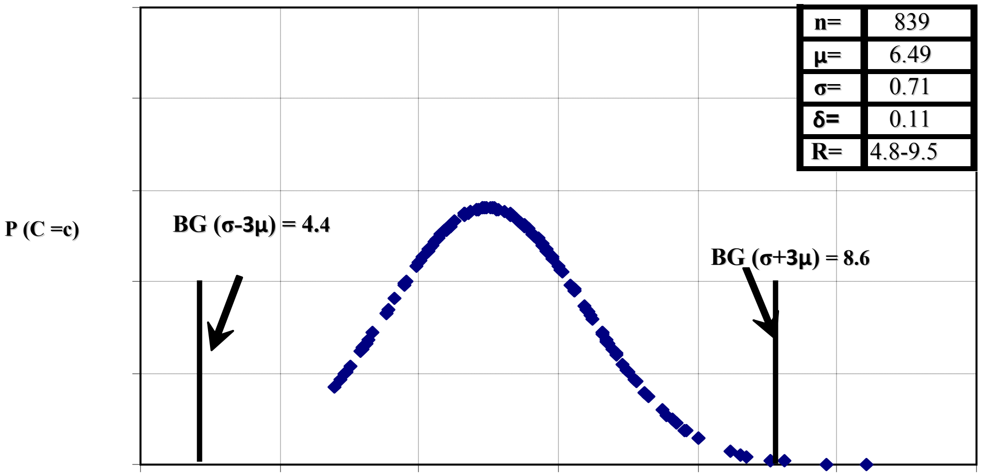

Figure 4.2- Pre-harvest pH normal probability density function and upper and lower background

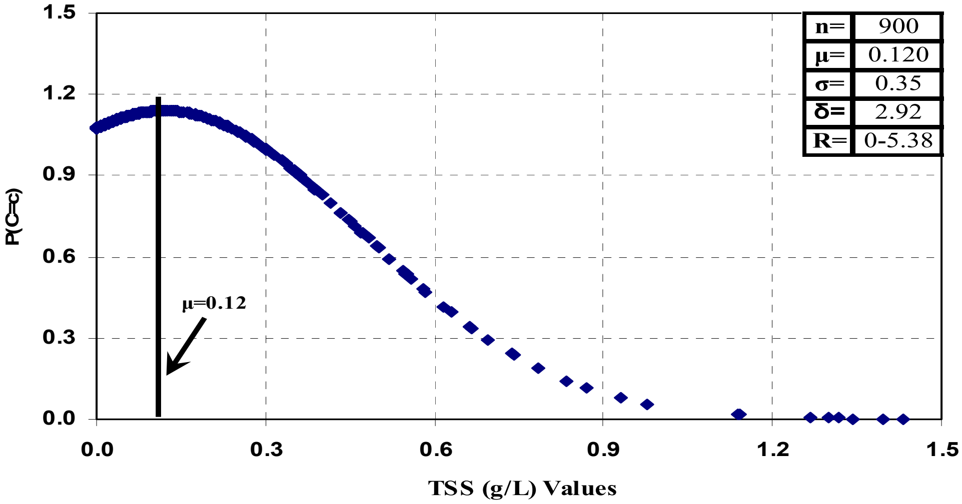

Figure 4.3- Pre-harvest normal probability density function of total suspended solids (TSS)(g/L)

4.3.2 Lognormal Distribution

Lognormal distributions for both pre-and post-harvest water samples were plotted. It was found that the water quality data fit the log normal distribution well except for pH. A log normal distribution of TSS (g/L) and histogram are shown in Figure 4.4.

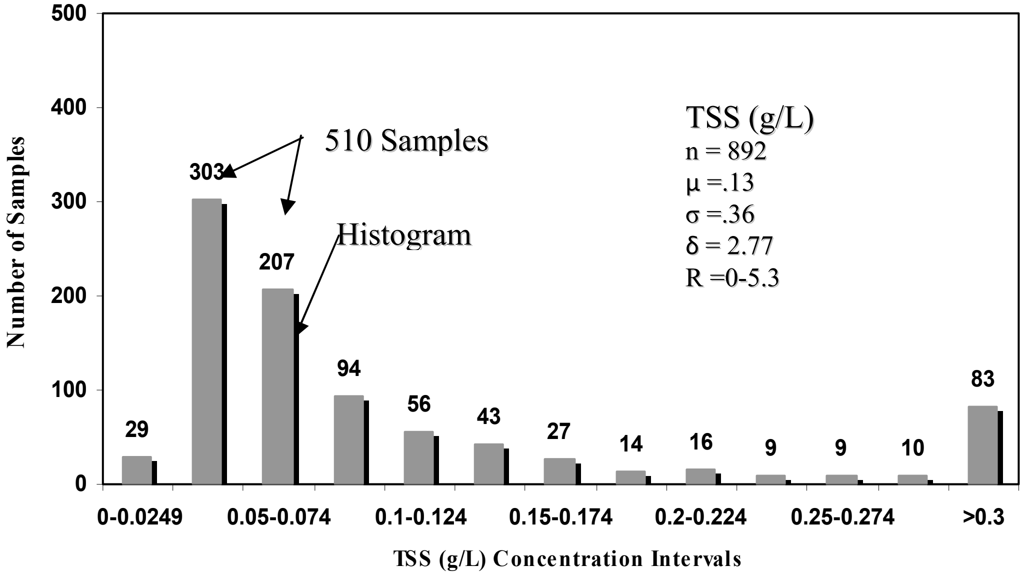

Figure 4.4- TSS (g/L) pre-harvest log normal distributions with a histogram

For TSS and ten other water quality parameters, the lognormal distribution was the most appropriate as it better represented the population data (Figure 4.5). it was apparent that there were no negative concentrations, the plot began at the origin (concentration = 0, frequency = 0), peaked relatively quickly, and decayed gradually.

The TSS data collected from water samples from low-order ephemeral streams, prior to timber harvest, exhibit a lognormal distribution. For preliminary analysis to determine the appropriate PDF, one must identify the range of the data and take note of the minimum value. If all values are non-negative and the minimum value is 0, the appropriate distribution is lognormal.

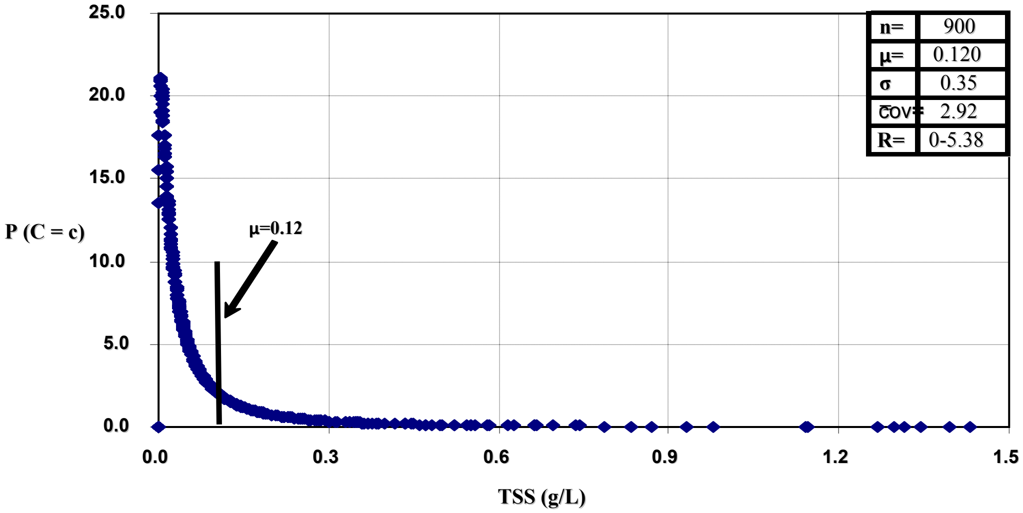

Figure 4.5- Pre-harvest lognormal probability density function for total suspended solids (TSS)(g/L)

4.4 Establishing a Background (Pre-harvest) Concentration

Establishing a background concentration is necessary to enable post-harvest concentrations to be evaluated for change from the pre-harvest concentration. Some issues were encountered when attempting to determine background concentrations for pre-harvest samples for different lognormal probability density functions (PDF's) i.e. larger outlier numbers. The percentage used to calculate the background concentration determines how many outliers are acceptable for a given number of data values. If a sample concentration in the post-harvest population is greater than the background concentration from the pre-harvest data set, it is said to be exceeding the background concentration and is noted as an "outlier". If the numbers of outliers exceed the number of acceptable "outliers", then the parameter is a parameter of interest requires further analysis.

The background concentration is synonymous with "baseline" or "undisturbed" behavior of water quality samples. This background level from the pre-harvest data is necessary to compare the post-harvest water sample to identify any significant changes in water quality. The following are some of the methods and discussions considered to determine background or baseline concentration for pre-harvest samples.

4.4.1 Method 1 - Reliability Background Limit ($\mu+X\sigma$)

Originally, the "three sigma method," as outlined by Duncan (2000), was used to determine background for both the normal distributions and the lognormal distributions. However, using the same background determination procedures for lognormal PDF's that were used for normal PDF's, resulted in a lower background concentration and, consequently, a greater number of pre-harvest samples designated as outliers. The fact that the background concentration was too small was made apparent by knowing that the normal probability rule, $\mu+3\sigma$, should account for 99.87 percent of the data points, i.e., 13 samples exceeding the background for every 10,000 samples. Table 4.1 details the pre-harvest water quality parameters and properties for all the water quality samples.

Table 4.1-Pre-harvest water quality parameters and their statistical properties for all sites

Parameters	TSS (g/L)	TVSS (g/L)	Ca (mg/L)	Mg (mg/L)	K (mg/L)	NO3- (mg/L)	NH3-N (mg/L)	SRP (mg/L)	TN (mg/L)	TP (mg/L)	pH	E. Cond. (µs/cm)
Count, n	895	744	808	808	808	816	802	812	769	769	834	834
Mean, μ	0.13	0.05	4.51	2.06	2.32	0.55	0.39	0.19	0.44	1.69	6.50	51.75
Std Dev, σ	0.38	0.17	7.05	3.83	2.71	1.65	1.35	0.54	1.12	2.47	0.71	64.31
c.o.v., δ	2.95	3.06	1.56	1.86	1.17	3.02	3.46	2.84	2.55	1.46	0.11	1.24
Max	5.38	3.33	89.84	33.85	30.14	15.40	22.86	7.46	19.59	20.95	9.49	670.0
Min	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	4.78	0.00
Xi, ξ	1.51	1.52	1.11	1.22	0.92	1.52	1.60	1.47	1.42	1.07	0.11	0.97
Lambda, λ	-3.19	-4.07	0.89	-0.02	0.41	-1.75	-2.22	-2.74	-1.84	-0.05	1.87	3.48

However, when the normal probability rule was used for lognormal PDF background calculations, some of the lognormal data sets were found to have 20 or more samples exceeding the background out of about 250 samples. This corresponds to an exceedance rate of 775 exceeding out of every 10,000 samples. Figure 4.6 provides a representation of how the μ+3σ background determination method was not applicable to lognormal PDF's as the number of pre-harvest samples exceeding the background value of μ+3σ can be observed. A similar observation was also evident in the earlier histogram (Figure 4.1).

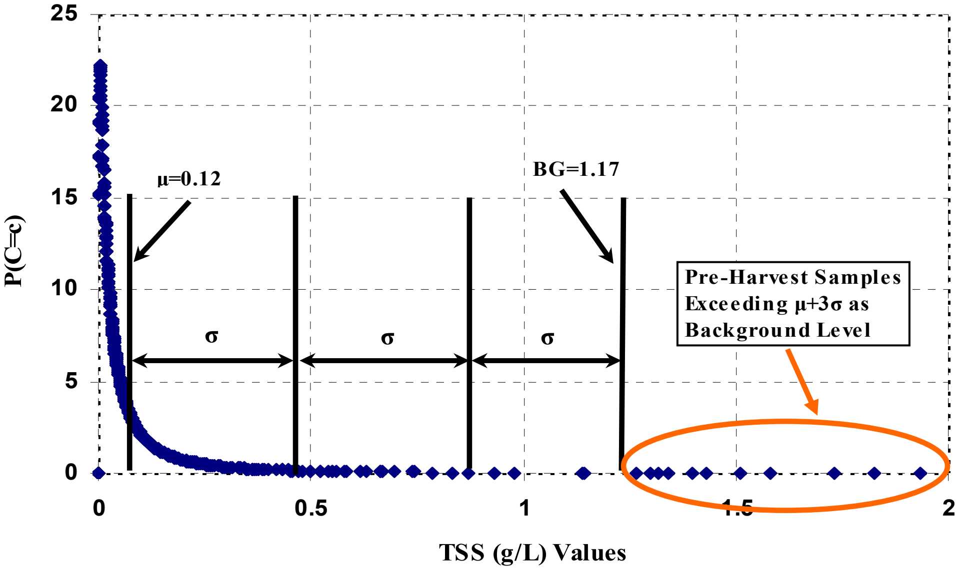

Figure 4.6- Total suspended solids (g/L) pre-harvest lognormal probability density function with a background concentration (μ+3σ) of 1.17 g/L

4.4.2 Method 2 - Level of Exceedance Limit for Background Distribution

A different approach was evaluated that could be adapted for normal and lognormal PDF’s. The calculated mean, μ, and the standard deviation, σ, and for the lognormal PDF’s, λ and ξ, could be used to evaluate the concentration by relating it to the integral of the function itself, or the cumulative distribution function (CDF).

For normal PDF’s:

$$P\ (C \leq c) = \Phi\ [(BG-\mu)/\sigma] \qquad \text{……......................(5)}$$

And for lognormal PDF's:

$$P\ (C \leq c\ ) = \Phi\ [(\ln(BG)-\lambda)/\ \xi] \qquad \text{…….............(6)}$$

such that Φ, the cumulative distribution function ($_{-\infty}\int^{\infty} f(x)dx$ for normal distributions, and $_{0}\int^{\infty} f(x)dx$ for lognormal distributions), corresponds to the standard normal distribution tables (Appendix A.1-Areas Under the Normal Curve) (Khisty and Mohammadi, 2001) that represent the probability that a concentration will be equal to or less than a given concentration). Using this technique, one can specify a particular desired area beneath the function. The background concentration can then be calculated utilizing the function's parameters, λ and ξ, required to plot the lognormal distribution (Equation 6).

A range of percentages varying from 80% to 100% was initially selected for the CDF value. For each desired percentage, the known λ and ξ values were substituted into Equation 7 and solved for the corresponding background concentration. Table 4.2 shows the background concentrations for a range of desired percentages of samples beneath the calculated background limit. Within this range of percentages, the graph of background concentrations corresponding to the specified percentage of sample peaks away from its linear trend (Figure 4.7). More specifically, above 98 percent, the plot becomes unpredictable. This behavior suggests 98 percent as the most appropriate CDF.

Table 4.2- Total suspended solids (g/L) lognormal background determination evaluation taking a percentage below the background limit (BG)

Desired % of samples within the BG concentration	Transformation	Respective background level	Actual no. of sample exceeding BG (out of 900)	% Actual exceeded
80	$P (C \leq c) = [(\ln(BG)-\lambda)/\xi]$	BG = 0.137 g/L	149	16.56
85		BG = 0.185 g/L	116	12.89
90		BG = 0.264 g/L	83	9.22
95		BG = 0.461 g/L	42	4.67
98		BG = 0.839 g/L	21	2.33
99.98		BG = 7.279 g/L	0	0.00

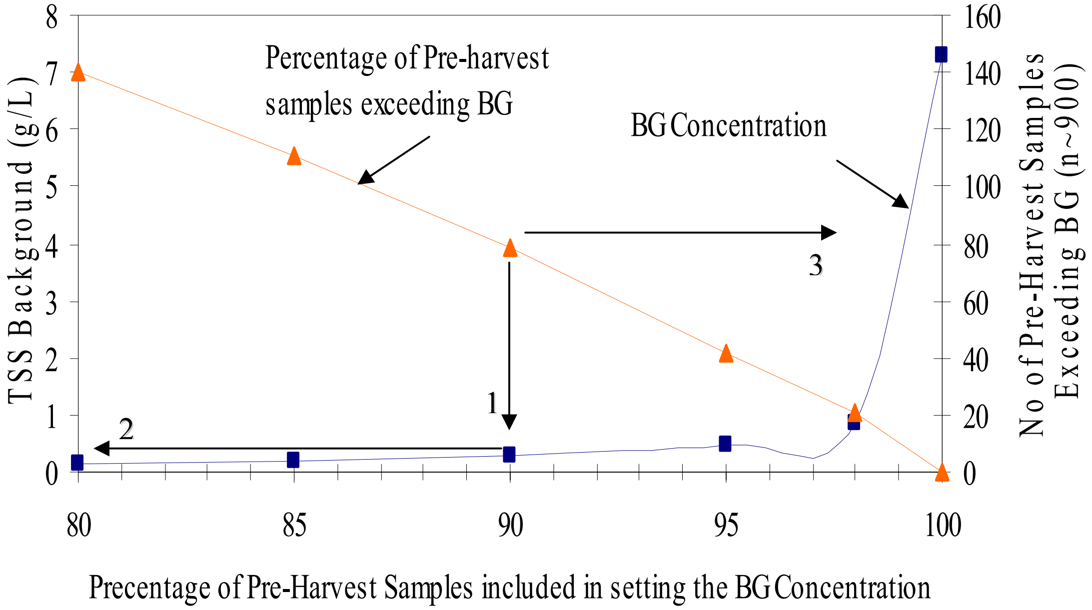

Figure 4.7- Total suspended solids (g/L) lognormal background determination evaluation. For example, a desired percentage (1) of pre-harvest samples beneath a corresponding background concentration (2). The desired percentage also relates directly to the amount of samples exceeding the specified concentration (3) (for a given total number of samples n = 900. A relationship can then be made between number of pre-harvest samples exceeding the background and a background concentration by means of a designated percentage that can be adapted for any population of data

For the TSS population in this study, a lognormal distribution approximation best fits the data. An adaptive method to determine background concentrations for both normal and lognormal distributions by designating a desired percentage of exceedance values was presented in Section 4. The percentage selected for this project was 98% (Figure 4.7) since this is where the graph of the calculated background specifically spikes away from its linear trend and becomes unstable.

4.4.3 Consideration of Probability of Exceedance (PoE) method

Pre-and post-harvest samples were analyzed using area exceedance method for all water quality parameters. The pre-harvest and post-harvest distributions using lognormal functions were plotted and area of exceedance was calculated from the point of intercept to infinity (Figure 4.8). The differences between two areas obtained will be designated “Probability of Exceedance (PoE)”.

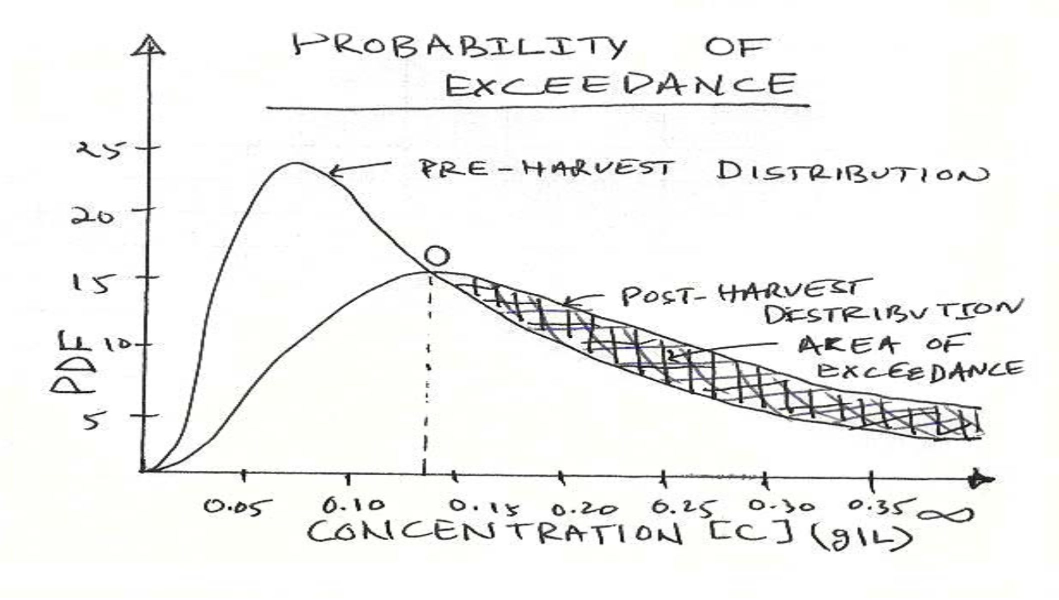

Figure 4.8- Schematic of pre-and post-harvest lognormal distribution showing an area of exceedance

4.4.4 Considerations for Probability of Exceedance Level

The probability of exceedance (PoE) method closely follows the established Total Daily Maximum Load (TMDL) method set forth by the USEPA with a few exceptions.

Table 4.3 illustrates a comparison of the two methods. TMDL is widely used to assess the water quality of the perennial streams that are threatened or impaired by human or natural activities. There are similarities in the PoE and TMDL methods that can be used for different types of streams to analyze surface water quality caused by disturbances.

Table 4.3- Comparison of Total Maximum Daily Load methodology to probability of exceedance (PoE) methodology

Total Maximum Daily Load Method (TMDL)	Probability of Exceedance(PoE) Method
Step 1. Identify Problematic streams.	Step 1. Identify possible threat to stream water quality (e.g. timber harvesting)
Step 2. Quantify Contaminant levels	Step 2. Test water quality before, during, and after timber harvest.
Step 3. Use EPA provided equation to determine TMDL for stream: $\text{TMDL}=\sum \text{LA}+\sum \text{WLA}+\text{MOS}$ Step 3a. Determine pollutant load allocation for nonpoint source discharges (LA)	Step 3. Identify differences between stream water quality before and after timber harvest Step 3a. Determine the distribution of a water quality parameter before harvest. Pre-harvest lognormal distribution = $\int_L^{\infty} f(C)_{\text{post-harvest}}$
Step 3b. Determine pollutant load allocation for point source discharges (WLA)	Step 3b. Determine the distribution of a water quality parameter post harvest Post-harvest lognormal distribution = $\int_L^{\infty} f(C)_{\text{pre-harvest}}$
Step 3c. An EPA regulator must determine a Margin of safety (MOS) to complete the equation.	Step 3c. Determine the difference between the pre and post-harvest water quality as follows: Probability of Exceedance = $\int_L^{\infty} f(C)_{\text{post}}\,dc - \int_L^{\infty} f(C)_{\text{pre}}\,dc$
Step 4. Develop a plan to reduce pollutant input into streams below the TMDL with some margin of safety (MOS).	Step 4. Determine an acceptable probability of exceedance between pre and post harvest.

Choosing an appropriate allowable exceedance level for the tested water quality parameters for harvested areas will have to take into account the current water quality standards set forth by the USEPA for the area. It would be useful to use a probabilistic risk analysis, assigning probability values to each potential consequence of alternative decisions, to help determine the probability of damage to the water quality (Lund 2008). It is important to consider all the effects and extent that poor water quality could have on the environment, including damaging habitat, aquatic life, ground water, and water quality in the surrounding rivers that are used for recreation and as a drinking water source for surrounding areas.

4.5 Summary and Conclusions

4.5.1 Summary

Timber harvesting practices have been suspected of impacting surface water quality. The Missouri Department of Conservation manages the State's forest lands, and has implemented a series of best management practices (BMP's) for timber harvest in order to protect the State's waterways and to comply with the federal government's Clean Water Act, 1972 that US EPA has the authority to enforce. Although the BMP's have been in practice for twenty years in the State of Missouri, there was no quantitative data base to provide evidence of the effect of the BMP's. This research was performed to close the gap by collecting quantitative evidence of the performance of the BMP's by testing water quality samples before and after timber harvest for twelve parameters that have the ability to impair or threaten the health of the streams and its inhabitants. The procedure for establishing background (baseline or undisturbed) concentrations for water quality parameters were discussed and outlined in this paper.

Fifteen watersheds of varying slopes and aspects were selected for monitoring in Shannon and Reynolds counties. The "monitoring" is in reference to the investigation of the concentration of twelve different water quality parameters among others; a) Index parameters: pH, Electric Conductivity; b) Solids: Total Suspended Solids (TSS), Total

Volatile Suspended Solids (TVSS); c) Minerals: Calcium (Ca), Magnesium (Mg), Potassium (K); and d) Nutrients: Nitrates (NO_3^-), Ammonium Nitrates (NH_4 -N), Total Nitrogen (TN), Soluble Reactive Phosphorus (SRP), and Total Phosphorus (TP). Of the fifteen sites, eight sites were harvested (treated) while the other seven sites were remained unharvested (control or undisturbed or untreated) sites. Water samples were taken from sites prior to and after harvesting to observe whether or not the clear cut harvesting practice posed any threat on water quality in the ephemeral streams in the watersheds.

Establishing a background concentration for water quality parameters in ephemeral streams were complex due to the wide variation in observed values, even during periods of no harvest for each water quality parameters. A large data set ($n \approx 900$) allowed good evaluation of appropriate distribution models which then enabled calculation of a background concentration based on an accepted exceedance percentage. This approach was illustrated with the analysis of the total suspended solids data. The histogram and distribution of concentrations best fit a lognormal distribution, the focus changed to how to effectively establish background concentrations with a lognormal distribution approximation. Once the method for determining the background was established, it became a question of what inclusion percentage should be used that would make the analysis most appropriate. The inclusion percentage that best fit this requirement was decided to be 98% since the almost liner curve of calculated background concentration became irregular (spikes away) (Fig. 4.8). Using the inclusion percentage and the cumulative distribution function equation (Eq. 6), the corresponding background concentration was calculated and utilized to determine how many post-harvest samples exceeded that concentration. If that number was greater than 2% of the total population of values, then the water quality parameter was noted as a parameter of interest and would require further analysis. The background concentration, essentially, allowed for a relationship between the pre-harvest and post-harvest data populations which, in turn, aided in verifying the effectiveness of MDC's timber harvesting best management practices in the prevention of detrimental effects to surface water quality due to timber harvest.

After further analysis of the water quality parameters, the post-harvest individual samples higher than the background concentration exceeded 2%. It was therefore determined to use the PoE method. PoE was also compared with USEPA's TMDL method for verification purpose for similarities. The TMDL method and PoE procedures closely reflected each other although the TMDL was used for impaired or threatened perennial streams as opposed to ephemeral Missouri Ozarks streams in this study.

4.5.2 Conclusions

In order to determine which parameters are affected by the timber harvest, a background concentration was established from the pre-harvest concentration population so that post-harvest data could be compared to the background. For normal distributions, a method for background determination was established (Smith, 2006). However, only the pH fit a normal distribution and was eligible for the mean plus three times the standard deviation or "three sigma method". The other eleven parameters were better represented by lognormal distributions.

The resulting procedure for establishing a background concentration for a specific water quality parameter thus involved: (1) selecting the best-fit distribution (normal or lognormal) for the background data; (2) selecting a desired probability for the measured parameter to fall within the background limit; (3) calculating the maximum concentration for the background with respect to the probability of a sample falling below that maximum concentration. The process is demonstrated for total suspended solids (TSS).

Determining baseline water quality standards for ephemeral streams in the Missouri Ozarks can be accomplished by using data before and after a timber harvest in conjunction with USEPA stated water quality standards. Assessing the effects on water quality and then the effects of varying water qualities on the environment is all a part of the process completed. It is important to consider the fact that while timber harvesting changes the way water reaches the streams it may not necessarily adversely change water quality. It appears that the most appropriate way to consider the effects of harvesting is to review changes in concentrations of the water quality parameters studied.

Furthermore, comparing the water quality of streams before and after the timber harvest requires an assessment strategy to determine if any change has occurred. This strategy must take into account the effects of the quality on the surrounding areas drinking water quality, ground water quality, and the aquatic life and habitat in the streams themselves. These concerns aid in determining whether or not the water quality meets the standards set forth for those parameters by the USEPA. The USEPA has stringent standards for drinking water and also maximum daily allowable loads for streams that are perennial and or threatened by pollution. To determine what sort of water quality is acceptable it would make sense to determine how much or what percentages of exceedance or if at all, the water samples of harvested sites exceed those of pre harvest sites when comparing water quality parameters. The next step was to determine probability of exceedance (PoE), if any, is acceptable to still meet water quality standards. In this study the area under the log normal distribution function for all water quality parameters for pre- and post-harvest samples was plotted and an area of exceedance was determined by integrating area from the intercept to infinity and calculating the difference or probability of exceedance between the two treatments. Finally, establishing an appropriate exceedance level to be used in the future to determine impacts of timber harvesting on water quality should help with the assessment of current and future harvesting practices.

4.6 Recommendations

It is valuable to remember that probability density functions were used as simplified models to help put the data into perspective. Not any one parameter was going to fit the model perfectly. Note that it was possible to over-simplify a population of values and associate them with a more generalized function, however, the effectiveness and accuracy of the representation would have been diminished.

The probability of exceedance comparing both pre-and post-harvest water quality samples should be completed for all parameters and then compared with the CWA (EPA 2008) limits for water quality to determine the capacities of the streams. The PoE method should include only harvesting effects, therefore, controls sites should also be analyzed.

4.7 Acknowledgements

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CHAPTER 5

Comparison of Pre- and Post- harvest Water Quality in the Low Order Streams of Missouri Ozarks

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Abstract: The anecdotal is that the forest harvesting adversely impacts downstream water quality. The severity is though proportional to harvest intensity and methods that are variable in a forest system. Much of this variability is attributable to differences in site conditions, including soils and geology, topography, slope and aspect and harvesting methods such as clear cutting, selection cutting or using other silvicultural methods with or without the Best Management Practices (BMPs). The SMZ that are meant to prevent loss of solids, nutrients and minerals as a part of BMP is being followed in the State of Missouri. The purpose of this paper is to determine if significant and measurable impacts exist between forest management practices and water quality in upland headwater watersheds within the Missouri Ozarks. State specified BMPs were followed during clear cutting in all sites but the extent of application varied among sites.

The probability of exceedance varied with parameter from no impact (negative) to some effect (positive) depending upon sites and practice adopted while harvesting. The probabilities of exceedance of twelve water quality parameters for pre- and post-harvest samples were obtained and compared between subgroups: all sites, harvested sites before and after harvest and conservation area specific sites that did or did not have BMPs implemented during clear cutting. Total suspended solids and total volatile suspended solids demonstrated higher probability of exceedance, where as calcium, magnesium, potassium, nitrate, ammonia nitrate and soluble reactive phosphorous showed higher exceedance probability in Current River Conservation area but no significant change on all other sites. pH and electrical conductivity showed no difference before and after the timber harvest. The probability of exceedance varied with parameter from negligible to low while rating depending on sites with or without stream side management zones adopted while harvesting. TSS and TVSS showed about 25 to 30% whereas Mg and SRP showed 1 to 13% probability of exceedance while comparing all sites and harvested sites considering all effect including harvest.

Key Words: Timber harvesting; Water quality; BMPs; Lognormal distribution; Probability of exceedance; Missouri Ozarks

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5.1 Introduction

The Missouri Ozarks, like many other underdeveloped and sparsely-populated areas of the country, has undergone several significant changes in land use. With the second growth oak-hickory and pine forests rapidly reaching commercial maturity, several relatively large blocks of land have been opened in both public and private lands through clearcutting (Settergren, 1972). Missouri is facing conflicts between forest management activities and adjacent stream quality; a frequent public concern is that normal present-day harvesting is abusive, exploitive, and accompanied by negative consequences, including degradation of water (Stuart, 2006).

Forested watersheds of the Missouri Ozark region are an important economic resource. They are also critical for maintaining water quality, sustaining important ecological services, and providing habitat to many animal and plant species of conservation concern (Schaberg and Abt, 2004). Forested areas are the source of more than eighty percent of all fresh water in Missouri (MDC, 1997). The forest vegetation not only provides some control over the rate of water discharge but it also protects the watershed and, thus, the water quality against the effects of erosion, sedimentation, leaching of nutrients, and overland flow (Pope, 1977). Additionally, forested watersheds provide significant and in some instances, potentially vital habitat to plant and animal species of conservation concern (Schaberg and Abt, 2004).

To control the impact of logging on soil erosion and the stream water quality, best management practices (BMPs) have been developed in many places including Missouri (Aust and Blinn, 2004; NFA, 2004). A streamside management zone (SMZ), a filter strip of vegetation under BMPs, often left undisturbed on both sides of ephemeral channels, act as a buffer to slow surface water velocity and contain sediments (Bunger, 2005). This buffer is intended to be effective in filtering sediment, nutrients and organic matter from surface and ground water flows (Ducros and Joyce, 2003; Martin and Hornbeck, 1994; Ice *et al*., 1997). Operational experience suggests that timber harvesting conducted in accordance with BMPs does not have a long-term deleterious effect on stream ecosystems, but there have been few quantitative studies of harvesting and water quality in the Missouri Ozarks.

Vegetation responds rapidly to stabilize exposed soil. Harvesting effects are of short duration and a return to a pre-cut condition occurs within a three to seven year period depending upon the source of contamination (Miller et al., 1985). Timber harvesting poses little threat to water quality when care is taken to prevent or minimize soil erosion (Mussalem and Patric, 1976). Similarly, Sheppard (1994) on logging in wetlands concluded that silviculture has temporary effects on water quality, with water quality parameters returning to pre-harvest levels within periods of months to several years. In the recent review of silvicultural activities in flood plain forests of the southeastern US, Lockably et al., 1997b concluded that clear cutting on hardwood forest followed by natural regeneration and accompanied by BMPs has a small and brief effect on water quality. A review of timber harvest in the southern coastal plain concludes that the short term effects of forestry activities on water quality can negatively impact the coastal environment (Herz, 1996). These studies and others cite that the cumulative water quality impacts from forestry activities is slight and transient compared with other land uses, because timber harvest in those lands are preformed infrequently at every 25-50 years (Herz, 1996). Moreover, a review of eastern forestry practices concluded that timber harvesting leads to only minor changes in stream nutrient concentration (Corbett et al., 1978). However, a high enough nutrient concentration can lead to booming phytoplankton species in the watershed in response to the nutrients (Mallin et al., 1997). Sedimentation has been as cited the most important water quality parameter concern related to forestry practice in the United States (Binkley and Brown, 1993).

It is well known, though, that the harvest takes away some or all of the many years accumulation of the aboveground vegetative stand (Stone, 1975). Such removal of crown allows for mass movement of soil sediment and nutrients more readily, and with the addition of skidder roads and trails, this movement is compounded (Doisy, 2002). Swank et al., 2001 concluded in the Appalachian catchments that the year after cutting, stream flow increased at 28% of the flow in an uncut site. Analysis of stream solute concentration and catchment nutrients fluxes showed increased nutrient losses following clear cutting and logging.

Effects of harvesting on stream water quality more commonly are regional or site-specific and thus cannot be generalized as a whole (Settergren, 1978). The Ozarks region has no long-term, instrumental record of hydrologic, water quality and sediment impacts at the scales of operable timber harvests; therefore, Missouri Department of Conservation (MDC) lacked a verifiable database to determine if its BMPs were effective in protecting water quality during clear cut timber operations (Mueller, 2006).

An understanding of the physical and chemical processes in ephemeral streams adjacent to harvested areas in the Missouri Ozarks is critical for developing management guidelines for private and public landowners that provide protection for the biodiversity of the stream ecosystem. Therefore, to come up with management guidelines as well as to evaluate the public perception that timber harvesting negatively impacts water quality by eroding sediments and leaching nutrients has driven this research to investigate whether MDC's best management practices are effective (Hollabaugh, 2006).

The objectives of this paper therefore, are to test the efficacy of MDC's current best management practice during regenerative oak clear cutting (ROCC) in the southern Ozark region of state of Missouri by acquiring and analyzing pre- and post-harvest water quality databases and comparing parameters to determine the impact on water quality after clear cut harvest. This study is critical to MDC in developing timber harvest management guidelines that provide protection for the stream ecosystem and the environment in the Southeast Missouri Ozark highlands.

5.2 Methods and Methodology

5.2.1 Site Selection and Characteristics

Fifteen sites were selected, instrumented and monitored to collect pre- and post-harvest water quality samples from late December 2004 through July 2009. The sites were scattered around 500 square miles of MDC's oak dominated hardwood forested land in the Angeline and Current River Conservation Areas in southeastern Missouri's Reynolds and Shannon counties. The aerial size of the individual sites range from 8 - 60 acres, and the cut areas within the site are about 6-60 acres depending upon sites, with all slope aspects harvested since late December 2006; average slope of the sites range from 20-30%. Precipitation averages approximately 115 cm annually with about of 22 percent of the total in annual runoff (Settergren, 1980). A profile view of the ephemeral stream of a typical site is shown in Figure 5.1.

Figure 5.1- A typical study site with regenerative oak hickory stand located within an upland headwater watershed in the Missouri Ozarks

Each site consists of at least one first order ephemeral stream and its corresponding drainage basin. Of the fifteen sites, four were “intensive” sites, which were most heavily instrumented and eleven were “extensive” sites, which had less instrumentation but covered a larger area. Of the fifteen sites, eight were harvested sites where post-harvest samples were collected, whereas seven were unharvested, or “control” sites, throughout the project duration. For intensive monitoring, four sites were located in close proximity on similar landforms and soils. For extensive monitoring, four sites were co-located with the intensive sites to provide opportunities to compare harvest to control behavior, while the remaining eleven sites were located on similar watersheds throughout the study area (Mueller, 2006).

The geology of the Missouri Ozarks is made up of steep side slopes, narrow ridges and floodplains with incised channels and structural benches with karst features including sinkholes; the Ozarks are dominated by limestone and dolomite. Four of the formations within the area of the project sites include: Rd = Roubidoux (sandstone and dolomite), UG = Upper Gasconade (cherty dolomite), LG = Lower Gasconade (dolomite) and the EM = Eminence-Potosi (dolomite) (Settergren, 1978; Smith, 2006).

5.2.2 Instrumentation and Water Sampling

During the study period, eight sites were harvested while seven remained unharvested "control" sites. Four "intensively" monitored sites were instrumented with a combination of automated and manual instruments and weather stations e.g., ISCO® automated water samplers, ECH$_2$O® weather station, hillslope water samplers, rising-gauge water in-stream water samplers, rain gauges and stream crest gauges.

A typical site instrumentation layout for site CR11-1 is depicted in Figure 5.2 that shows total acreage of 35.8 with the cut acreage of 10-15. Also illustrated in this site layout is the placement of the hillslope samplers and in-stream samplers.

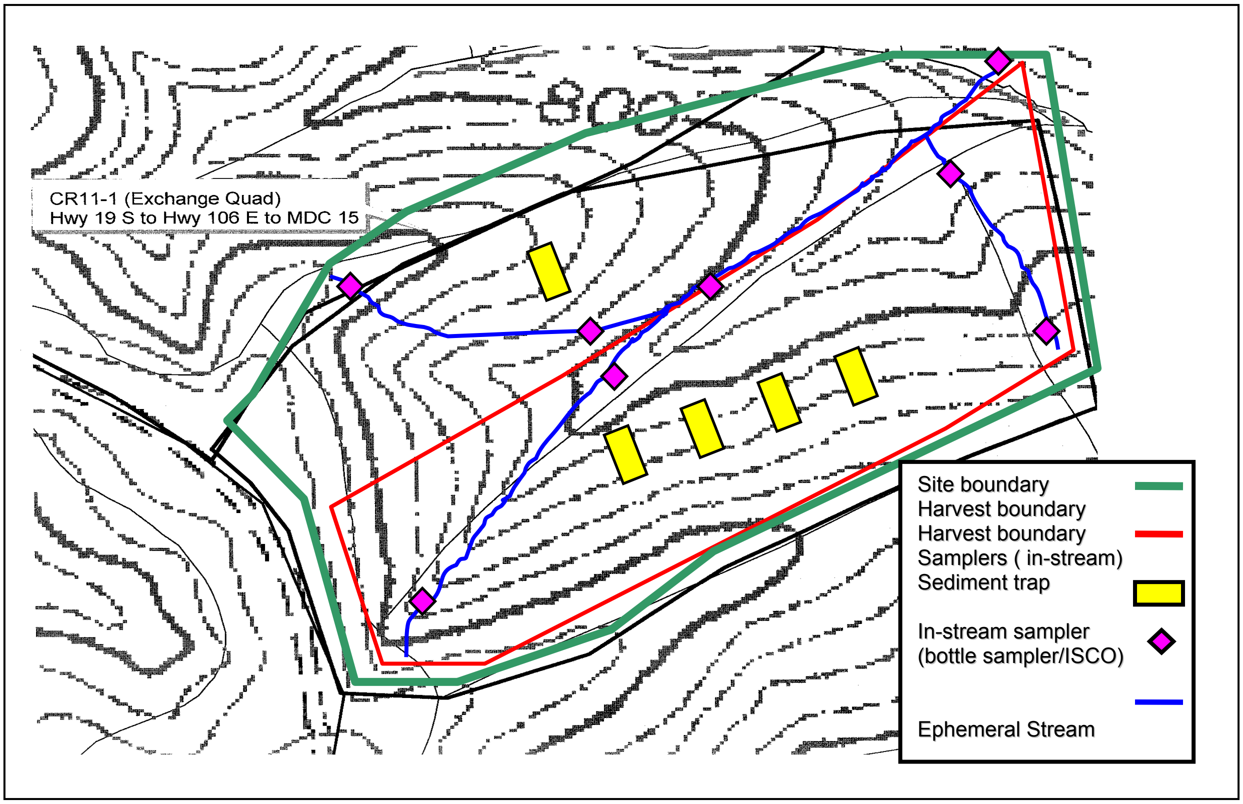


Figure 5.2- A typical water quality research site and instrumentation layout (CR11-1)

The in-stream samplers fill when the water level reaches the height of the inlet tubes. Samples are taken just below the surface of the water (Figure 5.3). In addition to water samplers, simple crest gauges were utilized to estimate the maximum gauge height and discharge rate of the ephemeral streams.

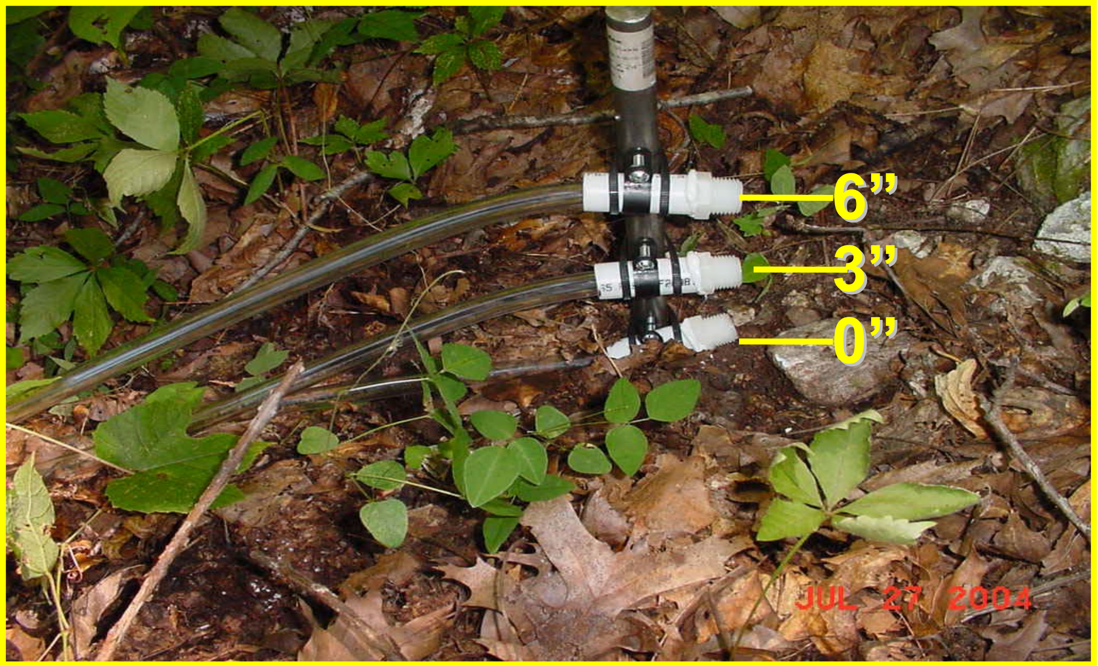


Figure 5.3- An in-stream rising stage water sampler installed in the stream channel

Hillslope samplers installed on side slopes provided a measure of sedimentation and overland flow. Each hillslope sampler or “plot” is approximately 1.25 m wide and 3 m long, with the long axis oriented with the slope of the site (Figure 5.4). Surface flow from inside the diamond shaped sampler area was collected through the lower end and diverted through a debris filter into a catchment for sample collection and measurement. Runoff and sediment accumulation (A34-1) (water balance) were also calculated by measuring the volume of water/solids accumulated in the catchment (Hollabaugh, 2006).

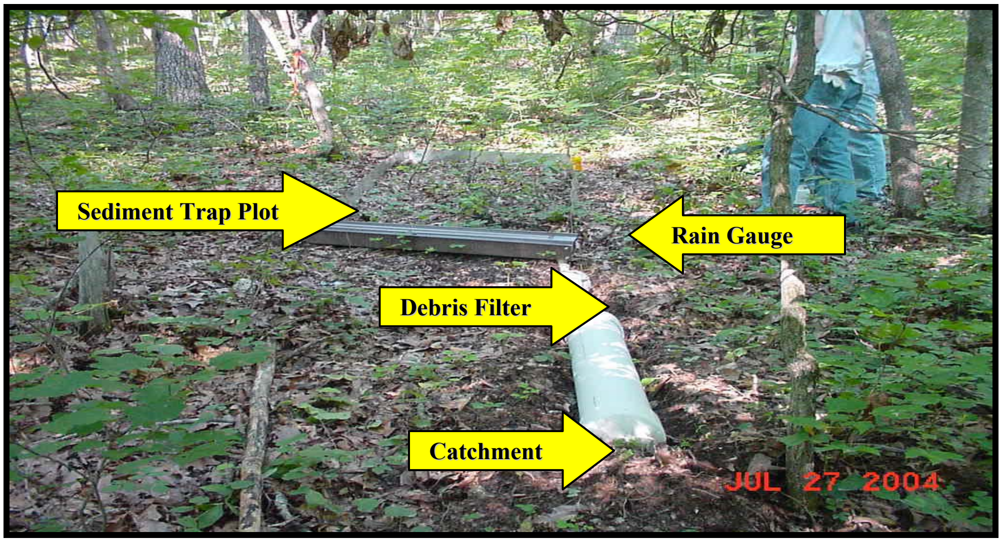


Figure 5.4- A typical diamond shaped (16 sq m) hillslope sampler and a collection tube installed on a side slope in each sites. The number of sampler varied from four to six depending on the size of the site

5.2.3 Water Analysis and Database

Pre-harvest water samples were collected from manual and automated samplers from December 2004 through July 2009. Harvesting timber on some sites started in late December 2006 and post harvest water samples were collected thereafter. ECH$_2$0® generated weather data were collected including: soil moisture, air temperature as well as precipitation. ISCO® automated water sampler recorded hydrological data, i.e., water depth, flow velocity, flow quantity and precipitation. An ISCO ® also collected a few water samples in some precipitation events. The capabilities to collect water samples at different times during and after precipitation events, and throughout the duration of flow, provided data about the variation of water quality as a function of flow depth and velocity. The information gathered from the ISCO® allowed to create hydrographs for the ephemeral drainage basin (Hollabaugh, 2006).

About 1150 pre- and post-harvest water samples were collected during the project from hill-slope, in-stream and automated samplers from all fifteen sites; about 260 samples were post-harvest samples from eight clear felled (all trees cut) sites. Water samples were analyzed for sediment and nutrient content as well as surrogate parameters. The goal was to collect as much pre-harvest data as practicable before the cut in a site and then collect up to three years of post-harvest data for comparison and analysis.

Samples were transported in a portable cooler and kept in the freezer at -10^0C for further processing. Water samples were thawed and separated in two 60 ml Nalgene® bottles for further processing. Sample separation was followed by the pH and electrical conductivity analyses; then the samples were filtered using 0.45 µm glass microfiber filters and oven-dried at two different temperatures (105 and 500^oC) to obtain suspended and volatile solids. A digestion step was required to breakdown the samples so that the various analyzable nutrients forms can be released and detected by the colorimeters (Smith, 2006).

Twelve water quality parameters were selected and analyzed in the laboratory: pH, conductivity (µs/cm), total suspended solids (TSS), total volatile solid (TVSS), calcium (Ca), magnesium (Mg), potassium (K), nitrate (NO3), ammonia Nitrate (NH3-N), Soluble reactive phosphorous (SRP), total phosphorous (TP), and total nitrogen (TN). Laboratory colorimeters a) Varian 240FF absorption Spectrometer for Ca, Mg, K, and b) Spectronic $20D^+$ for nitrate, ammonia Nitrate, soluble reactive phosphorous, total phosphorous, and total nitrogen were used in the laboratory to analyze the water quality parameters. Powder pillows (Hach Company, CO) as well as liquid standards were used to prepare samples for coloration.

The parameters selected for water quality analysis had specific benefits of being a) applicable and effective over a wide range of concentrations; b) a method detection limit ≤ 0.01 mg/L; c) could acquire acceptable production rate for larger number of samples; and d) methods were verifiable and relatively easy to use in the lab. The samples were analyzed in the laboratory for both pre- and post-harvest samples collected throughout the project duration using the American Public Health Standard, 1994.The water quality data were compiled using an Excel ® spread sheet.

5.3 Statistical Analyses

5.3.1 Probability of Exceedance (PoE) using Lognormal Distribution

Using pre-harvest data to establish a background concentration is important for determining the significance of post-harvest water quality values, but other criteria must also be considered. US Environmental Protection Agency's (USEPA) total daily maximum load (TMDL) limitations are established for perennial streams and streams threatened by pollutions. There are many parameters that are taken into consideration, including sediments and nutrients parameter that could contaminate the stream. While timber harvesting could affect the water quality of the stream, these effects may or may not have a significant negative impact on the stream's water quality. It is possible that the post-timber harvest concentrations may be higher than those of the pre-harvest data, but the USEPA may still not consider it a threatened or impaired stream until there is evidence of deterioration of the ecosystem and its associated components. It is possible then to use the post harvest data that was gathered to determine what effects might exist by comparing pre- and post-harvest water quality and whether or not the after harvest water quality is still impacted.

A probability of exceedance (PoE) method based on area exceedance illustrating the comparison between the pre-and post-harvest probability distribution function (PDF) is shown graphically in Figure 5.5. The first curve represents the lognormal statistical distribution of pre-harvest concentrations and the second curve represents post-harvest concentrations. The shaded area represents the probability of exceedance of post-harvest relative to pre-harvest concentrations. The probability of exceedance (PoE) can be defined as the "probability that the post harvest concentration will be greater than the pre-harvest concentration". The probability of exceedance can be ranged from zero to one ($0 \leq \text{PoE} \leq 1.0$).

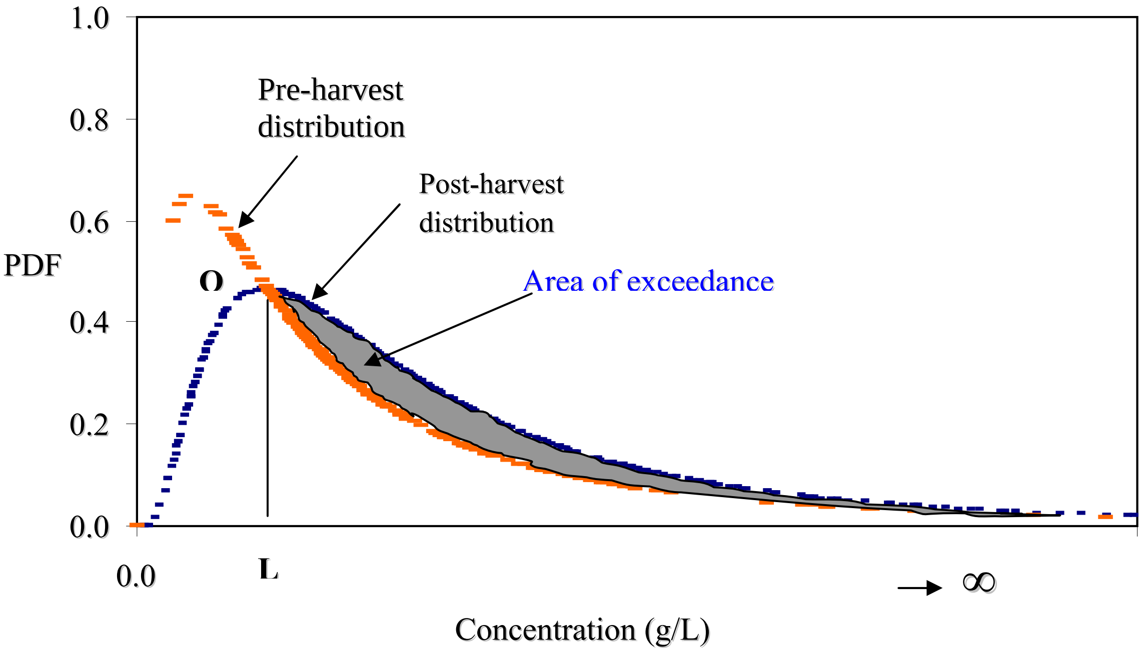


Figure 5.5- A schematic showing method to calculate PoE from pre-and post distributions

The probability of exceedance is found by calculating the shaded area beginning at intercept L and continuing to infinity (Figure 5.5) as shown in equation (1).

$$\text{Probability of Exceedance} = \int_{L}^{\infty} f(C)_{post}\, dc - \int_{L}^{\infty} f(C)_{pre}\, dc \quad \ldots\ldots\ldots\ldots\ldots\ldots(1)$$

$$= (\text{Post-harvest Cum area}) - (\text{Pre-harvest Cum Area})*100$$

$$= \text{Probability of Exceedance } (0 \leq \text{PoE} \leq 1.0)$$

Where,

L = Intersection of Pre- and post- harvest distributions

$f(C)_{post}$ = Post-harvest log normal distribution of concentrations

$f(C)_{pre}$ = Pre-harvest log normal distribution of concentrations

The PoE was used to compare pre-and post-harvest water quality samples for all parameters.

5.4 Results and Discussions

5.4.1 Probability of Exceedance (PoE)

Probability of Exceedances (PoE's) are analyzed and presented in three sub-groups. First, pre- and post-harvest water samples from all fifteen sites are grouped, analyzed and presented. Next, water samples only from the sites that were harvested are analyzed and presented. Finally, all the pre- and post-harvest samples were separated based on their respective conservation areas. The Angeline and Current River Conservation Areas were evaluated independently to understand the effect of use of streamside management zones (SMZs) as a part of the BMPs. The expected and observed behaviors are also discussed for all water quality parameters in a subsequent section.

5.4.1.1 PoE Comparison for Pre-and Post- Harvest Samples: All Sites

Statistical properties for distributions for both pre- and post-harvest water samples, i.e., mean (μ), standard deviation (σ) and their transformations yieta (ζ), and Lambda (λ), were calculated and tabulated along with the number of samples and the minimum and maximum concentrations for each parameter considered in the water quality analysis. The properties were essential to calculate PoE.

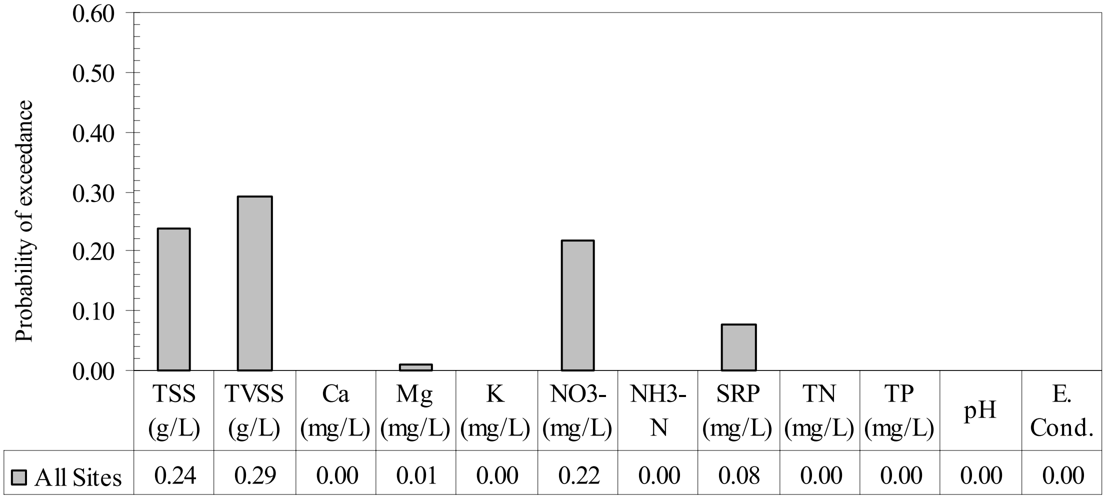
Table 5.1- Pre- and post-harvest water quality parameters and their statistical properties to calculate distributions for all samples collected from all of the research sites

Pre-harvest: All sites											
Para-meters	TSS (g/L)	TVSS (g/L)	Ca (mg/L)	Mg (mg/L)	K (mg/L)	$NO3^-$ (mg/L)	NH_3-N (mg/L)	SRP (mg/L)	TN (mg/L)	TP (mg/L)	pH	E Cond (µs/cm)
Count, n	895	744	808	808	808	816	802	812	769	769	834	834
Mean, µ	0.13	0.05	4.51	2.06	2.32	0.55	0.39	0.19	0.44	1.69	6.50	51.75
Std Dev σ	0.38	0.17	7.05	3.83	2.71	1.65	1.35	0.54	1.12	2.47	0.71	64.31
c.o.v., δ	2.95	3.06	1.56	1.86	1.17	3.02	3.46	2.84	2.55	1.46	0.11	1.24
Max	5.38	3.33	89.84	33.85	30.14	15.40	22.86	7.46	19.59	20.95	9.49	670.00
Min	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	4.78	0.00
Xi, ξ	1.51	1.52	1.11	1.22	0.92	1.52	1.60	1.47	1.42	1.07	0.11	0.97
Lambda λ	-3.19	-4.07	0.89	-0.02	0.41	-1.75	-2.22	-2.74	-1.84	-0.05	1.87	3.48
Post-harvest: All sites												
Para-meters	TSS (g/L)	TVSS (g/L)	Ca (mg/L)	Mg (mg/L)	K (mg/L)	$NO3^-$ (mg/L)	NH_3-N (mg/L)	SRP (mg/L)	TN (mg/L)	TP (mg/L)	pH	E Cond (µs/cm)
Count, n	253	253	241	241	241	242	248	251	248	193	253	253
Mean, µ	0.19	0.12	3.41	1.66	1.79	1.39	0.39	0.28	0.43	1.55	6.43	41.56
Std Dev σ	0.34	0.28	4.58	2.53	2.55	4.52	1.51	0.85	0.84	2.65	0.63	51.39
c.o.v., δ	1.82	2.28	1.34	1.52	1.42	3.25	3.87	3.04	1.95	1.71	0.10	1.24
Max	2.30	2.01	34.99	20.43	36.70	55.69	16.45	8.54	5.76	19.00	9.80	604.00
Min	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	5.20	4.38
Xi, ξ	1.21	1.35	1.02	1.09	1.05	1.56	1.66	1.52	1.25	1.17	0.10	0.96
Lambda λ	-2.41	-3.00	0.71	-0.09	0.03	-0.89	-2.32	-2.44	-1.61	-0.25	1.86	3.26

The maximum total number of pre-harvest samples analyzed was 895 for total suspended solids (TSS) while the least was 744 for total volatile suspended solids (TVSS). The number of post-harvest samples analyzed ranged from 253 for TSS and TVSS to 193 for total phosphorus (Table 5.1).

PoE analysis for all the water quality samples showed that TSS, TVSS, Nitrate (NO_3^-), Magnesium (Mg), and Dissolved Phosphorous (SRP) exhibited positive probabilities of exceedance ranging from 1% for Mg to 30% for TSS. The other parameters e.g., Ca, K, TN, TP, and Electrical Conductivity showed no probability of exceedance indicating that the harvest did not impact water quality. Similarly, pH and

Ammonia Nitrate (NH_3-N) showed no change between before and after harvest (Figure 5.6).



	TSS (g/L)	TVSS (g/L)	Ca (mg/L)	Mg (mg/L)	K (mg/L)	NO3- (mg/L)	NH3-N	SRP (mg/L)	TN (mg/L)	TP (mg/L)	pH	E. Cond.
▨ All Sites	0.24	0.29	0.00	0.01	0.00	0.22	0.00	0.08	0.00	0.00	0.00	0.00

Figure 5.6- Probability of Exceedance (PoE) comparison for pre-and post-harvest water quality parameters for all sites selected for timber harvest study

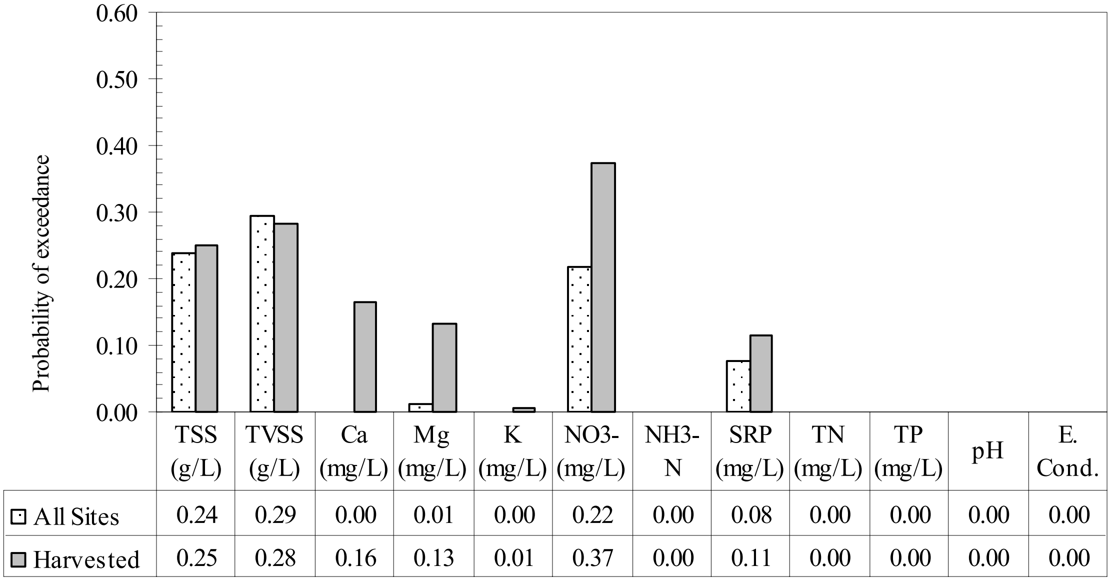
5.4.1.2 PoE Comparison: Harvested sites

Probability of Exceedance (PoE) for pre- and post-harvest samples from sites that were harvested (eight sites) was separated for each parameter category to compare before and after harvest effects from the same sites. This procedure eliminates biases that could come from inclusion of all samples (including the 7 control sites) and comparing with the samples collected from harvested sites (8 sites). The number of pre-harvest samples from the harvested sites before harvest and their statistical properties for each parameter are shown in Table 5.2. The post-harvest numbers and properties remain the same which were shown in Table 5.1. Note that for the harvested sites, the least number of samples, was for TVSS, and account for only 361 while the greatest number of samples, was for TSS, and included 469 water samples.

Table 5.2- Pre-harvest water quality parameters and their lognormal distribution properties for harvested sites only

Parameters	TSS (g/L)	TVSS (g/L)	Ca (mg/L)	Mg (mg/L)	K (mg/L)	$NO3^-$ (mg/L)	NH_3-N (mg/L)	SRP (mg/L)	TN (mg/L)	TP (mg/L)	pH	E Cond (µs/cm)
Count, n	469	361	421	421	421	427	416	418	401	404	434	434
Mean, μ	0.10	0.05	3.07	1.11	2.04	0.33	0.45	0.17	1.57	0.37	6.36	35.70
Std Dev σ	0.24	0.11	5.91	1.60	2.01	1.31	1.78	0.50	1.94	0.84	0.58	37.93
c.o.v., δ	2.34	2.47	1.92	1.44	0.99	3.96	3.97	2.92	1.23	2.30	0.09	1.06
Max	2.02	1.77	89.84	18.45	13.01	15.40	22.86	7.46	16.74	11.77	9.35	432.00
Min	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.02	0.00	4.78	4.16
Xi, ξ	1.37	1.40	1.24	1.06	0.82	1.68	1.68	1.50	0.96	1.36	0.09	0.87
Lambda λ	-3.21	-4.06	0.35	-0.45	0.37	-2.51	-2.21	-2.89	-0.01	-1.92	1.85	3.20

The PoE comparison of harvested sites only for pre-and post-harvest samples demonstrated positive exceedance for TSS, TVSS, calcium, magnesium, nitrate and dissolved phosphorous parameters up to 30 percent. Total phosphorous, total nitrogen and electrical conductivity showed no probability of exceedance when comparing pre-and post-harvest water quality samples. The comparison implies that the post-harvest downstream water quality would have no issues even after timber harvest operations when appropriate BMPs are in place. The pH, NH_3-N and potassium showed no change in terms of water quality resulting from timber harvest (Figure 5.7).



	TSS (g/L)	TVSS (g/L)	Ca (mg/L)	Mg (mg/L)	K (mg/L)	NO3- (mg/L)	NH3-N	SRP (mg/L)	TN (mg/L)	TP (mg/L)	pH	E. Cond.
☐ All Sites	0.24	0.29	0.00	0.01	0.00	0.22	0.00	0.08	0.00	0.00	0.00	0.00
▨ Harvested	0.25	0.28	0.16	0.13	0.01	0.37	0.00	0.11	0.00	0.00	0.00	0.00

Figure 5.7- PoE comparison for pre-and post-harvest samples from all sites and harvested sites

5.4.1.3 Probability of Exceedance Comparison for Pre-and Post-Harvest Samples: Angeline and Current River CA

About 350 (TSS) pre-harvest and 190 post-harvest samples were collected from Angeline CA sites (8 sites), whereas about 200 pre-harvest and 70 post-harvest samples were collected from Current River CA sites (7 sites) throughout the study period. The statistical properties are shown in Table 5.3 for Angeline CA and in Table 5.4 for Current River CA. PoE of the water quality parameters are shown in Figure 5.8.

Table 5.3- Pre- and post-harvest water quality parameters and their statistical properties for Angeline Sites that applied BMPs during the timber harvest

Pre-harvest: Angeline CA												
Para-meters	TSS (g/L)	TVSS (g/L)	Ca (mg/L)	Mg (mg/L)	K (mg/L)	NO3$^-$ (mg/L)	NH_3-N (mg/L)	SRP (mg/L)	TN (mg/L)	TP (mg/L)	pH	E Cond (µs/cm)
Count, n	364	361	324	324	324	339	336	339	315	404	344	434
Mean, µ	0.13	0.07	5.12	2.65	1.90	0.45	0.43	0.13	1.44	0.33	6.47	59.37
Std Dev σ	0.43	0.23	8.98	4.89	2.38	1.24	1.49	0.30	1.86	0.82	0.78	82.35
c.o.v., δ	3.20	3.42	1.75	1.85	1.26	2.76	3.44	2.25	1.29	2.46	0.12	1.39
Max	5.38	3.33	89.84	33.85	26.77	11.24	22.86	2.90	12.76	11.77	9.35	670.00
Min	0.00	0.00	0.00	0.01	0.02	0.00	0.00	0.00	0.00	0.00	4.78	6.69
Xi, ξ	1.56	1.59	1.18	1.22	0.97	1.47	1.60	1.34	0.99	1.40	0.12	1.04
Lambda λ	-3.22	-3.98	0.93	0.23	0.17	-1.88	-2.12	-2.91	-0.12	-2.08	1.86	3.55
Post-harvest: Angeline CA												
Para-meters	TSS (g/L)	TVSS (g/L)	Ca (mg/L)	Mg (mg/L)	K (mg/L)	NO3$^-$ (mg/L)	NH_3-N (mg/L)	SRP (mg/L)	TN (mg/L)	TP (mg/L)	pH	E Cond (µs/cm)
Count, n	194	295	169	169	169	169	175	178	318	248	194	253
Mean, µ	0.13	0.08	3.93	2.03	1.63	0.11	0.23	0.24	1.43	0.41	6.50	46.07
Std Dev σ	0.22	0.16	5.33	2.94	2.86	0.03	0.25	0.70	1.85	0.79	0.67	56.98
c.o.v., δ	1.65	2.05	1.36	1.45	1.76	0.25	1.06	2.95	1.29	1.92	0.10	1.24
Max	1.44	1.26	34.99	20.43	36.70	0.12	1.39	4.56	12.76	5.40	9.80	604.00
Min	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	5.20	4.38
Xi, ξ	1.15	1.28	1.02	1.07	1.19	0.24	0.87	1.51	0.99	1.24	0.10	0.96
Lambda λ	-2.70	-3.40	0.85	0.14	-0.22	-2.25	-1.83	-2.58	-0.13	-1.66	1.87	3.37

It should be noted that Angeline CA sites adopted BMPs using stream side management zones (SMZs) at all of the cut sites (A34-1, A34-2, A17-1 and A17-2) during timber harvest as opposed to Current River CA where the BMPs did not include SMZs (CR7-5C, CR7-5B, CR11-1 & CR11-3).

Table 5.4- Pre- and post-harvest water quality parameters and their properties for Current River conservation area sites where BMPs did not include SMZs during timber harvest operations.

Pre-harvest: Current River CA												
Para-meters	TSS (g/L)	TVSS (g/L)	Ca (mg/L)	Mg (mg/L)	K (mg/L)	$NO3^-$ (mg/L)	NH_3-N (mg/L)	SRP (mg/L)	TN (mg/L)	TP (mg/L)	pH	E Cond (µs/cm)
Count, n	227	185	209	209	209	207	199	199	196	198	212	209
Mean, µ	0.14	0.06	2.63	0.87	2.31	0.47	0.36	0.21	1.73	0.40	6.38	31.96
Std Dev σ	0.32	0.15	2.89	0.76	2.01	1.74	1.72	0.65	2.05	0.79	0.49	29.36
c.o.v., δ	2.37	2.71	1.10	0.87	0.87	3.74	4.76	3.04	1.19	1.96	0.08	0.92
Max	2.02	1.77	29.87	6.32	11.87	15.40	17.07	7.46	16.74	6.51	8.94	300.00
Min	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.02	0.00	5.37	4.16
Xi, ξ	1.37	1.46	0.89	0.75	0.75	1.64	1.78	1.53	0.94	1.26	0.08	0.78
Lambda λ	-2.95	-3.96	0.57	-0.42	0.55	-2.11	-2.60	-2.70	0.10	-1.69	1.85	3.16
Post-harvest: Current River CA												
Para-meters	TSS (g/L)	TVSS (g/L)	Ca (mg/L)	Mg (mg/L)	K (mg/L)	$NO3^-$ (mg/L)	NH_3-N (mg/L)	SRP (mg/L)	TN (mg/L)	TP (mg/L)	pH	E Cond (µs/cm)
Count, n	68	68	67	67	67	58	68	68	39	67	68	68
Mean, µ	0.33	0.25	2.14	0.78	2.18	1.94	0.81	0.38	1.09	0.50	6.18	28.09
Std Dev σ	0.48	0.45	1.32	0.34	1.58	7.39	2.84	1.17	1.72	1.00	0.38	17.62
c.o.v., δ	1.46	1.83	0.62	0.44	0.73	3.81	3.49	3.08	1.58	2.00	0.06	0.63
Max	2.10	2.02	6.35	1.86	7.14	55.69	16.46	8.54	10.67	5.77	7.77	118.10
Min	0.00	0.00	0.06	0.22	0.68	0.00	0.00	0.01	0.11	0.00	5.32	9.74
Xi, ξ	1.07	1.21	0.57	0.42	0.65	1.66	1.61	1.53	1.12	1.27	0.06	0.58
Lambda λ	-1.69	-2.13	0.60	-0.34	0.57	-0.71	-1.50	-2.14	-0.54	-1.50	1.82	3.17

PoE comparison of water quality parameters for Angeline CA sites demonstrated that total suspended solids, total volatile suspended solids, calcium, magnesium and dissolved phosphorous remained positive i.e. post-harvest exceeded pre-harvest water quality. Parameters including K, NO_3-, NH_3-N, TP and electrical conductivity showed post-harvest water quality was not different after disturbance, i.e., after- harvest water quality concentrations were not significant in terms of change. The pH and TN also remained unchanged throughout the study periods.

For the Current River CA sites, all water quality parameters except TP, TN and Electrical Conductivity were found to have positive probability of exceedance. The PoE found for those parameters were higher for Current River Conservation sites (Figure 5.8)

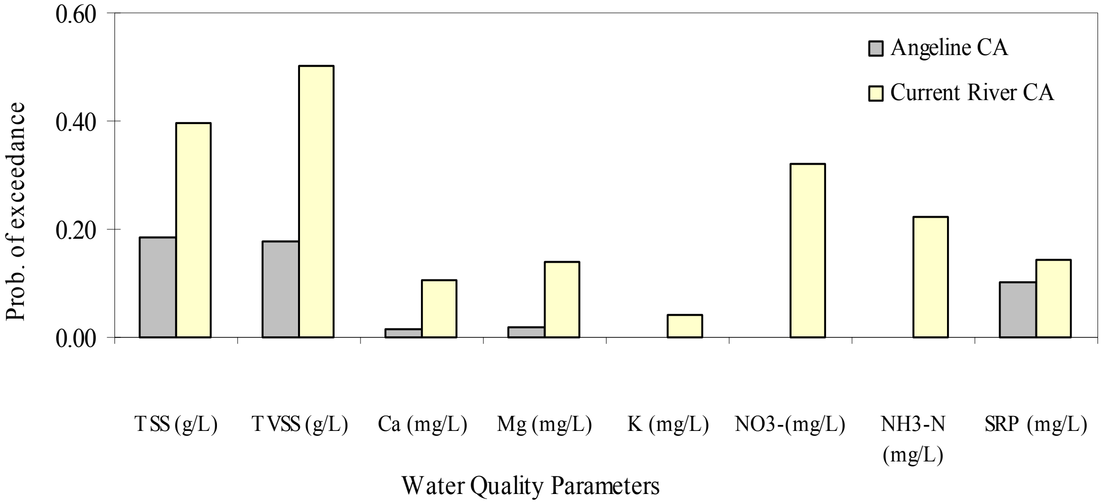


Figure 5.8- Probability of Exceedance comparison for Angeline CA sites that had SMZs during harvest operation and Current River CA sites that did not have SMZs while harvesting. SMZs are a part of BMP that MDC has adopted in the State of Missouri while clear felling timber lots

The comparison between sites with SMZs and without SMZs while harvesting showed a clear advantage of using SMZs. BMPs including SMZs applied in Angeline sites may have lowered chances of polluting water quality downstream more than the Current River CA sites that did not have SMZs applied during the timber harvesting. The probability of exceedance for Current CA sites was 0.4 for TSS, 0.5for TVSS, 0.11 for Ca, and 0.14 for Mg, 0.32 for NO3- and 0.22 for NH3-N (Table 5.5, Figure 5.8) which are higher than the corresponding values obtained for Angeline sites. The water quality analysis concluded therefore, that water samples from harvest sites with no SMZs could have a larger negative impact at least for some parameters. Total nitrogen, total phosphorous, pH and electrical conductivity remain unchanged throughout the study periods.

5.4.1.4 PoE Comparison for Pre-and Post-Harvest Samples: All Subgroups

Comparing all subgroups, PoE's for TSS, TVSS, Ca, Mg were obtained positive up to 0.18 for Angeline CA to 0.40 for Current River CA. Similarly, TVSS exceedance was 0.18 for Angeline sites increased to 0.50 for Current River CA. Overall, total nitrogen, total phosphorous and electrical conductivity showed no probability of exceedance for all sub-groups. All other parameters showed a positive exceedance in one or more sub-groups indicating that there might be a higher concentration after harvest operation (Table 5.5, Figure 5.9).

Table 5.5- Result of PoE for all water quality parameters in all sub-groups taken into consideration

Parameters / Sub-groups	TSS (g/L)	TVSS (g/L)	Ca (mg/L)	Mg (mg/L)	K (mg/L)	$NO3^-$ (mg/L)	NH_3-N (mg/L)	SRP (mg/L)	TN (mg/L)	TP (mg/L)	pH	E Cond (µs/cm)
All Sites	0.24	0.29	0	0.01	0	0.22	0.00	0.08	0	0	0.00	0
Harvested sites	0.25	0.28	0.16	0.13	0.01	0.37	0.00	0.11	0	0	0.00	0
Angeline CA	0.18	0.18	0.02	0.02	0	0	0	0.10	0.00	0	0.00	0
Current river CA	0.40	0.50	0.11	0.14	0.04	0.32	0.22	0.14	0	0	0.00	0

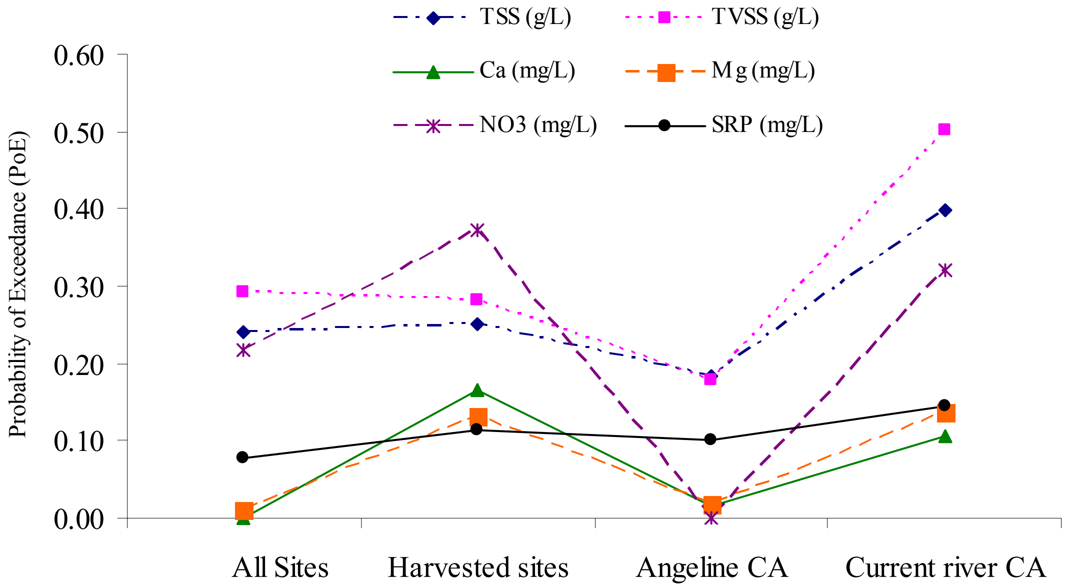


Figure 5.9- Probability of exceedance (PoE) for some water quality parameters obtained for Angeline and Current River Conservation sites

The PoE's for post-harvest water quality samples increased for six parameters except for total phosphorous, total nitrogen, pH and electrical conductivity. The largest PoEs for TSS and TVSS were found to be at 0.25 to 0.50 respectively. For Ca, Mg, and K, the PoE's were found to be up to 0.14 in Current River CA (Figure 5.9). Nitrate and ammonia nitrate showed higher PoEs for the Current River CA in compare to Angeline CA. Review of literature (Jacobson, 2004; Swank et al., 2001) indicated that TSS and TVSS increased after the timber harvest operation as well as impact of precipitation and run off were evident to the downstream catchment.

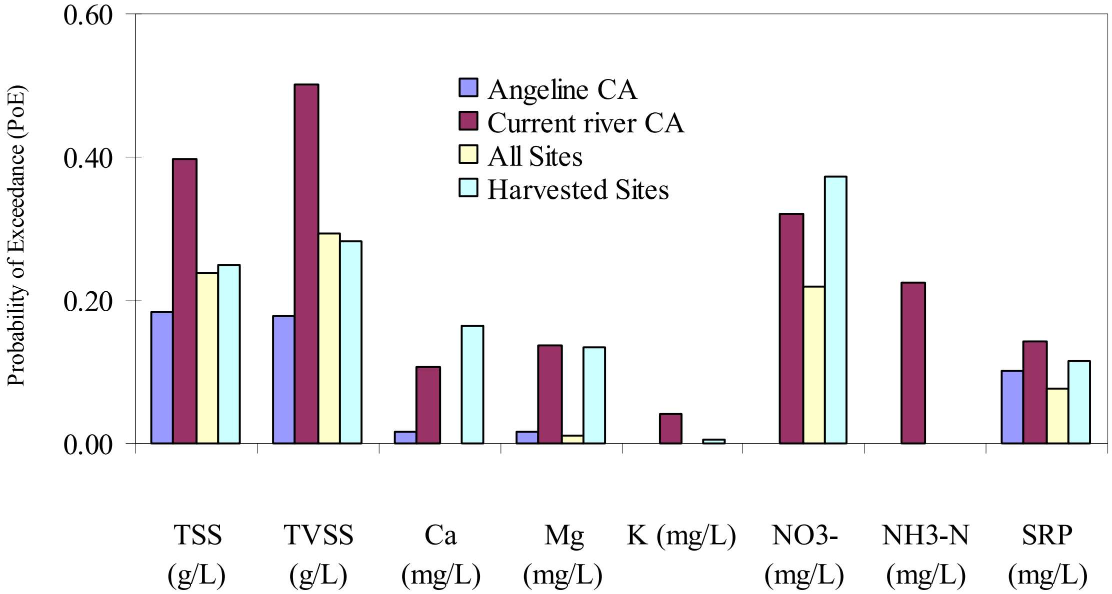


Figure 5.10- Probability of exceedance for all sub-groups shown together for all parameters

Overall, the comparison of all sites demonstrates that major parameters of water quality did exhibit positive PoE when comparing pre-and post-harvest samples (Figure 5.10) although, the change in concentrations for water quality parameters could be short-lived. The post- harvest samples were collected for only about two years after harvest. The results could change if more years of post-harvest samples from same sites would have included. The result is in line with previous timber harvest studies which revealed that the short term effects of timber harvest is prominent regardless of treatment applied but the impact lessens with time after re-vegetation takes place in the cut sites (Sheppard, 1994; Messina et. al., 1997; Herz, 1996; Stednick, 2000).

The observed and expected behavior of all water quality parameters were compared and evaluated for similarities and recommended were made to MDC. The observations are listed in Table 5.6 in detail which accounts for other factors including precipitation, leaf on/leaf off including timber harvest effects.

Table 5.6- Expected and observed performance of water quality parameters in low order ephemeral streams in Missouri Ozarks as function of cumulative effects including timber harvest

S.N	Water quality Parameters	Expected behavior of parameters concentration	Observed performance	Remarks	Past researches/observation
1	TSS (g/L) TVSS (g/L)	↑UP	↑UP	Post harvest exceeded 18-30% for three subgroups, went even higher (40-50%) for Current river sites that were harvested without SMZs	TSS, TVSS should increase right after harvest but loss balances out within a year and half.
2	Ca (mg/L) Mg (mg/L	↑UP	↑UP	Post harvest exceeded from non to 14-17% for all subgroups, found positive exceedance for Current river sites that were harvested without SMZs	Ca should increase after harvest b/c limestone and dolomite rock get exposed in Ozark
3	K (mg/L)	↑UP	↔No Change	Post harvest do not have much change from pre- and post harvest exceedance, was slightly positive for Current river sites that were harvested without SMZs	K should increase after harvest b/c limestone and dolomite rock get exposed in Ozark
4	NO_3-(mg/L)	↑UP	↑UP	Post harvest exceeded for three subgroups (+/- 30%), went negative for Current river conservation area with no SMZs	fixation or decomposition of leaf litter and branches after harvest - remain higher for a while before going down
5	NH_3-N (mg/L)	↑UP	↔No Change	No change with BMPs but for Current river conservation sites that did not have SMZs while harvesting; found some positive increase in exceedance	fixation or decomposition of leaf litters and branches after harvest - remain higher for a while before going down
6	SRP (mg/L)	↑UP	↑UP	Post harvest exceeded 8-14% of time for all subgroups, went highest for Current river sites that were harvested without SMZs	Soil with calcium phosphate has more soluble P, A-horizon exposed to weathering after harvest to some extent, comes from decomposed organic materials, not a big determinant of P while this is geochemical process formations
7	TN (mg/L) TP (mg/L)	↑UP	↔No change	Harvest operation does have no effect	TN comes from fixation or decomposition of leaf litters and branches- should remain higher for a while before going down TP should increase after harvest that exposes the rock to go geochemical change; not much effect by harvest though
8	pH E. Cond. (µs/cm)	↑UP	↔No Change	No change in pH and EC for both pre-and post-harvest water samples	pH should remain almost unchanged due to harvest operation EC increases with water gets more nutrients and sediments after harvest from decomposition of leaves and branches

5.5 Conclusions

5.5.1 Summary

Water quality samples were collected for both after and before harvest from Missouri Department of Conservation owned lands in the Missouri Ozarks. Fifteen sites were selected and samples were collected from both cut and control sites did or did not include streamside management zones as part of best management practice. Establishing a unique value for background concentration for water quality parameters in an ephemeral stream with a noisy sample population seemed unrealistic due to the wide variation in observed concentration values for a single parameter, during periods of no harvest. Instead, a large data set (n≈900) did allow evaluation of appropriate concentration distribution models, i.e., lognormal distribution (expect pH). The distributions enabled calculation of a probability of exceedance for post-harvest concentrations. Probability density functions are used as simplified models to help put the data into perspective. The cumulative areas under lognormal distribution for pre- and post- harvest samples were obtained and used to calculate the probability of exceedance (PoE).

5.5.2 Conclusions

The PoE of each parameter was calculated for all sites, harvested sites as well as Current River and Angeline CA separately, to appreciate differences in the applied SMZs. The Current River CA sites do not include SMZs in their applied BMPs. The PoE analyzed for most of the parameters did have positive exceedance for all subgroups due to all other effects including timber harvesting; only a few parameters (TN, TP and

Electrical Conductive) showed no probability of exceedance. pH from pre-and post-harvest samples remained unchanged for all subgroups.

- Sediment parameters, TSS and TVSS showed an increase in concentration after harvesting since December 2006- April 2008. The probabilities of exceedance of post-harvest samples were higher when SMZs were applied. Overall, sediments parameter showed positive exceedance and the exceedance may have come from very natural effects (precipitation intensity and frequency, season, leaf off /on, vegetation) including timber harvest.

- Nutrients parameters, Ca, Mg, and dissolved phosphorous demonstrated positive exceedance. The PoE's were higher when SMZs were not applied during the timber harvest operation

- Other nutrients parameters K, No_3^-, NH_3-N showed no exceedance indicating that the post-harvest sample posed no threat to water quality or no influence on the water quality after timber harvest operation. The PoE's tend to increase when no SMZs were applied.

- Similarly, total nitrogen and total phosphorous parameters showed no increase in post-harvest concentration indicating that there was no effect of timber harvest on the natural system.

- Surrogate parameters like pH and electrical conductivity demonstrated little change in concentration after harvest. They remain similar before and after timber harvest.

- Temporary effects are seen from timber harvest; but the effects might be from other factors e.g, precipitation or leaf on/leaf off. More data should be collected after harvest for a longer period. Control sites should be examined to obtain PoE's and isolate PoE's due to timber harvest effects should be obtained.

- Best management practices which include SMZs seem to be effective.

5.5.3 Recommendations

- Effects are seen for the parameters like total suspended solids, volatile solids and other nutrients parameters (Ca, Mg, SRP) for a short period of time after harvest; some management options (keeping SMZs when harvesting) should be followed.

- Other analysis methods e.g., discrete analyses (histograms, box plots) variation in concentration over time, change in concentration as the function of sampler location in the watershed should be considered for future analyses.

5.6 Acknowledgements

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CHAPTER 6

Analysis of Pre-and Post Timber Harvest Water Quality in the Ephemeral Streams in the Missouri Ozarks

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Abstract: While it is generally believed that forest harvesting adversely impacts stream water quality and that the severity of the impact is proportional to harvest intensity and methods that is highly variable within and among forest systems; although the impact may be of short duration. Much of this variability is attributable to differences in site conditions, including soils, topography and harvesting methods such as clear cutting, selection cutting or using other silvicultural methods with or without the Best Management (BMPs) Practices that are meant to keep nutrients and sediments from washing away. The purpose of this paper is to determine if there is significant and measurable downstream water quality effects by forest management practices (clear cutting) in upland headwater watersheds within the Missouri Ozarks. State specified BMPs were followed during clear cutting in some sites but ignored in other sites during the research period.

The probabilities of exceedance of twelve water quality parameters for pre- and post-harvest samples were obtained and compared between subgroups: all sites, harvested sites only, and conservation area specific sites that did or did not have streamside management zones implemented during clear cutting. The probability of exceedance varied with parameter from no effect (negative) to some minimal effect (positive) depending upon sites and practice adopted while harvesting. The probabilities of exceedance were calculated for both harvested and unharvested sites and harvesting effects on exceedance were obtained by subtracting effects unrelated to harvesting. The effects resulting from timber harvest operation were found to be minimal. For Total Suspended Solids, a probability of exceedance (PoE) of 4% was found, while for Total Volatile suspended solids a PoE of 13% was found. Similarly, calcium, nitrate and soluble reactive phosphorous and potassium are found to have positive, but low exceedance values. The results indicate that BMPs specially with vegetative streamside management zones (SMZ's) in place are effective in the Missouri Ozarks while harvesting timber.

Key Words: Timber harvesting; Water quality; BMPs & SMZs; Probability of exceedance; Lognormal distribution; Discrete analysis; Missouri Ozarks

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6.1 Introduction

The Missouri Ozarks, like many other underdeveloped and sparsely-populated regions, has experienced significant changes in land use thanks to its abundant second growth oak-hickory and pine forests. With several blocks of public and private land opened for clearcutting (Settergren, 1972), Missouri faces conflicts between forest management and stream quality in these areas, since there are public concerns that timber harvesting is abusive and detrimental to water quality (Stuart, 2006). However, Best Management Practices (BMPs) have been developed to control erosion and stream water quality during harvest (Aust and Blinn, 2004; NFA, 2004); operational experience suggests that BMPs prevent long-term negative impacts, but few quantitative studies have been conducted to verify this.

Forested watersheds are not only important as an economic resource, but also for providing habitat, controlling water discharge rate, and protecting the watershed from the effects of erosion, sedimentation, leaching of nutrients, and overland flow (Pope 1977). Harvesting, however, removes much of the years of accumulated vegetative stand (Stone, 1975), which increases the movement of soil and nutrients in the watershed (Doisy, 2002). Since the specific effects of harvesting on water quality tend to be regional (Settergren, 1978), and the Ozarks have no large-scale record of the impacts of timber harvesting, the Missouri Department of Conservation (MDC) lacked a database to determine the effectiveness of its BMPs (Mueller, 2006).

To evaluate the current BMPs and help MDC refine its timber harvest management guidelines, comparisons of pre-and post-harvest water quality database were preformed. If harvesting in accordance with BMPs does not impact water quality, the study will reaffirm the use of the current BMPs; if a significant impact is discovered, MDC will have an opportunity to revise its BMPs to better protect water quality in ephemeral streams.

6.2 Water Sampling and Database

Fifteen sites of MDC's oak dominated hardwood forest located over a 500 square mile area in the southeastern Missouri Ozarks were selected for monitoring and water sample collection from December 2004 through July 2009. Eight sites were harvested in December 2006; the other seven are designated control sites (remained unharvested or untreated). The sites ranged from 6-60 acres in aerial extent, and on the harvested sites, up to 40 (A34-1) acres are cut. The average slope was 20-30%, the average precipitation was 115 cm, and the average total runoff was 22%.

Automated samplers ECH_20® and ISCO® collected weather data (soil moisture, air temperature, precipitation) and hydrological data (water depth, flow velocity, flow quantity), respectively. Hill-slope samplers, in-stream samplers, and automated samplers were used to collect 1150 samples over the course of the study period from all fifteen sites including 250 samples from sites that were harvested (Post-harvest samples). All samples were analyzed in accordance with the American Public Health Standard, 1994 and subsequent revision of standards.

The parameters selected for analysis in the lab were chosen for their range of effectiveness, production rate, and ease of use. Samples were first analyzed for pH and electrical conductivity, surrogate parameters that indicate general stream characteristics. The samples were then filtered with 0.45 µm glass microfiber filters and dried in ovens at 105 and at 500 °C to determine suspended and volatile solids, respectively. Nutrient concentrations were measured once the samples were processed using specified combinations of powder pillows, standards, and digestion. These parameters were: Calcium (Ca), Magnesium (Mg), Potassium (K), Nitrate (NO_3), Ammonia Nitrate (NH_3-N), Soluble Reactive Phosphorous (SRP), Total Phosphorous (TP), and Total Nitrogen (TN). Once the analyses accomplished, the data was compiled using an Excel ® spreadsheet.

6.3 Methods and Methodology

6.3.1 Statistical Analyses

6.3.1.1 Best Fit of Water Quality Concentration Populations

To verify that the distributions of the water quality parameters resemble lognormal distributions, the sets of sampled concentrations were plotted against theoretical distributions. All sample concentrations were ordered from least to greatest. The concentrations below the detectable limit of measuring devices, which have been given a value of 0, were reassigned the value of 0.0001—also below the detectable limit—because the natural log cannot be taken of a value of 0. Then, each sample concentration were assigned a rank, which was the consecutive integer that numbers its order. From this rank, the sample was given an associated probability of rank (Equation 1). Using the probability, the sample was matched with its standard normal variable (z). The concentration of pre-and post-harvest samples were plotted against its standard normal variable (z).

To produce the theoretical normal (Equation 2) and lognormal (Equation 5) models of the distribution, the descriptive statistics, particularly mean and standard deviation, were found for the sample population. The mean and standard deviation of the actual datasets were used to produce a theoretical normally-distributed set of concentrations. This dataset was then plotted against their equivalent normal standard variables. Then, the actual mean and standard deviation were used to find the equivalent theoretical lognormal parameters, lambda (λ) (Equation 3) and Xi (ξ) (Equation 4). These lognormal variables provide the basis for the theoretical lognormal set of concentrations (Equation 5) and that set is also plotted against equivalent standard normal variables (z). Some of the equations used are as follows:

Probability of rank = $i / (n + 1)$…………………………………………..(1)

Where,

i = rank

n = total number of samples

Theoretical normal concentration = $\mu + (\sigma * z)$ ....(2)

Lognormal mean $\lambda = \ln(\mu) - 0.5 * \xi^2$ ……………………………………........(3)

Lognormal standard deviation $\xi = (\ln(\sigma / \mu)^2 + 1)^{1/2}$ ………………………..(4)

Theoretical lognormal concentration = $\exp(\lambda + (\xi * z))$……………………..(5)

Where,

μ = mean concentration of samples

σ = standard deviation of samples

λ = lognormal mean

ξ = lognormal standard deviation

z = standard normal variable

6.3.1.2 Discrete Analysis of Histograms

Histograms display the concentrations of parameters grouped into discrete intervals to provide a graphic of the distributions. The pre- and post-harvest distributions can be compared with side-by-side histograms. To produce a histogram of a set of concentrations, concentration intervals of equal range were chosen to group the concentrations so that the data are clearly shown. Since the water quality data follow a lognormal trend, with a long "tail" at the higher concentration, the highest concentrations were grouped, yielding a spike in frequency found at the right end (high concentration) of many parameter histograms.

A histogram of a single set of concentrations typically includes frequency as the number of samples; however, when comparing data sets with different sample sizes, the frequency must be adjusted to relative frequency, which is the number of samples within an interval divided by the total number of samples in the data set. Then, pre- and post-harvest distributions can be plotted side-by-side and compared.

Once the distributions have been qualitatively compared, the histograms may be used to quantitatively approximate the probability of exceedance. The pre-harvest relative frequency subtracted from the post-harvest relative frequency for the same concentration interval, for each interval over the concentration range of interest. The sum of these differences provides the total probability of exceedance for over the analyzed concentration range.

The concentration ranges were chosen using three different methods, and the probability of exceedance was found for each. A critical concentration range that was set by MDC or EPA for surface or drinking water standards limits and guidelines were considered for analysis. The lower and upper limits provided by MDC determine range, and a second range was derived from the upper limit to the ends of the distributions.

A second method of determining concentration range of interest used intersections of the pre-and post-harvest distributions. The first intersection occurred where the pre-harvest concentration relative frequency ceases to exceed the post-harvest concentration relative frequency, and the second intersections occurred when the relative frequencies switched again. The interval of interest were obtained from between these two intersections.

The final method used the distribution among percentiles to determine the interval of interest. The concentrations at the 50th, 75th, and 95th percentiles were found using the data set of concentrations. The selected percentiles determined limit for the interval.

The discrete methods did not exclude though other effects including precipitation, leaf on/off etc but included all the effect including timber harvest.

6.3.1.3 Box Plots of the Population

A box plot (box-and-whisker diagram) is a convenient way of graphically depicting groups of numerical data through their five-number summaries (the smallest observation, lower quartile (Q1), median (Q2), upper quartile (Q3), and largest observation. A box plot may also indicate which observations, if any, might be considered outliers. The spacing between the different parts of the box help indicate the degree of dispersion (spread) and Skewness in the data, and identify outliers. Box plots provide a quick visual overview of some key values in the distribution

To make the box plots, the 25th, 50th, 75th percentile concentrations were found. The 25th and 75th percentile concentrations form the lower and upper sides of the box that represents the interquartile range (Equation 6), which gives an illustration of the middle fifty percent of all the sample concentrations, while the median gives a visual center of the data. The lower and upper fences (Equation 7 and 8) indicate what sample concentrations are reasonably close to the center of the data, while the concentrations outside the fences are considered outliers. The number of outliers is determined, and the percentage of samples that are considered outliers is calculated so that the differently-sized unharvested and harvested population can be compared. The fences provides a sense of the spread in the concentrations.

Interquartile range (IQR) = Q3 – Q1……………………………………(6)

Upper fence = Q3 + 1.5 * IQR………………………………………….(7)

Lower fence = Q1 – 1.5 * IQR………………………………………….(8)

Where,

Q1 = first quartile, 25th percentile

Q3 = third quartile, 75th percentile

The unharvested and harvested box plots may be compared side-by-side to qualitatively observe differences in median and spread in the concentration data.

6.3.1.4 Probability of Exceedance (PoE) using Lognormal Distribution

Significance of post-harvest data related to pre-harvest (background) data is a function of how the background concentrations are established; though it is not the only criteria that can be considered. When US Environmental Protection Agency's total daily maximum load (TMDL) limitations were established for water bodies, many parameters that were taken into consideration, including sediments and nutrients that could degrade water quality in the stream. While timber harvesting could affect the water quality of the stream, these effects may or may not have a significant impact on the stream's overall water quality. It is possible then to use the post harvest data that was gathered to determine what effects might exist by comparing pre- and post harvest water quality.

A probability of exceedance (PoE) method based on area exceedance illustrating the comparison between the pre-and post-harvest probability density function (PDF) is shown in Figure 6.1. Curve "A" represents the statistical distribution of pre- harvest concentrations. Curve "B" represents the distribution of post- harvest concentrations.

The shaded area represents the probability of exceedance (PoE) of post- harvest to pre-harvest concentrations. The probability of exceedance is defined as the “ probability that the post-harvest concentration will be greater than the pre-harvest concentration”. The probability of exceedance can range between zero and one ($0 \leq \text{PoE} \leq 1.0$).

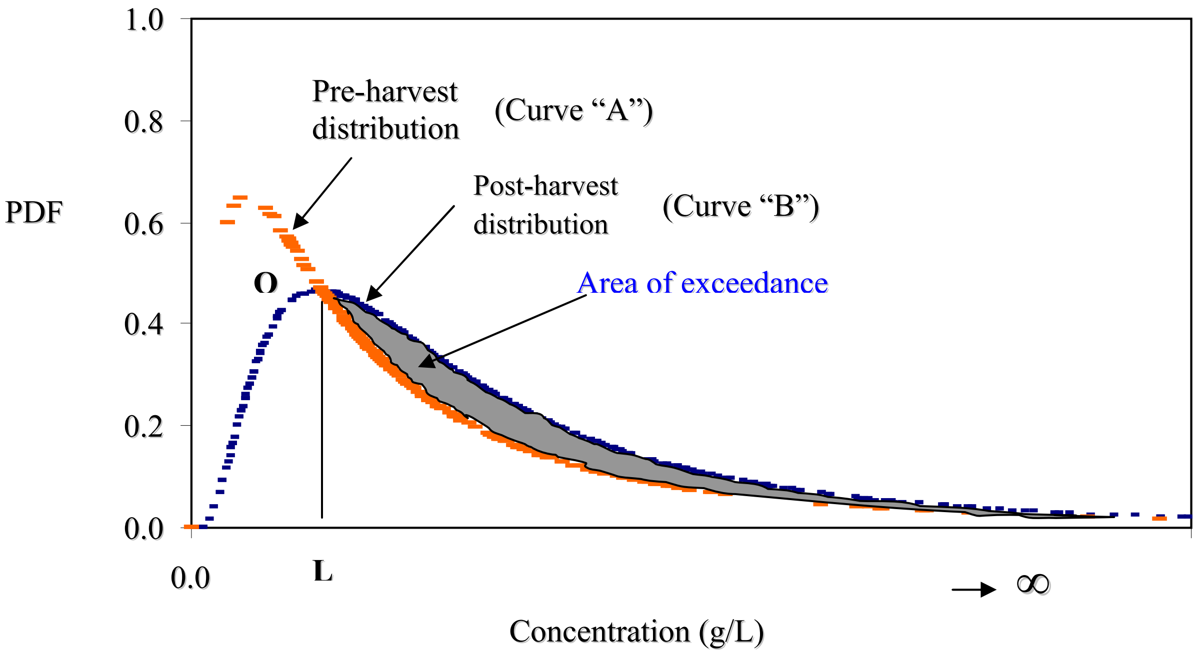

Figure 6.1- Method used to calculate probability of exceedance (PoE) when comparing pre-and post-harvest concentration distributions.

The probability of exceedance of pre-harvest and post-harvest exceedance may be calculated by solving for the shaded area beyond intercept O in Figure 6.1 as shown below in equation (9).

$$\text{Probability of Exceedance (PoE)} = \int_L^{\infty} f(C)_{post}\, dc - \int_L^{\infty} f(C)_{pre}\, dc \ldots\ldots\ldots\ldots\ldots(9)$$

$$\text{PoE} = (\text{Post-harvest cum area}) - (\text{Pre-harvest cum area})*100$$

$$= \text{Probability of exceedance } (0 \leq \text{PoE} \leq 1.0)$$

Where,

L = Intersection of Pre- post harvest distribution

$f(C)_{post}$ = Post harvest log normal distribution of concentration

$f(C)_{pre}$ = Pre harvest log normal distribution of concentration

The PoE is defined as the difference between the area beneath the post-harvest curve (from L to infinity (∞)) to pre-harvest curve (from L to infinity (∞)) (Equation 9).

6.3.1.5 Variation of Concentration with Time

The concentrations of all sites were grouped to obtain changes in concentration over the course of the study for both pre-and post-harvest water quality sample. The maximum, minimum, and mean concentration values for each collection date were plotted. The mean concentrations provide a general view of the changing concentrations over time, while the minimum and maximum concentrations reveal the changing spread in concentrations at each sampling date. A linear regression was fit to the mean concentrations to evaluate change in concentration over time. The slope indicates the rate of change in concentration over time, while the R^2 value indicates how well the linear trend fits the data sets.

6.3.1.6 Variation of Concentration with Location of In-stream Samplers

Concentrations were also grouped by location of in-stream the samplers. The samplers are considered at a equidistance from each other in the watershed. The maximum, minimum, and mean concentrations were plotted at each physical location in the stream bed. A linear regression was fit to the mean concentrations to obtain slope and linear fit of the data set to evaluate change in concentration with the watershed form head to toe for both pre-and post harvest concentrations for each sites.

6.4 Results and Discussions

6.4.1 Best Fit of Water Quality Concentration Population

The distributions of total suspended solids (TSS) concentrations for unharvested and harvested sites follow a lognormal trend; in fact, all parameters except pH follow the same distribution. When each water quality parameter concentrations are plotted against its standard normal variable (z), the scatter-plot of the points logarithmic. A summary of the normal and lognormal means and standard deviations obtained from the TSS concentration population and used for the theoretical models are given in Table 6.1.

Table 6.1- Total Suspended Solids(g/L) properties used to determine the appropriate distribution

TSS	Unharvested	Harvested
normal mean, μ	0.12	0.18
normal std deviation, σ	0.35	0.32
lognormal mean, λ	-3.34	-3.16
lognormal std deviation, ξ	1.72	2.20

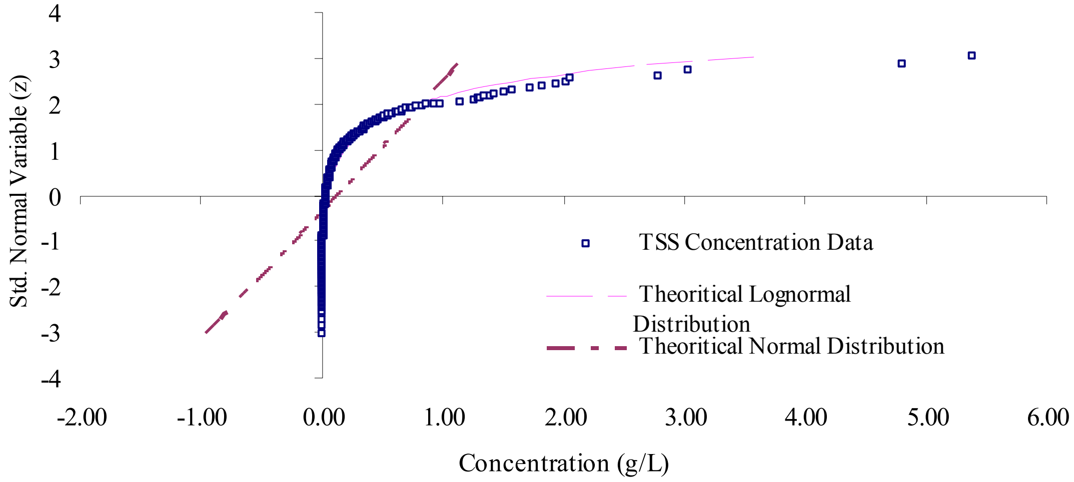

Figure 6.2- Pre-harvest TSS distribution model of best fit of the concentration population

When distributions were compared to the data set of concentrations, the sample population closely follows the lognormal model, particularly when the standard normal variable is less than 2 (Figure 6.2). The highest TSS concentrations do not follow the lognormal distribution as closely as the rest of the samples. All fell below the predicted values for the standard normal variable of the model. Thus, these concentrations were more frequent than the lognormal model predicts they should be.

The harvested sample concentrations also follow the lognormal distribution fairly well, though not as closely as the unharvested samples (Figures 6.2 and 6.3). The differences between the distributions and the population for higher concentration are exaggerated in the harvested sites. The lower concentrations are less than the distribution suggests, while the higher concentrations are greater than the model predicts. This is evident in Figure 6.3, where the sample concentrations intersect theoretical distribution only around standard normal variable of 1.

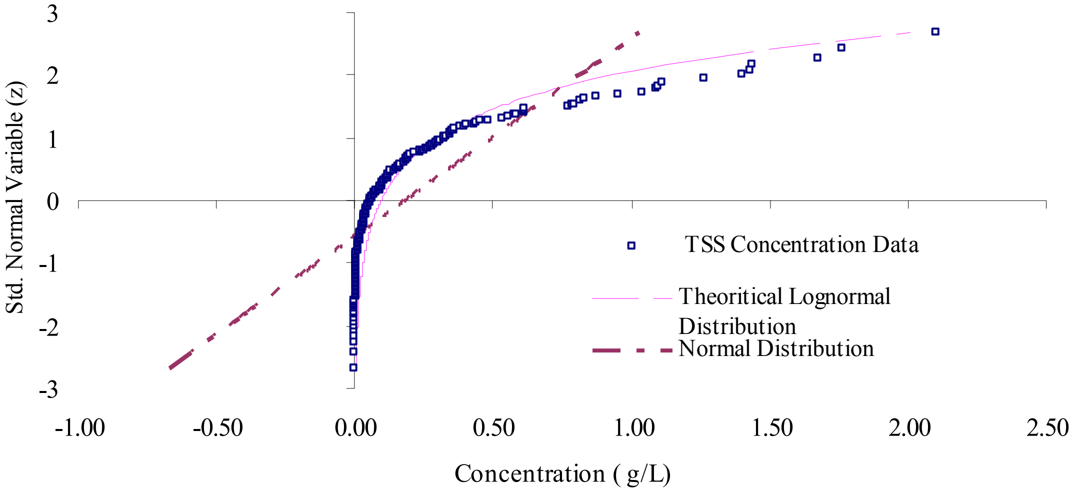

Figure 6.3- Post-harvest TSS distribution model and best fit of the concentration population

All parameters (except for pH) are similar to TSS, exhibiting a nearly lognormal distribution. Like TSS, most parameters exhibit a similar trend of deviation from the distribution, where the samples follow the distribution more closely at smaller concentrations, and the higher concentrations are more frequent than the distribution predicts. All of the parameters also exhibit greater irregularity among samples from the harvested sites than the unharvested sites. The harvested site samples stray from the lognormal models in the shapes of their curves and lack of smoothness. Electrical conductivity, ammonia nitrate, and potassium show notably strong differences from the distribution in their graph of harvested site samples, particularly because such variation from the distribution is not evident in graphs of unharvested site samples.

The fit of the lognormal distribution to sample concentrations for each parameter was quantified using one-factor ANOVA statistical analysis (Table 6.2). The difference between the theoretical lognormally-distributed concentrations and the actual concentrations was found to be statistically insignificant for all of the water quality parameters except for pH, as indicated by the large p-values found in Table 6.2. The smallest p-value (except for pH) is unharvested calcium of 0.69. The very low p-values for pH for pre-and post-harvest samples respectively, 0.13 and 0.03, indicate that the lognormal model is not a good fit pH.

Table 6.2 Anova statistical comparison between sample concentrations and lognormal model

Parameter	Treatment	Count	sample variance	model variance	F	P-value	F critical	Remarks
TSS	UH[1]	900	0.13	0.07	0.08	0.77	3.85	Insig.[3]
	H[2]	262	0.10	0.06	0.08	0.78	3.86	Insig.
TVSS	UH	749	0.03	0.01	0.10	0.75	3.85	Insig.
	H	263	0.08	0.03	0.10	0.75	3.86	Insig.
Ca	UH	813	49.47	78.44	0.15	0.69	3.85	Insig.
	H	236	21.45	16.10	0.07	0.79	3.86	Insig.
Mg	UH	813	14.63	9.55	0.05	0.82	3.85	Insig.
	H	236	6.54	4.23	0.08	0.78	3.86	Insig.
K	UH	813	7.32	8.00	0.04	0.83	3.85	Insig.
	H	236	6.63	4.59	0.07	0.78	3.86	Insig.
TP	UH	774	1.26	0.67	0.08	0.78	3.85	Insig.
	H	243	0.72	0.37	0.09	0.77	3.86	Insig.
SRP	UH	817	0.29	0.15	0.09	0.77	3.85	Insig.
	H	246	0.73	0.26	0.14	0.71	3.86	Insig.
NH3-N	UH	807	1.82	0.84	0.12	0.73	3.85	Insig.
	H	243	2.34	0.67	0.18	0.68	3.86	Insig.
NO3	UH	821	2.72	1.35	0.10	0.75	3.85	Insig.
	H	237	20.82	6.99	0.15	0.70	3.86	Insig.
TN	UH	774	6.08	4.87	0.05	0.83	3.85	Insig.
	H	188	7.16	3.96	0.09	0.77	3.87	Insig.
pH	UH	839	722.27	0.50	2.27	0.13	2.71	Sig.[4]
	H	262	313.70	0.39	4.67	0.03	3.86	Sig.
EC	UH	839	4120.77	4016.87	0.04	0.84	3.85	Insig.
	H	262	2543.10	2262.56	0.07	0.79	3.86	Insig.

[1] Unharvested [2] Harvested [3] Insignificant [4] Significant

The pH samples appear normally distributed (Figure 6.4) and clearly align closely with the linear distribution. There is a slight curve in the pH values, which shows that the extremes in pH—the high and low pH values—are more frequent that the model predicts, while the pH values closer to the mean are slightly less frequent than predicted.

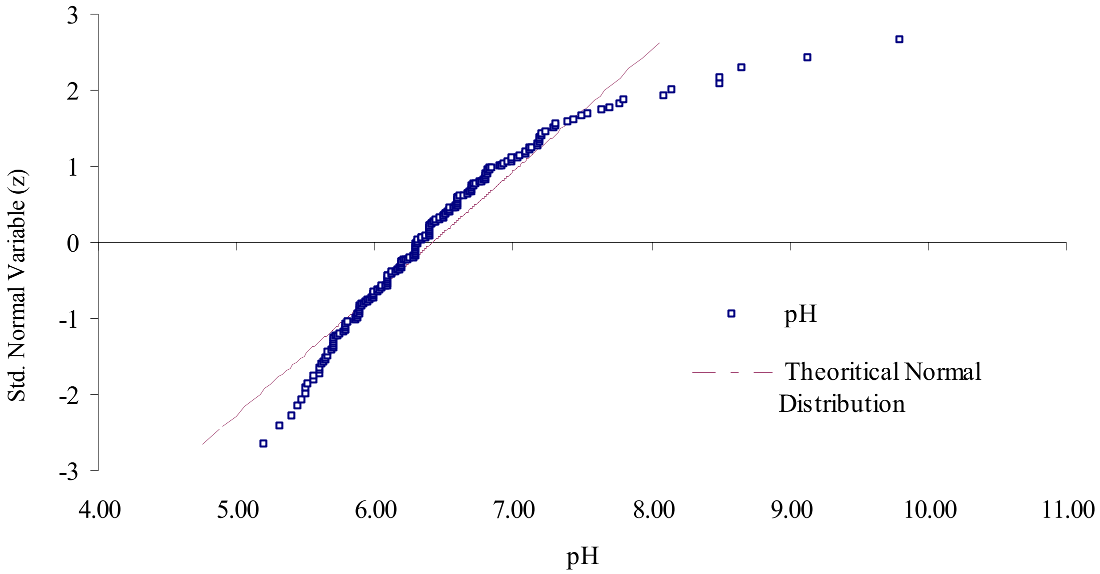

Figure 6.4- Harvested pH normal distribution model and best fit of the concentration population

In Figure 6.5, a total suspended solids post-harvest histogram is plotted against a lognormal distribution function. The probability density function (PDF) was found using lambda (λ) and Xi (ξ), the properties that were determined from the lognormal distribution of the concentration population. Though λ and ξ were determined from the data, the probability distribution function did not model the histogram very well for the harvested population. The peak in the model almost coincides with the histogram peak, but the model does not show as rapid a decline in frequency after the peak as exists in the actual population.

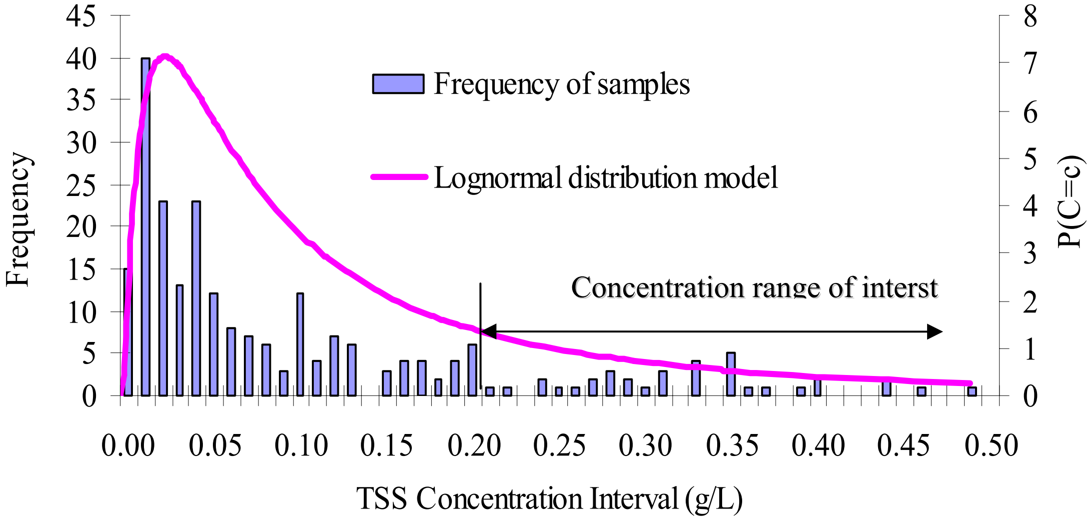

Figure 6.5- Post-Harvest lognormal distribution and histogram from the TSS concentration population

In an attempt to better fit the probability distribution function to the concentration range of interest, the values of λ and ξ were modified. Figure 6.6 shows the modified model for the harvested sites. The lefthand peak of the histogram does not fit well, but these smaller concentrations lie below the limits of interest (TSS 0.2-0.5 g/L) and are less important to compare. The larger concentrations are of greater interest because these provide a more telling indication of water quality. Therefore, λ and ξ were chosen so that the probability distribution function would better fit the interval of interest. This new probability density function peaks too far to the left, but it more closely aligns with the data at concentrations greater than 0.05 g/L than the model in Figure 6.5 does. The irregularity in the harvested data made producing a better fit more difficult since there are several peaks at higher concentrations, such as at the 0.10-0.11, 0.20-0.21, and 0.35-0.36 g/L concentration intervals, that make the distribution less smooth and apt to fit to a model.

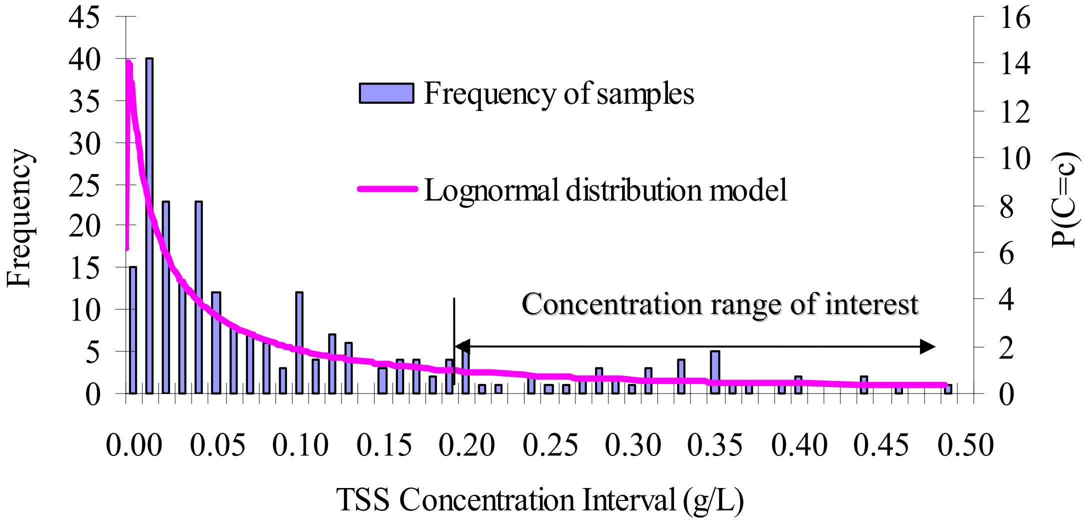

Figure 6.6- Best fit of the TSS lognormal distribution model using revised Lambda (λ) and Xi (ξ)

The modified probability distribution function was also found for the unharvested concentrations. A comparison of the two best-fit (theoretical) lognormal distributions is shown in Figure 6.7. The unharvested model exceeds the harvested model until the intersection point around 0.18 g/L. After this intersection point lies the interval of interest for determining PoE.

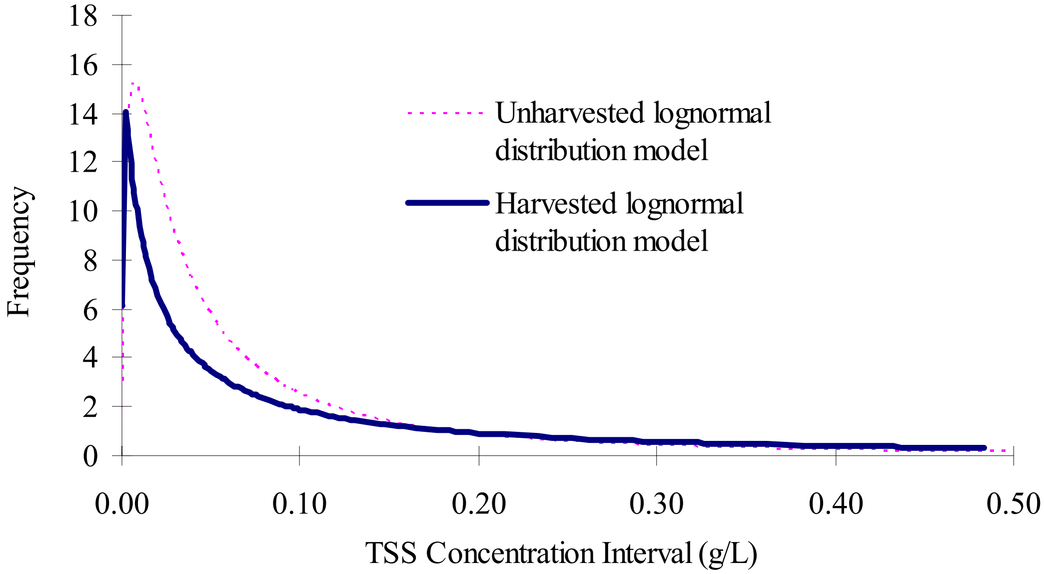

Figure 6.7- Comparison of unharvested and harvested TSS modified lognormal distribution models

6.4.2 Discrete Analysis of Histograms

The histograms of unharvested and harvested TSS concentrations also reveal a lognormal trend, with a single mode on the left end of a very skewed-right distribution (Figure 6.8). Table 6.3 contains the frequencies used to graph the histograms in Figure 6.8, and Table 6.3 contains the cumulative percentages used to graph the curves. When the unharvested and harvested relative frequencies of concentration values are compared (Figure 6.8), the unharvested values are clustered with greater frequency on the low end of the histogram, making the mode higher for the unharvested than the harvested population. The harvested samples, on the other hand, have slightly higher frequencies than the unharvested samples on the high end of the distribution. Thus, the contrast between the frequencies of low and high concentrations is sharper for the unharvested distribution than the harvested distribution. There is also more regularity in the unharvested distribution, while the harvested distribution has some small peaks toward the right end of the histogram that make the distribution less smooth.

It may be that since there are many more samples from the unharvested sites (900 samples) than the harvested sites (262 samples), the harvested distribution could have experienced a greater effect on its relative frequencies from those few unusually high concentrations than the unharvested population, which more easily absorbs those values into its spread.

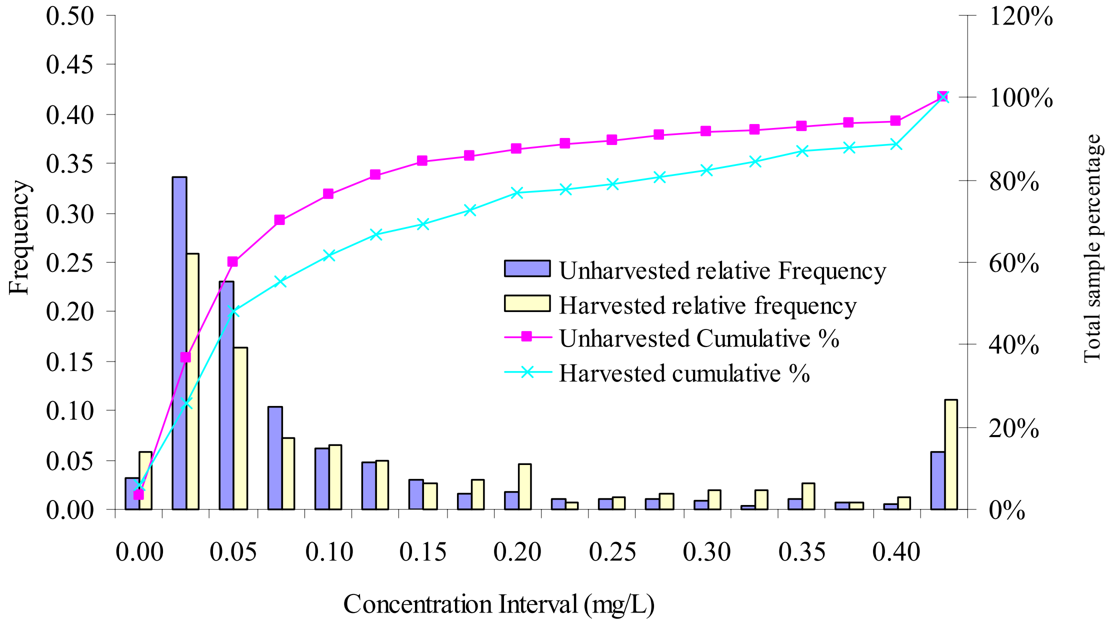

Figure 6.8- Comparison of harvested and unharvested histograms for TSS concentrations

All of the other parameters (excluding pH) are also lognormally distributed and their histograms and cumulative percentage curves strongly resemble the basic shape of the TSS shown in Figure 6.8. Like TSS, the TVSS concentrations from unharvested sites were found with greater frequency on the low end of the histogram, producing a higher unharvested peak, and the harvested samples had less regularity in frequency. The minerals (Ca. Mg and K), however, tended to have greater harvested frequencies in the lower concentrations, though the harvested samples also tended to show greater irregularity. The phosphorus parameters exhibited very high frequencies of low concentrations that were not well balanced by the spread in their concentrations, producing very lopsided histograms. These have higher frequencies of low concentrations and more irregularity in the harvested samples, as well. The group of nitrogen parameters did not give an obvious cohesive trend, but the harvested site irregularity seen in the ammonia nitrate concentration against standard normal variable was again evident. Electrical conductivity also showed some significant irregularity.

Table 6.3- Frequency distributions of harvested and unharvested TSS concentration population

Concentration Interval (g/L)	Unharvested Frequency	Unharvested Cumulative %	Harvested Frequency	Harvested Cumulative %
0	29	3.22%	15	6.00%
0.025	303	36.89%	68	25.95%
0.05	207	59.89%	43	48.09%
0.075	94	70.33%	19	55.34%
0.1	56	76.56%	17	61.83%
0.125	43	81.33%	13	66.79%
0.15	27	84.33%	7	69.47%
0.175	14	85.89%	8	72.52%
0.2	16	87.67%	12	77.10%
0.225	9	88.67%	2	77.86%
0.25	9	89.67%	3	79.01%
0.275	10	90.78%	4	80.53%
0.3	8	91.67%	5	82.44%
0.325	3	92.00%	5	84.35%
0.35	9	93.00%	7	87.02%
0.375	6	93.67%	2	87.79%
0.4	5	94.22%	3	88.93%
>0.4	52	100.00%	29	100.00%

The pH distribution follows a normal distribution (Figure 6.9). The source of the slight curve found in the graph of concentration against standard normal variable can be noted in the slightly right-skewed histogram.

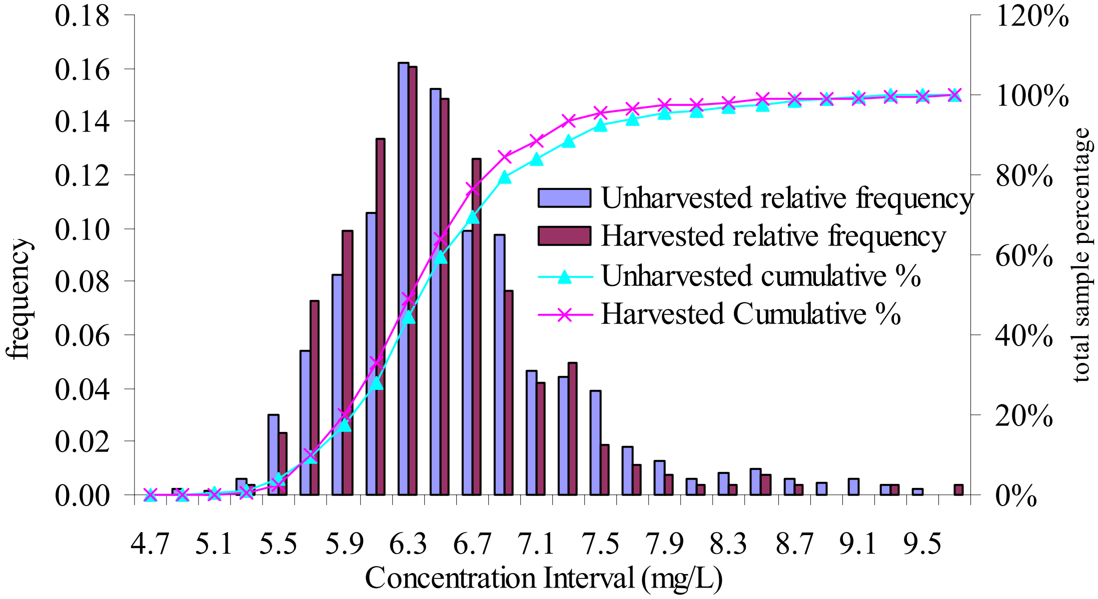

Figure 6.9- Comparison of unharvested and harvested histograms for pH parameter

The limits that define the intervals over which PoE is found for each parameter are shown in Tables 6.4 and 6.5. Within MDC's TSS concentration limits of 0.2-0.5 g/L, the PoE is 5.5%, while the PoE above MDC's range is 5.1%. This indicates that there is little difference between harvested and unharvested conditions in the frequency of concentrations that are within MDC's limits and that are above MDC's limits. Most parameters also showed a similarly low PoE above the EPA's and MDC's limits. Except for nitrate, the highest PoE for the other parameters was potassium's 6.7%. However, nitrate showed a significant PoE of 29.0% above MDC's upper limit. The harvested samples contain an abnormally high concentration from the April 2008 sample; other high concentrations from the harvested samples may also be responsible for this large PoE value.

Table 6.4- MDC and EPA limits that were used to calculate exceedance for all water quality parameters

Given Interval Restraints												
Discrete Analyses	pH	EC	TSS	TVSS	Ca	Mg	K	TP	SRP	NH3-N	NO3	TN
MDC lower limit	6.0	5	0.2	0.2	NA	NA	0.1	0.15	NA	0.1	0.02	NA
MDC upper limit	9.0	150	0.5	0.5			5.0	0.5		32	0.06	
EPA upper limit--DWS	NA				82	76	NA					
EPA upper limit--CSWS	NA								4	NA		35

Table 6.5- Intersection and percentile limits that were used to calculate exceedance for all water quality parameters

Interval Restraints Determined from Distribution													
Discrete Analyses		pH	EC	TSS	TVSS	Ca	Mg	K	TP	SRP	NH3-N	NO3	TN
Intersection lower limit		6.9	30	0.1	0.05	6.0	1.0	2.0	0.4	0.04	0.2	0.2	1
Intersection upper limit		9.3	60	0.4	0.5	16.0	16.0	7.0	1.2	0.08	0.5	0.7	4.5
Percentile lower limit	50th	6.35	28.7	0.037	0.055	2.34	0.75	1.525	0.15	0.04	0.18	0.03	0.865
	75th	6.81	50.75	0.092	0.192	5.0	1.48	2.740	0.37	0.15	0.21	0.223	1.89
	95th	7.851	164.5	0.459	0.828	14.8	8.9	6.742	1.56	0.801	1.39	2.73	5.55

*EC in µs/cm **TSS and TVSS in g/L ***All other parameters in mg/L

The TSS histograms (Figure 6.8) indicate that the harvested distribution intersected the unharvested distribution first at a concentration of 0.1 g/L and again at 0.4 g/L (Table 6.5), and the PoE between these limits was found to be 9.7%. This means that the frequency of harvested concentrations over this range exceeds the unharvested concentrations by 9.7%. Since this is an interval of intersection, it examines only the interval during which the harvested concentrations are always greater than the unharvested concentrations; thus, it represents the maximum probability of exceedance that is found over an interval of continuous positive exceedance.

TVSS resembles the TSS PoE for the intersection interval, as does electrical conductivity. The minerals all tend to have lower PoE values over their intersection concentration range, attributed to the irregularity of their histograms; harvested site samples were not consistently higher than unharvested site samples through the concentration range. The nutrients had much higher PoE values except for total phosphorus and total nitrogen. The negative values for pH, calcium, total phosphorus, and total nitrogen indicate that over the intersection interval, the unharvested concentration exceeded the harvested concentrations, contrary to the usual trend. As a result, it can be concluded that harvesting had no effect on the concentrations of these parameters.

Table 6.6- Exceedance results of discrete analysis of histogram for all parameters for three different methods

% Exceedance													
Discrete Analyses		pH	EC	TSS	TVSS	Ca	Mg	K	TP	SRP	NH3-N	NO3	TN
Within limits (MDC/EPA)		-1.9	5.0	5.5	4.4	NA	NA	0.5	-7.6	NA	26.0	-23.3	NA
Above upper limit (MDC/EPA)		-0.4	-4.2	5.1	4.0	-0.1	0.0	6.7	0.6	0.0	0.0	29.0	0.0
Within intersection limits		-5.0	10.5	9.7	4.3	-10.8	1.1	3.0	-14.7	15.8	34.0	22.9	-20.2
Above percentile limit	50th	-4.9	-0.6	8.9	18.0	-6.0	12.9	-13.9	-11.6	-0.1	29.6	19.9	-11.7
	75th	-7.2	-5.2	14.3	8.4	-10.9	2.3	-13.0	-13.8	-6.5	23.1	28.9	-5.3
	95th	-2.5	-3.1	5.4	3.3	-1.8	-2.7	-3.8	2.7	1.9	-1.6	6.0	2.4

The percentile methods look at how much harvested concentrations exceed unharvested concentrations over the ranges of concentrations greater than 50%, 75%, and 95% of the distribution. In the upper half of the distribution, the PoE of TSS is 8.9%. The PoE in the top quartile is 14.3% which is higher than the PoE for the top half of the distribution and thus is a sum of fewer differences. However, an examination of the differences used to calculate PoE, in Table 6.7, reveals that on the concentration range 0.03-0.08 g/L, the difference between unharvested and harvested frequencies is negative. This interval is included in the top 50% but not the top 25% of the distribution. Therefore, in the top quarter of samples, the harvested concentrations exceed the unharvested concentrations with greater frequency than in the top half of samples.

Table 6.7- Relative frequencies of unharvested and harvested TSS concentrations

Concentration Interval (g/L)	Unharvested relative frequency	Harvested relative frequency	difference
0.00	0.032	0.06	0.025
0.03	0.337	0.26	-0.077
0.05	0.230	0.16	-0.066
0.08	0.104	0.07	-0.032
0.10	0.062	0.06	0.003
0.13	0.048	0.05	0.002
0.15	0.030	0.03	-0.003
0.18	0.016	0.03	0.015
0.20	0.018	0.05	0.028
0.23	0.010	0.01	-0.002
0.25	0.010	0.01	0.001
0.28	0.011	0.02	0.004
0.30	0.009	0.02	0.010
0.33	0.003	0.02	0.016
0.35	0.010	0.03	0.017
0.38	0.007	0.01	0.001
0.40	0.006	0.01	0.006
>0.4	0.058	0.11	0.053

For the extremely high TSS concentrations, above the 95th percentile, the PoE is 5.4%, so the high concentrations found after harvesting are not that much more frequent than they are for unharvested conditions. All of the parameters show similarly small PoE values above the 95th percentile, including nitrate and ammonium nitrate, which have high PoE values for the other intervals. Electrical conductivity, pH, calcium, and potassium display negative PoE values for each interval above the 50th, 75th, and 95th percentiles, indicating that the harvested site samples exceeded the unharvested site samples only at smaller concentrations.

For the parameters in which harvested does exceed unharvested concentrations significantly on the 50th and 75th percentile intervals, the exceedance is insignificant for the top 5% of samples. Since the samples follow a logarithmic distribution, the 50th and

75th percentile values are low concentrations (Table 6.5). Only the 95th percentile is an unusually high concentration, and for this range, the PoE is low. Therefore, the high PoE values on the 50th and 75th percentile intervals do not signal any impact on concentration resulting from harvesting, and the low PoE values on the 95th percentile interval reinforces that there is little difference between harvested and unharvested concentrations.

Of these different concentration intervals, the most important limits for determining water quality are those given by MDC or the EPA. High PoE values for concentration intervals that exceed MDC's limits indicate that the water quality of the stream may be impacted by the effects of harvesting. However, since the PoE is only 5% for the TSS concentration interval above MDC's limit of 0.5 g/L, the harvesting did not have a large effect on the frequency of unusually high TSS concentrations. Such is the case for most parameters, with nitrate as the notable exception. Therefore, it is concluded that the water quality is not significantly impacted by MDC's standards due to harvesting.

6.4.3 Box Plots of the Population

Since TSS and TVSS (Total Volatile Suspended Solids) follow a lognormal model, the minimum within the fence, first quartile, and median are very low concentrations, so these are located close to the lower end of the distribution, while the maximum concentrations within the fence of both the unharvested and harvested sets are much higher than the third quartile. Since the distribution is well-fit to a logarithmic model, the box plots look skewed. Since the higher-end concentrations are spread out more than the low-end concentrations, it is clear that the distribution is skewed right.

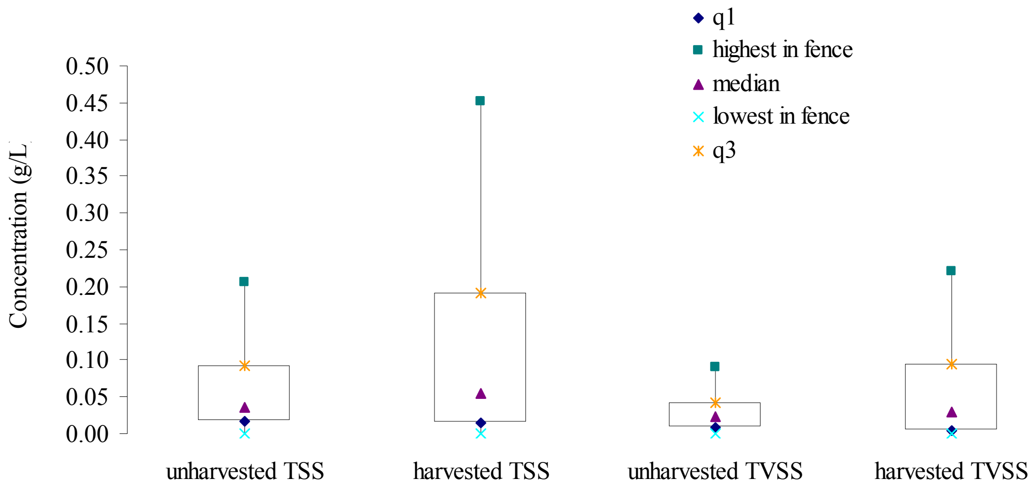

Figure 6.10- Box plots of TSS and TVSS for unharvested and harvested sites

From the box plots, it can be observed that the harvested TSS distribution has a greater spread than the unharvested distribution. From the smallest concentration above the lower fence to the highest concentration beneath the upper fence, the unharvested TSS samples have a range of 0.21 g/L, while the harvested samples have a larger range of 0.45 g/L (Table 6.8). Within the interquartile range, harvested samples also have a wider spread than unharvested samples, which have ranges of 0.177 g/L and 0.075 g/L, respectively. The unharvested and harvested medians do not differ greatly, though the harvested median concentration of 0.055 g/L is slightly greater than the unharvested median of 0.037 g/L (Table 6.8). The TVSS unharvested and harvested box plots show a similar trend in median and spread.

The lower fences for all parameters are negative, so the number of outliers is determined solely from the number of concentrations greater than the upper fence. The percentage of outliers for most parameters is between 7% and 16%, and unharvested and harvested sample sets do not tend to differ greatly in the percentage of outliers. Half of the parameters have higher outlier percentages for the unharvested population, while the other half have a greater percentage of outliers among harvested samples. NH3-N and pH have significantly smaller percentages of outliers than the other parameters; from unharvested sites and harvested sites, respectively, NH3-N has only 4.1 and 1.2% outliers, and pH has 4.4 and 3.4% outliers. The highest percentage of outliers is for harvested TP, at 16.9%, which is 6.6% greater than for unharvested TP.

Table 6.8- Statistics of unharvested and harvested water quality samples for all parameters used to obtain box plots

Statistic	Treatment	q1	lowest in fence	median	highest in fence	q3	IQR	upper fence	lower fence	Skewness	% Outliers
TSS	UH	0.02	0.00	0.04	0.21	0.09	0.08	0.21	-0.02	R*	12.2
	H	0.02	0.00	0.05	0.45	0.19	0.18	0.46	-0.07	R	9.9
TVSS	UH	0.01	0.00	0.02	0.09	0.04	0.03	0.09	-0.01	R	11.7
	H	0.01	0.00	0.03	0.22	0.10	0.09	0.23	-0.04	R	12.2
Ca	UH	1.29	0.00	2.34	10.50	5.00	3.71	10.57	-4.28	R	9.3
	H	1.28	0.00	2.05	6.35	3.45	2.17	6.70	-1.97	R	11.4
Mg	UH	0.52	0.00	0.75	2.90	1.48	0.96	2.92	-0.92	R	15.9
	H	0.64	0.00	0.87	2.64	1.46	0.82	2.68	-0.59	R	12.3
K	UH	0.89	0.00	1.53	5.52	2.74	1.85	5.52	-1.89	R	8.4
	H	0.94	0.00	1.26	3.20	1.99	1.05	3.57	-0.64	R	7.2
TP	UH	0.05	0.00	0.15	0.85	0.37	0.32	0.85	-0.43	R	10.3
	H	0.05	0.00	0.11	0.75	0.33	0.28	0.76	-0.37	R	16.9
SRP	UH	0.01	0.00	0.04	0.35	0.15	0.14	0.36	-0.20	R	12.7
	H	0.02	0.00	0.04	0.19	0.09	0.07	0.19	-0.08	R	17.5
NH3-N	UH	0.25	0.00	0.50	1.41	0.75	0.50	1.50	-0.50	R	4.1
	H	0.25	0.00	0.50	1.39	0.75	0.50	1.49	-0.49	R	1.2
NO3	UH	0.02	0.00	0.06	0.52	0.22	0.20	0.52	-0.27	R	16.8
	H	0.09	0.00	0.26	1.75	0.84	0.75	1.97	-1.04	R	15.2
TN	UH	0.41	0.00	0.87	4.06	1.89	1.48	4.11	-1.81	R	8.7
	H	0.33	0.00	0.56	3.08	1.49	1.15	3.22	-1.40	R	11.7
pH	UH	6.07	4.78	6.35	7.92	6.81	0.74	7.93	4.95	No**	4.4
	H	6.00	5.20	6.32	7.70	6.70	0.70	7.75	4.95	No	3.4
EC	UH	19.80	0.00	28.70	97.10	50.75	30.95	97.18	-26.63	R	13.1
	H	20.30	4.40	28.30	73.70	42.58	22.28	75.99	-13.11	R	11.1

*Right **Not skewed

The minerals (NO3, NH3-N, TP, TN, SRP), unlike the suspended solids, have smaller spreads and smaller interquartile ranges for the samples from the harvested sites than from the unharvested sites (Figure 6.11). Unharvested calcium, with the largest spread between minimum and maximum values between the fences, has a range of about

13 mg/L, while harvested potassium has the smallest range of about 1 mg/L. As with the suspended solids, there is little difference between their medians, and they all appear right-skewed due to the lognormal distribution.

Figure 6.11- Box plots of unharvested and harvested minerals (Ca, Mg, K)

The nutrients in the box plots found in Figure 6.12 also show similar medians between harvested and unharvested concentrations, except for nitrate, which has the greatest difference in medians at 0.2 mg/L. This is probably a result of those high-end concentrations that are also responsible for the high PoE value for the interval above MDC's upper limit. Most of the parameters show similar spreads for both the unharvested and harvested sample sets, though the spread varies widely between parameters. TN clearly has the widest interquartile range and range between minimum and maximum values within the fences, though it has only a moderate percentage of outliers when compared with the other parameters. SRP, on the other hand, has a much smaller range, and as a result, it has a much closer upper fence, so there are higher percentages of outliers. All of the nutrients appear right skewed, following the lognormal pattern.

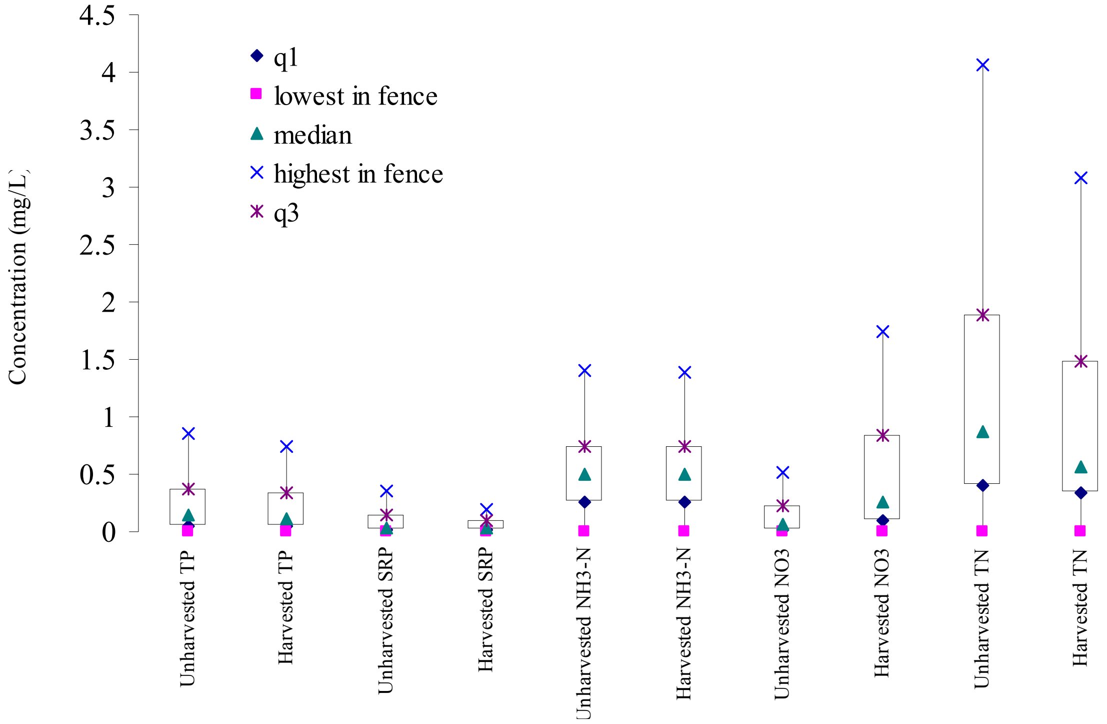

Figure 6.12- Box plots of unharvested and harvested nutrient parameters

6.4.4. Probability of Exceedance (PoE)

The probability of exceedance (PoE) values of the concentrations found in the harvested sites and the control sites were compared (Table 6.9). The sites were divided into treated (harvested) sites and untreated (control) sites, and the samples from these sites were divided by harvesting cut off date, before and after December 2006 when harvesting operation started. While analyzing only the samples from the treated (harvested) sites, the site location was consistent while the climate was inconsistent, which means the climate, rather than the treatment, might be responsible for differences in concentration. In comparing the treated sites to the untreated (control) sites at equivalent dates, the concentration is examined with inconsistent location but a consistent climate.

Figure 6.13 shows comparisons for TSS, comparing the consistent sites as well as climate. It provides a visual representation of how the sample sites are handled for PoE analysis. The left-hand sets of samples are taken from the sites that were harvested after December 2006, while the right-hand sets of samples are taken from sites that were never harvested. Each set of sites is divided by the harvesting date. The samples in boxes 1A, 2A, and 2B are controls because they are unharvested sites to be compared to the harvested sites (1B).

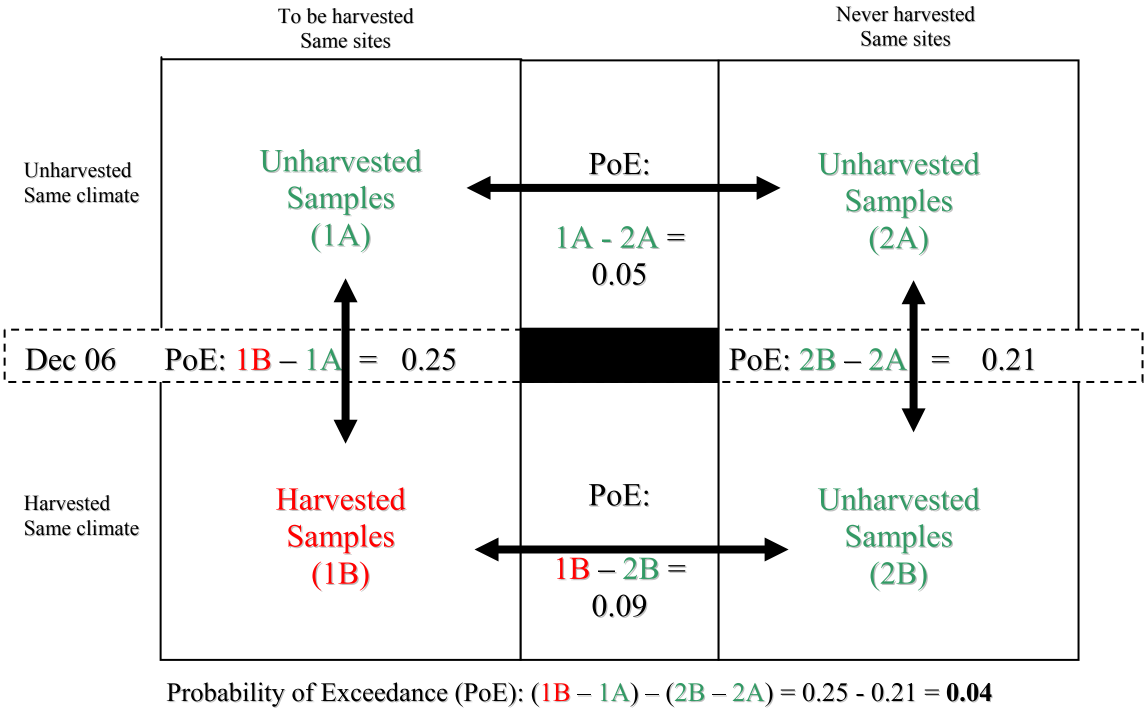

Figure 6.13- Categories of samples and probability of exceedance results for total suspended solids taking into account both control and harvested sites

To obtain PoE, the harvested lognormal distribution function were compared to the unharvested distribution function. The PoE is found by determining the area of exceedance between the two specified distributions on the interval from their intersection to infinity (∞). First, the difference was found between pre-harvest and post-harvest concentrations within consistent sites. These differences are for the harvested (treated) sites and the unharvested (untreated) sites separately. Then, the difference in PoE's between the harvested sites difference and unharvested sites difference were found, which gave a comparison in which the climate is consistent in the sites. As a result, the effect of the harvesting treatment was found independently of climate factors that may change over time but are the same for both treated and untreated sites. The PoE results are shown in Figure 6.13.

Table 6.9- PoE Comparison of harvested and control sites to evaluate harvest effect on water quality

Parameters	**PoE Harvest Sites (A)** (Before vs. After Dec. 2006) (Eliminates geology, soil, aspect as well as size and area of sites but includes precipitation variation and treatments)	**PoE Control Sites (B)** (Before vs. After Dec. 2006) (Eliminates harvest effects soil type, geology, slope and aspect as well as size and area of site but Includes leaf on/off and Precipitation)	**Difference (A)-(B)** (PoE w/out Background Variation/ harvest effects only) (Eliminates background PoE but includes site differences, aspect and slope, size as well as soil and geology)	% PoE	**Remarks**
TSS (g/L)	0.25	0.21	0.04	4.06	Very Low
TVSS (g/L)	0.28	0.15	0.13	13.20	Low
Ca (mg/L)	0.16	0.11	0.05	5.49	Very Low
Mg (mg/L)	0.13	0.17	-0.04	-3.70	No effect
NO3- (mg/L)	0.37	0.28	0.09	9.21	Low
SRP (mg/L)	0.11	0.00	0.11	11.49	Low
NH3-N (mg/L)	0.00	0.00	0.00	0.00	No effect
TN (mg/L)	0.00	0.00	0.00	0.00	No effect
TP (mg/L)	0.00	0.00	0.00	0.00	No effect
pH	0.00	0.00	0.00	0.00	No effect
Cond. (µs/cm)	0.00	0.00	0.00	0.00	No effect
K (mg/L)	0.01	0.00	0.01	0.65	Very Low

*<0 No effect **0-8% Very low **8-15% Low *** >15% Significant

When the treated sites are compared before and after harvesting, the PoE for TSS is 25%, as seen in Table 6.9. Table 6.10 shows the PoE for each site separately, separating the harvested sites into the Angeline and Current River sites. The difference in PoE before and after treatment may be a result of the harvest, but it may also be affected by other factors like precipitation, soil, geology, slope, and aspect. Comparison with the control sites checks for these other factors.

Table 6.10- PoE of all subgroups for both treated (harvested) and untreated (control) sites for all the water quality parameters

Parameters/Sub-Groups	Harvested Sites (Before vs. After 2006)	Control Sites (Before vs. After Dec. 2006)	Harvested vs. Control Sites (After Dec. 2006)	Harvest vs. Control Sites (Before Dec. 2006)
TSS (g/L)	0.25	0.21	0.00	0.05
TVSS (g/L)	0.28	0.15	0.17	0.03
Ca (mg/L)	0.16	0.11	0.00	0.00
Mg (mg/L)	0.13	0.17	0.00	0.00
N03(mg/L)	0.37	0.00	0.02	0.00
SRP (mg/L)	0.11	0.28	0.04	0.00
NH3-N (mg/L)	0.00	0.00	0.03	0.02
TN (mg/L)	0.00	0.00	0.06	0.01
TP (mg/L)	0.00	0.00	0.00	0.00
pH	0.00	0.00	0.00	0.00
EC (µs/cm)	0.00	0.00	0.00	0.00
K (mg/L)	0.01	0.00	0.00	0.00

Any difference in control site concentrations before and after the harvesting date cannot be attributed to harvesting. The probability of exceedance must be attributed to factors other than harvesting because there is no harvesting at control sites. For five of the twelve parameters, positive exceedance ranging from 0.11 to 0.28 is found for control sites compared before and after the date of the harvest (Table 6.10). This means that, over the concentration of interest, the concentrations of these parameters were 11% to 28% greater after the harvesting date (Dec 2006) than before. For TSS, 21% probability of exceedance is found for the control sites (Table 6.10).

The difference in PoE for TSS between the harvested sites (25%) and the control sites (21%) yields a PoE of about 4% (Table 6.9). Since this calculation of PoE eliminates the effects of climate and location differences. Based on PoE of 4%, it is concluded that there was little impact on TSS as a result of harvest activities. This result indicates that the best management practices (BMPs) are effective at preserving the quality of water that leaves the harvesting area.

Similarly to TSS, calcium and potassium also exhibit very low PoE values (5.49% and 0.65%, respectively), further indicating lower impact of the harvesting on water quality with respect to these parameters. The parameters of ammonium nitrate, total nitrogen, total phosphorus, pH, and electrical conductivity, which all had PoE values of 0%, and magnesium, which had a negative PoE value, experienced no measurable difference as a result of harvesting. TVSS, nitrate, and soluble reactive phosphorus had the greatest differences in concentration as a result of harvesting, with PoE values of 13.2%, 9.21%, and 11.49%, respectively.

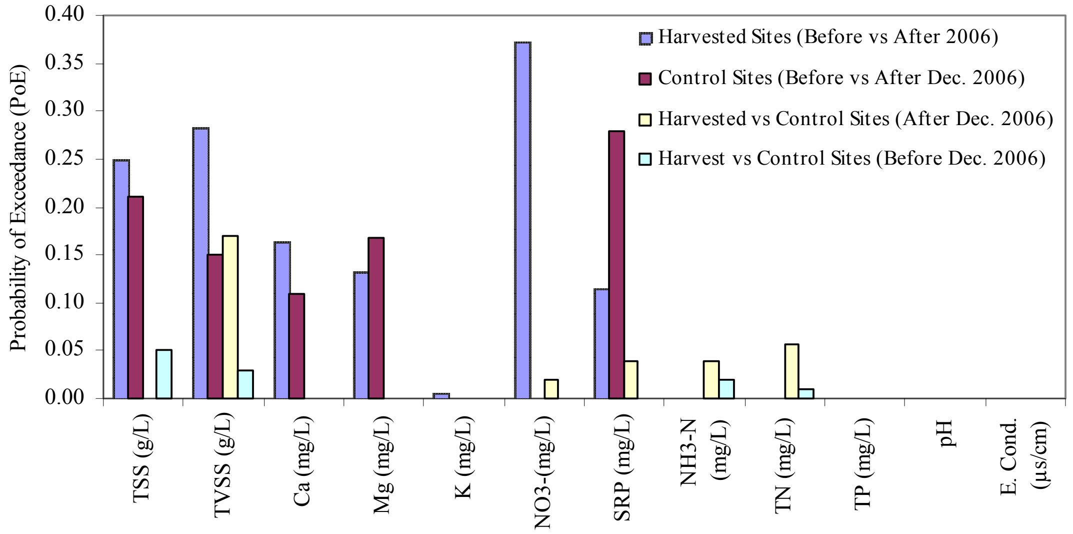

Figure 6.14- Comparison of positive probability of exceedance for water quality parameters of interest

A comparison was made for all the methods used to compare pre-and post harvest water quality (Figure 6.15). The comparison showed average PoE of about 6.0 for total suspended solids and 6.5% for total volatile suspended solids. The post-harvest timber effect is therefore, very minimal as the samples are noisy itself.

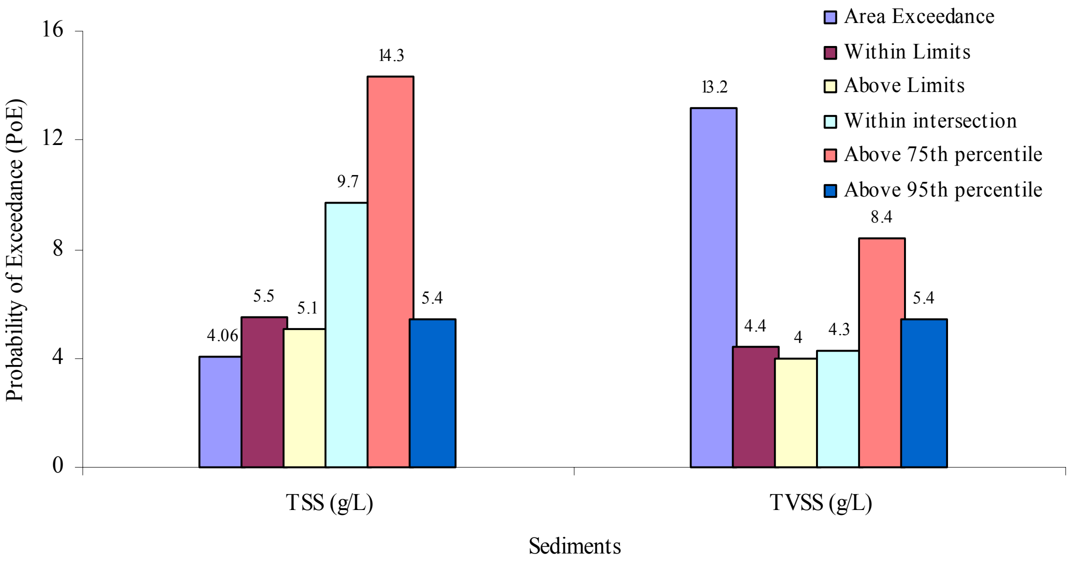

Figure 6.15- Comparison of PoE for TSS (g/L) and TVSS (g/L) using methods of area exceedance as well as histogram analysis

Some extreme pre-and post harvest concentration (Table 6.11) were separated for TSS (g/L) and TVSS (g/L). The TSS pre-harvest was found to be 5.38 g/L whereas post-harvest found to be 2.10 g/L whereas for TVSS (g/L), the pre-harvest concentration was 3.33 g/L and post-harvest concentration was 2.02 g/L. The concentration came from the event that had exceptionally high precipitation (6-16”) within a small period of time. The unusually high precipitation could have contributed a higher flow and depth of the overland flow in the sites and thereby carried more sediments and nutrients.

Table 6.11- Top ten extreme concentrations obtained for pre-and post-harvest water samples for TSS (g/L) and TVSS (g/L)

Parameter	TSS (g/L)		TVSS (g/L)	
Counter	Pre-harvest	Post-harvest	Pre-harvest	Post-harvest
1	5.38	2.1	3.33	2.02
2	4.8	1.77	1.77	1.58
3	3.04	1.67	1.17	1.57
4	2.78	1.44	1.15	1.38
5	2.06	1.43	0.68	1.37
6	2.02	1.4	0.6	1.26
7	1.94	1.27	0.58	1.22
8	1.83	1.12	0.43	1.06
9	1.73	1.1	0.38	0.95
10	1.58	1.09	0.37	0.86

6.4.5 Variation of Concentration Over Time

The concentration was examined with respect to time over the course of the study, from 2004 to 2008, where unharvested concentrations were compared to harvested concentrations. Figures 6.16-6.19 display the minimum, maximum, and mean values of TSS concentrations gathered at each date of sample collection, differentiating between harvested and unharvested sites. When fitting a linear trend to a set of TSS unharvested mean concentrations, the trend could account for only 13% of the variation in the concentrations, as indicated by the R^2 value in Figure 6.16. The slope of the trend line in Figure 6.16 is 0.00009, indicating that the mean concentrations remain nearly constant, rising only slightly, over the entire unharvested period. However, there is great variation in the maximum concentrations, with many maximum concentrations much larger than the mean concentrations. The minimum concentrations did not very much and were close to the mean concentrations.

Table 6.12- Trend line correlation properties for time variation of concentration for all water quality parameters

Parameter	Property	Unharvested	Harvested	Year 2007	Year 2008
TVSS	R²	0.2705	0.5297	0.3139	0.0465
	Slope (m)	0.00009	0.0003	0.0002	-0.0004
Ca	R²	0.0362	0.0663	0.0401	0.285
	Slope (m)	0.0011	0.0019	0.1999	0.0113
Mg	R²	0.0673	0.0605	0.5344	0.3427
	Slope (m)	0.0008	0.0008	0.3237	0.0062
K	R²	0.0011	0.0047	0.195	0.5002
	Slope (m)	0.0001	-0.0004	-0.3386	0.0055
TP	R²	0.0582	0.228	0.5381	0.0027
	Slope (m)	0.0004	0.0006	0.0351	0.0003
SRP	R²	0.1859	0.2381	0.1401	0.0209
	Slope (m)	0.0002	0.0005	0.0242	0.0006
NH3-N	R²	0.0124	0.0819	0.0605	0.0823
	Slope (m)	0.0001	-0.0012	0.088	0.0007
NO3	R²	0.02778	0.4782	0.1285	0.002
	Slope (m)	0.001	0.004	0.039	0.0015
TN	R²	0.013	0.0005	0.3943	0.6
	Slope (m)	0.0004	0.0005	-0.1627	-0.095
pH	R²	0.1239	0.1084	0.1	0.3073
	Slope (m)	-0.0003	-0.0005	-0.0014	0.0018
EC	R²	0.012	0.0194	0.0795	0.2354
	Slope (m)	-0.008	-0.0099	-0.053	0.0967

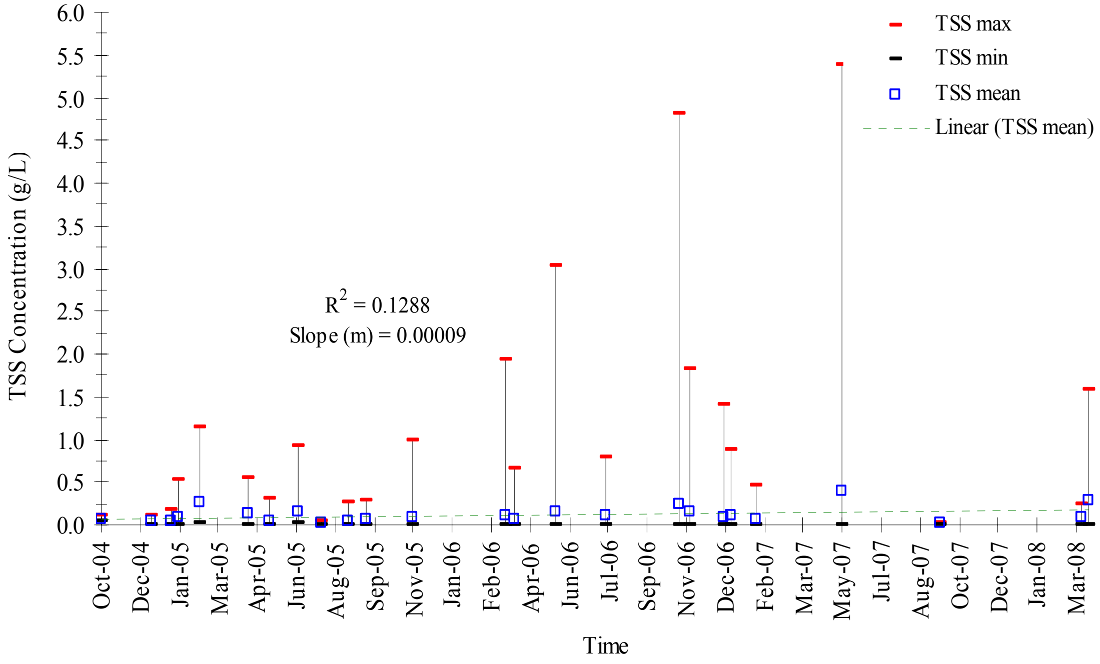

Figure 6.16- Mean, maximum and minimum unharvested TSS concentrations with a mean linear fit with time for the entire research period

Harvested concentrations exhibit a slightly stronger correlation with time, showing a slight increase in concentration over two years (2007-2008), as can be observed in the trend line with a slope of 0.0003 in Figure 6.17. The linear model accounts for 37% of variation in the mean concentrations during the harvested period, from December 2006 to mid 2008. The maximum concentrations fluctuate significantly, as occurred during the unharvested time period, while the minimum concentrations remained relatively constant and closer to the mean concentrations.

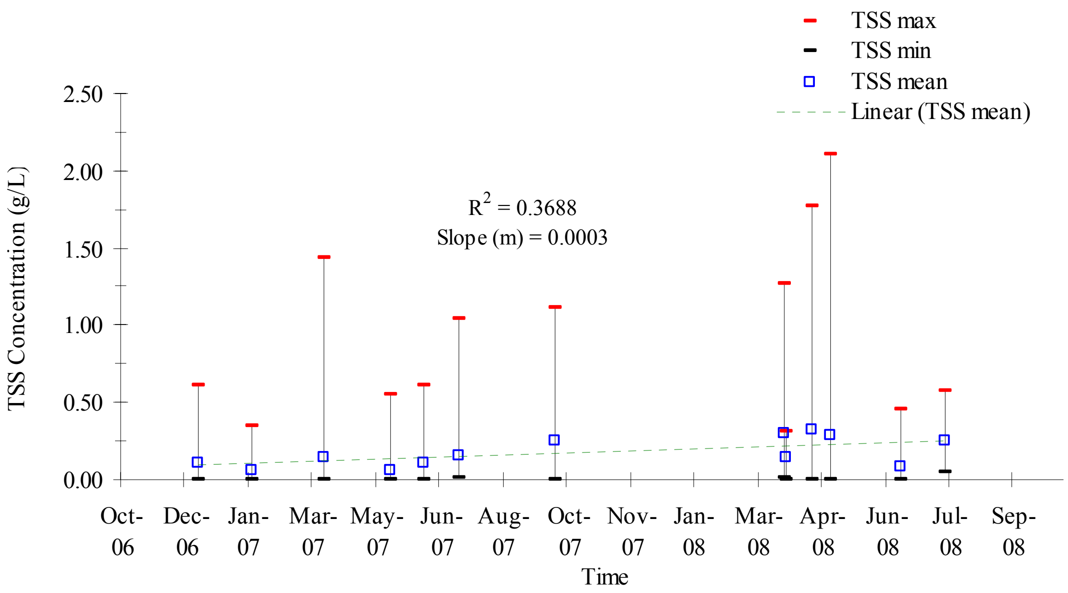

Figure 6.17- Mean, maximum and minimum harvested TSS concentrations with a mean linear fit with time for the entire research period

After examining the harvested concentrations over the entire harvested period, the harvested time period was split into years 2007 and 2008. These periods were analyzed separately because the literature indicates that the parameter concentration increases during the first year-and-a-half after timber harvest, then decreases and stabilizes in subsequent years (Ensign & Mallin, 2001; Lockaby et al., (1997b); Stednick, 2000). The concentration trend over time aligns with the previous similar study of water quality. The result shows that the concentration increases slightly for the first year (2007) and tends to decrease in the second year (2008). Overall, the trend shows an increasing pattern for TSS.

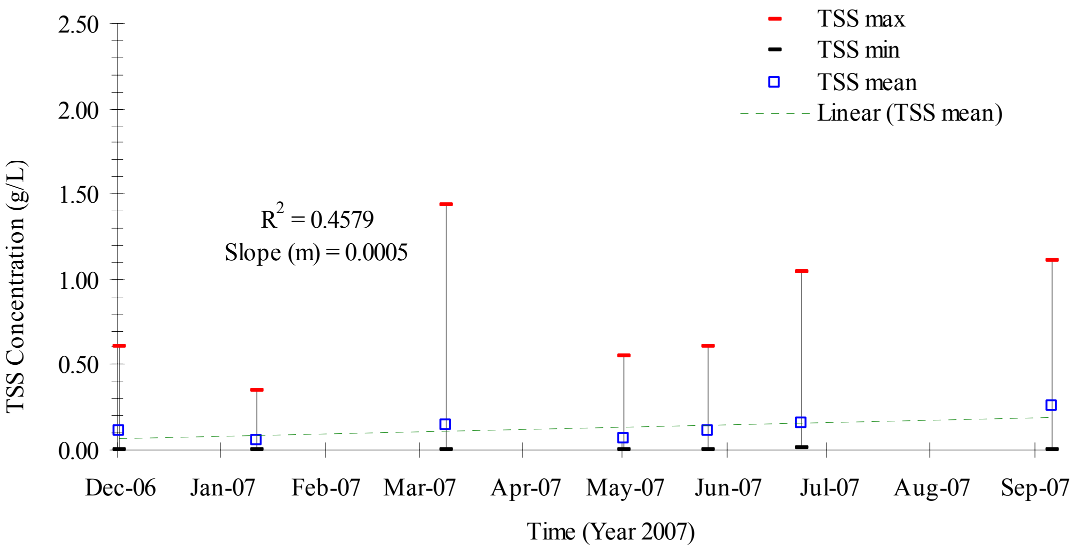

Figure 6.18- Mean, maximum and minimum unharvested TSS concentrations with a mean linear fit with time for the year 2007

In Figure 6.18, the slope of 0.0005 indicates that the concentrations from year 2007 show a slight increase in concentration through the year. The linear model accounts for 46% of the variation in the concentrations and thus is the strongest relationship seen in the analysis of concentration variation with time. As Figure 6.19 shows, however, the linear model accounts for only 9% of the variation in the concentrations in 2008. In 2008, the mean concentrations tend to decrease through the year, with a negative slope of 0.0006, perhaps tending toward a more stable concentration as time goes on. However, fluctuations in the mean concentration through the year weaken any such trend. The streams will need continued observation and collection of TSS samples to be conform of a decreasing and stabilizing trend.

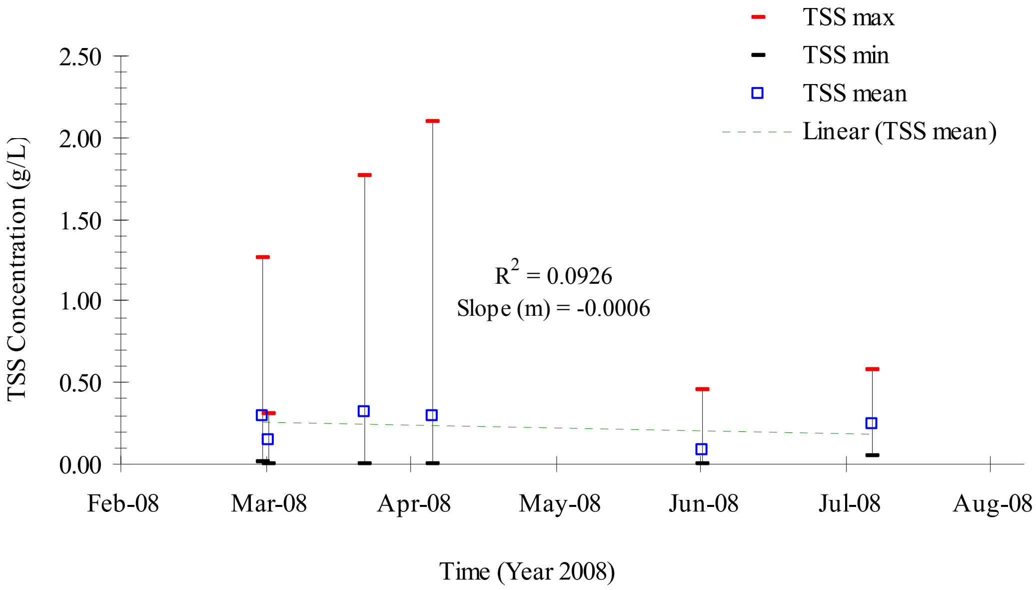

Figure 6.19- Mean, maximum and minimum unharvested TSS concentrations with a mean linear fit with time for the year 2008

Similarly to TSS, TVSS showed an increasing trend in 2007 followed by a decreasing trend in 2008 that weakly showed less of a decrease than the previous year. The minerals tended to increase or stay the same in the slope of their trend line from 2007 to 2008. However, only potassium's 2008 trend line substantially accounted for the variation in the samples; the other trends were weakly supported by their linear models. The phosphorus parameters tended to increase in concentration once the sites were harvested, and this rate of increase changed little between 2007 and 2008. The strongest trends for the nitrogen parameters were found for total nitrogen, which slightly increased once the site were harvested. Ammonia nitrate and nitrate did not show strong trends, but ammonia nitrate tended to decrease while nitrate increased. pH and electrical conductivity generally decreased through 2007 and tended to show less of an increase or stable later in the year 2008 (Table 6.12).

6.4.6 Variation of Concentration With Location of In-stream Samplers

The concentration of TSS was also analyzed with respect to the locations of the in-stream water samplers assuming the equidistance for easy of analysis, at both the Angeline Conservation Area site (A34-1) and the Current River Conservation Area site (CR7-5C). The concentrations were evaluated at for both unharvested and harvested samples to compare the variation in concentration over the entire watershed, from the highest to the lowest in-stream sampler in the stream. It was found that the mean concentration at the Angeline site (A34-1) tended to increase from the crest to the toe of the watershed during the unharvested period, as seen in the slope of 0.0089 of the trend line found in Figure 6.19. The linear model for these data accounts for 46% of the variation in the concentration samples. The minimum concentrations showed little variation while the maximum concentrations were sometimes much higher than the mean, particularly lower in the watershed. The increasing concentrations from head to toe indicate that sediments accumulates at the bottom of the watershed if no trees are harvested.

Table 6.13- R^2 value and slope of linear trend lines for concentration variation over the location of the sample in the watershed

Watershed	Treatment	R^2	Slope (m)
Angeline (A34-1)	Unharvested	0.0089	0.4594
	Harvested only	0.2513	-0.0124
Current River (CR7-5C)	Unharvested	0.0001	-0.0004
	Harvested only	0.0437	-0.0204

As seen in Figure 6.19, after the harvest, the concentration decreases from the first to the last site in the Angeline watersheds. The trend line, which has a negative slope of 0.0124, accounts for 25% of the variation in concentration, which may be considered reasonably strong since timber harvest research is a study of a natural system. It must be noted that, as seen in Figure 6.20, there is no TSS concentration at site 10 in the harvested data set for the Angeline watershed, unlike in the unharvested data.

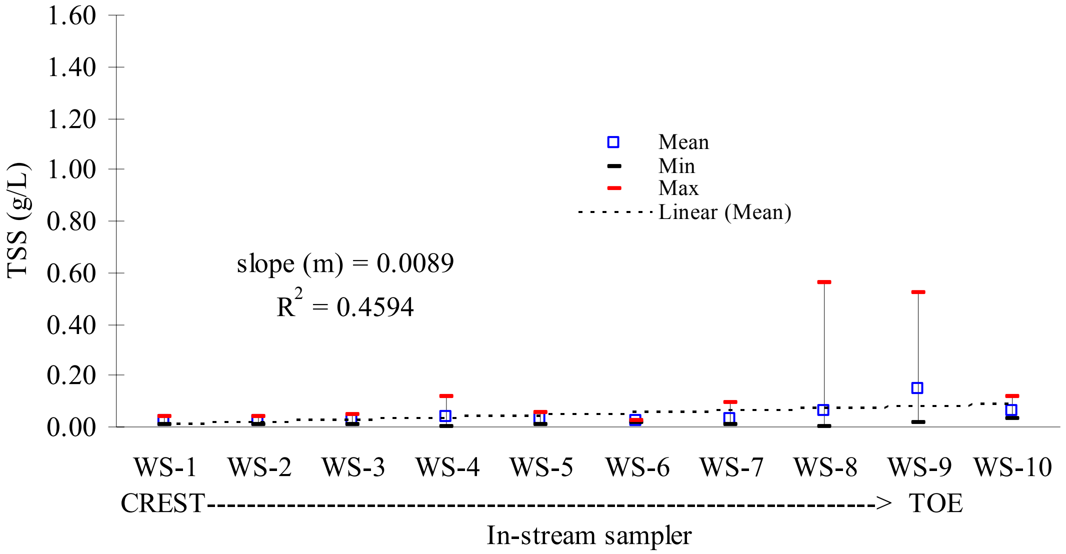

Figure 6.20- Mean, Maximum and Minimum of unharvested TSS concentration with a mean liner fit for in-stream samples located in A34-1.The samplers were assumed equidistance from each other

However, concentrations at the Current River site showed much less regularity, with an essentially horizontal trend line (slope of -0.0004) that accounts for less than 1% of the variation in the concentration. There was not much difference between the concentrations of the samples at the beginning of the watershed and at the end of the watershed. As with the Angeline site, the minimum concentrations changed little. The maximum concentrations fluctuate greatly, with little apparent pattern as seen in Figure 6.21.

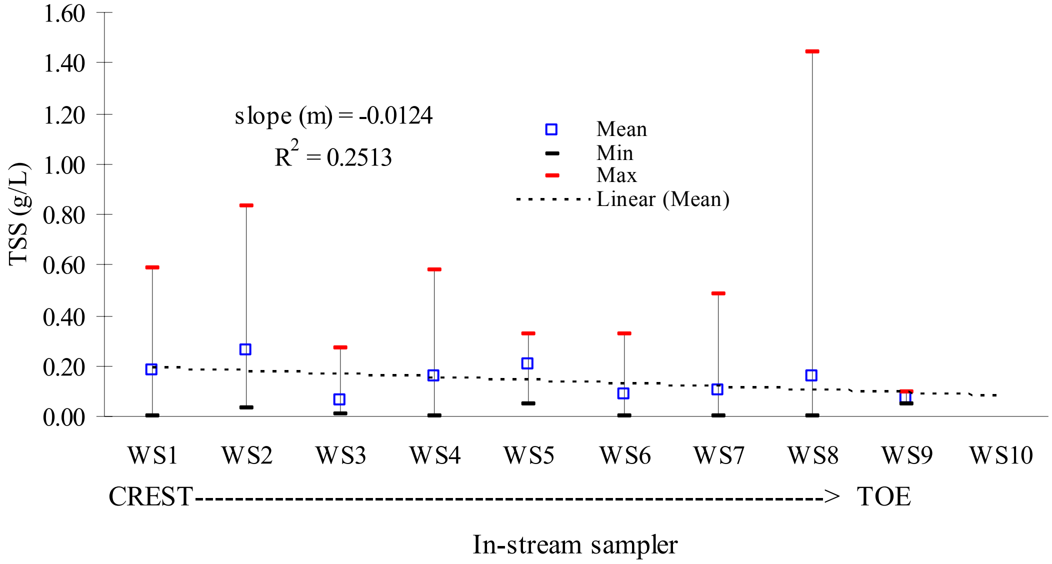

Figure 6.21- Mean, Maximum and Minimum of harvested TSS concentration with a mean liner fit for in-stream samples located in A34-1. The samplers were assumed equidistance from each other

The TSS samples from the harvested Current River watershed (CR7-5C) also show less regularity than the Angeline (A34-1). The trend line indicates a decrease in concentration through the watershed, with a negative slope of 0.0204, which is similar to the Angeline watershed. However, the Current River trend only accounts for 4% of the variation in concentrations at that site. The Current River watershed may show less regularity and weaker trends than the Angeline because samples are taken at only fives sites rather than ten.

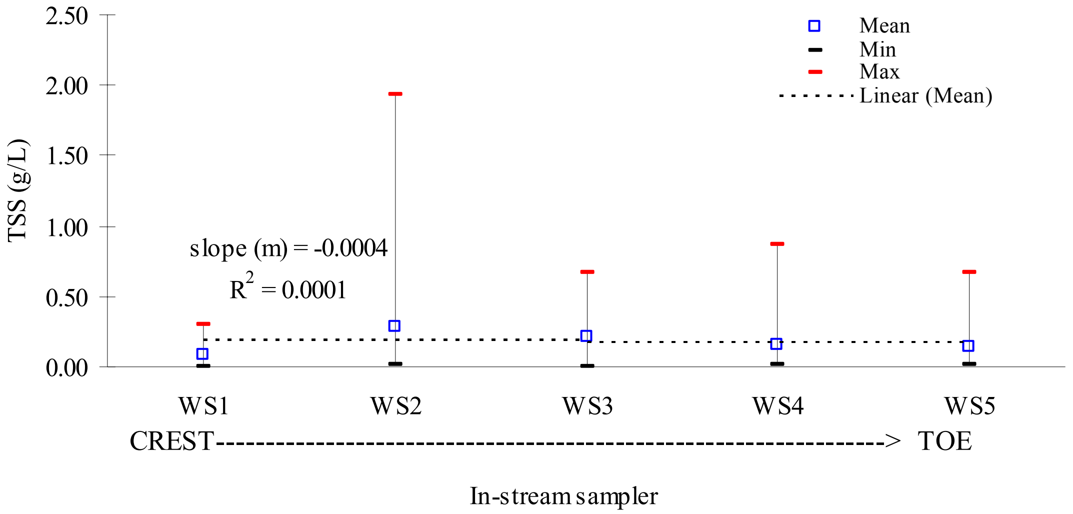

Figure 6.22- Mean, Maximum and Minimum of unharvested TSS concentration with a mean liner fit for in-stream samples located in CR7-5C. The samplers were assumed equidistance from each other

The overall trend of decreasing concentration for both harvested sites is likely the result of green biomass, such as branches and treetops, left from harvest and slashing operation, that slowed the movement of water through the watershed and reduced the passage of TSS from the crest to toe of the watershed. The decrease in velocity of the overland flow of water may have allowed for settlement of sediments so that the water carried less sediment in the direction of the watershed's outlet. The maximum concentrations varied greatly for both sites, while the minimum concentrations changed little between samplers.

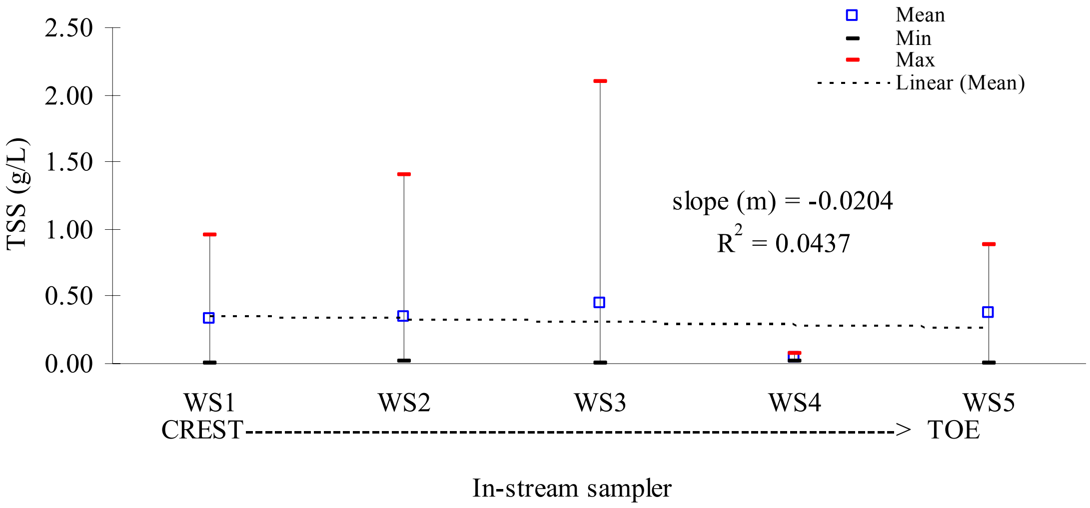

Figure 6.23- Mean, Maximum and Minimum of harvested TSS concentration with a mean liner fit for in-stream samples located in CR7-5C. The samplers were assumed equidistance from each other.

6.5 Conclusions

6.5.1 Summary

Pre-and post harvest water quality samples were collected to determine the impact of harvesting on water quality in the ephemeral streams of Missouri Ozarks. The study started in 2004 until 2009 where about twelve water quality parameters were considered and analyzed in the laboratory following standard procedures (APHA, 1998). The statistical analyses performed on pre-and post-harvest data sets including determination of appropriate distribution, discrete analysis (histograms and box plots comparison), determination of probability of exceedance (area exceedance method). The concentration variation over time for both pre-and post harvest samples were obtained by fitting the mean concentrations among mean, maximum and minimum concentrations. Finally, the change in concentration at the physical location of the in-stream sampler in both Angeline and Current River CA sites were obtained to appreciate the differences in concentration before and after harvest effects on downstream water quality.

6.5.2 Conclusions

- Concentrations of TSS, TVSS, NO_3, NH_3-N, SRP, TN, TP, EC, Ca, Mg, K were lognormally distributed. Histograms of pre-and post harvest distributions of these concentrations supported the lognormal approximation except pH which was normally distributed.
- A comparison of the pre-and post-harvest histograms showed qualitatively that at higher concentrations, the harvested distribution of TSS tended to have slightly larger frequencies. However, the calculation of probability of exceedance quantitatively described that this difference was not very significant, a trend among all parameters.
- For TSS concentrations, it was found that the harvesting was responsible for only 4% exceedance, indicating a little change in the TSS concentration caused by timber harvesting. The probability of exceedance for control sites, though, accounts for 21% which included other factors i.e., precipitation, soil, geology, slope, and aspect contributed to most of the positive exceedance even in non-harvested sites. The post harvest probability of exceedance was accounted for 25%. TVSS had about 13% PoE excluding all other factors but the harvesting effects.
- Ca and K showed similarly low PoE attributable to harvesting, while TVSS, NO_3, and SRP showed slightly higher PoE. Mg, TN, TP, pH, and EC showed no change which indicates that harvesting had no effect on the concentrations of these parameters.
- The probability of exceedance of concentrations above the MDC limit for TSS was only 5% from discrete analysis of histograms, which meant that the frequency of excessive concentrations was not much greater for the harvested sites than the unharvested sites. This analysis also agreed with the outcome from the area

exceedance method. Most parameters also showed a similarly low PoE above the EPA's and MDC's limits.

- Except for nitrate, the highest PoE for the other parameters was 6.7%. All parameters also had low PoE values for concentrations above the 95th percentile, which reaffirmed that there was little concern about changes in sediment and nutrient concentrations.
- The box plot of TSS concentrations showed similar median concentrations for unharvested (0.055 g/L) and harvested (0.037 g/L) sites, but a greater spread in the harvested distribution (0.828 g/L) compared to unharvested distribution (0.487 g/L). TVSS concentrations showed a similar trend, with close medians but a greater spread in harvested site concentrations. The minerals and nutrients followed the same trend for both pre-and post-harvest samples.
- In the analysis of concentration variation with time, it was found that the TSS mean concentrations changed very little over time before the harvest, though there was some variation in maximum values. The trend was not very strong, with the linear model accounting for only 10% of the variation in concentration.
- After the harvest, the overall trend was an increase in mean concentration over the whole harvest period, with a slope of 0.0138, but when data from 2007 was examined separately from 2008, during the first year harvested, TSS concentration increased with a slope of 0.0205, while afterward, the concentration slightly decreased (slope -0.0132). This trend supports previous results indicating that the increase in concentration balances out over time after timber harvest.

- The linear model of increasing concentration through 2007 accounts for 45% of variation in concentration, while for 2008, the decreasing trend line accounts for only 7%.
- Few of the other parameters demonstrated strong trends of concentration over time. TVSS resembled the TSS trend, the minerals and phosphorus parameters tended to increase after harvest, however, the nitrogen parameters decreased after harvest while pH and EC decreased throughout the study period.
- Concentration was also examined with respect to in-stream sampler location in the watershed. In the Angeline watershed, TSS concentration increased from head to toe before harvest, probably because TSS accumulates as the water travels and reaches at the end of the stream in the watershed.
- The linear model for TSS accounted for 46% of the variation in concentration. After harvest, the concentration tends to decreased moving down the stream, which likely occurred because the green biomass that accumulated from harvesting and slashing slowed the water velocity and gave sufficient time for sediments to settle before reaching the outlet in the watershed. The linear model for this trend accounted for 25% of concentration variation for TSS.
- The Current River watershed showed similar trends to the Angeline, though they were not as strong. The unharvested trend line accounted for less than 1% of variation, while the harvested trend line accounted for 4%.
- TSS and TVSS concentrations increased slightly for a year after harvest, then demonstrated a trend toward stability. Minerals and phosphorus tended to increase after harvest while nitrogen decreased after harvest.

- TSS concentration tended to increase from head (top of the watershed) to toe (bottom of the watershed) in a watershed in unharvested sites but decreased from head to toe in harvested sites. This finding suggests towards the usefulness of after harvest biomass left on the site in reducing runoff velocity by decreasing sediment erosion.

- With the effects of precipitation and other factors taken into account, all parameters showed insignificant post-harvest probability of exceedance. TVSS, NO_3, and SRP showed low probability of exceedance, whereas TSS, Ca, and K had very low PoE, and Mg, TN, TP, pH, and EC showed no effect.

6.5.3 Recommendations

- Discrete analysis method included all the effect. The control sites should be analyzed separately and various effects should be isolated to obtain timber harvesting exceedance as in case of area exceedance method.

- More data should be collected from the time of harvest to compare the results to better document long term behavior of sediments, nutrients and minerals.

- Some management options including SMZs should be adopted while timber harvesting operation is performed.

- Best management practice including SMZs appear effective. In Current River Conservation area SMZs were applied while harvesting, the probability of exceedances were higher for almost all water quality parameters.

6.6 Acknowledgements

The authors would like to thank former graduate students Abe Smith, Craig Bunger, Ryan Mueller and Eric Hollabaugh for their valuable time and effort during the various stages of this project. We would also like to give special thanks to Paul Koenig for his help in logistics and field data collection. An appreciation goes for a help from Dr. Ross Dresbach at the Soil Characterization Lab in analyzing water quality parameters during the project period. This research study would not have been possible without the generous funding from Missouri Department of Conservation and Missouri Department of Natural Resources. Also, our sincere thanks goes to I2G at MU, Department of Civil and Environmental Engineering for coordination and cooperation throughout the project duration.

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CHAPTER 7: CONCULSIONS AND RECOMMENDATIONS

7.1 Summary

The Missouri Department of Conservation (MDC) manages the State's forest lands and has implemented Best Management Practices (BMPs) including streamside management zones (SMZs) while harvesting timber in order to protect the state's waterways and to comply with the federal government's Clean Water Act. In Missouri, MDC regulates and assists private forestry practices to help woodland owners. Although the BMP's have been in practice for more than twenty years, no quantitative database exists to support the effectiveness of the BMPs. The goal of this seven year project was to provide a quantitative evaluation of the effectiveness of MDC's BMPs and hence SMZs for Regenerative Oak Clear Cutting (ROCC) in the Missouri Ozarks.

The timber harvest water quality project commenced in June 2003, and the major tasks undertaken included: maintaining over 200 pieces of instrumentation, collecting both pre- and post-harvest water samples from all fifteen sites for about seven years, analyzing the water samples in the lab throughout the project periods and interpreting the data to quantify harvest effects on water quality. Timber harvest was completed in December 2007 in eight out of fifteen sites on both Angeline and Current River CA. The timber harvesting was followed by slashing , an after-harvest procedure consisting of chopping branches, treetops and undergrowth by loggers to improve natural regeneration. Seven sites (control) remained un-harvested during the entire study period. There were 32 water collection trips throughout the project duration in which maintenance works were also performed as necessary. A total of about 1150 samples, including 250 post-harvest samples, were collected from in-stream, hillslope and automated samplers. The water quality parameters of interest were: pH, electrical conductivity (EC), total suspended solids (TSS), total volatile solids (TVSS), total nitrogen (TN), nitrate ($N0_3$), ammonia nitrate (NH_4 -N), total phosphorous (TP), soluble reactive phosphorous (SRP), calcium (Ca), magnesium (mg), and potassium (K).

A background pre-harvest concentration for each parameter had to be established to facilitate comparison with post-harvest samples. Several procedures were considered and a method called "Probability of Exceedance" (PoE) was developed to compare pre- and post-harvest water quality samples. The probability of exceedance (PoE) of each parameter was calculated separately for all sites, harvested sites, and Current and Angeline CA to evaluate differences. To eliminate the contribution of climate to changes in parameter concentration, the PoE change from before to after December 2006 in control sites was subtracted from the PoE change from pre- to post-harvest in harvested sites. Effects of different site areas were also evaluated.

7.2 Conclusions

The following conclusions are based on the results of analyses of water quality data from pre-and post-harvest:

- It was concluded from the statistical analysis (normal and log normal distributions) that the concentrations of sediments, nutrients and surrogate parameters considered for water quality analysis are highly variable. Pre-harvest background concentrations were important but too noisy to establish a single concentration limit to use as a comparison. So, distributions were used to compare pre-and post-harvest water quality.

- Calcium, Potassium, Nitrate, and Dissolved phosphorous demonstrated a small positive exceedance. Magnesium and Soluble Reactive Phosphorous showed positive exceedance in almost all sub-group categories whereas Calcium showed no exceedance when all samples were analyzed.

- The result from comparison of Current River vs Angeline CA demonstrated that the PoE was higher when SMZ's were absent during the timber harvest operation.

- Magnesium and ammonia nitrate showed no positive exceedance of the post-harvest concentrations once impacts due to variable precipitation were taken into account. However, in the analysis of separate sites, it was found that Mg and NH_3-N tend to increase (up to 30%), when no SMZs were used.

- Total nitrogen (TN) and total phosphorous (TP) showed no change indicating that timber harvesting has no effect on these water quality parameters. No change might be a result of harvest methods, i.e., the harvest area was covered with biomass thereby holding nutrients and sediments from erosion and transport .

- Excluding effects other than harvest on water quality, TSS showed a 4% (4 percent chance that post-harvest concentration will exceed pre-harvest concentration) probability of exceedance of 4%, while TVSS had a PoE of 13%.

- TSS concentrations above MDC's limit (0.2-0.5 g/L) had a PoE of 5%. All other water quality parameters, except ammonia nitrate, had a PoE under 6.7%.

- TSS and TVSS concentrations increased slightly during the first year after harvest, thereafter demonstrated a trend toward stability.

- Minerals and phosphorus tended to increase after harvest while nitrogen decreased after harvest.

- TSS concentration tended to increase from the head (top) to toe (bottom) in a watershed in unharvested sites but decreased from head (top) to toe (bottom) in the harvested sites.

- Best management practice seemed to be effective; in the case of the Current river conservation area, where streamside management zone of tree buffers was removed during harvesting of trees, the probability of exceedance tended to be higher for almost all water quality parameters.

- Much of the increase of the concentration seemed to have come from other factors, i.e., season, rainfall, aspect and slope etc, which are accounted for in the comparison of the harvested sites with the control sites. The positive exceedance from those factors (other-than-harvest effects) for TSS was 21%, even in control sites.

7.3 Recommendations

- Continue water sampling from all fifteen sites, if possible, to add to the database, especially post-harvest water samples.

- Post-harvest samples were collected for about two years. Post-harvest samples should be collected over a larger time period to allow comparison of the results over multiple years.

- It is important to instrument downstream of the harvest area to understand the “beyond-site” effect of timber harvest.

- A few sites should be monitored with the automatic samples and data loggers
- The extreme concentrations for some water quality parameters from a sampling event should be investigated more closely with respect to the characteristics of the "events", i.e., rainfall influence, flow intensity, prolonged period of wet soil, seasonal effects etc.
- The research only evaluated the concentrations, future work should be directed towards evaluating mass flux (Concentration* flow rate).
- Since the sites acquire tree tops, branches and other biomass after harvest, the effect of biomass in cut sites should be critically analyzed on the ground, that a recommend could be made to MDC about their harvest process (all biomass vs bald site) to answer what happens after the biomass is completely removed.
- The current study focused on stream side management zones only however, anecdotal observations of the logging roads and skidder trails indicated substantial sediment and nutrients contribution from them. The logging roads and trails should be given a priority consideration for future study in the area.
- Further analysis of the existing data can be performed with respect to precipitation and soil moisture characteristics, site size (drainage basin and harvest area) and basal area of harvest.

LIST OF APPENDICES

APPENDIX A: LAB PROCEDURE FOR DETERMINING WATER QUALITY PARAMETERS

Procedure for determining Ammonia-Nitrate

Adapted from:
Methods for the Chemical Evaluation of Waste Water. MCWW[3] 351.2. Salicylate Method. And changed with regard to Hach Method 8155.

Introduction
In solution, ammonia combines with chlorine to form monochloramine which then reacts with salicylate to form 5-amoinosalicylate. This chemical is oxidized by sodium nitroprusside to form a blue color which is masked by the yellow color of excess reagent to form a green color which is then analyzed colorimetrically by the Spectron 20D+.

Chemicals

Ammonia Cyanurate Powder Pillows. . . cat no. 26531-99
Ammonia Salicylate Powder Pillows. . . cat no. 26532-99
Ammonium Chloride

Operating Notes:

1. All glassware and sample holders must be cleaned by a sulfuric acid bath
2. Refrigerate samples at 4°C until they are run. If they will not be run within 24 hours, add 5 drops of 100% sulfuric acid per 100 ml. Usually we freeze samples so the sample must be totally thawed out before the sample for analyses can be poured. Freezing of samples has been shown to minimize degradation for years if needed.
3. Use DI water or better for the preparation of stocks, standards, and reagents.
4. Operate colorimeter using a 655 nm filter. Set machine to red filter.
5. If color is present analyze sample before the addition of reagents to establish a baseline reading and then after. The difference between the two readings is the reading that must be used for the amount of nitrogen that is present. Set the spectrophotometer to absorbance mode. After both pillows are added decant mixed sample into another vial. This is to prevent the particles from getting sucked into the sampling tube.
6. 1.572 g of ammonia chloride are needed to make 0.4 g/L $NH3-N$
7. Add 10 mls of sample and add the salicylate pillow first and then add the cyarurate pillow a few minutes later. Wait 20 minutes for analyzing.

Procedure for Determining Total Suspended Solids (TSS)

Adapted From:
2540 C. Total Solids Dried at 180°C Standard Methods for the Examination of Water and Wastewater, 1992

Introduction
In this procedure, solids are collected from samples by filtering the sample through a glass fiber filter and then dried.

Materials

A 1000 ml vacuum flask
A glass fiber filter of 0.45 µm pore size
An oven capable of temperature above 100°C
A holding container for the filter

Operating Notes:

1. The filters must be washed, dried and then weighed. Washing includes either (1) holding the filter with tongs and then washing the filter with DI water (2) floating the filters in a container with DI water.

2. The sample that will be filtered must be completely thawed out. To enhance thawing a hot water bath can be used.

3. Pour 100 ml of sample through filter.

4. Place the filter in the holding container

5. Pour the filtrate into the “dissolved” plastic container (60 ml Nalgene bottle)

6. Wash all parts of the filtering apparatus with DI water three times

7. Every five samples use a filter blank

Procedure for Fixed and Volatile Solids Ignited at 500^{o}C (TVSS)

Adapted From:
2540 E. Fixed and Volatile Solids Ignited at 500^{o}C Standard Methods for the Examination of Water and Wastewater, 1992

Introduction
In this procedure, filters are burned at 500^{o}C in order to ascertain the amount of volatile and fixed samples are in the collected sample.

Materials

A glass fiber filter of 0.45 um pore size
An oven capable of temperature above 500^{o}C
A holding container for the filter
A balance capable of 0.0000 g

Operating Notes:

1. Place filter and holder into blast furnace at 500^{o}C

2. Leave overnight

3. Re-weigh

Procedure for determining Nitrate and Total Nitrogen after alkaline persulfate digestion

Adapted from:
APHA 1992. 4500-NO3 E. Cadmium Reduction method in Standard Methods for the Examination of Water and Wastewater 18th edition. American Public Health Association. 1992. Also utilizing Hach method 8192 (Powder pillows)

Introduction
In this procedure nitrate is reduced to nitrite in the presence of cadmium. The nitrite produced is determined by diazotizing with sulfanilamide and coupling with N-(1-napthyl)-ethylenediamine dihydrochloride to form a highly colored dye that is measured.

Chemicals

NitraVer 6 Nitrate Powder Pillows. . . cat no. 21072-49
NitraVer 3 Nitrite Powder Pillows. . . cat no. 21071-69
Potassium nitrate for standards

Operating Notes:

1 All glassware and sample holders must be cleaned by a sulfuric acid bath
2 Refrigerate samples at 4°C until they are run. If they will not be run within 24 hours, add 5 drops of 100% sulfuric acid per 100 ml. Usually we freeze samples so the sample must be totally thawed out before the sample for analyses can be poured. Freezing of samples has been shown to minimize degradation for years if needed.
3 Use DI water or better for the preparation of stocks, standards, and reagents.
4 Operate colorimeter using a 543 nm filter. Set machine to white filter.
5 If color is present analyze sample before the addition of reagents to establish a baseline reading and then after. The difference between the two readings is the reading that must be used for the amount of nitrogen that is present. Set the spectrophotometer to absorbance mode.
6 Potassium nitrate is used for standards. To make a 800 mg/L standard, use 1.305 g of potassium nitrate
7 Pour 10 mls out of sample container. Add Nitrate pillows wait a few minutes then add nitrite pillows and wait for 20 minutes

Procedure for determining Dissolved Phosphorous or Total Phosphorous following alkaline persulfate digestion

Adapted from:
APHA 1992. 4500-P E. Ascorbic Acid Method in Standard Methods for the Examination of Water and Wastewater 18th edition. American Public Health Association. 1992.

Introduction
In this procedure phosphate reacts with ammonium molybdate and potassium antimonyl tartrate to form antimony-phosphomolybdate complex, which reacts with ascorbic acid to form a blue colored solution whose color is proportional to the initial phosphorous concentration of the sample.

Chemicals (ACS grade or equivalent)

Potassium antimonyl tartrate
Ammonium molybdate
Ascorbic acid
Sulfuric Acid
Potassium phosphate monobasic anhydrous (standards)

Operating Notes:

1. All glassware and sample holders must be cleaned by a sulfuric acid bath
2. Refrigerate samples at 4°C until they are run. If they will not be run within 24 hours, add 5 drops of 100% sulfuric acid per 100 ml. Usually we freeze samples so the sample must be totally thawed out before the sample for analyses can be poured. Freezing of samples has been shown to minimize degradation for years if needed.
3. Use DI water or better for the preparation of stocks, standards, and reagents.
4. Operate colorimeter using a 650 nm filter. Set machine to red filter.
5. Use potassium phosphate for standards. For 300 mg/L of phosphate use 1.321g of potassium phosphate. Dilute to reach standards that are in range of sample concentrations. A 1 mg/L, a 0.1 mg/L and a 0.02 mg/L standard is made.
6. If color is present analyze sample before the addition of reagents to establish a baseline reading and then after. The difference between the two readings is the reading that must be used for the amount of phosphate that is present. Set the spectrophotometer to absorbance mode.
7. Take 10 mls from sample container add mixed reagent and wait for 20 minutes

Preparation of Reagents

Dilute Sulfuric Acid

	1L
Concentrated Sulfuric Acid	140 ml
DI water	860 ml

Initially place DI water into volumetric flask; slowly add concentrated sulfuric acid to water while stirring. Allow to cool and store in room temperature or refrigerator. Good for about 1 year.

Potassium antimonyl tartrate solution

For 100 ml: add 0.3g Potassium antimonyl tartrate (same as antimonyl potassium tartrate) to approximately 50 ml DI water. Dissolve and dilute to 100 ml. Store refrigerated. The solution is stable for three months. Proportionately adjust mixture for varying volumes.

Ammonium molybdate solution

For 100 ml: Add 4g ammonium molybdate to approximately 50 ml DI water. Dissolve and dilute to 100 ml. Store refrigerated. The solution is stable for three months. Proportionately adjust mixture for varying volumes.

Ascorbic acid solution

For 100 ml: Add 1.76g ascorbic acid to approximately 50 ml DI water. Dissolve and dilute to 100 ml. Store refrigerated. The solution is stable for about 1 month. Proportionately adjust mixture for varying volumes.

Combined Reagent

For 100 ml: Add in order; 50 ml Dilute Sulfuric acid, 5 ml potassium antimonyl tartrate solution, 15 ml ammonium molybdate solution and 30 ml ascorbic acid solution. Mix well by swirling after adding each solution. Mix fresh daily.

1. Each tray should have a blank at the beginning, followed by a high standard and two other lower standards. The end of the tray should have a Hach standard. Although the Hach standard reads 1 mg/L PO4, since we are testing for phosphate the concentration is really 0.326 mg/L.

Potassium Persulfate Digestion for use before Analyzing Total Phosphorous and Total Nitrogen

Potassium persulfate digestion, method APHA Method 4500-N C, is required for digestion of total phosphorous and total nitrogen. The samples are digested together as outlined by Ebina, Tsutsui, and Shirai (1983). This technique of digestion oxidizes all nitrogenous compounds to nitrate at 100°C. The method is important for phosphorous because phosphorous may occur in combination with organic matter; and, digestion releases the phosphorous in its orthophosphate form

Mix 20.5 g of potassium persulfate and 3.0 g of sodium hydroxide in 1000 ml of DI water
Mixture takes a long time to mix therefore a sonicator can assist in mixing the solution
A daily mixture must be made to properly digest the sample

Mix 10 ml of sample with 2.2 ml of digestion mixture

The mixture is placed in an autoclave for 30 minutes at 98 – 137 kPa.

Standards must be analyzed with each batch of samples digested. The standards analyzed will be of equal concentrations that are analyzed for the dissolved nutrients – nitrate and soluble reactive phosphorous.

A glutamic acid standard will be analyzed for digestion quality -

Digestion tape is used to verify proper digestion conditions in the autoclave

APPENDIX B: PRE-HARVEST WATER QUALITY SAMPLES ALL PARAMETERS

Table B.1- Pre-harvest water quality parameters and concentration for Oct. 2004 and Jan. 2005

Date	Site	Sampler ID	pH	EC (µs/cm)	TSS (g/L)	Ca (mg/L)	Mg (mg/L)	K (mg/L)	TP (mg/L)	SRP (mg/L)	NH3-N(mg/L)	NO3 (mg/L)	TN (mg/L)
10/12/2004	CR7-5C	ST3	6.12	70.8	0.11	9.3	0.4	3.29	0.01	0.01	0.03	0.05	1.02
10/12/2004	CR11-3	WS1-0	6.56	52.43	0.07	7.6	0.9	3.19	0.02	0.02	0.00	0.08	0.75
10/12/2004	CR11-3	WS1-0	6.42	49.8	0.05	8.5	0.9	3.46	0.45	0.45	1.02	0.07	1.10
12/14/2004	CR7-2	WS1-0	8	120.1	0.11	8.4	5.2	1.03	0.04	0.01	0.02	0.02	1.07
12/14/2004	CR7-2	GRAB	7.36	244	0.002	17.7	6.2	0.77	0.01	0.00	0.02	0.02	0.04
12/14/2004	CR7-5B	WS1-0	6.32	23.1	0.014	0.7	0.4	0.44	0.04	0.04	0.12	0.02	2.34
12/14/2004	CR7-5C	ST5	6.65	32.4	0.046	2.5	0.5	6.41	0.17	0.04	0.02	0.04	0.47
12/14/2004	CR7-6	WS2-0	7.74	12.11	0.014	0.5	0.2	2.55	0.04	0.02	0.02	0.02	0.84
12/14/2004	CR11-1	WS4-0	7.39	16.3	0.012	1.1	0.5	0.76	0.23	0.01	0.03	0.02	1.68
12/14/2004	CR11-1	WS5-0	7.35	34.4	0.009	2.3	0.4	0.93	0.02	0.01	0.17	0.04	0.45
12/14/2004	CR11-3	WS1-0	7.03	38	0.084	3.2	1.6	1.99	0.01	0.01	0.02	0.02	0.82
12/14/2004	CR11-3	WS3-0	7.25	170.3	0.026	0.7	0.3	0.41	0.61	0.03	0.08	0.04	2.98
1/10/2005	A27-2	WS3-0	5.47	18.22	0.025	1	0.8	1.28	0.09	0.08	0.29	0.00	1.17
1/10/2005	A34-1	WS4-0	6.72	26.7	0.047	1.4	1.4	0.37	0.02	0.02	0.02	0.01	0.04
1/10/2005	A34-1	WS6-0	6.22	14.45	0.022	0.7	0.6	0.24	0.03	0.02	0.01	0.00	0.10
1/10/2005	A34-1	WS7-0	6.88	28.8	0.009	1.7	0.9	1.46	0.05	0.01	0.01	0.69	1.09
1/10/2005	A34-1	WS7-3	7.34	22.5	0.09	1.2	1.2	0.28	0.03	0.02	0.02	0.01	0.50
1/10/2005	A34-1	WS7-6	7.21	25.2	0.068	1.1	1.1	0.49	0.02	0.02	0.01	0.01	0.21
1/10/2005	A34-1	WS8-0	6.84	27	0.019	1.4	1.6	0.28	0.02	0.02	0.00	0.03	0.53
1/10/2005	A34-1	WS8-3	7	26.4	0.028	1.2	1.3	0.3	0.02	0.01	0.00	0.01	0.04
1/10/2005	A34-1	WS8-6	7.19	25	0.015	1.2	1.4	0.28	0.02	0.02	0.01	0.02	0.06
1/10/2005	A34-1	WS9-0	6.83	24.2	0.021	1.8	1.1	0.35	0.03	0.01	0.09	0.02	0.11
1/10/2005	A34-1	WS10-0	6.54	19.7	0.073	1	0.8	0.41	0.04	0.02	0.03	0.03	0.08
1/10/2005	A34-1	GRAB	6.46	36.8	0.034	2.2	2	0.26	0.02	0.00	0.01	0.02	0.23
1/10/2005	A34-2	WS2-0	6.08	22.3	0.03	1.7	0.9	0.38	0.01	0.01	0.01	0.11	0.86
1/10/2005	CR7-2	WS1-0	7.12	99.3	0.081	3.3	5.8	0.31	0.02	0.02	0.01	0.01	0.12
1/10/2005	CR7-2	ST4	7.12	91.6	0.178	10.5	0.7	0.26	0.31	0.30	0.02	2.13	2.16
1/10/2005	CR7-5C	ST3	7.56	4.16	0.044	0.1	0.1	0	0.09	0.08	0.01	0.01	3.87
1/10/2005	CR7-6	WS5-0	7.5	17.87	0.073	1.4	0.7	0.22	0.03	0.03	0.01	0.00	1.09
1/10/2005	CR7-6	WS6-0	7.2	57.1	0.042	3.5	3.3	1.62	0.02	0.02	0.00	0.01	0.09
1/10/2005	CR7-6	WS6-3	7.85	44.4	0.007	2.4	2.7	0.59	0.20	0.09	0.01	0.01	0.10
1/10/2005	CR7-6	WS6-6	7.31	44.8	0.031	3.1	2.9	0.37	0.07	0.01	0.00	0.02	0.11
1/10/2005	CR7-6	WS8-0	7.84	236	0.135	7.1	13.2	0.22	0.04	0.00	0.01	0.00	0.25
1/10/2005	CR11-1	WS2-0	7.09	36.3	0.031	1.1	0.8	3.97	0.57	0.06	0.01	0.00	1.20
1/10/2005	CR11-1	WS5-0	7.41	17.26	0.015	0.9	0.7	0.35	0.09	0.08	0.01	0.01	0.17
1/10/2005	CR11-3	WS3-0	6.73	34.1	0.021	2.2	1.9	0.28	0.01	0.01	0.03	0.00	0.16
1/10/2005	CR11-9	WS1-0	7.49	160.1	0.008	9.3	7.2	2.78	0.03	0.02	0.04	0.05	0.11
1/19/2005	A17-2	WS1-0	6.83	45.5	0.067	2.1	1.1	0.38	0.26	0.01	0.01	0.01	0.03
1/19/2005	A17-2	WS2-0	6.37	16.87	0.032	1.4	0.6	0.52	0.01	0.01	0.01	0.01	0.05
1/19/2005	A25-2	ST3	6.49	26.5	0.051	2.4	0.4	1.39	0.06	0.05	0.79	0.03	0.85
1/19/2005	A34-1	WS1-0	5.51	20.7	0.023	3	0.7	1.05	0.56	0.01	0.00	0.40	0.06
1/19/2005	A34-1	WS4-0	6.22	10.82	0.009	0.8	0.4	0.15	0.01	0.00	0.00	0.01	1.48
1/19/2005	A34-1	WS6-0	5.43	10.32	0.022	0.8	0.6	0.23	0.25	0.00	0.00	0.04	0.30
1/19/2005	A34-1	WS7-0	6.72	33.4	0.046	1.2	1.1	0.38	0.37	0.00	0.00	0.01	0.33

Table B.2- Pre-harvest water quality parameters and concentration for Jan. 2005

Date	Site	Sampler ID	pH	EC (µs/cm)	TSS (g/L)	Ca (mg/L)	Mg (mg/L)	K (mg/L)	TP (mg/L)	SRP (mg/L)	NH3-N(mg/L)	NO3 (mg/L)	TN (mg/L)
1/19/2005	A34-1	WS7-3	6.56	23.1	0.015	2.6	1.2	0.35	0.27	0.00	0.00	0.02	0.07
1/19/2005	A34-1	WS7-6	6.37	21.4	0.01	1.1	1.1	0.23	0.38	0.00	0.00	0.02	4.92
1/19/2005	A34-1	WS8-0	6.67	21.9	0.036	1.5	1.2	0.39	0.26	0.00	0.00	0.01	0.13
1/19/2005	A34-1	WS8-3	6.96	27.6	0.032	1.2	1.3	0.34	0.02	0.01	0.01	0.01	0.47
1/19/2005	A34-1	WS8-6	6.57	22.3	0.014	1.1	1.2	0.3	0.01	0.01	0.01	0.01	0.11
1/19/2005	A34-1	WS9-0	6.91	39.1	0.52	1.7	1.2	0.51	0.01	0.00	0.00	0.01	0.26
1/19/2005	A34-1	WS9-3	6.52	22.3	0.067	2.8	1.4	0.97	0.01	0.00	0.03	0.01	0.21
1/19/2005	A34-1	WS10-0	6.37	16.87	0.071	1.2	0.7	0.24	0.01	0.01	0.00	0.02	1.10
1/19/2005	A34-1	WS10-6	6.45	17.92	0.028	2	1.8	0.22	0.17	0.00	0.00	0.02	3.66
1/19/2005	A34-2	WS2-0	6.09	20.7	0.095	1.4	0.6	0.41	0.28	0.02	0.02	0.06	0.13
1/19/2005	A34-2	WS3-0	6.06	18.9	0.101	2.4	0.7	0.3	0.02	0.02	0.03	0.03	0.03
1/19/2005	A34-2	WS4-0	5.48	20.2	0.041	0.7	0.9	0.63	0.15	0.03	0.09	0.01	0.06
1/19/2005	A34-2	WS4-6	6.76	24.1	0.028	1.5	0.6	0.21	0.01	0.01	0.01	0.02	0.13
1/19/2005	A34-2	WS5-0	8.93	87.1	0.043	5	5.2	0.86	0.01	0.01	0.00	0.01	0.10
1/19/2005	A34-2	WS6-0	6.82	76.4	0.067	4.1	5	0.31	0.01	0.01	0.01	0.01	0.02
1/19/2005	A34-2	WS6-3	8.62	68.6	0.037	5	4.8	0.47	0.01	0.01	0.00	0.02	0.21
1/19/2005	CR7-2	WS1-0	7.84	62.4	0.254	7.5	9.2	0.47	0.01	0.01	0.01	0.10	0.35
1/19/2005	CR7-2	WS3-0	6.32	17.53	0.016	1.3	0.4	0.64	1.17	0.02	0.06	0.01	1.46
1/19/2005	CR7-2	WS3-3	7.62	69.6	0.169	5.2	1.1	8.67	1.01	0.72	0.28	0.00	1.32
1/19/2005	CR7-2	WS6-0	6.73	127.3	0.032	5.2	1.6	0.53	0.09	0.03	0.06	0.01	0.42
1/19/2005	CR7-2	WS6-6	7.11	46.5	0.042	2.7	2.7	0.55	0.23	0.06	0.01	0.01	0.56
1/19/2005	CR7-5B	WS1-0	6.41	18.04	0.063	1.3	0.6	0.75	0.12	0.05	0.03	0.02	0.25
1/19/2005	CR7-5B	WS3-0	6.11	16.6	0.038	1.2	0.5	0.93	0.05	0.04	0.09	0.01	0.25
1/19/2005	CR7-5B	WS4-0	6.7	11.72	0.114	0.9	0.3	0.33	0.13	0.10	0.06	0.01	0.08
1/19/2005	CR7-5B	WS4-3	6.33	18.11	0.059	1.5	0.6	0.88	0.06	0.05	0.03	0.04	2.41
1/19/2005	CR7-5C	WS1-0	6.66	5.78	0.302	0.6	0.2	0.05	0.16	0.01	0.03	0.01	2.48
1/19/2005	CR7-5C	WS5-0	6.82	17.72	0.091	1.3	0.7	0.61	0.14	0.05	0.03	0.02	2.75
1/19/2005	CR7-5C	WS5-3	6.78	17.95	0.045	1.2	0.6	0.66	0.06	0.00	0.05	0.02	0.16
1/19/2005	CR7-5C	ST4	5.83	23.8	0.052	0.8	0.3	1.5	0.03	0.09	0.37	0.22	0.58
1/19/2005	CR7-6	WS4-0	5.6	13.32	0.023	0.6	0.4	0.84	0.28	0.04	0.02	0.02	0.93
1/19/2005	CR7-6	WS5-0	5.9	12.62	0.256	0.8	0.5	0.33	0.34	0.05	0.03	0.01	0.56
1/19/2005	CR7-6	ST4	6.92	118	0.186	12	2.3	4.26	0.03	0.08	0.03	0.65	0.69
1/19/2005	CR11-1	WS2-0	6.52	18.55	0.03	1.2	0.7	0.5	0.12	0.03	0.06	0.01	0.20
1/19/2005	CR11-1	WS3-0	6.03	6.94	0.04	0.4	0.3	0.12	0.03	0.03	0.03	0.01	0.09
1/19/2005	CR11-1	WS4-0	7.2	17.55	0.039	1	0.7	0.44	0.03	0.03	0.02	0.00	0.15
1/19/2005	CR11-1	WS5-0	6.33	14.15	0.295	0.8	0.5	0.43	0.13	0.13	0.13	0.01	0.42
1/19/2005	CR11-3	WS1-0	6.89	26	0.142	2.2	1.2	0.82	0.08	0.02	0.00	0.00	0.02
1/19/2005	CR11-3	WS2-0	7.23	9.96	0.016	1.2	0.5	0.03	0.22	0.22	0.02	0.01	4.26
1/19/2005	CR11-3	WS3-0	6.82	27.5	0.14	1.7	1.4	0.27	0.07	0.03	0.05	0.00	5.04
1/19/2005	CR11-3	WS3-3	7.11	43.1	0.059	2.2	1.3	2.57	1.56	1.37	1.55	0.18	1.82
1/19/2005	CR11-3	WS3-6	6.83	20.1	0.047	2	1.2	0.9	0.21	0.14	0.00	0.21	1.95
1/19/2005	CR11-9	WS1-0	7.56	53.9	0.018	1.3	0.9	0.48	0.32	0.01	0.11	0.13	0.62
1/19/2005	CR11-9	WS1-3	8.52	109.5	0.082	8	4.8	3.16	0.29	0.01	0.00	0.02	1.01
1/19/2005	CR11-9	WS3-0	7.12	21.1	0.047	1.2	1	0.88	0.06	0.05	0.10	2.33	6.50
2/14/2005	A17-1	WS3-0	5.91	15.66	0.026	1.7	0.7	0.29	0.02	0.00	0.03	0.00	0.30

Table B.3- Pre-harvest water quality parameters and concentration for Feb., Apr. and May 2005

Date	Site	Sampler ID	pH	EC (µs/cm)	TSS (g/L)	Ca (mg/L)	Mg (mg/L)	K (mg/L)	TP (mg/L)	SRP (mg/L)	NH3-N(mg/L)	NO3 (mg/L)	TN (mg/L)
2/14/2005	A27-2	WS6-0	7.91	143.1	0.389	8.6	3.3	0.38	0.20	0.01	0.05	0.01	1.06
2/14/2005	A27-2	WS7-0	8.35	118.6	0.24	6.9	1.5	0.36	0.08	0.01	0.04	0.01	0.14
2/14/2005	A27-2	GRAB	8.52	135.1	0.35	7.8	2.7	0.28	0.40	0.01	0.12	0.01	0.18
2/14/2005	A34-1	WS4-0	7.02	17.86	0.12	1.9	0.5	0.49	0.31	0.02	0.04	0.09	0.37
2/14/2005	A34-1	WS5-0	5.61	22.5	0.017	1.5	0.9	0.2	0.15	0.04	0.03	0.03	0.16
2/14/2005	A34-1	WS5-3	6.01	20.8	0.021	1.2	0.8	0.4	0.23	0.00	0.13	0.03	0.54
2/14/2005	A34-1	WS7-0	6.91	34.3	0.023	2.3	1.8	0.27	0.51	0.01	0.06	0.00	0.07
2/14/2005	A34-1	GRAB	6.93	31.4	0.19	2.1	2.4	0.32	0.04	0.01	0.05	0.00	0.06
2/14/2005	A34-1	WS8-0	6.91	36.3	0.559	1.8	1.9	0.35	0.16	0.00	0.05	0.00	0.47
2/14/2005	A34-1	WS9-0	6.95	25.6	0.37	2	1	0.34	0.22	0.01	0.05	0.02	0.25
2/14/2005	A34-1	WS10-0	6.51	21.5	0.12	1.3	0.8	0.5	0.22	0.21	0.04	1.85	1.89
2/14/2005	A34-1	ST1	8	82.7	0.58	10.5	0.8	0.35	0.73	0.01	0.59	0.03	0.62
2/14/2005	A34-2	WS6-0	8.31	106.2	0.028	7.4	2.1	0.17	0.15	0.01	0.01	0.03	2.93
2/14/2005	A34-2	SPRING	7.78	196.1	0.037	11.4	4.2	0.41	0.24	0.02	0.28	0.02	0.38
2/14/2005	CR7-5C	ST4	6.75	6.17	0.031	1.1	0.4	0.17	0.37	0.09	0.36	0.04	0.32
2/14/2005	CR7-6	WS2-0	5.64	4.22	0.47	0.8	0.2	0.04	0.34	0.01	0.07	0.01	0.41
2/14/2005	CR7-6	WS5-0	6.43	17.19	1.14	1.7	0.7	0.35	0.43	0.08	0.32	0.02	0.43
4/17/2005	A17-1	ST1	6.88	51.6	0.01	4.6	1.4	1.05	0.17	0.11	0.01	1.42	1.49
4/17/2005	A17-1	ST5	6.89	46.8	0.06	4.7	0.8	2	0.12	0.12	0.05	0.18	0.85
4/17/2005	A17-2	ST1	6.86	11.07	0.5	9.9	1.1	1.81	1.03	0.82	1.23	0.06	1.33
4/17/2005	A17-2	WS1-0	7.46	61.5	0.04	2.9	1.2	1.93	0.26	0.01	0.08	0.00	0.14
4/17/2005	A25-3	GRAB	7.55	223	0.02	5.7	15.2	0.38	0.05	0.00	0.00	0.00	3.26
4/17/2005	A25-3	WS3-0	9.21	214	0.4	5.3	12.8	0.28	1.99	0.05	0.04	0.00	0.37
4/17/2005	A27-1	ST3	6.89	37.3	0.06	3.6	0.7	0.75	1.17	0.08	0.00	0.00	0.14
4/17/2005	A27-1	ST5	6.89	18	0.012	5.5	1	0.38	0.12	0.04	0.39	0.02	0.81
4/17/2005	A34-1	ST5	6.33	47	0.025	4.7	1.1	1.39	0.10	0.09	0.23	0.03	1.52
4/17/2005	A34-2	ST5	6.85	83.6	0.065	8.6	1.3	1.55	2.22	0.02	0.06	0.17	0.81
4/17/2005	CR7-2	WS1-0	7.65	91.8	0	3.7	5.2	0.65	1.30	0.03	0.04	0.00	0.78
4/17/2005	CR7-5C	ST2	7.31	63.5	0.549	6.3	0.5	0.33	0.43	0.33	0.00	0.26	0.33
4/17/2005	CR7-5C	ST3	6.66	39.6	0.089	3.4	1.3	0.95	0.48	0.37	0.00	0.12	3.35
4/17/2005	CR7-5C	ST4	5.76	34.1	0.04	3.6	1.6	1.6	0.23	0.23	0.00	0.03	0.31
4/17/2005	CR7-5C	ST5	6.47	51.9	0.06	5.1	0.9	1.92	0.20	0.16	0.00	0.25	0.37
4/17/2005	CR7-6	ST3	6.78	52.5	0.1	5.4	1.8	1.04	0.37	0.37	0.07	0.01	0.24
5/14/2005	A17-1	ST1	6.26	85.7	0.027	5.6	1	11.95	1.00	1.00	0.14	0.02	4.54
5/14/2005	A17-2	WS1-0	6.66	51.6	0.038	2.7	1.1	1.87	0.15	0.09	0.22	0.08	2.00
5/14/2005	A17-2	ST2	6.22	66.2	0.012	8.3	1	6.05	0.29	0.04	0.00	0.09	1.15
5/14/2005	A17-2	ST5	6.75	432	0.015	4.7	1	12.78	0.33	0.08	1.60	0.11	1.82
5/14/2005	A17-2	ST1	6.41	66.5	0.031	4	0.8	13.01	0.26	0.24	3.59	0.00	4.26
5/14/2005	A17-2	ST3	6.49	114.9	0.011	5.8	4.8	4.2	1.61	1.21	1.28	0.12	4.43
5/14/2005	A25-2	ST1	6.07	113	0.037	7.7	1.8	13.94	0.28	0.20	2.20	0.17	3.04
5/14/2005	A27-1	WS3-0	8.23	382	0.316	6	1	5.32	0.10	0.06	0.23	0.07	1.19
5/14/2005	A27-1	WS4-0	7.92	241	0.087	13.5	25	1.02	0.66	0.26	0.11	0.18	0.61
5/14/2005	A27-1	WS7-0	7.82	186.2	0.013	9.9	16	1.07	0.28	0.12	0.11	0.00	1.21
5/14/2005	A27-1	ST1	6.26	49.2	0.058	11.5	2	0.47	0.28	0.17	0.78	0.08	10.04
5/14/2005	A27-2	ST3	6.82	133.2	0.014	6.2	1.2	8.2	0.03	0.01	0.28	0.08	3.75

Table B.4- Pre-harvest water quality parameters and concentration for May and June 2005

Date	Site	Sampler ID	pH	EC (µs/cm)	TSS (g/L)	TVSS (g/L)	Ca (mg/L)	Mg (mg/L)	K (mg/L)	TP (mg/L)	SRP (mg/L)	NH3-N(mg/L)	NO3 (mg/L)	TN (mg/L)
5/14/2005	A27-2	ST1	6.46	90.9	0.025		5.8	0.8	6.8	1.16	0.58	0.14	0.31	1.16
5/14/2005	A27-2	ST2	6.47	80.9	0.019		4.7	2.5	7.2	0.33	0.23	0.28	0.01	1.79
5/14/2005	A27-2	WS6-0	7.42	263	0.02		6.2	1.8	4.9	0.24	0.03	0.09	0.00	0.24
5/14/2005	A34-1	WS3-0	6.82	87.9	0.006		12.2	1.5	5.8	0.91	0.82	0.57	0.00	0.70
5/14/2005	A34-1	ST3	6.45	186.2	0.046		4.8	2.2	4.5	0.79	0.60	3.57	0.02	4.79
5/14/2005	A34-2	WS4-0	7.32	25.2	0.133		6.2	4.8	5.8	0.75	0.68	0.56	0.07	1.08
5/14/2005	CR7-2	ST4	6.92	53.9	0.033		5	1	3.92	0.35	0.32	0.52	0.97	3.05
5/14/2005	CR7-2	ST3	6.82	98	0.044		5.2	1.9	15.98	1.08	0.52	1.63	0.16	2.14
5/14/2005	CR7-5B	ST3	6.35	23	0.022		2.9	0.9	2.76	0.85	0.25	0.12	0.06	1.89
5/14/2005	CR7-5C	ST2	6.12	51.8	0		3.2	1.4	7.51	0.32	0.30	0.05	0.02	0.12
5/14/2005	CR7-5C	ST3	6.61	34.2	0.039		2.3	0.72	8.95	1.07	0.83	2.00	0.01	2.41
5/14/2005	CR7-5C	ST5	6.19	46.6	0.009		1.3	0.7	8.4	0.83	0.80	2.71	0.06	3.38
5/14/2005	CR7-6	ST4	6.17	46.9	0.025		3.5	1.2	7.96	0.62	0.46	0.04	0.03	1.08
5/14/2005	CR11-1	ST5	6.08	41.1	0.019		3.1	0.8	6.12	0.36	0.13	0.03	0.06	1.05
5/14/2005	CR11-1	ST1	6.45	57.9	0.028		5.3	1.1	5.93	0.50	0.43	0.25	0.08	1.66
5/14/2005	CR11-1	ST3	6.43	33.6	0.056		3.2	0.7	3.58	0.51	0.30	0.00	0.11	5.57
5/14/2005	CR11-9	WS1-0	8.31	149.1	0.094		14	28	3.88	0.29	0.22	0.66	0.02	1.21
6/20/2005	A17-1	ST5			0.932	0.361								
6/20/2005	A17-2	ST1			0.336	0.236								
6/20/2005	A17-2	ST2			0.162	0.104								
6/20/2005	A17-2	ST3			0.354	0.271								
6/20/2005	A17-2	ST5			0.336	0.08								
6/20/2005	A25-2	ST5			0.036	0.023								
6/20/2005	A25-2	ST4			0.126	0.01								
6/20/2005	A25-2	ST1			0.064	0.06								
6/20/2005	A25-2	ST4			0.02	0.022								
6/20/2005	A27-1	ST5			0.017	0.008								
6/20/2005	A27-2	ST2			0.097	0.072								
6/20/2005	A27-2	ST1			0.053	0.043								
6/20/2005	A27-2	WS6-0			0.014	0.003								
6/20/2005	A34-1	ST3			0.014	0.007								
6/20/2005	A34-1	ST5			0.161	0.023								
6/20/2005	A34-2	ST2			0.07	0.056								
6/20/2005	A34-2	ST5			0.368	0.025								
6/20/2005	A34-2	ST1			0.07	0.006								
6/20/2005	CR7-2	ST4			0.174	0.015								
6/20/2005	CR7-2	ST4			0.012	0.08								
6/20/2005	CR7-5C	ST3			0.039	0.027								
6/20/2005	CR7-5C	ST5			0.031	0.001								
6/20/2005	CR7-6	ST3			0.218	0.033								
6/20/2005	CR7-6	ST2			0.012	0.009								
6/20/2005	CR7-6	ST4			0.07	0								
6/20/2005	CR11-1	ST2			0.117	0.075								
7/20/2005	A25-2	ST1			0.004	0.002								
7/20/2005	A25-2	ST4			0.007	0.003								

NO DATA AVAILABLE

Table B.5- Pre-harvest water quality parameters and concentration for July and Aug. 2005

Date	Site	Sampler ID	pH	EC (µs/cm)	TSS (g/L)	TVSS (g/L)	Ca (mg/L)	Mg (mg/L)	K (mg/L)	TP (mg/L)	SRP (mg/L)	NH3-N(mg/L)	NO3 (mg/L)	TN (mg/L)
7/20/2005	A25-2	ST4			0.007	0.003								
7/20/2005	A25-2	ST5			0.003	0								
7/20/2005	A25-3	ST1			0.003	0								
7/20/2005	A25-3	ST4			0.006	0								
7/20/2005	A27-2	ST1			0	0								
7/20/2005	A27-2	ST2			0.008	0.001								
7/20/2005	A34-1	ST1			0.051	0.011								
7/20/2005	A34-1	ST3			0.02	0.008								
7/20/2005	A34-1	CONT			0.003	0								
7/20/2005	A34-2	ST4			0.001	0								
7/20/2005	CR7-5B	ST1			0.004	0								
7/20/2005	CR7-5B	ST5			0.013	0.007								
7/20/2005	CR7-5B	CONT			0.008	0.006								
7/20/2005	CR7-5C	ST1			0.019	0.01								
7/20/2005	CR7-5C	ST3			0.023	0.013								
7/20/2005	CR7-5C	ST4			0.001	0								
7/20/2005	CR7-5C	ST5			0.025	0.012								
7/20/2005	CR7-6	ST3			0.034	0.008								
7/20/2005	CR11-1	ST2			0.002	0								
7/20/2005	CR11-1	ST4			0.022	0.009								
7/20/2005	CR11-3	ST4			0.016	0.006								
7/20/2005	CR11-9	ST1			0.025	0.015								
7/20/2005	CR11-9	ST4			0.036	0.023								
8/24/2005	A17-1	WS2-0	6.41	27.5	0.088	0.003	1.36	0.39	0.85	0.32	0.31	0.00	0.10	1.71
8/24/2005	A17-1	CONT	5.62	28.5	0.022	0.012	1.57	0.32	2.51	0.11	0.10	0.26	0.05	1.59
8/24/2005	A17-1	ST1	5.39	20.2	0.018	0.003	2.2	0.27	1.06	0.28	0.27	0.00	0.47	1.57
8/24/2005	A17-1	WS1-0	6	18.42	0.077	0.006	3.8	1.79	2.1	1.63	0.17	1.70	0.06	3.75
8/24/2005	A17-1	ST5	5.59	29.2	0.032	0.015	3.01	0.66	0.66	0.79	0.68	0.00	0.39	0.91
8/24/2005	A17-1	ST4	6.08	16.9	0.016	0.004	1.26	0.29	2.61	0.90	0.70	0.06	0.16	0.88
8/24/2005	A17-2	ST5	6.12	18.22	0.068	0.014	4.18	0.68	1.18	0.16	0.10	0.43	0.05	1.01
8/24/2005	A17-2	ST1	6.22	23.7	0.018	0.01	1.26	0.32	2.75	0.12	0.03	0.00	0.05	0.75
8/24/2005	A17-2	WS7-0	6.21	23	0.259	0.204	9.64	4.41	4.58	0.93	0.21	0.24	0.07	2.91
8/24/2005	A17-2	ST2	6.33	103.5	0.095	0.034	3.75	0.68	2.21	0.13	0.09	0.23	0.02	4.50
8/24/2005	A17-2	ST3	5.67	34.6	0.018	0.01	2.75	0.44	1.86	0.88	0.05	0.29	0.13	1.25
8/24/2005	A25-2	WS1-0	6.12	20.7	0.138	0.023	10.23	1.35	1.37	0.16	0.03	0.00	0.02	1.37
8/24/2005	A25-2	ST1	6.14	69.1	0.034	0.028	3.84	0.97	4.99	0.16	0.11	1.27	0.12	2.17
8/24/2005	A25-2	ST4	6.18	23.9	0.011	0.006	2.19	0.42	3.35	0.15	0.05	0.02	0.02	0.81
8/24/2005	A25-2	WS2-3	5.78	19.6	0.021	0.002	2.46	0.73	1.43	0.11	0.08	0.12	0.01	0.29
8/24/2005	A25-2	ST2	5.58	22.1	0.039	0.02	4.37	0.74	3.39	0.16	0.14	0.23	0.08	2.10
8/24/2005	A25-2	ST5	5.98	28.2	0.026	0.01	2.17	0.45	5.71	0.14	0.12	0.00	0.13	1.63
8/24/2005	A25-3	WS1-0	6.16	30.4	0.014	0.003	3.12	0.89	2.06	0.48	0.11	0.35	0.08	3.59
8/24/2005	A25-3	ST1	5.76	44.6	0.018	0.01	3.32	0.69	4.69	0.26	0.26	0.54	0.06	5.38
8/24/2005	A27-1	ST1	5.89	33.2	0.248	0.06	5.58	0.95	2.74	0.09	0.07	0.01	0.20	4.00
8/24/2005	A27-2	ST1	6.02	36.3	0.012	0.003	4.45	0.8	5.94	0.13	0.37	0.06	0.58	7.71
8/24/2005	A27-2	ST4	6.07	42.2	0.034	0.018	8.75	1.47	11.39	0.21	0.11	0.71	3.70	4.23
8/24/2005	A27-2	ST2	6.32	98.8	0.018	0.009	4.08	0.9	4.22	1.11	0.97	0.23	0.33	0.95

NO DATA AVAILABLE

Table B.6- Pre-harvest water quality parameters and concentration for Aug. and Sep. 2005

Date	Site	Sampler ID	pH	EC (μs/cm)	TSS (g/L)	TVSS (g/L)	Ca (mg/L)	Mg (mg/L)	K (mg/L)	TP (mg/L)	SRP (mg/L)	NH3-N(mg/L)	NO3 (mg/L)	TN (mg/L)
8/24/2005	A34-1	CONTROL	6.13	38.9	0.015	0.004	1.38	0.3	1.23	0.10	0.02	0.20	0.04	1.09
8/24/2005	A34-1	ST3	5.62	14.56	0.018	0.01	1.67	0.54	2.6	0.83	0.02	0.00	0.06	2.99
8/24/2005	A34-1	ST5	5.95	19.78	0.134	0.108	1.76	0.51	3.05	0.27	0.16	0.69	0.06	1.20
8/24/2005	A34-2	ST4	5.42	20.3	0.065	0.018	2.29	0.58	2.18	0.06	0.09	0.15	0.04	0.99
8/24/2005	CR7-2	ST3	6.55	27.9	0.012	0.006	4.62	1.22	2.91	1.16	1.04	0.00	0.01	1.29
8/24/2005	CR7-5B	ST5	6.39	10.42	0.007	0.007	1.62	0.39	0.59	0.18	0.14	0.06	0.03	0.13
8/24/2005	CR7-5B	ST1	5.81	18.86	0.005	0.001	2.96	0.44	1.38	0.08	0.06	1.73	0.23	2.66
8/24/2005	CR7-5B	WS7-0	6.48	52.88	0.025	0.013	9.04	1.14	3.21	0.05	0.01	0.20	0.05	3.46
8/24/2005	CR7-5B	CONTROL	6.19	25.5	0.035	0.023	0.71	0.18	0.42	0.19	0.18	0.24	0.02	1.49
8/24/2005	CR7-5C	WS3-0	6.11	33.3	0.017	0.02	3.56	1.13	2.62	0.38	0.02	0.31	0.01	4.62
8/24/2005	CR7-5C	ST1	6.69	10.92	0.014	0.006	1.61	0.44	2.12	0.57	0.48	0.00	0.53	1.03
8/24/2005	CR7-5C	ST3	6.06	11.15	0.024	0.009	1.44	0.44	2.16	0.36	0.19	0.15	0.01	0.67
8/24/2005	CR7-5C	WS2-0	6.38	19.45	0.151	0.013	2.04	0.67	0.87	0.72	0.39	0.06	0.00	1.69
8/24/2005	CR7-5C	ST4	6.2	20	0.002	0.001	3.52	0.56	1.8	0.13	0.06	0.04	0.14	0.99
8/24/2005	CR7-6	WS5-0	6.14	23.7	0.046	0.012	2.21	0.9	1.09	0.56	0.37	0.13	0.02	1.19
8/24/2005	CR7-6	WS4-0	5.78	18.5	0.027	0.014	2.01	0.85	1.6	0.12	0.08	0.61	0.04	1.51
8/24/2005	CR7-6	ST2	5.39	19.8	0.074	0.045	7.85	1.52	2.78	0.15	0.03	0.20	0.47	2.52
8/24/2005	CR7-6	WS2-0	6.7	46.4	0.04	0.028	1.22	0.66	1.93	0.24	0.14	0.05	0.03	0.93
8/24/2005	CR7-6	ST3	5.33	12.3	0.037	0.009	2.34	0.61	1.65	0.34	0.28	0.37	0.30	1.03
8/24/2005	CR7-6	ST4	6.26	19.45	0.052	0.014	2.79	0.68	0.78	0.26	0.14	0.00	0.24	1.77
8/24/2005	CR11-1	ST2	6.33	17.33	0.019	0.007	3.47	0.44	1.38	0.13	0.10	0.04	0.26	1.03
8/24/2005	CR11-1	ST1	6.12	20.1	0.017	0.009	2.54	0.54	2.54	0.12	0.06	0.19	0.06	2.05
8/24/2005	CR11-1	ST4	5.86	19.89	0.005	0.001	1.35	0.36	1.68	0.13	0.06	0.06	0.02	1.14
8/24/2005	CR11-1	ST5	5.65	14.3	0.024	0.015	1.93	0.48	1.77	0.41	0.08	0.08	0.30	2.77
8/24/2005	CR11-3	ST1	6.18	19.9	0.015	0.01	4.54	0.87	4.98	0.09	0.05	0.09	0.17	3.49
8/24/2005	CR11-3	ST5	6.15	36.5	0.023	0.005	1.29	0.34	1.34	0.62	0.02	0.01	0.17	2.29
8/24/2005	CR11-3	ST4	6.16	19.7	0.089	0.056	8.22	1.03	4.49	0.06	0.06	0.33	2.45	6.21
8/24/2005	CR11-3	WS1-0	5.55	69.5	0.037	0.009	5.2	1.99	2.41	3.35	1.76	0.05	0.06	1.18
8/24/2005	CR11-9	ST1	6.23	36.5	0.018	0.008	4.81	1.77	6.57	0.61	0.45	0.00	1.54	3.44
8/24/2005	CR11-9	ST4	6.29	53	0.015	0.007	4.07	0.73	0.85	0.19	0.15	2.17	1.26	1.78
9/15/2005	A17-1	WS3-0	6.62	25.1	0.062	0.012	1.98	0.88	1.39	0.84	1.49	0.70	0.39	3.74
9/15/2005	A17-1	ST5	6.18	24.7	0.231	0.021	4.2	1.01	2.18	0.37	0.30	0.01	1.23	3.74
9/15/2005	A17-1	ST1	5.85	11.91	0.04	0.019	2.99	0.33	0.93	0.08	0.03	0.33	0.09	0.78
9/15/2005	A17-1	CONTROL	6.23	15.28	0.031	0.019	3.11	0.6	4.67	0.13	0.19	0.48	0.03	1.81
9/15/2005	A17-1	ST4	6.63	19.33	0.026	0.013	2.75	0.47	1.79	0.15	0.11	0.03	0.56	1.57
9/15/2005	A17-2	ST1	6.52	28.5	0.287	0.165	3.41	0.56	2.13	0.08	0.07	0.56	1.12	2.20
9/15/2005	A17-2	ST3	6.61	57.6	0.019	0.013	1.49	0.4	4.08	0.39	0.15	0.40	0.25	1.41
9/15/2005	A17-2	ST5	6.62	23.4	0.122	0.116	1.27	0.35	1.5	0.15	0.14	0.12	0.89	2.27
9/15/2005	A25-2	ST1	6.29	38.5	0.012	0.003	3.41	0.61	2.39	0.18	0.22	0.00	0.86	3.65
9/15/2005	A25-2	ST2	6.32	28.5	0.007	0.003	2.09	0.4	2.54	0.15	0.05	0.04	0.12	0.97
9/15/2005	A25-2	ST5	6.26	18.61	0.003	0.003	8.13	0.97	12.83	0.63	0.15	1.20	0.52	0.80
9/15/2005	A25-3	ST3	6.09	21.5	0.051	0.015	4.92	0.97	3.41	0.43	0.41	0.61	0.62	1.57
9/15/2005	A25-3	ST1	6.44	27.5	0.033	0.019	10.68	1.58	14.74	0.60	0.47	0.00	0.09	0.73
9/15/2005	A27-1	ST1	6.39	26	0.033	0.014	2.62	0.57	1.86	0.06	0.02	0.04	0.16	1.61
9/15/2005	A27-1	ST3	6.16	12.67	0.041	0.011	3.26	0.64	2.66	0.19	0.14	0.05	0.09	0.99

Table B.7- Pre-harvest water quality parameters and concentration for Sep. and Nov. 2005

Date	Site	Sampler ID	pH	EC (µs/cm)	TSS (g/L)	TVSS (g/L)	Ca (mg/L)	Mg (mg/L)	K (mg/L)	TP (mg/L)	SRP (mg/L)	NH3-N(mg/L)	NO3 (mg/L)	TN (mg/L)
9/15/2005	A27-2	ST2	6.32	23.4	0.048	0.011	8.64	1.08	8.1	0.16	0.10	0.73	0.24	1.69
9/15/2005	A27-2	ST4	6.33	25.73	0.101	0.057	11.61	2.77	5.84	0.05	0.03	2.07	1.38	2.58
9/15/2005	A27-2	ST1	6.6	19.18	0.287	0.025	4.24	1.48	10.19	0.20	0.15	0.30	0.08	0.45
9/15/2005	A34-1	CONTROL	6.78	32.5	0.027	0.016	1.01	0.28	1.73	0.08	0.06	0.05	0.04	1.48
9/15/2005	A34-1	ST1	6.32	37.6	0.039	0.023	4.68	0.9	2.84	0.12	0.08	0.14	0.35	1.12
9/15/2005	A34-1	ST5	6.07	16.76	0.064	0.023	1.76	0.47	2.52	0.31	0.29	0.14	0.13	2.14
9/15/2005	A34-1	ST3	6.79	18.96	0.031	0.02	8.54	1.08	6.98	0.10	0.06	0.22	0.69	1.26
9/15/2005	CR7-2	ST3	6.74	18.523	0.218	0.057	7.54	2.11	18.1	0.12	0.06	2.07	0.05	2.58
9/15/2005	CR7-5B	CONTROL	6.61	6.48	0.025	0.007	3.37	1.09	2.12	0.07	0.07	0.03	0.08	0.82
9/15/2005	CR7-5C	ST4	6.6	18.69	0.007	0.006	1.12	0.52	3.38	0.30	0.24	0.04	0.49	1.94
9/15/2005	CR7-5C	ST3	5.92	16.15	0.012	0.006	4.34	0.94	3.42	0.90	0.88	0.05	1.36	2.55
9/15/2005	CR7-5C	ST5	6.21	21.6	0.008	0.003	1.6	0.41	3.98	0.52	0.50	0.05	0.82	1.99
9/15/2005	CR7-6	ST3	6.62	19.62	0.181	0.062	5.02	0.76	1.54	0.30	0.25	0.07	0.83	0.91
9/15/2005	CR7-6	ST4	6.31	38.1	0.091	0.033	3.83	0.94	1.74	0.24	0.22	0.11	0.56	2.24
9/15/2005	CR7-6	ST2	6.73	11.6	0.114	0.041	1.11	0.22	2.14	0.47	0.15	0.06	0.53	1.40
9/15/2005	CR11-1	ST4	6.52	9.71	0.014	0.008	2.19	1.08	1.47	0.71	0.61	0.17	0.08	0.63
9/15/2005	CR11-1	ST2	6.88	17.63	0.014	0.003	3	1.44	1.38	0.34	0.05	0.27	0.12	2.58
9/15/2005	CR11-3	WS1-0	6.48	16.17	0.054	0.022	5.2	1.99	2.41	0.16	0.11	0.12	0.02	0.80
9/15/2005	CR11-3	ST5	6.32	27.3	0.036	0.022	12.62	6.32	2.47	0.18	0.16	0.26	0.15	0.62
9/15/2005	CR11-3	ST1	6.18	21.6	0.047	0.023	1.47	0.32	2.92	0.48	0.21	0.26	0.39	1.30
9/15/2005	CR11-9	ST2	6.18	37	0.04	0.002	5.48	0.69	2.59	0.07	0.02	0.60	0.92	1.21
9/15/2005	CR11-9	ST4	6.53	18.57	0.022	0.012	1.97	0.48	1.84	0.84	1.49	0.38	0.30	0.62
9/15/2005	CR11-9	ST1	6.45	19.6	0.048	0.031	3.47	1.31	4.26	0.26	0.12	1.12	1.23	3.43
11/15/2005	A17-1	WS3-3	5.47	18.62	0.018	0.019	1.54	0.58	1.29	0.08	0.02	0.04	0.00	2.91
11/15/2005	A17-1	WS1-0	5.33	19.16	0.031	0.031	0.06	0.01	0.02	0.16	0.07	0.00	0.04	1.75
11/15/2005	A17-1	ST1	5.58	15.03	0.078	0.078	0.08	0.04	0.05	0.62	0.53	0.00	0.09	4.26
11/15/2005	A17-1	WS1-3	5.79	19.32	0.023	0.029	0.06	0.01	0.02	0.06	0.04	0.00	0.00	1.42
11/15/2005	A17-1	WS4-6	5.46	18.44	0.118	0.114	1.61	0.63	1.73	0.73	0.03	0.00	0.00	2.30
11/15/2005	A17-1	WS4-3	5.59	19.33	0.025	0.025	1.8	0.65	1.63	0.06	0.02	0.00	0.05	1.04
11/15/2005	A17-1	WS3-0	5.51	18.01	0.058	0.021	1.28	0.65	0.96	0.12	0.03	0.15	0.02	0.18
11/15/2005	A17-1	CONTROL	5.89	19.76	0.003	0.015	0.05	0.02	0.03	0.28	0.26	0.16	0.02	1.48
11/15/2005	A17-1	ST3	6.06	17.32	0.035	0.023	1.66	0.86	1.74	0.09	0.07	0.14	0.04	0.29
11/15/2005	A17-1	WS3-6	6.15	24.5	0.135	0.026	1.33	0.33	4.24	1.04	0.19	0.02	0.06	1.65
11/15/2005	A17-1	WS4-0	6.67	33.4	0	0	1.28	0.65	0.96	0.36	0.34	0.00	0.04	1.58
11/15/2005	A17-2	WS1-0	6.03	21.5	0.028	0.026	1.55	0.31	2.61	0.22	0.19	0.16	0.01	1.92
11/15/2005	A17-2	WS7-0	6.82	95.4	0.274	0.256	2.68	0.91	1.71	0.63	0.35	0.88	0.01	2.75
11/15/2005	A17-2	WS7-3	7.31	79.8	0.019	0.017	5.74	0.78	2.01	0.25	0.06	0.01	0.02	0.31
11/15/2005	A25-2	WS1-6	6.46	38.7	0.077	0.034	3.79	1.17	2.74	0.13	0.06	0.05	0.20	1.65
11/15/2005	A25-2	WS4-3	6.19	26.2	0.067	0.025	2.67	0.65	3	0.04	0.03	0.01	0.02	1.25
11/15/2005	A25-2	ST4	6.4	20.3	0.001	0.015	0.04	0.01	0.03	0.02	0.01	0.00	0.00	2.64
11/15/2005	A25-2	WS4-0	6.86	44.1	0.696	0.182	3.95	0.97	2.73	0.71	0.64	0.00	0.03	2.85
11/15/2005	A25-2	WS1-3	7.06	27.7	0.028	0.023	2.58	0.9	2.51	0.08	0.08	0.01	0.04	0.65
11/15/2005	A25-3	ST3	6.13	23	0.02	0.021	2.66	0.76	1.69	0.08	0.01	0.09	0.00	1.82
11/15/2005	A25-3	WS5-0	6.52	44.5	0.087	0.097	1.32	0.47	1.84	1.04	0.56	0.88	0.01	4.48
11/15/2005	A25-3	WS5-0	6.2	24.7	0.05	0.046	1.76	0.73	1.54	0.21	0.18	0.02	0.03	2.12

Table B.8- Pre-harvest water quality parameters and concentration Nov. 2005

Date	Site	Sampler ID	pH	EC (µs/cm)	TSS (g/L)	TVSS (g/L)	Ca (mg/L)	Mg (mg/L)	K (mg/L)	TP (mg/L)	SRP (mg/L)	NH3-N(mg/L)	NO3 (mg/L)	TN (mg/L)
11/15/2005	A34-1	WS4-0	6.32	24.7	0.016	0.013	2.3	0.76	1.32	0.03	0.02	0.04	0.03	0.48
11/15/2005	A34-1	WS8-6	6.65	30.9	0.015	0.02	3.14	1.88	1.38	0.05	0.01	0.02	0.03	0.98
11/15/2005	A34-1	WS1-3	6.36	29.3	0.018	0.018	2.09	0.7	0.76	0.12	0.12	0.76	0.15	1.41
11/15/2005	A34-1	WS5-0	6.51	21.8	0.025	0.021	1.7	0.81	1.01	0.15	0.04	0.03	0.00	1.13
11/15/2005	A34-1	ST3	6.44	15.23	0.008	0.016	0.97	0.32	2.53	0.19	0.03	0.02	0.05	0.38
11/15/2005	A34-1	WS5-3	5.93	21.9	0.052	0.035	1.71	0.67	1.26	0.16	0.00	0.02	0.03	0.49
11/15/2005	A34-1	WS2-0	4.9	19.8	0.038	0.042	1.14	0.65	1.38	0.06	0.06	0.01	0.04	7.79
11/15/2005	A34-1	WS9-0	5.98	21.7	0.03	0.021	1.63	0.82	0.94	0.11	0.10	0.00	0.00	0.62
11/15/2005	A34-1	WS4-3	6.48	28.5	0	0.052	2.82	0.99	2.38	0.06	0.06	0.02	0.02	1.98
11/15/2005	A34-1	CONTROL	5.83	18.35	0.021	0.031	0.88	0.34	4.04	0.04	0.04	0.01	0.07	4.23
11/15/2005	A34-1	WS10-0	6.6	45.7	0.043	0.037	0.06	0.01	0.09	0.17	0.17	0.00	0.00	1.51
11/15/2005	A34-1	WS6-0	5.32	17.41	0.013	0.021	2.98	1.69	1.04	0.01	0.00	0.02	0.00	0.70
11/15/2005	A34-2	WS2-0	5.89	23.7	0.026	0.014	2.11	0.81	0.88	0.05	0.02	0.16	0.04	2.15
11/15/2005	A34-2	WS6-0	6.18	26.4	0.016	0.02	1.95	0.86	0.92	0.06	0.01	0.02	0.00	0.28
11/15/2005	A34-2	ST5	5.71	16.89	0.026	0.021	0.8	0.22	2.94	0.06	0.03	0.02	0.04	0.81
11/15/2005	A34-2	WS4-0	5.29	18.61	0.054	0.02	0.7	0.73	1.09	0.16	0.02	0.01	0.03	1.23
11/15/2005	A34-2	WS3-0	6.48	68.3	0.051	0	7.72	4.49	0.58	0.03	0.03	0.08	0.01	0.27
11/15/2005	A34-2	WS5-0	6.02	24	0.06	0.062	7.63	3.96	1.84	0.53	0.15	0.01	0.08	3.26
11/15/2005	A34-2	WS7-0	7.88	72.8	0.035	0.024	1.4	0.68	0.86	0.14	0.01	0.01	0.04	0.61
11/15/2005	CR7-2	GRAB	9.17	93.6	0.027	0.014	5.61	6.42	0.78	0.04	0.01	0.04	0.00	2.69
11/15/2005	CR7-2	ST2	8.77	46.2	0.076	0.076	6.28	0.75	3.72	0.17	0.07	0.06	0.01	0.71
11/15/2005	CR7-2	WS6-3	6.77	40	0.03	0.019	3.99	1.8	1.6	0.05	0.05	0.01	0.00	0.78
11/15/2005	CR7-2	WS4-3	6.22	31.2	0.006	0.013	3.17	1.3	2.87	0.08	0.05	0.37	0.03	0.51
11/15/2005	CR7-2	WS2-0	6.5	113.8	0.112	0.099	2.01	0.66	1.19	1.42	0.19	0.03	0.11	1.30
11/15/2005	CR7-2	WS5-0	6.81	42.2	0.042	0.045	9.27	1.23	1.62	0.61	0.45	0.00	0.00	0.53
11/15/2005	CR7-2	ST4	6.55	19.9	0.016	0.016	3.49	0.66	0.93	0.40	0.03	0.01	0.04	2.05
11/15/2005	CR7-2	WS4-0	6.96	59	0.121	0.064	9.27	1.23	1.62	1.21	1.19	0.32	0.04	1.55
11/15/2005	CR7-5B	ST1	5.92	37.9	0.043	0.038	1.01	0.44	4.02	0.85	0.45	0.47	0.05	1.93
11/15/2005	CR7-5B	WS5-6	5.95	27.5	0.039	0.021	2.33	0.81	3.1	0.09	0.07	0.08	0.00	0.74
11/15/2005	CR7-5B	WS5-3	6.11	27.8	0.048	0.023	3.99	0.87	2.96	0.25	0.24	0.03	0.04	1.69
11/15/2005	CR7-5B	WS3-0	5.87	22.7	0.979	0.07	2.08	0.7	1.42	0.05	0.04	0.11	0.03	2.97
11/15/2005	CR7-5B	WS1-0	6.53	30.7	0.011	0.019	7.59	3.15	1.1	0.14	0.11	0.03	0.68	1.55
11/15/2005	CR7-5B	WS6-3	6.8	32.9	0.092	0.041	4.61	0.79	1.91	0.47	0.45	0.02	0.00	0.18
11/15/2005	CR7-5B	WS6-6	6.26	18.28	0.078	0.07	3.89	0.43	1.23	0.03	0.02	0.00	0.02	0.86
11/15/2005	CR7-5B	CONTROL	5.92	33.9	0.022	0.028	0.75	0.29	3.99	0.36	0.19	0.18	0.02	0.23
11/15/2005	CR7-5C	WS5-6	6.48	21.4	0.664	0.158	0.99	0.31	4.08	0.14	0.04	0.30	0.03	1.02
11/15/2005	CR7-5C	WS4-0	6.01	17.81	0.117	0.078	1.45	0.62	1.08	0.21	0.07	0.63	0.03	0.67
11/15/2005	CR7-5C	WS5-3	6.29	20.5	0.025	0.021	1.68	0.61	1.55	0.06	0.01	0.09	0.00	1.49
11/15/2005	CR7-5C	ST4	6.86	31.6	0.005	0.016	0.94	0.51	5.96	0.32	0.06	0.02	0.03	0.47
11/15/2005	CR7-5C	WS6-3	6.23	21.1	0.026	0.021	1.7	0.65	2.14	0.37	0.06	0.02	0.00	0.39
11/15/2005	CR7-5C	ST3	6.28	23	0.002	0.014	1.47	0.52	5.16	0.49	0.04	0.01	0.05	0.58
11/15/2005	CR7-5C	ST5	6.33	32.5	0.009	0.018	0.09	0.01	0.05	0.66	0.43	0.12	0.06	0.93
11/15/2005	CR7-5C	WS2-0	6.31	23	0.019	0.016	3.57	0.74	1.23	0.10	0.05	0.18	0.05	0.94
11/15/2005	CR7-6	WS2-0	5.5	17.44	0.02	0.024	1.08	0.53	1.26	0.03	0.02	0.04	0.02	0.23
11/15/2005	CR7-6	WS5-0	6.11	18.29	0.116	0.012	1.25	0.64	0.54	0.10	0.03	0.08	0.02	0.30

Table B.9- Pre-harvest water quality parameters and concentration for Nov. 2005 and Mar. 2006

Date	Site	Sampler ID	pH	EC (µs/cm)	TSS (g/L)	TVSS (g/L)	Ca (mg/L)	Mg (mg/L)	K (mg/L)	TP (mg/L)	SRP (mg/L)	NH3-N(mg/L)	NO3 (mg/L)	TN (mg/L)
11/15/2005	CR7-6	WS3-0	6.73	25.3	0.742	0.167	2.42	0.71	1.72	0.12	0.06	0.15	0.00	1.39
11/15/2005	CR7-6	ST4	6.74	22.4	0.027	0.031	2.01	0.4	2.87	0.08	0.04	0.00	0.02	0.61
11/15/2005	CR7-6	WS4-6	6.7	36.9	0.033	0.023	6.06	1.17	2.43	0.82	0.82	0.00	0.01	0.84
11/15/2005	CR7-6	WS6-0	7.24	48.2	0.471	0.134	5.19	2.69	0.85	0.19	0.11	0.72	0.03	0.76
11/15/2005	CR7-6	WS6-3	6.94	44.3	0.344	0.089	1.86	0.7	1.24	0.05	0.02	0.00	0.00	0.94
11/15/2005	CR7-6	WS6-6	6.59	37.4	0.056	0.023	0.79	0.24	3.47	0.07	0.06	0.10	0.00	0.65
11/15/2005	CR11-3	ST5	5.81	42.2	0.02	0.025	3.74	0.84	6.08	0.20	0.14	0.89	0.18	3.54
11/15/2005	CR11-3	WS2-0	5.94	23.5	0.05	0.021	2.16	1.03	1.76	0.20	0.08	0.02	0.00	1.03
11/15/2005	CR11-3	GRAB	6.63	31	0.183	0.156	3.43	1.47	1.05	0.13	0.04	0.01	0.00	0.81
11/15/2005	CR11-3	ST1	6.12	14.74	0.013	0.025	1.44	0.69	0.84	0.07	0.03	0.01	0.06	0.41
11/15/2005	CR11-3	WS6-0	6.73	31.8	0.023	0.014	3.16	1.63	0.95	0.06	0.06	0.01	0.00	0.53
11/15/2005	CR11-3	WS1-0	6.7	33.5	0.026	0.035	3.09	1.32	1.24	0.27	0.02	0.01	0.00	0.56
11/15/2005	CR11-9	ST4	6.63	27.1	0.045	0.045	8.09	4.43	1.5	0.06	0.00	0.05	0.09	2.24
11/15/2005	CR11-9	WS1-0	7.45	114.8	0.045	0.04	13.34	5.13	2.63	0.28	0.25	0.02	0.03	0.82
11/15/2005	CR11-9	WS2-0	6.29	24	0.074	0.073	1.56	0.39	2.33	0.14	0.01	0.02	0.01	5.36
11/15/2005	CR11-9	ST1	6.6	35.8	0.007	0.017	2.04	0.7	5.99	0.10	0.01	0.01	0.03	0.74
11/15/2005	CR11-9	WS1-3	7.23	143.9	0.026	0.026	19.65	5.42	3.64	0.06	0.05	1.41	0.35	1.81
11/15/2005	CR11-9	ST2	6.22	17.28	0.009	0.018	1.56	0.39	2.33	0.48	0.29	0.02	0.03	0.37
11/15/2005	CR-106	GRAB	9.08	135.1	0.101	0.026	10.66	9.83	1.42	0.05	0.03	0.06	0.03	3.47
11/15/2005	CR-106 (2)		8.27	169.9	0.035	0.023	7.72	4.49	0.58	0.03	0.03	0.03	0.05	3.91
11/15/2005	Current River @ 106 Bridge	Grab	9.49	108	0.084	0.025	8.86	7.5	0.89	0.02	0.02	0.01	0.03	0.26
11/15/2005	Shop Hollow	Grab	7.25	85	0.016	0.014	10.07	7.55	1	0.03	0.01	0.02	0.03	0.14
11/15/2005	Shop Hollow 2	Grab	7.09	127.5	0.146	0.033	8.33	5.66	0.69	0.01	0.01	0.02	0.06	0.51
3/13/2006	A17-1	WS1-0	6.52	30.9	0.040	0.005	2.02	0.63	1.02		0.04	3.55	0.02	
3/13/2006	A17-1	WS1-3	5.85	39.1	0.000	0.000	2.79	1.06	2.60	0.01	0.07	0.26	0.16	6.50
3/13/2006	A17-1	WS2-0	5.8	19.66	0.050	0.013					0.04	2.05	0.06	
3/13/2006	A17-1	WS3-0	6.01	28.4	0.145	0.012	0.97	0.52	0.95		0.07	5.15	0.02	
3/13/2006	A17-1	WS4-0	6.45	18.9	0.028	0.022	1.01	0.56	0.87		0.01	1.13	1.22	
3/13/2006	A17-1	WS4-6	5.62	20.3	0.133	0.042	1.54	0.61	1.20		0.03	0.64	0.21	
3/13/2006	A25-2	ST1	6.03	25.8	0.008	0.017	1.60	0.64	2.96	0.00	0.03	0.28	0.17	1.97
3/13/2006	A25-2	ST4	5.77	28.2	0.008	0.008	0.18	0.08	0.75	0.00	0.12	0.38		1.73
3/13/2006	A25-2	ST5	6.24	40.1	0.013	0.002	1.05	0.45	5.01	0.04	0.04	4.73	0.89	5.92
3/13/2006	A25-2	WS1-0	6.32	54.5	0.053	0.007	2.43	0.83	1.58		0.00	0.64	0.01	
3/13/2006	A25-2	WS1-3	7.01	57	0.023	0.005	2.45	0.83	1.52		0.01	0.09	0.29	
3/13/2006	A25-2	WS2-0	6.28	39.1	0.417	0.023	2.75	0.62	1.69		0.07	1.23	1.77	
3/13/2006	A25-2	WS4-0	6.43	29.3	0.078	0.012	5.17	0.75	1.62	0.00	0.02	0.74	0.21	4.61
3/13/2006	A25-2	WS4-3	6.21	23.3	0.012	0.005	1.97	0.35	1.52	0.00	0.01	0.12	0.03	2.95
3/13/2006	A25-3	WS1-0	7.15	91.7	0.045	0.027	1.97	0.72	1.92	0.02	0.06	0.22	0.01	4.06
3/13/2006	A27-1	ST1	5.27	28	0.008	0.003	2.32	0.68	3.26	0.01	0.05	0.10	0.44	0.33
3/13/2006	A27-1	WS3-0	7.41	247	0.252	0.032	22.15	12.69	0.77	0.00	0.03	0.64	0.09	4.42
3/13/2006	A27-1	WS3-3	7.32	86.2	0.017	0.023					0.03	0.11	0.01	
3/13/2006	A27-1	WS3-6	6.77	53.3	0.017	0.010	4.51	2.40	1.86			0.18	0.03	
3/13/2006	A27-1	WS4-2	7.18	163.2	0.247	0.033	15.43	8.11	1.23		0.05	0.27	1.84	
3/13/2006	A27-1	WS4-3	8.28	86.7	0.042	0.010	7.68	4.03	1.10	0.01	0.04	0.12	0.05	3.32
3/13/2006	A27-1	WS4-8	7.22	118.3	0.082	0.015	12.14	6.11	1.16	0.01	0.04	0.17	0.44	3.83

Table B.10- Pre-harvest water quality parameters and concentration for March 2006

Date	Site	Sampler ID	pH	EC (µs/cm)	TSS (g/L)	TVSS (g/L)	Ca (mg/L)	Mg (mg/L)	K (mg/L)	TP (mg/L)	SRP (mg/L)	NH3-N(mg/L)	NO3 (mg/L)	TN (mg/L)
3/13/2006	A27-1	WS6-0	6.45	33.6	0.062	0.007	3.63	1.69	0.98		0.00	0.14	0.02	
3/13/2006	A27-1	WS6-3	6.53	45	0.015	0.005					0.06	0.43	0.03	
3/13/2006	A27-2	ST2	6.11	44.6	0.018	0.032	1.83	0.56	3.72	0.25	0.51	5.52	8.78	15.42
3/13/2006	A27-2	WS4-0	6.43	29.3	0.042	0.010	1.78	0.43	1.09	0.01	0.03	1.82	0.62	2.09
3/13/2006	A27-2	WS5-0	6.28	8.71	0.020	0.005	0.19	0.01	0.33	0.05	0.06	0.21	0.07	1.00
3/13/2006	A27-2	WS7-0	7.02	128.9	0.058	0.008	12.33	6.85	0.91		0.02	0.16	0.08	
3/13/2006	A27-2	WS7-3	7.15	91.7	0.020	0.008	8.77	4.68	1.34		0.00	0.09	0.02	
3/13/2006	A34-1	ST2	6.09	28.8	0.005	0.003	2.77	0.77	2.53	0.00	0.05	0.30	0.08	1.53
3/13/2006	A34-1	WS1-0	6.2	36.9	0.037	0.002	1.54	0.70	2.81		0.00	0.17	0.04	
3/13/2006	A34-1	WS1-3	6.58	35.8	0.007	0.003					2.76	0.09	0.01	
3/13/2006	A34-1	WS2-0	5.88	23.5	0.020	0.010	0.65	0.53	1.97		0.04	0.15	0.06	
3/13/2006	A34-1	WS4-6	6.45	56.4	0.020	0.007	2.96	1.10	2.33	0.00	0.02	1.54	0.25	5.10
3/13/2006	A34-1	WS5-0	6.33	29.2	0.043	0.007	2.02	0.57	1.05		0.00	0.13	0.05	
3/13/2006	A34-1	WS5-3	6.37	40.5	0.052	0.007	2.34	0.61	1.63	0.05	0.08	0.15	0.03	2.00
3/13/2006	A34-1	WS7-0	6.13	25.6	0.022	0.010	2.97	1.47	0.82		0.00	0.24	0.02	
3/13/2006	A34-1	WS8-0			0.000	0.000	2.88	1.30	1.23		0.07		7.75	
3/13/2006	A34-1	WS8-6	6.81	33.7	0.015	0.005	2.47	1.22	1.18	0.00	0.02	0.10	0.00	2.66
3/13/2006	A34-1	WS9-0	6.46	56	0.027	0.005	4.07	1.21	3.47	0.77	1.46	3.59		3.03
3/13/2006	A34-2	ST2	6.22	36.8	0.008	0.008	3.74	0.88	3.63	0.16	0.39	0.28	1.80	8.76
3/13/2006	A34-2	WS2-0	6.48	36.5	0.048	0.007	1.89	0.67	1.07		0.05	2.67	0.05	
3/13/2006	A34-2	WS2-3	6.32	79.5	0.033	0.013	2.77	1.44	5.19	0.55	0.84	22.86	0.27	12.76
3/13/2006	A34-2	WS3-0	6.26	28.7	0.042	0.012				1.56	0.05	0.23	0.15	5.85
3/13/2006	A34-2	WS4-0	5.88	26.7	0.227	0.022	0.06	0.63	1.10		0.02	5.29	0.02	
3/13/2006	A34-2	WS5-0	6.22	36.8	0.030	0.005	9.61	4.71	1.63		0.03	0.23	0.05	
3/13/2006	A34-2	WS7-0	7.29	129.7	0.073	0.040	13.59	7.23	0.70	0.02	0.05	0.14	0.02	2.31
3/13/2006	CR7-2	WS1-0			0.348	0.012	10.35	5.37	0.97		0.10	0.16	0.21	
3/13/2006	CR7-2	WS2-0	5.85	18.39	0.018	0.002	1.80	0.44	1.25		0.03		0.09	
3/13/2006	CR7-2	WS2-0			0.000	0.000					0.25	0.10	5.13	
3/13/2006	CR7-2	WS3-0	6.74	54.8	0.027	0.007	5.17	1.23	3.66			0.24	0.06	
3/13/2006	CR7-2	WS4-0	6.45	25.1	0.105	0.008	2.13	0.79	1.33		0.04	0.15	0.06	
3/13/2006	CR7-2	WS7-3	6.79	52	0.030	0.005	5.52	2.86	1.19	0.00	0.02	0.09	0.09	1.87
3/13/2006	CR7-5B	WS3-0	6.11	19.4	0.177	0.013	1.35	0.53	0.89		0.01	0.10	0.03	
3/13/2006	CR7-5B	WS4-0	6.24	21.3	0.062	0.002	1.46	0.48	1.26	0.00	0.03	0.26	0.10	1.23
3/13/2006	CR7-5B	WS5-0	6.15	18.8	0.068	0.008	1.37	0.57	1.04	0.01	0.03	0.12	0.08	1.86
3/13/2006	CR7-5B	WS5-3	6.42	28	0.310	0.012	1.62	0.57	1.60	0.01	0.03	1.21	0.01	3.10
3/13/2006	CR7-5B	WS5-6	6.27	12.74	0.047	0.007	0.64	0.26	1.03	0.00	0.02	0.34	0.00	1.04
3/13/2006	CR7-5B	WS6-0	6.45	29.5	1.343	1.768	2.77	0.63	1.72		0.22	0.11	1.57	
3/13/2006	CR7-5B	WS6-3	6.34	23.9	0.520	0.038	2.02	0.57	1.64	0.00	0.02	0.16	0.02	2.04
3/13/2006	CR7-5C	WS1-0	6.07	26.1	0.070	0.008	2.37	0.58	1.04		0.02	0.14	0.13	
3/13/2006	CR7-5C	WS1-3			0.000	0.000	2.31	0.61	1.44	0.00	0.01		0.03	2.02
3/13/2006	CR7-5C	WS2-0	6.18	92.1	1.935	0.272	4.44	1.30	2.45	0.03	0.12		0.02	3.43
3/13/2006	CR7-5C	WS2-3	6.77	29.3	0.030	0.005	1.52	0.56	0.89	0.01	0.01	0.10	0.02	0.02
3/13/2006	CR7-5C	WS3-3	6.08	19.5	0.112	0.013	1.20	0.52	1.66		0.04	0.16	0.02	
3/13/2006	CR7-5C	WS3-6	6.19	33.7	0.000	0.000	2.37	0.61	2.10		0.14	0.08	0.15	
3/13/2006	CR7-5C	WS4-3	6.15	35.9	0.015	0.005	2.42	0.66	1.88	0.00		0.14	0.07	2.38

Table B.11- Pre-harvest water quality parameters and concentration for March and May 2006

Date	Site	Sampler ID	pH	EC (µs/cm)	TSS (g/L)	TVSS (g/L)	Ca (mg/L)	Mg (mg/L)	K (mg/L)	TP (mg/L)	SRP (mg/L)	NH3-N(mg/L)	NO3 (mg/L)	TN (mg/L)
3/13/2006	CR7-5C	WS5-0	6.32	20.6	0.252	0.008	1.29	0.50	1.61	0.02	0.13	0.15	0.10	1.30
3/13/2006	CR7-6	ST4	6.36	19.6	0.028	0.008	1.97	0.68	21.78	0.00	0.04	0.38	0.13	4.03
3/13/2006	CR7-6	WS2-0			0.067	0.008	0.57	0.48	1.16		0.01	0.59	0.02	
3/13/2006	CR7-6	WS3-0	6.29	27.8	0.000	0.000	2.65	0.61	1.90	0.00	0.06	0.14	0.11	3.44
3/13/2006	CR7-6	WS4-6	6.11	9.85	0.035	0.002	0.43	0.19	0.52		0.02	0.27	0.06	
3/13/2006	CR7-6	WS5-0			0.178	0.013	1.59	0.63	0.96		0.06	0.10	0.05	
3/13/2006	CR7-6	WS5-3	6.06	20.6	0.017	0.008	1.67	0.76	1.82		0.02	0.09	0.03	
3/13/2006	CR11-3	ST4	6.32	42.1	0.020	0.025	4.05	0.72	3.76		0.20	0.28	4.28	
3/13/2006	CR11-3	WS1-0	6.32	42.1	0.148	0.012	4.79	1.99	2.04		0.02	0.10	0.06	
3/13/2006	CR11-3	WS3-0	6.45	27.6	0.068	0.005	1.91	0.88	1.01		0.00	0.11	0.04	
3/13/2006	CR11-3	WS3-3	6.29	33.6	0.033	0.008	3.20	0.93	1.69		0.00	0.19	0.04	
3/13/2006	CR11-9	WS1-0	7.14	141.9	0.008	0.012	16.19	5.46	3.39	0.02	0.03	6.71	0.03	5.83
3/13/2006	CR11-9	WS3-0	6.62	32.1	0.037	0.003	1.73	0.93	1.94	0.00	0.03	2.06	0.03	2.40
5/16/2006	A17-1	WS1-0	5.95	19.8	0.020	0.027	1.29	0.66	0.83	0.20	0.01	0.02	0.08	0.61
5/16/2006	A17-1	WS1-3	6.13	34.7	0.020	0.035	6.74	0.425	2.38	0.16	0.11	7.08	0.00	0.35
5/16/2006	A17-1	WS2-0	6.67	83.7	0.228	0.222	4.14	0.79	1.59	0.04	1.16	4.11	3.86	0.10
5/16/2006	A17-1	WS2-3	5.8	18.6	0.003	0.025	1.51	0.84	1.31	0.32	0.00	0.04	0.00	0.59
5/16/2006	A17-1	WS2-6	5.61	20	0.067	0.077	1.24	0.76	1.20	0.05	0.01	0.06	0.27	0.50
5/16/2006	A17-1	WS3-0	5.9	19.8	0.020	0.027	0.97	0.53	0.87	0.20	0.00	0.12	0.04	0.75
5/16/2006	A17-1	WS3-3	6.2	47.8	0.025	0.033	2.44	0.49	3.53	0.20	0.01	0.81	0.01	0.40
5/16/2006	A17-1	WS4-0	5.97	18.75	0.028	0.030	1.18	0.60	1.04	0.06	0.00	0.02	0.17	0.11
5/16/2006	A17-1	WS4-3	5.94	22.7	0.013	0.033	1.13	0.66	0.97	0.12	0.07	0.08	2.74	0.59
5/16/2006	A17-1	WS5-0	6.41	44.9	0.097	0.087	1.1	1.27	0.75	0.48	0.15	0.14	0.30	0.62
5/16/2006	A17-2	WS1-0	6.42	43.3	0.033	0.048	89.84	14.76	2.2	0.51	0.27	6.90	0.34	
5/16/2006	A25-2	ST1	6.43	33.5	0.028	0.040	1.88	0.53	6.14	0.09	0.03	0.09	0.91	1.28
5/16/2006	A25-2	ST4	5.82	23.7	0.005	0.030	0.93	0.48	4.98	0.12	0.02	0.40	0.27	0.40
5/16/2006	A25-2	ST5	6.22	28.4	0.002	0.028	2.34	0.62	2.16	0.15	0.02	0.00	0.12	0.49
5/16/2006	A25-2	WS1-0	6.36	40.4	0.032	0.032	6.03	1.49	2.88	0.03	0.00	0.41	0.04	0.57
5/16/2006	A25-2	WS1-3	6.58	35.2	0.010	0.028	3.97	1.02	3.35	0.05	0.00	0.35	0.09	0.71
5/16/2006	A25-2	WS2-0	6.35	23.1	0.048	0.028	1.79	0.56	5.03	0.03	0.00	0.20	0.03	0.50
5/16/2006	A25-2	WS2-3	5.92	27.8	0.102	0.045	1.18	0.32	0.93	0.02	0.00	0.20	0.04	0.07
5/16/2006	A25-2	WS2-6	7.42	157.5	0.067	0.058	0.069	0.167	0.725					0.06
5/16/2006	A25-2	WS4-0	6.75	50.1	0.585	0.143	1.43	0.55	1.6	2.27	2.27	0.28	1.19	1.54
5/16/2006	A25-3	ST1	6.34	8.48	0.012	0.028	1.79	0.53	5.19	0.71		0.15	0.15	1.65
5/16/2006	A25-3	ST1	5.85	26.6	0.000	0.027	1.24	0.27	1.24	0.02	0.01	0.21	0.15	0.59
5/16/2006	A25-3	WS1-0	6.14	24.9	0.020	0.028	2.77	0.51	5.76	0.42	0.01	0.09	0.09	0.11
5/16/2006	A25-3	WS5-0	5.97	30.4	0.052	0.057	1.05	0.31	1.07	0.19	0.17	0.48	0.07	0.57
5/16/2006	A27-1	ST1	6.5	23.2	0.058	0.042	3.71	1.20	1.80	0.04	0.02	0.21	0.12	0.10
5/16/2006	A27-1	ST1	5.55	15.86	0.000	0.025	0.38	0.21	6.99	0.08	0.02	0.19	0.58	0.51
5/16/2006	A27-1	WS2-0	8.41	163.9	0.037	0.023	16.71	9.84	1.01		0.03	0.15	0.03	1.36
5/16/2006	A27-1	WS3-3	8.26	160.1	0.027	0.025	15.44	8.99	0.7	0.17	0.00	0.19	0.07	0.56
5/16/2006	A27-1	WS3-6	7.85	138.2	0.113	0.045	2.69	0.32	0.70	0.06	0.00	0.20	0.63	0.09
5/16/2006	A27-1	WS6-0	6.93	38.1	0.025	0.027	12.64	6.12	0.775	0.04	0.00	0.26	0.07	0.10
5/16/2006	A27-1	WS6-3	6.69	36.2	0.060	0.035	0.43	0.23	1.61	0.10	0.01	0.19	0.23	1.73
5/16/2006	A27-1	WS7-0	7.65	115.8	0.263	0.090	5.92	2.85	26.77	0.21	0.05	0.20	0.34	0.10

Table B.12- Pre-harvest water quality parameters and concentration for May 2006

Date	Site	Sampler ID	pH	EC (µs/cm)	TSS (g/L)	TVSS (g/L)	Ca (mg/L)	Mg (mg/L)	K (mg/L)	TP (mg/L)	SRP (mg/L)	NH3-N(mg/L)	NO3 (mg/L)	TN (mg/L)
5/16/2006	A27-2	ST2	6.39	35.2	0.003	0.022	5.73	1	4.46	0.88	0.63	0.19	9.75	0.78
5/16/2006	A27-2	ST4	6.52	76.8	0.038	0.045	6.40	1.82	3.39	0.15	0.15	0.18	5.35	0.61
5/16/2006	A27-2	WS4-0	6.8	22.2	0.010	0.030	6.88	1.07	2.12	0.05	0.00	0.20	0.03	0.38
5/16/2006	A27-2	WS5-0	6.64	19.1	0.010	0.025	56.87	16.48	2.05	0.14	0.00	0.28	0.04	0.27
5/16/2006	A27-2	WS6-6	7.15	102.5	0.032	0.032	0.99	0.39	0.645	0.05	0.00	0.63	0.04	0.10
5/16/2006	A27-2	WS7-0	7.24	136.4	0.040	0.035	23.2	12.05	1.105	0.03	0.00	0.20	0.01	0.49
5/16/2006	A27-2	WS7-3	7.68	101.6	0.020	0.025	9.26	3.8	10.14	0.06	0.02		0.08	0.12
5/16/2006	A27-2	WS7-6	7.87	88.1	0.027	0.030	3.15	1.59	1.44	0.02	0.00	0.20	0.01	0.10
5/16/2006	A34-1	ST CONTROL	5.93	15.9	0.002	0.027	1.18	0.71	0.59	0.06	0.03	0.87	0.26	1.54
5/16/2006	A34-1	ST1	6.31	18	0.022	0.027	0.97	0.41	2.95	0.17	0.04	0.20	0.25	0.31
5/16/2006	A34-1	ST3	5.77	20.8	0.005	0.030	0.43	0.23	1.59	0.01	0.09	0.67	0.53	0.17
5/16/2006	A34-1	ST5	5.65	14.95	0.012	0.032	1.015	0.37	2.9	0.12	0.04	0.20	0.06	0.10
5/16/2006	A34-1	WS10-0	5.64	20.4	0.057	0.052	35.64	18.45	0.81	0.03	0.00	0.80	0.03	0.36
5/16/2006	A34-1	WS2-0	4.78	19.3	0.007	0.027	0.38	0.53	0.92	0.00	0.00	0.20	0.21	0.56
5/16/2006	A34-1	WS3-3	5.56	26.4	0.045	0.043	1.14	0.75	1.71	0.04	0.01	0.48	0.13	0.73
5/16/2006	A34-1	WS4-0	5.84	32.4	0.012	0.027	0.00	0.16	0.19	0.07	0.00	0.11	0.37	0.67
5/16/2006	A34-1	WS4-3	6.1	41.8	0.063	0.055	2.70	0.74	1.42	0.73	0.21	0.15	0.29	0.57
5/16/2006	A34-1	WS5-0	6.22	22	0.017	0.027	0.92	0.57	1.09	0.03	0.01	0.19	0.01	0.49
5/16/2006	A34-1	WS5-3	5.72	24.3	0.007	0.027	1.84	0.89	1.62	0.01	0.00	0.20	0.07	0.77
5/16/2006	A34-1	WS5-6	6.2	40.6	0.032	0.047	1.24	0.79	1.26	0.03	0.00	0.20	0.04	0.45
5/16/2006	A34-1	WS6-0	5.48	18.62	0.027	0.037	1.8	0.56	0.72	0.00	0.00	0.20	0.04	0.65
5/16/2006	A34-1	WS7-0	6.63	47.3	0.028	0.032	1.21	0.78	0.86	0.11	0.00	0.20	0.02	0.65
5/16/2006	A34-1	WS8-0	6.64	29.9	0.032	0.035	7.18	4.12	0.83	0.15	0.00	0.45	0.12	0.49
5/16/2006	A34-1	WS8-3	6.28	23.9	0.008	0.025				0.03	0.00	0.20	0.02	0.65
5/16/2006	A34-1	WS8-6	6.91	30.3	0.002	0.023	1.26	0.67	1.94	0.03	0.00	0.20	0.02	0.63
5/16/2006	A34-1	WS9-0	6.58	41.1	0.012	0.025				0.12	0.00	0.32	0.05	0.36
5/16/2006	A34-2	ST2	6.28	18.93	0.003	0.023	2.58	0.7	5.04	0.31	0.14	0.04	0.05	1.22
5/16/2006	A34-2	WS2-0	6.14	26.2	0.037	0.023				0.19	0.01	0.35	0.11	0.74
5/16/2006	A34-2	WS2-3	6.74	197.8	0.105	0.115	4.12	0.8	2.75			0.69		
5/16/2006	A34-2	WS4-0	5.65	30.7	0.115	0.040				0.23	0.12	0.10	0.09	0.18
5/16/2006	A34-2	WS7-0	8.96	161.9	0.037	0.032	15.73	11.75	0.51	0.33		0.19	0.04	0.29
5/16/2006	A34-2	WS7-3	9.35	100.4	0.018	0.023	11.53	5.94	0.9	0.28	0.02	0.19	0.03	1.99
5/16/2006	CR7-2	ST2	7.02	36.2	0.012	0.028	2.03	0.53	1.73	0.17	0.05	0.20	0.17	0.10
5/16/2006	CR7-2	WS1-0	6.42	53.3	1.267	0.200	22.17	9.33	0.61	0.05	0.01	0.20	0.16	0.04
5/16/2006	CR7-2	WS2-0			0.118	0.050	7.83	4.49	1.29	0.10	0.01	0.40	0.07	0.67
5/16/2006	CR7-2	WS2-3	6.21	27.4	0.135	0.068	0.1	0.05	1.53	0.02	0.00	0.20	0.03	0.38
5/16/2006	CR7-2	WS2-6	5.97	23.8	0.218	0.132	14.44	6.01	0.82	0.05	0.01	0.20	0.06	0.68
5/16/2006	CR7-2	WS3-0	5.97	22.1	0.015	0.028	5.21	2.63	0.79	0.10	0.00	0.39	0.01	0.61
5/16/2006	CR7-2	WS5-0	7.13	39.4	0.032	0.030	48.74	17.29	0.57	0.09	0.01	0.20	0.04	0.30
5/16/2006	CR7-2	WS6-0	6.31	30.8	0.080	0.032	1.35	0.59	1.26	0.03	0.01	0.20	0.03	0.02
5/16/2006	CR7-2	WS6-6	6.18	26.2	0.065	0.057	2.28	0.93	2.73	0.78		0.19	0.04	2.84
5/16/2006	CR7-5B	ST CONTROL	5.88	14.3	0.032	0.040	0.17	0.33	1.02	0.36	0.10	0.20	0.07	
5/16/2006	CR7-5B	ST2	6.67	33.3	0.020	0.028	4.99	0.67	1.66	0.07	0.02	0.19	0.11	0.49
5/16/2006	CR7-5B	ST4	6.62	17.72	0.047	0.028	2.46	0.29	0.605	0.48	0.03	0.18	0.01	0.93
5/16/2006	CR7-5B	WS1-0	5.94	23.8	0.040	0.023	1.67	0.72	1.34	0.01	0.00	0.06	0.11	0.89

Table B.13- Pre-harvest water quality parameters and concentration for May 2006

Date	Site	Sampler ID	pH	EC (µs/cm)	TSS (g/L)	TVSS (g/L)	Ca (mg/L)	Mg (mg/L)	K (mg/L)	TP (mg/L)	SRP (mg/L)	NH3-N(mg/L)	NO3 (mg/L)	TN (mg/L)
5/16/2006	CR7-5B	WS2-0	6.12	31.3	0.163	0.053	3.22	0.95	2.18	0.33	0.24	0.17	0.04	2.93
5/16/2006	CR7-5B	WS3-0	6.37	23.2	1.143	0.067	1.94	0.62	1.99	0.05	0.03	0.19		0.68
5/16/2006	CR7-5B	WS3-3	5.71	19.04	0.045	0.043	0.63	0.395	1.96		0.25	0.14	0.03	1.92
5/16/2006	CR7-5B	WS3-6	6.13	20.6	0.137	0.027	13.7	5.45	1.03	0.09	0.01	0.19	0.08	0.80
5/16/2006	CR7-5B	WS4-0	6.73	29.2	0.375	0.062	2.25	0.80	1.37	0.09	0.19	0.08	1.30	
5/16/2006	CR7-5B	WS5-0	6.38	56.8	2.017	0.303	5.05	1.19	3.32	1.20			12.69	7.15
5/16/2006	CR7-5B	WS5-3	6.73	300	1.732	0.328	9.31	2.96	7.88	0.20	0.23	0.69	1.46	0.33
5/16/2006	CR7-5B	WS5-6	6.2	40.6	1.432	0.262	5.15	1.51	2.99	0.09	0.00	0.49	1.07	
5/16/2006	CR7-5B	WS6-0	6.42	40.5	1.298	0.210	3.95	1.34	1.95	0.20	0.06	0.20	0.02	
5/16/2006	CR7-5C	ST1	6.62	37.4	0.037	0.025	4.51	0.695	4.64	0.81		0.01	0.34	3.29
5/16/2006	CR7-5C	ST3	6.42	18.5	0.008	0.025	1.15	0.54	1.30	0.38	0.12	0.19	0.91	0.56
5/16/2006	CR7-5C	ST3	5.64	11.5	0.050	0.047	0.72	0.42	2.01	0.04	0.05	0.40	0.15	
5/16/2006	CR7-5C	ST4	6.09	21.4	0.005	0.023	0.74	0.765	2.55	0.41		0.06	2.10	2.14
5/16/2006	CR7-5C	WS1-0	6.22	30.8	0.082	0.033	2.365	0.51	1.28	0.33	0.03	0.15	0.03	0.93
5/16/2006	CR7-5C	WS1-3	6.17	23.2	0.017	0.023						0.18		
5/16/2006	CR7-5C	WS2-3	6.21	27.7	0.038	0.025	1.81	0.64	1.28	0.66	0.64	0.15	0.00	0.31
5/16/2006	CR7-5C	WS3-0	6.32	31.2	0.667	0.153	2.745	0.79	1.15		0.01	0.17	1.27	1.74
5/16/2006	CR7-5C	WS3-3	6.31	34.8	0.170	0.052	3.34	1.09	2.74	0.47	0.39	0.13	2.91	1.75
5/16/2006	CR7-5C	WS3-6	6.35	27.1	0.030	0.035	1.01	0.61	3.81	0.01		0.19	0.07	0.63
5/16/2006	CR7-5C	WS3-6	5.8	21.2	0.117	0.063	3.35	1.02	2.72	0.97	0.02	0.19		0.95
5/16/2006	CR7-5C	WS4-3	6.2	21.7	0.075	0.028	1.39	0.59	1.04	0.12	0.03	0.20	0.11	0.74
5/16/2006	CR7-5C	WS5-0	6.08	28.5	0.013	0.020	1.39	0.68	6.01	0.40	0.04	0.19	0.05	0.53
5/16/2006	CR7-6	ST2	6.77	62.4	0.083	0.060	7.45	1.47	3.04	1.60	1.57	0.19	10.02	1.70
5/16/2006	CR7-6	ST3	6.64	20.4	0.005	0.025	1.59	0.53	1.35		0.01	0.16	2.24	1.80
5/16/2006	CR7-6	ST4	6.08	14.88	0.033	0.033	1.75	0.58	0.88					0.10
5/16/2006	CR7-6	WS1-0	5.98	61.2	0.138	0.147	5.14	1.54	3.54	3.80	0.03	0.00	0.28	0.10
5/16/2006	CR7-6	WS2-0	6.25	18.1	0.447	0.263	0.73	0.54	1.68	0.05	0.00	1.14	0.05	0.10
5/16/2006	CR7-6	WS3-0	6.38	38.3	0.170	0.053	3.61	0.87	1.99	0.12	0.01	0.20	0.07	0.09
5/16/2006	CR7-6	WS3-3	6.34	29.1	0.363	0.052	2.88	0.71	2.61	0.09	0.03	0.64	0.31	0.10
5/16/2006	CR7-6	WS4-0	5.89	29.2	3.038	0.222	1.58	0.64	1.92	0.31	0.04	0.18	0.48	0.10
5/16/2006	CR11-1	ST1	5.76	27.8	0.002	0.022	0.93	0.73	2.85	0.26		0.16	0.46	1.67
5/16/2006	CR11-1	ST2	5.37	23.7	0.003	0.023	1.36	0.82	3.05	6.51	7.46	0.19	0.88	2.59
5/16/2006	CR11-1	ST4	5.39	18.7	0.000	0.020	0.75	0.65	1.55	1.02		0.17	1.86	3.37
5/16/2006	CR11-1	ST5	5.97	24.3	0.013	0.028	0.9	0.57	4.18	0.62		0.19	0.28	1.42
5/16/2006	CR11-1	WS1-0	8.75	145.8	0.013	0.020	1.56	0.61	4.83	0.01	0.03	0.18	0.09	0.63
5/16/2006	CR11-1	WS2-0	6.08	23.1	0.008	0.025	3.51	0.72	1.06	0.25	0.05	0.20	0.04	0.74
5/16/2006	CR11-1	WS3-0	6.31	25.1	0.027	0.027	1.15	0.76	0.76	0.78	0.74	0.19	0.08	0.75
5/16/2006	CR11-1	WS5-6	6.22	19.8	0.022	0.025	1.35	0.72	1.08	0.01	0.02	0.19	0.01	0.25
5/16/2006	CR11-3	GRAB 1	6.94	30.2	0.013	0.020	9.18	3.92	0.88	0.57	0.11	0.20	0.03	0.77
5/16/2006	CR11-3	ST4	6.44	106.6	0.032	0.038	1.36	0.71	1.41	4.14	3.56	0.20	13.47	2.84
5/16/2006	CR11-3	ST5	6.2	17.63	0.030	0.038	0.67	0.28	1.38	0.19	0.14	0.11	1.08	2.21
5/16/2006	CR11-3	WS1-0	6.45	45.6	0.052	0.022	5.19	2.105	2.09	0.17		0.19	0.00	1.27
5/16/2006	CR11-3	WS3-0	6.11	31.9	0.048	0.023	2	0.97	1.05	0.83		0.16	0.00	1.45
5/16/2006	CR11-3	WS5-0	6.33	48.3	0.628	0.182	4.32	2.115	1.22	0.61		0.12	0.08	2.21
5/16/2006	CR11-9	ST1	6.13	32.8	0.012	0.027	2.60	1.26	5.96	2.26	3.90	0.04	0.19	2.13

Table B.14- Pre-harvest water quality parameters and concentration for July and Oct. 2006

Date	Site	Sampler ID	pH	EC (µs/cm)	TSS (g/L)	TVSS (g/L)	Ca (mg/L)	Mg (mg/L)	K (mg/L)	TP (mg/L)	SRP (mg/L)	NH3-N(mg/L)	NO3 (mg/L)	TN (mg/L)
5/16/2006	CR11-9	ST2	6.12	20.1	0.010	0.027	2.54	0.65	1.47	0.33	0.27	0.19	1.13	0.55
5/16/2006	CR11-9	WS2-0	6.33	25.9	0.018	0.023	1.45	1.17	2.08	0.07	0.02	0.19	0.01	1.19
5/16/2006	Control	CONTROL	5.26	56.21	0.000	0.018	2.73	1.98	0.99					
7/20/2006	A17-1	WS3-0	6.43	29.1	0.015	0.018	1.4100	0.7100	2.6	0.10	0.04		0.05	0.24
7/20/2006	A25-2	ST1	5.62	26.2	0.057	0.001	1.5400	0.5100	2.5	0.89	0.25		0.43	0.62
7/20/2006	A25-2	ST4	6.13	32	0.189	0.055	0.1900	0.2200	2.12	1.01	0.40		0.37	0.57
7/20/2006	A25-2	ST5	6.72	97.1	0.024	0.002	1.9700	0.6900	8.21	1.07	0.59	0.05		0.32
7/20/2006	A25-2	WS1-0	6.87	99.3	0.027	0.097	7.0900	1.4800	2.04	0.37	0.29		0.63	0.82
7/20/2006	A25-3	ST1	5.6	24.5	0.179	0.063	0.6000	0.3400	1.38	1.04	0.43		0.32	1.35
7/20/2006	A25-3	ST3	5.98	33.9	0.037	0.000	1.8900	0.7900	4.73	0.56	0.32	0.01	0.03	0.11
7/20/2006	A27-1	WS3-0	8.42	242	0.135	0.091	11.6900	23.3400	1.31	0.06	0.01		0.25	0.34
7/20/2006	A27-1	WS4-3	8.82	192	0.182	0.127	####	14.7300	0.94	0.13	0.02	0.21	0.17	0.43
7/20/2006	A27-1	WS5-6	8.68	243	0.234	0.169	11.7200	19.4500	1.02	0.02	0.01	0.00	0.15	0.16
7/20/2006	A27-1	WS7-0	8.16	161	0.182	0.091	####	10.9000	0.87	0.01	0.00	0.12	0.12	0.44
7/20/2006	A27-2	ST1	6.78	187.7	0.016	0.000	2.4100	0.6600	6.76	1.98	1.34	0.20	0.18	0.21
7/20/2006	A27-2	ST2	6.11	41.4	0.074	0.011	2.9000	0.7000	4.3		0.64		0.30	0.71
7/20/2006	A34-1	CONTROL	6.72	23.2	0.036	0.001	0.0300	0.1600	1.92	0.67	0.08	0.10	0.07	0.18
7/20/2006	A34-1	ST1	6.21	38.4	0.023	0.000	3.0700	0.7500	4.35	1.88	0.88	0.22	0.16	0.43
7/20/2006	A34-1	ST5	5.91	19.7	0.035	0.003	0.4600	0.3100	3.04	0.40	0.15	0.20	0.19	0.87
7/20/2006	A34-2	ST2	5.63	40.2	0.091	0.024	2.1600	0.6500	2.39	0.55	0.37	0.12	0.21	0.32
7/20/2006	CR7-2	ST4	6.39	35.1	0.211	0.124	3.5300	0.8900	1.48	0.75	0.32	0.21	0.09	0.14
7/20/2006	CR7-5B	CONTROL	5.85	19.2	0.054	0.017	0.6500	0.2800	1.87	0.72	0.15		0.92	1.43
7/20/2006	CR7-5C	ST4	6	30.1	0.006	0.000	1.1300	0.7600	2.28	0.42	0.22	0.10	0.17	0.34
7/20/2006	CR7-5C	WS2-0	6.22	19.8	0.139	0.100	1.0300	0.5200	1.77	0.12	0.01	0.02	0.12	0.87
7/20/2006	CR7-6	ST4	5.51	51.5	0.113	0.009	3.2100	1.1700	3.48	1.03	0.58	0.13		0.20
7/20/2006	CR11-3	ST1	6.32	29	0.109	0.023	1.6000	0.2300	1.21	0.34	0.20			
7/20/2006	CR11-3	WS1-0	6.43	38.1	0.785	0.681	3.4000	1.5100	1.85	0.04	0.00	0.20	0.13	0.22
7/20/2006	CR11-3	WS5-0	5.84	49.8	0.000	0.000	0.00	0.00	0					
7/20/2006	CR11-9	ST1	6.14	80.2	0.293	0.032	3.3100	1.4600	8.69	2.43	1.17	0.19	0.12	0.51
7/20/2006	CR11-9	ST2	6.09	23.5	0.044	0.008	2.0200	0.5100	1.67	0.33	0.23	0.03	0.55	0.99
7/20/2006	CR11-9	WS1-0	8.43	179.2	0.037	0.009	####	6.4500	3.05	0.04	0.01	0.12	0.15	0.33
10/22/2006	A17-1	WS1-3	6.78	72.1	0.045	0.065	3.37	0.84	12.49				0.03	
10/22/2006	A17-1	WS3-3	6.14	25	0.045	0.047	1.88	0.51	3.35	2.45			2.40	10.90
10/22/2006	A25-2	ST1	6.15	30.2	0.017	0.033	1.51	0.58	6.73	1.51	0.11	0.19	0.12	3.32
10/22/2006	A25-2	ST4	5.99	22.6	0.035	0.037	0.83	0.475	5.9	0.50	0.04	0.19	0.06	1.40
10/22/2006	A25-2	ST5	6.22	62.1	0.265	0.238	2.91	0.84	11.22	5.49	0.83	0.18	5.63	16.11
10/22/2006	A25-2	WS1-0	6.57	64.9	0.103	0.045	6.48	1.78	7.91	3.75	0.33	0.11	3.33	12.92
10/22/2006	A25-2	WS1-3	6.23	44	0.065	0.058	3.92	1.13	3.34	0.58	0.07	0.15	2.27	9.99
10/22/2006	A25-2	WS1-6	6.58	71.4	0.030	0.043	6.13	1.77	7.92		0.18	0.01	2.95	15.12
10/22/2006	A25-3	ST3	5.78	30.3	0.008	0.028	1.165	0.57	5.43	1.55	0.13	0.18	1.11	5.54
10/22/2006	A25-3	ST4	5.79	34.9	0.030	0.045	2.69	0.49	5.31	4.90	0.56	0.19	2.16	6.54
10/22/2006	A27-1	ST1	5.88	13.76	0.002	0.030	0.27	0.1	3.4	0.57	0.01	0.18	0.02	0.98
10/22/2006	A27-1	ST5	6.79	58.8	0.030	0.035	5.65	1.01	3.935	2.88	0.38	0.19	2.71	9.65
10/22/2006	A27-1	WS1-0	7.59	207	4.803	0.358					0.09	0.19	1.05	5.01
10/22/2006	A27-1	WS1-3	5.81	14.29	0.135	0.143	0.505	0.09	0.69		0.13	0.19	1.19	4.40

Table B.15- Pre-harvest water quality parameters and concentration for Oct., Nov. and Dec. 2006

Date	Site	Sampler ID	pH	EC (µs/cm)	TSS (g/L)	TVSS (g/L)	Ca (mg/L)	Mg (mg/L)	K (mg/L)	TP (mg/L)	SRP (mg/L)	NH3-N(mg/L)	NO3 (mg/L)	TN (mg/L)
10/22/2006	A27-1	WS1-3	5.81	14.29	0.055	0.080	1.18	0.38	3.035		0.12	0.17	0.38	
10/22/2006	A27-1	WS3-0	7.32	216	0.063	0.043	21.57	13.815	1.115	2.62	0.00	0.11	0.36	2.74
10/22/2006	A27-1	WS4-0	6.9	77.8	0.033	0.047	1.29	0.32	4.27		0.03	0.19	0.14	2.98
10/22/2006	A27-1	WS4-3	5.91	149.2	0.012	0.030					2.90	0.68	11.24	
10/22/2006	A27-1	WS5-0	6.61	33.3	0.012	0.033	1.49	0.6	5.71		0.00	0.03	0.06	3.07
10/22/2006	A27-1	WS6-0	7.32	114	0.090	0.053	13.07	7.42	1	1.81	0.01	0.18	0.22	1.96
10/22/2006	A27-2	ST2	5.89	37.9	0.043	0.063	1.82	0.6	8.08	4.34	0.80	0.18	1.99	9.28
10/22/2006	A27-2	WS2-3	6.11	45.5	0.220	0.223	5	0.31	3.325	6.24	0.64	0.05	4.03	11.18
10/22/2006	A27-2	WS5-3	5.8	28.7	0.205	0.222	5.81	0.45	3.81			0.17		
10/22/2006	A27-2	WS5-3	5.8	28.7	0.385	0.373	8.17	4.135	30.14	19.60	5.00	1.08		
10/22/2006	A34-1	CONTROL	5.94	14.63	0.020	0.037	0	0.07	1.17	0.32	0.02	0.19	0.16	2.63
10/22/2006	A34-1	ST3	5.92	13.67	0.033	0.048	0.48	0.18	1.73	0.25	0.01	0.19	0.60	3.80
10/22/2006	A34-1	ST5	5.58	18.52	0.065	0.068	0.81	0.36	3.14	0.51	0.06	0.19	0.07	2.53
10/22/2006	A34-1	WS1-0	5.58	26.8	0.015	0.032	1.345	0.78	2.29	0.44	0.02	0.19	0.23	2.95
10/22/2006	A34-2	ST2	6.23	35.1	0.020	0.037	1.91	0.46	3	1.28	0.12	0.19	0.49	5.74
10/22/2006	CR11-1	WS6-3	7.52	106.4	0.093	0.070				0.27	0.09	0.19	0.02	
11/4/2006	CR7-5B	CONTROL	6.08	20.8	0.023	0.035	0.16	0.25	5.25	0.28	0.20	0.20	0.10	1.02
11/4/2006	CR7-5B	ST2	6.55	118.9	0.130	0.083	11.33	2.785	5.64	0.23	1.76		3.08	13.53
11/4/2006	CR7-5B	ST4	6.29	26.5	0.013	0.033	0.96	0.48	6.57	0.29	0.12	0.20	0.17	1.94
11/4/2006	CR7-5B	WS4-0	6.28	35.8	0.155	0.138	4.95	2.46	3.43	0.29	0.03	0.20	0.03	1.65
11/4/2006	CR7-5C	ST3	6.14	45	0.138	0.078	3.38	0.73	9.39	0.28	0.42	0.19	1.15	2.74
11/4/2006	CR7-5C	ST4	6.55	26.3	0.008	0.023	1.13	0.7	4.14	0.29	0.08	0.20	3.83	2.14
11/4/2006	CR7-5C	ST5	6.28	31.2	0.000	0.033	1.32	0.67	6.42	0.28	0.21	0.21	1.56	2.68
11/4/2006	CR7-5C	WS3-0	7.32	155.5	0.360	0.338	29.87	2.74	6.58	0.16	2.60	0.19	0.01	3.79
11/4/2006	CR7-5C	WS5-0	6.26	11.86	0.012	0.025	0	0.04	2.61	0.28	0.18	0.19	0.01	0.59
11/4/2006	CR7-6	WS5-0			0.000	0.000				0.29	0.03	0.20	0.03	1.77
11/4/2006	CR11-1	ST3	7.18	37.3	0.018	0.030	2.91	1.085	5.52	0.29	0.03	0.20	0.57	1.63
11/4/2006	CR11-3	ST1	6.31	46.8	0.008	0.027	2.35	0.68	11.87	0.29	0.10	0.19	0.17	1.77
11/4/2006	CR11-3	ST4	6.77	41	0.005	0.015	2.16	0.69	8.91	0.29	0.18	0.20	1.28	3.11
11/4/2006	CR11-3	WS1-0	6.24	52	1.825	0.180				0.29	0.03	0.19	0.13	1.81
11/4/2006	CR11-3	WS3-0	5.99	26.4	0.053	0.063	2.29	1.04	1.35	0.29	0.02		0.03	1.67
11/4/2006	CR11-3	WS5-0	6.9	32.2	0.013	0.025	2.58	0.92	2.5	0.29	0.03		0.01	1.11
11/4/2006	CR11-3	WS5-3	6.87	32.3	0.022	0.030	1.75	0.98	1.94	0.29	0.03	0.20	0.03	1.86
11/4/2006	CR11-9	ST1	6.29	53	0.022	0.030	2.57	1.32	10.53	0.28	0.34	0.19	2.28	4.12
11/4/2006	CR11-9	ST2	6.33	32.6	0.003	0.023	2.145	0.735	5.6	0.29	0.12	0.20	2.91	3.23
11/4/2006	CR11-9	WS1-0	6.81	155.8	0.100	0.083	19.05	6.99	4.22	0.29	0.02	0.06	0.03	6.51
12/18/2006	A17-1	WS1-0	6.61	16.87	0.027	0.008	0.65	0.60	2.08	0.08	0.01	0.20	0.09	0.67
12/18/2006	A17-1	WS1-3	6	17.43	0.007	0.002	0.355	0.47	1.04	0.00	0.01	1.37	0.01	0.56
12/18/2006	A17-1	WS1-6	6.65	17.18	0.000	0.000	0.43	0.50	1.30	0.03	0.02	0.19	0.03	1.09
12/18/2006	A17-1	WS2-0	5.78	17.31	0.072	0.020	0.19	0.50	1.01	0.01	0.01	0.20	0.02	0.96
12/18/2006	A17-1	WS3-0	5.81	16.03	0.118	0.032	0.27	0.47	0.81	0.03	0.02	0.20	0.02	0.75
12/18/2006	A17-1	WS3-6	5.66	17.55	0.175	0.080	0.11	0.36	1.92	0.12	0.08	0.19	0.08	2.60
12/18/2006	A17-1	WS4-0	7.46	30	0.033	0.013	2.505	0.8	1.525	0.60	0.57	1.33	0.09	3.31
12/18/2006	A17-1	WS4-3	6.8	24.4	0.008	0.005	1.42	0.75	2.06	0.02	0.01	1.38	0.01	0.99
12/18/2006	A17-1	WS4-6	6.25	32.2	0.198	0.067	2.39	0.95	3.45	0.20	0.24	1.34	0.69	5.19

Table B.16- Pre-harvest water quality parameters and concentration for December 2006

Date	Site	Sampler ID	pH	EC (µs/cm)	TSS (g/L)	TVSS (g/L)	Ca (mg/L)	Mg (mg/L)	K (mg/L)	TP (mg/L)	SRP (mg/L)	NH3-N(mg/L)	NO3 (mg/L)	TN (mg/L)
12/18/2006	A17-2	WS1-0	6.31	23.3	0.267	0.083	1.33	0.5	1.98	0.06	0.37		0.01	1.62
12/18/2006	A17-2	WS4-0	8.15	50.3	0.052	0.008				0.00	0.00	0.10	0.03	0.40
12/18/2006	A27-1	ST1	6.1	11.21	0.010	0.003	0.00	0.09	1.53	0.01	0.01	0.19	0.07	0.27
12/18/2006	A27-1	ST3	6.92	31.7	0.005	0.002	3.005	0.51	4.45	0.82	0.84	1.41		0.96
12/18/2006	A27-1	ST5	6.95	18.1	0.005	0.003	0.64	0.25	3.18	0.00	0.01	0.19	0.03	0.32
12/18/2006	A27-1	WS3-0	5.77	109.3	0.108	0.062	0.4	0.33	1.92	0.04	0.04	0.20	0.00	0.91
12/18/2006	A27-1	WS3-0	7.59	35.3	0.132	0.005	19.30	28.67	0.31					
12/18/2006	A27-1	WS3-3	8.31	97.8	0.025	0.005	0.00	0.37	2.49	0.04	0.02	1.40	0.00	0.90
12/18/2006	A27-1	WS3-6	6.05	22.4	0.220	0.232	1.5	0.17	5.26	0.18	0.05	0.32	0.41	3.07
12/18/2006	A27-1	WS4-0	7.78	170.4	1.397	0.258	14.94	13.24	0.64	0.03	0.02	1.40	0.02	0.74
12/18/2006	A27-1	WS4-3	6.8	24.4	0.040	0.007	8.14	6.02	0.71	0.03	0.03	0.19	0.02	0.51
12/18/2006	A27-1	WS5-0	7.02	33	0.127	0.010	2.00	1.81	0.55	0.02	0.03	0.20	0.02	0.86
12/18/2006	A27-1	WS5-3	7.09	29.3	0.118	0.033	7.37	3.92	1.15	0.03	0.02	0.19	0.03	1.38
12/18/2006	A27-1	WS7-6	7.35	70.1	0.078	0.012	7.17	3.66	2.26	0.04	0.02	1.39	0.01	1.30
12/18/2006	A27-2	ST1	6.65	21.5	0.015	0.003	0.6	0.34	4.75	0.56	0.51	1.39	0.07	0.76
12/18/2006	A27-2	ST2	6.68	19.8	0.025	0.008	0.17	0.21	2.85	0.54	0.46	0.20	0.02	0.45
12/18/2006	A27-2	ST3	7.07	335	0.067	0.022	0.04	0.45	8.71	6.43	6.53	0.61	0.03	19.36
12/18/2006	A27-2	WS4-0	7.14	134.7	0.107	0.107	21.46	2.86	1.53	2.77	2.86	0.01		11.83
12/18/2006	A27-2	WS5-0 #1	6.36	14.24	0.035	0.042	4.19	0.53	1.965	0.02	0.01	0.25	0.22	0.39
12/18/2006	A27-2	WS5-0 #2	6.29	35.8	0.007	0.030	1.29	0.325	1.78					
12/18/2006	A27-2	WS6-0	7.86	104.8	0.058	0.012	10.26	7.17	1.38	0.27	0.20	0.19	2.57	4.50
12/18/2006	A27-2	WS6-3	8.88	149.2	0.092	0.012	4.47	3.02	0.18	0.00	0.01	1.39	0.00	
12/18/2006	A27-2	WS7-0	7.2	132	0.078	0.053	13.59	6.75	1.38	0.13	0.11	0.55	8.50	3.98
12/18/2006	A27-2	WS7-3	8.6	100	0.105	0.033	9.68	4.85	1.74	0.02	0.02	1.34	0.06	0.40
12/18/2006	A27-2	WS7-6	6.86	66.6	0.013	0.030	6.03	3.59	2.31	0.14	0.10	0.27	0.35	1.05
12/18/2006	A34-2	WS5-0	6.43	55.9	0.165	0.108	6.58	2.825	1.59	0.19	0.01	0.25	0.06	1.09
12/18/2006	A34-2	WS5-6	7.03	97.9	0.007	0.028	5.72	2.76	4.5	0.61	0.53			
12/18/2006	A34-2	WS6-0	6.99	70.2	0.032	0.045	7.75	3.88	2.1	0.02	0.01	0.30	0.05	0.91
12/18/2006	A34-2	WS6-3	6.82	91.6	0.200	0.138	11.63	4.02	2.9	0.04	0.02	0.06	0.62	1.75
12/18/2006	CR7-6	ST4	6.23	15.2	0.020	0.030	2.82	0.76	4.17	0.18	0.16	0.41	1.93	5.21
12/18/2006	Control	CONTROL	5.47	51.2	0.000	0.025	3.34	0.41	1.60					
12/18/2006	CR11-9	ST1	6.56	28.8	0.005	0.002	0.54	0.49	5.75	0.12	0.10	1.39	0.05	1.24
12/18/2006	CR11-9	ST2	6.68	20.7	0.007	0.002	0.11	0.37	5.28	0.06	0.05	0.19	0.10	0.84
12/18/2006	CR11-9	WS1-0	6.89	92.4	0.000	0.000	9.18	2.99	1.43	0.03	0.03	0.20	0.02	0.37
12/18/2006	CR11-9	WS1-3	9.12	98.8	0.012	0.005	11.79	3.86	2.49	0.02	0.03	1.37	0.01	1.57
12/18/2006	CR11-9	WS3-3	6.94	22.5	0.013	0.003	0	0.45	8.66	0.26	0.31	1.40	0.00	0.76
12/28/2006	CR7-2	WS1-0	6.33	44.4	0.020	0.030	4.72	1.995	1.05		0.00	0.17	0.06	0.81
12/28/2006	CR7-2	WS2-0	6.15	59.5	0.063	0.073				0.27	0.20	0.40	13.64	10.04
12/28/2006	CR7-2	WS2-3	5.89	31.1	0.103	0.103	2.385	0.67	5.515		0.33	0.08	0.16	1.98
12/28/2006	CR7-2	WS2-6	5.94	25.5	0.112	0.123	2.05	0.52	3.65	0.56	0.10	0.15	0.06	1.22
12/28/2006	CR7-2	WS6-3	5.56	32.5	0.165	0.158	1.69	0.83	2.23	1.13	0.05	3.22	0.10	2.92
12/28/2006	CR7-2	WS6-6	6.07	40.8	0.048	0.035	4.2	0.93	2.8	0.57	0.01	0.06	0.56	1.49
12/28/2006	CR7-5B	ST1	5.99	31.1	0.005	0.028	1.23	0.57	5.38	0.55	0.11	0.13	0.38	1.08
12/28/2006	CR7-5B	ST4	5.78	11.38	0.003	0.027	0	0.08	1.37	0.11	0.01	0.12	0.09	0.65
12/28/2006	CR7-5B	WS1-0	6.39	105.2	0.328	0.050	2.25	0.85	3.45	3.97	1.15	17.07	15.40	16.74

Table B.17- Pre-harvest water quality parameters and concentration for Dec. 2006 and Jan. 2007

Date	Site	Sampler ID	pH	EC (μs/cm)	TSS (g/L)	TVSS (g/L)	Ca (mg/L)	Mg (mg/L)	K (mg/L)	TP (mg/L)	SRP (mg/L)	NH3-N(mg/L)	NO3 (mg/L)	TN (mg/L)
12/28/2006	CR7-5B	WS3-0	5.98	18.11	0.035	0.030	1.32	0.525	0.96	0.16	0.01	0.04	0.15	0.46
12/28/2006	CR7-5B	WS3-3	5.83	19.9	0.038	0.035	1.66	0.51	1.24	0.10	0.01	0.03	0.18	0.96
12/28/2006	CR7-5C	ST3	5.98	16.55	0.005	0.028	0.655	0.41	4.905	0.54	0.16	0.01	0.67	2.49
12/28/2006	CR7-5C	ST5	5.98	16.55	0.002	0.028	0.08	0.13	3.61	0.79	0.04	0.00	0.07	2.50
12/28/2006	CR7-5C	WS1-0	5.9	23.7	0.037	0.033	1.69	0.4	0.72	0.32	0.04	1.21	0.47	1.77
12/28/2006	CR7-5C	WS2-0	6.14	20.6	0.053	0.040	1.535	0.53	0.99	0.26	0.06	0.03	0.04	0.65
12/28/2006	CR7-5C	WS2-6	6.07	30.2	0.077	0.085	2.4	0.5	4.75	0.66	0.01	0.01	0.13	1.04
12/28/2006	CR7-5C	WS3-0	6.08	65	0.497	0.235	2.86	1.01	3.8	4.05	1.10	17.07	0.12	13.72
12/28/2006	CR7-5C	WS4-0	5.71	24.7	0.870	0.152	1.91	0.65	1.66	0.21	0.02	0.02	0.18	1.39
12/28/2006	CR7-5C	WS4-3	6.04	16.72	0.012	0.028	1	0.42	1.065	0.10	0.03	0.40	0.06	0.20
12/28/2006	CR7-5C	WS4-6	5.89	15.99	0.025	0.035	1.29	0.405	0.52	0.08	0.01	0.06	0.10	0.30
12/28/2006	CR7-5C	WS5-0	5.84	18.54	0.030	0.032	1.13	0.51	0.9	0.11	0.01	0.03	0.13	0.52
12/28/2006	CR7-6	WS5-0	5.83	19.3	0.030	0.030	1.34	0.7	0.83	0.09	0.03	0.12	1.38	0.74
12/28/2006	CR7-6	WS6-0	5.69	31.2	0.142	0.123	2.29	0.83	4	0.16	0.01	0.01	0.10	1.19
12/28/2006	CR11-3	ST4	6.35	35.5	0.007	0.027	1.64	0.565	7.61	0.30	0.03	0.01	0.16	1.59
12/28/2006	CR11-3	WS1-0	6.45	32.5	0.022	0.035	3.19	1.47	1.22	0.03	0.01	0.11	0.22	0.73
12/28/2006	CR11-3	WS5-0	6.3	41.1	0.482	0.187	4.36	1.81	0.89	0.25	0.01	0.40	1.39	3.72
12/28/2006	Control	CONTROL	5.32	23.1	0.000	0.020								
1/28/2007	CR7-2	WS3-0	5.77	10.41	0.006	0.004	0	0.26	0.7	0.06	0.00	0.03	0.07	0.74
1/28/2007	CR7-2	WS3-3	6.45	18.7	0.009	0.003	1.21	0.42	1.42	0.12	0.08	0.06	0.11	0.24
1/28/2007	CR7-2	WS3-6	6.96	72.8	0.027	0.026	1.29	0.57	3.05	1.30	0.59		0.07	20.95
1/28/2007	CR7-5B	WS1-0	6.08	5.5	0.005	0.004	0.39	0.15	0.17	0.05	0.04	0.05	0.14	1.09
1/28/2007	CR7-5B	WS3-0	6.68	16.35	0.009	0.005	1.39	0.49	1.24	0.12	0.02	0.23	0.08	1.63
1/28/2007	CR7-5B	WS3-3	5.5	12.65	0.085	0.056	0.25	0.25	1.81	0.06	0.03		0.11	1.36
1/28/2007	CR7-5B	WS5-0	6.92	47.9	0.459	0.308						0.50		5.95
1/28/2007	CR7-5C	WS4-0	6.2	18.37	0.016	0.002	1.19	0.5	1.04	0.08	0.00	0.06	0.12	1.11
1/28/2007	CR7-6	WS5-0	7.6	8.12	0.006	0.004	0	0.16	0.34	0.07	0.02	0.05	0.06	1.36
1/28/2007	CR7-6	WS6-0	7.61	68.1	0.360	0.328	5.45	3.17	0.99		0.01	0.06	0.10	1.90
1/28/2007	CR7-6	WS6-3	7.13	61.3	0.254	0.225	5.17	3.13	1.07	0.13	0.03	0.21	0.08	1.03
1/28/2007	CR11-1	WS2-0	6.45	19.1	0.015	0.013	1	0.53	0.94	0.11	0.01	0.15	0.06	0.93
1/28/2007	CR11-1	WS2-3	8.94	18.1	0.092	0.050	1.3	0.58	1.44	0.14	0.09	0.09	0.08	1.87
1/28/2007	CR11-1	WS3-0	6.27	22.1	0.063	0.030	1.32	0.6	0.96		0.00		0.06	0.67
1/28/2007	CR11-3	WS1-0	6.67	37	0.065	0.057	2.83	1.62	0.83		0.00		0.10	1.36
1/28/2007	CR11-3	WS1-0			0.000	0.000	3.98	1.96	1.96	0.09	0.02		0.06	3.66
1/28/2007	CR11-3	WS5-0	8.43	38	0.009	0.006				0.09		0.05		3.39
1/28/2007	CR11-3	WS5-3	7.44	23.2	0.018	0.016	1.67	1.12	0.75	0.14	0.01		0.06	4.33
1/28/2007	CR11-3	WS5-6	6.36	29.4	0.054	0.045	3.1	1.41	2.07	0.81	0.01	0.25	0.08	2.58
1/28/2007	CR11-9	ST1	5.89	15.87	0.001	0.001	0.49	0.31	2.04	0.21	0.09	0.55	0.69	12.03
1/28/2007	CR11-9	ST2	5.93	15.04	0.001	0.000	0.38	0.28	1.93	0.27	0.09	0.43	0.16	14.73
1/28/2007	CR11-9	WS1-0	6.9	21.2	0.023	0.018	0.97	0.42	0.74	0.13	0.00	0.03	0.08	11.76
1/28/2007	CR11-9	WS2-3	5.48	8.96	0.228	0.131	0.4	0.32	1.22	0.12	0.01	0.07	0.10	0.87
1/28/2007	CR11-9	WS3-0	6.53	41.4	0.064	0.055	1.61	0.97	1.89	0.30	0.34	1.04	0.09	12.03
1/28/2007	CR11-9	WS5-3	6.72	33	0.011	0.008	1.29	0.35	1.18	0.46	0.33	1.39	0.21	1.08
3/26/2007	A17-1	WS2-3	6.4	53.1	0.010	0.004	4.65	3.16	0.75	0.05	0.01	0.13	0.03	0.71
3/26/2007	A17-1	WS3-0	5.54	14.02	0.148	0.013	1.17	1.06	0.95	0.01	0.01	0.24	0.02	0.67

Table B.18- Pre-harvest water quality parameters and concentration for March 2007

Date	Site	Sampler ID	pH	EC (µs/cm)	TSS (g/L)	TVSS (g/L)	Ca (mg/L)	Mg (mg/L)	K (mg/L)	TP (mg/L)	SRP (mg/L)	NH3-N(mg/L)	NO3 (mg/L)	TN (mg/L)
3/26/2007	A17-1	WS3-3	6.74	24.3	0.112	0.005					0.01	0.25	0.03	0.57
3/26/2007	A17-1	WS4-0	5.53	15.85	0.076	0.034				0.01	0.01	0.02	0.02	0.60
3/26/2007	A17-1	WS4-3	5.59	40	0.192	0.135				0.67	0.81	0.15	0.03	0.88
3/26/2007	A25-2	ST4	5.5	7.04	0.010	0.003	0	0.005	0.65	0.12	0.06	0.54	0.09	0.31
3/26/2007	A25-2	WS1-0	6.06	19.14	0.001	0.000	0.54	0.26	0.55	0.01	0.01	0.14	0.02	0.56
3/26/2007	A25-2	WS1-3	5.7	5.19	0.002	0.001	0	0.02	0.55	0.08	0.02	0.03	0.35	0.76
3/26/2007	A25-2	WS1-6	6.6	46.1	0.020	0.018	0	0	0	0.01	0.01	0.01	0.03	
3/26/2007	A25-2	WS2-0	5.66	27.5	0.064	0.020	0.21	0.16	0.34	0.02	0.01	0.30	0.02	1.58
3/26/2007	A25-2	WS2-3	5.56	14.79	0.048	0.024				0.07	0.03	0.10	0.09	0.35
3/26/2007	A25-2	WS3-0	5.34	18.94	0.012	0.003	0.45	0.43	1.6	0.01	0.00		0.03	
3/26/2007	A25-3	ST3	5.3	21.5	0.026	0.014	0.47	0.35	0.64	0.12	0.14	1.09	1.54	5.32
3/26/2007	A25-3	ST4	5.27	16.04	0.002	0.000				0.06	0.03	0.14	0.02	0.65
3/26/2007	A25-3	WS1-0	5.68	8.86	0.198	0.055	1.78	0.71	1.46	0.05	0.05	0.00	0.02	0.61
3/26/2007	A25-3	WS1-3	6.06	16.5	0.010	0.004	0.75	0.42	1.94	0.00	0.01	0.07	0.19	0.37
3/26/2007	A25-3	WS1-6	6.79	16.41	0.020	0.002	0.46	0.095	1.31	0.01	0.00	0.18	0.02	0.61
3/26/2007	A25-3	WS2-0	6.26	66	0.662	0.149	6.58	0.71	1.37	0.80	0.76		0.03	
3/26/2007	A25-3	WS2-6	5.84	20	0.120	0.004	0.71	0.42	1.39	0.00	0.01	0.07	0.29	1.59
3/26/2007	A25-3	WS4-6	5.88	6.96	0.008	0.001	0.51	0.16	1.31	0.03	0.02	0.62	0.08	2.34
3/26/2007	A25-3	WS5-3	6.07	6.69	0.388	0.018	0	0.01	0.23	0.00	0.00	0.16	0.03	0.59
3/26/2007	A25-3	WS6-6	6.07	13.51	0.028	0.005	0.93	0.24	0.56	0.01	0.01	0.18	0.02	0.57
3/26/2007	A27-1	ST1	5.1	15.22	0.001	0.001	0.5	0.345	1.27	0.01	0.01	0.26	0.02	
3/26/2007	A27-1	ST2	5.44	26.5	0.0050	0.0063	2.07	0.48	1.84	0.20	0.21	0.23	5.08	7.23
3/26/2007	A27-1	WS2-0	6	30	0.005	0.000				0.04	0.01	0.18	0.03	0.66
3/26/2007	A27-1	WS3-0	5.4	18.45	0.040	0.004				0.00	0.01	0.05	0.12	0.29
3/26/2007	A27-1	WS3-3	5.66	149.9	0.042	0.015	0.765	0.45	0.95	0.12	0.12	0.01		0.65
3/26/2007	A27-1	WS3-6	5.63	21.6	0.036	0.009				0.04	0.06	0.01	0.03	0.62
3/26/2007	A27-1	WS5-0	8.25	56.6	0.208	0.030					0.02		0.03	
3/26/2007	A27-1	WS6-0	6.65	394	0.040	0.015	36.84	19.92	1.58	0.04	0.00	0.21		0.65
3/26/2007	A27-1	WS7-0			0.000	0.000				0.04	0.02	1.76	0.29	1.45
3/26/2007	A27-1	WS7-3	6.9	197	0.010	0.001	21.6	10.11	0.615	0.06	0.01	0.26		0.22
3/26/2007	A27-1	WS7-6			0.000	0.000						0.06	4.92	4.20
3/26/2007	A27-2	ST2	5.44	26.5	0.005	0.006							0.00	
3/26/2007	A27-2	WS4-3	5.87	9.63	0.018	0.005	0	0.03	2.02	0.11	0.09	0.71	0.01	0.77
3/26/2007	A27-2	WS7-6	7.17	117.9	0.023	0.004	10.81	5.57	0.71	0.01	0.01	0.13	0.09	0.24
3/26/2007	CR7-5C	WS2-3	6.9	17.3	0.074	0.006	0.88	0.52	0.825	0.02	0.01	0.08	0.04	0.70
3/26/2007	CR7-6	GRAB 1	8.1	235	0.001	0.000	17.66	23.52	0.725	0.02	0.01	0.23	0.03	0.56
3/26/2007	CR7-6	WS2-0	6.12	18.8	0.089	0.010	0.9	0.65	0.92	0.06	0.07	0.25	0.03	0.66
3/26/2007	CR7-6	WS5-0	5.69	14.54	0.016	0.010	0	0.57	1.28	0.04	0.00	0.26		
3/26/2007	CR7-6	WS6-0	6.97	55	0.118	0.019	4.26	2.62	0.63	0.03	0.01	0.09	0.03	1.11
3/26/2007	CR7-6	WS6-3	7.25	59.8	0.004	0.003	6.29	3.21	0.92	0.02	0.01	0.15	0.01	1.52
3/26/2007	CR7-6	WS7-0	7.6	28.3	0.006	0.001	12.98	14.43	0.45	0.00	0.00	0.09		
3/26/2007	CR7-6	WS7-3	7.3	302	0.007	0.006	25.3	11.36	0.58	0.18	0.01	0.09	0.00	0.35
5/18/2007	A17-1	WS1-0	6.35	19.6	0.043	0.000	0.59	0.575	1.16	0.08	0.01	0.20	0.02	0.36
5/18/2007	A17-1	WS2-0	6.27	29.7	0.093	0.005	4.21	3.04	0.81	0.66	0.02	0.13	0.03	0.33
5/18/2007	A17-1	WS3-0	5.87	18.19	0.042	0.003	0.6	0.55	1.03	0.09	0.01	0.20	0.02	0.29

Table B.19- Pre-harvest water quality parameters and concentration for May and Sep. 2007

Date	Site	Sampler ID	pH	EC (µs/cm)	TSS (g/L)	TVSS (g/L)	Ca (mg/L)	Mg (mg/L)	K (mg/L)	TP (mg/L)	SRP (mg/L)	NH3-N(mg/L)	NO3 (mg/L)	TN (mg/L)
5/18/2007	A17-1	WS3-3	5.86	23.7	0.047	0.002	1.24	0.77	2.44	0.07	0.01	0.20	0.03	0.41
5/18/2007	A17-1	WS3-6	6.26	18.9	0.058	0.000	1.4	0.83	1.06	0.04	0.01	0.20	0.02	0.38
5/18/2007	A17-1	WS4-0	5.87	18.6	0.047	0.002	0.39	0.49	0.92	0.00	0.01	0.17	0.02	0.40
5/18/2007	A17-1	WS4-3	6.05	18.9	0.107	0.013	0.9	0.9	1.24	0.01	0.01	0.20	0.02	0.47
5/18/2007	A17-1	WS4-6	6.42	22.2	0.045	0.008	1.59	0.67	1.44	0.04	0.01	0.20	0.02	0.47
5/18/2007	A17-2	WS1-0	6.21	32.5	0.093	0.012	2.69	0.72	2.18	1.34	0.02	0.19	0.02	0.40
5/18/2007	A17-2	WS6-0	7.33	330	0.737	0.075	55.66	8.84	0.03	11.77	0.02	0.19	0.02	0.33
5/18/2007	A17-2	WS6-6	6.28	20.8	0.067	0.003	2.19	0.7	0.15	0.33	0.01	0.20	0.02	0.40
5/18/2007	A27-1	GRAB 1	7.34	349	0.003	0.002	36.18	20.62	0.71	0.77	0.01	0.20	0.03	0.92
5/18/2007	A27-1	ST1	5.52	31.2	0.020	0.030	0	0.45	0.575	0.99	0.02	0.20	0.02	0.77
5/18/2007	A27-1	WS4-0	6.85	458	2.062	0.137	39.27	20.25	1.29	0.24	0.01	0.01	0.03	0.30
5/18/2007	A27-1	WS4-3	6.91	208	0.543	0.175	20.07	12.15	0.7	0.09	0.01	0.19	0.02	0.25
5/18/2007	A27-1	WS4-6	7.5	173.3	0.125	0.013	16.7	9.69	0.69	0.03	0.01	0.20	0.02	0.33
5/18/2007	A27-1	WS5-0	6.67	501	5.382	0.583	6.8	4.65	0.88	0.02	0.01	0.20	0.02	0.22
5/18/2007	A27-1	WS6-0	6.74	68.2	0.023	0.000	5.87	3.77	0.81	0.12	0.01	0.20	0.02	0.27
5/18/2007	A27-1	WS7-0	6.89	670	0.222	0.002	58.18	33.85	3.16	0.11	0.01	0.01	0.05	0.16
5/18/2007	A27-1	WS7-3	7.2	137.3	0.348	0.023	14.37	7.84	1.07	0.02	0.01	0.18	0.02	0.30
5/18/2007	A27-1	WS7-6	7.36	130.3	0.052	0.003	13.23	7.94	0.95	0.96	0.01	0.20	0.02	0.76
5/18/2007	A27-2	WS4-0	5.93	21.2	0.062	0.003	1.24	0.45	0.93	3.95	0.01	0.01	0.02	0.87
5/18/2007	A27-2	WS5-0	6.32	32.3	0.068	0.000	3.5	0.55	1.87	4.16	0.04	0.18	0.03	0.35
5/18/2007	A27-2	WS6-0	7.48	269	2.783	0.272	25.05	15.3	1.4	4.27	0.01	0.18	0.02	0.75
5/18/2007	A27-2	WS6-6	7.31	89.5	0.167	0.007	7.11	4.12	0.77	0.31	0.01	0.19	0.02	0.76
5/18/2007	A27-2	WS7-0	6.97	146.7	0.328	0.022	13.44	8.195	0.68	0.34	0.01	0.20	0.02	0.80
5/18/2007	A27-2	WS7-3	6.89	134.6	0.155	0.012	12.62	7.75	0.76	2.26	0.01	0.19	0.02	0.63
5/18/2007	A27-2	WS7-6	6.94	96.3	0.090	0.005	8.37	5.17	0.69	0.26	0.01	0.20	0.02	0.69
5/18/2007	CR7-2	GRAB 1	7.41	309	0.017	0.002	29.77	19.13	0.84	4.23	0.01		0.02	0.88
5/18/2007	CR7-2	WS1-0	6.67	52.1	0.067	0.000	5.23	2.89	1.07	3.41	0.01		0.02	0.92
5/18/2007	CR11-1	WS3-0	6.11	18.54	0.042	0.002	0.1	0.62	1.21	5.07	0.01	0.20	0.03	0.91
5/18/2007	CR11-1	WS2-0	6.35	22	0.035	0.028	0.97	0.685	0.92	0.36	0.01	0.20	0.02	0.89
5/18/2007	CR11-3	WS1-0	6.64	52.2	0.045	0.023	5.125	2.56	2.53	0.00	0.01	0.20	0.02	0.64
5/18/2007	CR11-3	WS2-0	6.21	23.2	0.042	0.003	0.97	0.525	2.18	0.06	0.01	0.20	0.02	0.67
5/18/2007	CR11-3	WS3-0	5.93	26.2	0.103	0.005	1.99	1.16	0.89	0.37	0.01		0.02	0.73
5/18/2007	CR11-3	WS4-0	6.17	33.2	0.280	0.198	2.46	1.18	1.01	0.34	0.01	0.19	0.02	0.68
5/18/2007	CR11-3	WS4-3	6.35	27	0.115	0.005	1.83	1.04	0.89	0.36	0.01	0.20	0.02	0.81
5/18/2007	CR11-3	WS4-6	6.65	29.6	0.082	0.007	2.64	1.11	1.09	0.12	0.01	0.20	0.02	0.84
9/23/2007	CR7-2	WS1-0	6.6	23	0.0183	0.0150	4.115	1.52	1.68	0.13	0.12	0.08	0.08	0.51
9/23/2007	CR7-2	WS1-3	5.8	35.1	0.0283	0.0117	3.51	1.37	1.68	0.48	0.49	0.10	0.15	0.23
9/23/2007	CR7-2	WS2-3	6.8	75.6	0.0217	0.0133	3.18	1.16	2.1	0.57	0.52	0.39	0.13	0.53
9/23/2007	CR11-3	WS1-0	6.7	33.5	0.0000	0.0000	3.57	1.63	2.22	0.14	0.06	0.09	0.10	0.34
9/23/2007	CR11-3	WS3-0	6.5	25.6	0.0000	0.0000	1.65	0.67	3.76	0.39	0.39	0.10	0.20	0.26
3/22/2008	CR7-2	GRAB 1	7.51	0.002	0.077	0.013	14.3	8.82	0.86	0.07	0.03	0.20	0.31	0.15
3/22/2008	CR7-2	ST3	6.46	0.176	0.083	0.212	6.77	1.23	3.62	1.67	1.40	0.20	0.23	0.98
3/22/2008	CR7-2	WS2-0	6.31	0.037	0.057	0.145				0.33	0.31	0.21	0.15	1.00
3/22/2008	CR7-2	WS2-6	6.43	0.011	0.232	0.055	2.9	1.06	1.94	0.38	0.10	0.20	0.27	0.75
3/22/2008	CR11-9	GRAB 1	6.47	0.005	0.091	0.015	6.56	3.9	0.79	0.07	0.06	0.18	0.11	0.15

Table B.20- Pre-harvest water quality parameters and concentration for March 2008

Date	Site	Sampler ID	pH	EC (µs/cm)	TSS (g/L)	TVSS (g/L)	Ca (mg/L)	Mg (mg/L)	K (mg/L)	TP (mg/L)	SRP (mg/L)	NH3-N(mg/L)	NO3 (mg/L)	TN (mg/L)
3/22/2008	CR11-9	ST1	6.01	0.175	0.104	0.015	3.2	0.96	2.16	1.26	1.40	0.20	3.27	7.34
3/22/2008	CR11-9	ST2	5.85	0.016	0.081	0.038	1.63	0.72	1.81	0.23	0.14	0.20	0.48	0.90
3/22/2008	CR11-9	WS1-0	6.80	0.004	0.074	0.017				0.07	0.05	0.20	0.19	0.74
3/22/2008	CR11-9	WS1-6	6.99	0.004	0.079	0.082	16.43	4.62	1.99	0.12	0.05	0.20	0.15	0.79
3/22/2008	CR11-9	WS2-0	6.21	0.003	0.068	0.077	1.51	0.99	1.26	0.17	0.04	0.20	0.07	0.45
3/22/2008	CR11-9	WS3-0	6.18	0.002	0.074	0.048	2.68	0.96	1.08	0.12	0.03	0.20	0.11	0.26
3/23/2008	CR7-2	ST1	5.77	13.30	0.0033	0.013	1.09	0.45	0.71	0.15	0.16	0.21	0.16	
3/23/2008	CR7-2	WS2-3	6.65	33.30	0.1550	0.067	3.28	1.395	1.61	0.10	0.09	0.21	0.16	
3/23/2008	CR11-9	WS3-0	6.18	25.80	0.0950	0.048				0.12	0.10	0.21	0.11	
3/30/2008	A25-2	WS1-0	6.57	38.2	0	0.000	1.88	0.57	0.96	0.04	0.07	0.21	0.10	0.00
3/30/2008	A25-2	WS1-6	7.15	66.1	0.017	0.017	5.70	0.72	4.74	0.82	0.17	0.20	1.01	0.00
3/30/2008	A25-2	WS2-0	6.06	23.4	0.433	0.350	2.10	0.55	1.45	0.05	0.10	0.21	0.72	0.00
3/30/2008	A25-3	ST1	6.06	21.6	0.033	0.017	2.69	0.89	2.07	0.06	0.15	0.20	0.89	0.70
3/30/2008	A25-3	ST3	5.93	18.5	0.283	0.250	1.45	0.61	0.85	0.12	0.16	0.21	1.98	0.57
3/30/2008	A25-3	WS1-0	5.82	19.7	1.317	1.167	2.80	0.76	1.40	0.12	0.62	0.20	7.40	0.00
3/30/2008	A25-3	WS1-3	5.63	18.6	0.45	0.367				0.26	0.23	0.20	5.07	0.18
3/30/2008	A25-3	WS2-0	5.97	20	0.15	0.083	1.83	0.71	1.70	0.25	0.54	0.20	3.60	0.00
3/30/2008	A25-3	WS2-3	5.81	20	0.3	0.100	1.72	0.62	1.83	0.02	0.16	0.18	5.94	0.00
3/30/2008	A25-3	WS4-6	5.38	15.8	0.12	0.000	0.70	0.30	2.61	0.03	0.11	0.20	5.53	0.00
3/30/2008	A25-3	WS5-0	5.65	15.5	0.05	0.033	1.08	0.46	1.21	0.08	0.12	0.21	2.52	0.23
3/30/2008	A25-3	WS5-3	5.93	19.7	0.1	0.067	2.47	0.72	1.47	0.12	0.14	0.21	4.36	0.00
3/30/2008	A27-1	ST2	6.74	20	0.033	0.000	1.37	0.47	3.36	0.52	0.39	0.20	1.10	0.17
3/30/2008	A27-1	ST3	5.59	13	0.033	0.017	1.77	0.42	1.05	0.15	0.12	0.19	0.72	0.44
3/30/2008	A27-1	ST5	6.55	17	0.033	0.000	2.47	0.23	0.69	0.62	0.54	0.20	6.49	0.00
3/30/2008	A27-1	WS2-0	7.29	328	1.583	1.150	37.53	21.00	1.17	0.15	0.25	0.20	2.73	0.22
3/30/2008	A27-1	WS2-3	6.92	119.1	0.617	0.433	14.17	7.37	1.05	0.10	0.22	0.20	1.93	0.55
3/30/2008	A27-1	WS2-6	7.4	258	0.55	0.383	29.78	15.91	1.12	0.11	0.16	0.20	1.47	0.62
3/30/2008	A27-1	WS3-0	7.65	293	0.083	0.017	33.60	18.68	0.64	0.11	0.09	0.20	0.47	0.58
3/30/2008	A27-1	WS3-3	7.11	49.5	0.1	0.050	6.14	3.13	1.06	0.09	0.11	0.20	0.85	0.48
3/30/2008	A27-1	WS3-6	7.4	89.2	0.067	0.017	10.50	5.57	0.88	0.07	0.08	0.20	1.43	0.47
3/30/2008	A27-1	WS5-0	7.17	328	1.51	3.333	25.15	11.26	1.79	0.75	0.28	0.20	2.52	0.59
3/30/2008	A27-1	WS5-3	7.18	67.7	0.833	0.600	9.45	4.23	1.66	0.13	0.17	0.20	1.31	0.07
3/30/2008	A27-1	WS5-6	9.05	128.1	0.35	0.200	14.71	8.38	0.97	0.05	0.06	0.20	0.35	0.52
3/30/2008	A27-1	WS7-0	6.95	52.9	0.433	0.333	7.25	3.34	1.56	0.26	0.25	0.20	4.48	0.00
3/30/2008	A27-1	WS7-3	7.36	137.8	0.433	0.333	16.27	7.83	1.70	0.14	0.13	0.20	2.43	0.44
3/30/2008	A27-2	ST2	6.5	19.7	0.017	0.017	3.44	0.73	1.41	0.54	0.50	0.18	2.39	0.20
3/30/2008	A27-2	ST3	6.11	18.5	0	0.017	2.74	0.62	2.28	0.34	0.33	0.20	2.48	0.05
3/30/2008	A27-2	WS1-0	6.08	20	0.017	0.000	1.67	0.55	1.05	0.08	0.11	0.20	0.64	0.63
3/30/2008	A27-2	WS1-6	6.4	50.2	0.05	0.017	5.55	1.54	3.82	3.58	3.30	0.20	12.71	0.00
3/30/2008	A27-2	WS2-0	7.15	105.7	0.133	0.100	13.35	3.83	1.35	0.56	0.56	0.20	3.60	0.34
3/30/2008	A27-2	WS2-3	6.75	76.3	0.05	0.000	9.53	2.94	3.13	0.34	0.21	0.20	5.94	0.00
3/30/2008	A27-2	WS4-0	6.63	27.8	0.083	0.017	5.12	0.63	2.37	0.17	0.19	0.20	1.18	0.48
3/30/2008	A27-2	WS4-3	6.46	34.4	0.017	0.000	3.28	0.73	2.66	0.90	0.76	0.20	14.09	0.29
3/30/2008	A27-2	WS4-6	6.33	20.8	0.117	0.017	3.22	0.54	1.03	0.25	0.26	0.21	3.81	0.23
3/30/2008	A27-2	WS5-0	6.14	22.7	0.083	0.017	2.69	0.62	1.44	1.44	1.21	0.21	3.98	0.00
3/30/2008	CR11-9	WS2-3	6.45	38.6	0.3	0.117	4.94	1.75	2.26	0.21	0.23	0.20	0.43	0.20

APPENDIX C: POST-HARVEST WATER SAMPLES ALL PARAMETERS

Table C.1- Post- harvest water quality parameters and concentration for Dec. 06, Jan. & Mar. 07

Date	Site	Sampler ID	pH	EC (µS/cm)	TSS (g/L)	TVSS (g/L)	Ca (mg/L)	Mg (mg/L)	K (mg/L)	TP (mg/L)	SRP (mg/L)	NH3-N (mg/L)	NO3 (mg/L)	TN (mg/L)
12/18/2006	A34-1	WS1-0	5.56	6.1	0.005	0.002	0.00	0.13	0.25	0.02	0.00	1.38	0.01	0.41
12/18/2006	A34-1	WS2-3	6.13	21.3	0.095	0.038	0.76	0.65	1.14	0.02	0.02	0.20	0.03	1.04
12/18/2006	A34-1	WS2-6	6.3	27.2	0.610	0.265	0.96	0.37	4.13	0.06	0.04	1.33	0.17	4.64
12/18/2006	A34-1	WS3-0	5.67	98.2	0.008	0.003	0.00	0.10	0.21	0.02	0.01	1.39	0.02	0.32
12/18/2006	A34-1	WS3-6	6.82	23.4	0.040	0.012	1.19	0.54	1.32	0.02	0.02	0.19	0.02	0.66
12/18/2006	A34-1	WS4-3	5.89	21	0.020	0.007	0.84	0.62	1.34	0.05	0.02	1.39	0.04	1.07
12/18/2006	A34-1	WS6-0	5.65	15.67	0.057	0.015	0.06	0.49	0.57	0.03	0.02	0.19	0.02	0.31
12/18/2006	A34-1	WS8-0	6.42	18.68	0.008	0.002	0.52	0.76	1.00	0.03	0.00	1.39		0.64
12/18/2006	A34-1	WS8-3	6.32	45.21	0.122	0.023	0.48	0.69	0.47	0.03	0.01	1.39	0.01	1.23
12/18/2006	A34-1	WS8-6	7.2	100.3	0.233	0.090	1.17	1.00	2.79	2.79	3.34		5.31	19.00
12/18/2006	A34-1	WS12-0	5.8	9.94	0.012	0.000	0.00	0.24	0.54	0.01	0.03	1.39	0.00	0.74
1/28/2007	A34-1	WS6-0	5.94	4.4	0.003	0.001	0.00	0.03	0.21		0.20	0.14	0.38	2.04
1/28/2007	A34-1	WS7-0	7.13	24.7	0.023	0.009	1.83	1.35	1.15	0.07	0.01	0.15	0.26	0.78
1/28/2007	A34-1	WS7-6	7.05	30.0	0.008	0.005	2.10	1.45	0.70	0.05	0.00	0.02	0.21	0.25
1/28/2007	A34-1	WS8-0	8.66	34.4	0.024	0.006	2.04	1.72	0.80	0.06	0.01	0.04	0.12	1.77
1/28/2007	A34-1	WS8-3	7.31	4.7	0.011	0.003	2.67	1.76	1.14	0.62	0.00	0.08	0.07	0.24
1/28/2007	A34-2	WS1-0	7.55	604.0	0.345	0.060	34.99	4.22	36.70	0.94				1.36
1/28/2007	A34-2	WS1-3	6.85	24.6	0.103	0.064	1.85	0.71	1.28		0.01		0.35	0.78
1/28/2007	A34-2	WS3-0	6.69	35.0	0.031	0.004	4.42	1.80	0.75	0.08	0.03	0.12	0.12	0.98
1/28/2007	A34-2	WS3-3	8.15	32.0	0.109	0.031	3.47	0.31	3.99	0.51	0.36	0.17	0.09	1.50
1/28/2007	A34-2	WS4-0	5.75	18.9	0.010	0.001	0.59	0.60	1.25	0.04	0.01	0.09	0.07	0.43
1/28/2007	A34-2	WS5-0	9.13	73.7	0.003	0.001	10.65	3.07	1.15		0.06	0.05	0.12	1.50
3/26/2007	A34-1	GRAB 1	7.44	33.3	0.011	0.001	14.43	17.32	0.70	0.01	0.01	0.07	0.06	0.83
3/26/2007	A34-1	GRAB 2	6.76	79.8	0.006	0.002	5.73	3.87	0.80	0.01	0.01	0.05		0.20
3/26/2007	A34-1	WS1-0	6.65	43.5	0.396	0.024	2.98	1.73	2.42	0.08	0.02	0.75	0.22	6.10
3/26/2007	A34-1	WS2-3	6.55	30.4	0.046	0.011	1.12	1.05	0.60	0.05	0.02	0.21		0.57
3/26/2007	A34-1	WS4-0	6.09	41.8	0.165	0.031	1.89	0.93	1.00	0.36	0.29	0.39	0.02	1.38
3/26/2007	A34-1	WS4-3	6.18	21.8	0.002	0.001	1.54	0.58	1.20	0.01	0.02	0.16	0.03	0.85
3/26/2007	A34-1	WS6-0	8.5	16.3	0.034	0.028	0.52	0.69	1.12	0.01	0.00	0.26	0.03	0.70
3/26/2007	A34-1	WS7-0	7.31	29.7	0.002	0.001	1.30	1.01	0.60	0.02	0.01	0.05	1.28	1.00
3/26/2007	A34-1	WS8-0	6.72	41.4	1.440	0.108	0.93	0.87	0.45	0.01	0.01	0.07	0.05	0.87
3/26/2007	A34-1	WS8-3	6.68	39.9	0.005	0.003	1.70	1.69	0.61	0.01	0.01	0.44		0.53
3/26/2007	A34-1	WS8-6	7.65	37.5	0.006	0.001	2.75	2.11	1.05	0.01	0.01	0.10	0.02	3.30
3/26/2007	A34-2	GRAB 1	5.47	23.0	0.029	0.007	0.56	0.78	0.59	0.03	0.02	0.04	0.01	0.79
3/26/2007	A34-2	WS1-3	5.78	24.9	0.006	0.001	1.58	0.59	0.94	0.02		0.11	0.16	4.99
3/26/2007	A34-2	WS2-0	7.21	145.2	0.007	0.002	16.14	7.71	1.11	0.26	0.04	0.51	0.03	0.69
3/26/2007	A34-2	WS4-0	6.34	58.2	0.038	0.024	3.28	1.19	2.74	0.58	0.58		0.02	
3/26/2007	A34-2	WS4-3				0.005	7.42	3.41	0.29		0.00			
5/18/2007	A34-1	GRAB 1	6.45	83.4	0.000	0.000	12.73	7.96	0.78	0.02	0.01	0.20	0.02	0.32
5/18/2007	A34-1	ISCO 1	6.52	55.6	0.013	0.013	4.15	2.69	0.98	0.10	0.01	0.19	0.03	0.54
5/18/2007	A34-1	ISCO 2	7.14	46.3	0.003	0.002	0.00	0.01	0.00	0.02	0.01	0.12	0.02	0.54
5/18/2007	A34-1	ISCO 3	6.59	53.7	0.045	0.000	3.61	2.64	1.05	0.09	0.01	0.17	0.02	0.57
5/18/2007	A34-1	ISCO 4	7.19	44.7	0.042	0.000	3.07	2.16	1.04	0.12	0.01	0.17	0.02	0.00
5/18/2007	A34-1	ISCO 5	6.83	36.2	0.038	0.000	2.30	1.60	0.98	0.12	0.01	0.17	0.02	0.00

Table C.2- Post- harvest water quality parameters and concentration for May and June 2007

Date	Site	Sampler ID	pH	EC (µS/cm)	TSS (g/L)	TVSS (g/L)	Ca (mg/L)	Mg (mg/L)	K (mg/L)	TP (mg/L)	SRP (mg/L)	NH3-N (mg/L)	NO3 (mg/L)	TN (mg/L)
5/18/2007	A34-1	ISCO 6	6.59	30.8	0.040	0.000	1.99	1.32	0.92	0.07	0.01	0.18	0.02	0.40
5/18/2007	A34-1	ISCO 8	6.94	38.7	0.007	0.012	1.80	1.53	0.66	0.16	0.01	0.18	0.02	0.00
5/18/2007	A34-1	ISCO 9	7.18	54.9	0.003	0.013	2.37	1.80	0.63	0.11	0.01	0.17	0.03	0.43
5/18/2007	A34-1	ISCO 10	6.81	47.4	0.008	0.003	5.28	3.00	1.44	0.11	0.01	0.18	0.02	0.49
5/18/2007	A34-1	ISCO 11	6.61	37.1	0.000	0.000	3.23	2.33	0.97	0.15	0.01	0.20	0.02	0.56
5/18/2007	A34-1	ISCO 12	6.96	31.0	0.003	0.003	2.57	1.80	0.84	0.45	0.01	0.20	0.02	0.58
5/18/2007	A34-1	ISCO 13	6.81	31.1	0.042	0.000	1.74	1.43	0.82	0.10	0.01	0.19	0.02	0.56
5/18/2007	A34-1	ISCO 14	6.48	31.4	0.037	0.002	1.83	1.41	0.83	0.08	0.01	0.20	0.02	0.53
5/18/2007	A34-1	ISCO 14	6.48	31.4	0.000	0.000	2.13	1.49	0.87	0.16	0.01	0.20	0.02	0.47
5/18/2007	A34-1	ISCO 15	6.74	35.7	0.002	0.013	2.53	1.80	0.83	0.10	0.01	0.20	0.03	0.43
5/18/2007	A34-1	ISCO 16	6.83	41.1	0.002	0.005	2.53	1.95	0.58	0.02	0.01	0.20	0.02	0.47
5/18/2007	A34-1	ISCO 17	6.79	52.2	0.053	0.000	3.83	2.72	0.89	0.04	0.01	0.20	0.02	0.44
5/18/2007	A34-1	ISCO 18	7.12	43.5	0.002	0.015	3.07	2.33	0.87	0.03	0.01	0.20	0.02	0.38
5/18/2007	A34-1	WS1-0	5.88	27.1	0.002	0.010	1.10	0.93	1.96	0.12	0.01	0.20	0.02	0.40
5/18/2007	A34-1	WS3-0	5.69	24.2	0.145	0.057	0.43	0.65	0.81	0.17	0.01	0.20	0.02	0.00
5/18/2007	A34-1	WS3-3	5.95	21.1	0.043	0.027	0.43	0.64	0.78	0.09	0.01	0.20	0.02	0.44
5/18/2007	A34-1	WS6-0	5.74	19.0	0.065	0.000	4.32	3.14	0.79	0.08	0.01	0.18	0.02	0.41
5/18/2007	A34-1	WS7-0	6.31	54.6	0.118	0.005	12.62	7.87	0.78	0.12	0.01	0.19	0.02	0.36
5/18/2007	A34-1	WS7-3	6.37	42.8	0.040	0.002	3.45	2.23	0.83	0.15	0.01	0.20	0.02	0.43
5/18/2007	A34-1	WS7-6	5.88	30.4	0.032	0.002	1.62	1.23	1.02	0.20	0.01	0.19	0.02	0.32
5/18/2007	A34-1	WS8-0	6.45	50.5	0.358	0.005	3.45	2.40	0.86	0.15	0.01	0.12	0.02	0.33
5/18/2007	A34-1	WS8-3	6.24	31.0	0.025	0.015	1.99	1.47	0.82	0.11	0.01	0.20	0.02	0.35
5/18/2007	A34-1	WS8-6	6.71	54.9	0.003	0.000	4.52	3.00	1.01	0.03	0.01	0.19	0.03	0.33
5/18/2007	A34-2	WS2-0	5.81	27.4	0.097	0.002	1.75	0.79	0.87	0.11	0.01	0.20	0.02	0.43
5/18/2007	CR7-5B	WS5-0	6.05	28.3	0.553	0.007	2.21	0.76	1.99	1.23	0.02	0.17	0.03	0.25
5/18/2007	CR7-5B	WS5-3	6.53	23.1	0.097	0.025	1.29	0.77	1.38	4.38	0.01	0.19	0.02	0.52
5/18/2007	CR7-5B	WS5-6	6.3	26.3	0.118	0.003	2.30	0.76	1.84	0.34	0.01	0.19	0.02	0.58
6/12/2007	A34-1	WS1-0	5.56	6.1	0.005	0.002								
6/12/2007	A34-1	WS2-3	6.13	21.3	0.095	0.038								
6/12/2007	A34-1	WS2-6	6.3	27.2	0.610	0.265								
6/12/2007	A34-1	WS3-0	5.67	98.2	0.008	0.003								
6/12/2007	A34-1	WS3-6	6.82	23.4	0.040	0.012								
6/12/2007	A34-1	WS4-3	5.89	21.0	0.020	0.007								
6/12/2007	A34-1	WS6-0	5.65	15.7	0.057	0.015								
6/12/2007	A34-1	WS8-0	6.42	18.7	0.008	0.002								
6/12/2007	A34-1	WS8-3	6.32	45.2	0.122	0.023								
6/12/2007	A34-1	WS8-6	7.2	100.3	0.233	0.090								
6/12/2007	A34-1	WS12-0	5.8	9.9	0.012	0.000								
6/12/2007	A34-2	WS5-0	6.43	55.9	0.165	0.108								
6/12/2007	A34-2	WS5-6	7.03	97.9	0.007	0.028								

Table C.3- Post- harvest water quality parameters and concentration for June, July, Sep. 07

Date	Site	Sampler ID	pH	EC (µS/cm)	TSS (g/L)	TVSS (g/L)	Ca (mg/L)	Mg (mg/L)	K (mg/L)	TP (mg/L)	SRP (mg/L)	NH3-N (mg/L)	NO3 (mg/L)	TN (mg/L)
6/12/2007	A34-2	WS6-0	6.99	70.2	0.032	0.045								
6/12/2007	A34-2	WS6-3	6.82	91.6	0.200	0.138								
7/10/2007	A34-2	WS2-0	6.18	41.9	0.015	0.030	3.58	1.06	0.91	0.15	0.03	0.41	0.15	0.43
7/10/2007	CR7-5B	WS1-0	5.88	25.6	0.012	0.032	1.72	0.73	1.99	0.10	0.03	0.31	0.10	1.14
7/10/2007	CR7-5B	WS2-0	5.72	9.7	1.040	0.295	0.80	0.52	1.03	0.11	0.07	1.13	0.23	1.46
7/10/2007	CR7-5B	WS4-0	5.91	14.2	0.202	0.070	0.06	0.30	1.61	0.12	0.06	0.31	0.18	0.28
7/10/2007	CR7-5C	WS2-0	7.77	13.7	0.033	0.043				0.12	0.03	0.21	0.19	0.23
7/10/2007	CR7-5C	WS2-3	6.05	18.8	0.012	0.027	1.18	0.65	0.68	2.31	0.03	0.21	0.19	0.32
7/10/2007	CR7-5C	WS2-6	6.35	21.8	0.028	0.037	1.34	0.69	1.32	0.45	0.05	0.41	0.12	1.11
7/10/2007	CR7-5C	WS3-0	5.45	19.3	0.342	0.345	0.38	0.22	3.20	2.21	0.06	16.46	0.00	2.43
7/10/2007	CR7-5C	WS3-3	5.32	35.1	0.147	0.128	1.61	0.70	2.66	0.65	0.52	13.16	0.18	10.67
7/10/2007	CR7-5C	WS4-0	6.08	17.5	0.022	0.035	0.80	0.50	1.05	0.15	0.03	0.21	0.17	0.29
7/10/2007	CR7-5C	WS4-3	6.09	19.1	0.042	0.060	1.02	0.57	1.51	0.07	0.05	0.41	0.18	0.69
7/10/2007	CR7-5C	WS4-6	6.17	22.5	0.027	0.038	1.13	0.62	2.22	0.11	0.04	0.62	0.18	1.08
7/10/2007	CR7-5C	WS5-0	5.81	16.9	0.090	0.105	0.59	0.51	0.94	0.05	0.04	11.62	0.19	1.14
7/10/2007	CR7-5C	WS5-3	5.62	16.8	0.130	0.133	0.27	0.40	2.03	0.11	0.07	0.41	0.18	2.04
9/23/2007	CR7-5C	WS1-0	6.5	65.1	0.000	0.003	3.50	0.64	1.12	0.10	0.05	0.16	1.31	0.58
9/23/2007	CR7-5C	WS1-3	6.7	28.5	0.037	0.020	1.87	0.77	4.66	0.12	0.11	0.08	0.20	0.13
9/23/2007	CR7-5C	WS2-0	6.3	44.2	0.177	0.070	5.38	1.86	6.57	0.12	0.08	0.11	2.24	0.36
9/23/2007	CR7-5C	WS2-3	5.9	36.2	0.252	0.120	5.54	1.74	5.38	1.61	1.82	0.11	1.95	0.34
9/23/2007	CR7-5C	WS3-0	6.3	32.5	0.053	0.015	2.53	0.87	6.21	0.19	0.13	0.15	0.21	0.43
9/23/2007	CR7-5C	WS3-3	6.4	54.1	0.035	0.015	6.35	1.77	2.98	0.18	0.18	0.13	0.40	0.40
9/23/2007	CR7-5C	WS3-6	6.5	51.4	1.115	0.210	3.12	1.07	5.82	0.47	0.44	0.23	0.12	0.34
9/23/2007	CR7-5C	WS4-3	6.6	34.6	0.072	0.013	4.31	1.37	4.38	0.09	0.16	0.08	2.02	0.19
9/23/2007	CR7-5C	WS5-3	6.7	118.1	0.792	0.192	3.50	1.35	2.92	2.46	2.68	0.41	1.75	0.62
9/23/2007	CR7-5C	WS5-6	7.2	31.0	0.000	0.000	2.85	0.85	2.08	0.33	0.30	0.09	0.14	0.11
3/22/2008	A17-1	WS1-0	5.87	18.5	0.028	0.030	1.46	0.61	1.05	0.12	0.06	0.19	0.35	1.13
3/22/2008	A17-1	WS2-0	6.32	68.9	1.098	0.863				4.21	3.37	0.02	25.64	11.53
3/22/2008	A17-1	WS2-3	5.95	19.5	0.265	0.272				0.07	0.04	0.20	0.23	0.90
3/22/2008	A17-1	WS2-6	5.88	20.2	1.265	1.258	1.57	0.84	1.57	0.12	0.18	0.07	0.07	1.81
3/22/2008	A34-1	GRAB 1	6.62	36.7	0.035	0.020	3.87	2.44	0.80	0.07	0.03	0.20	1.20	0.43
3/22/2008	A34-1	WS1-0	6.26	24.5	0.400	0.083				0.17	0.04	0.19	0.39	1.53
3/22/2008	A34-1	WS1-3	5.98	25.3	0.278	0.053	3.32	1.05	1.57	0.41	0.10	0.19	0.27	2.93
3/22/2008	A34-1	WS1-6	6.58	33.2	0.587	0.310	1.28	0.66	1.59	0.17	0.05	0.19	0.56	2.94
3/22/2008	A34-1	WS2-3	6.45	20.3	0.828	0.177				0.07	0.04	0.20	0.19	0.60
3/22/2008	A34-1	WS3-0	5.93	20.5	0.035	0.023	3.65	0.73	1.27	1.52	0.99	0.21	15.28	6.40
3/22/2008	A34-1	WS3-3	6.40	33.2	0.065	0.025	1.92	0.59	1.03	0.07	0.53	0.20	0.44	1.26
3/22/2008	A34-1	WS5-0	6.77	28.8	0.275	0.043	1.34	0.75	1.23	0.07	0.06	0.20	0.44	0.85
3/22/2008	A34-1	WS5-6	6.35	28.3	0.215	0.065	2.85	1.25	1.39	0.12	0.05	0.17	0.68	1.77
3/22/2008	A34-1	WS7-3	7.00	35.2	0.483	0.140				0.07	0.04	0.20	0.39	0.42
3/22/2008	A34-1	WS7-6	6.35	36.6	0.035	0.023	2.04	1.21	1.36	0.07	0.04	0.20	0.31	0.95
3/22/2008	A34-1	WS8-0	6.19	34.5	0.017	0.017	3.06	1.67	0.96	0.00	0.08	0.19	0.84	2.03
3/22/2008	A34-1	WS8-6	7.40	352.0	0.165	0.007				0.07	0.03	0.12	0.27	3.73
3/22/2008	A34-2	GRAB 1	6.72	54.1	0.088	0.083	2.74	1.14	0.98	0.17	0.04	0.18	5.86	2.24
3/22/2008	A34-2	GRAB 2	6.00	40.9	0.342	0.000	33.57	20.43	1.02	0.07	0.03	0.20	0.35	0.20
3/22/2008	A34-2	WS1-0	6.51	17.1	0.055	0.033				5.40	4.56	0.19	0.92	2.25

Table C.4- Post- harvest water quality parameters and concentration for March 2008

Date	Site	Sampler ID	pH	EC (µS/cm)	TSS (g/L)	TVSS (g/L)	Ca (mg/L)	Mg (mg/L)	K (mg/L)	TP (mg/L)	SRP (mg/L)	NH3-N (mg/L)	NO3 (mg/L)	TN (mg/L)
3/22/2008	A34-2	WS1-3	6.68	34.0	0.018	0.030	4.66	1.31	6.43	0.00	0.28	0.20	0.39	4.26
3/22/2008	A34-2	WS2-0	6.55	87.1	0.195	0.095	1.50	0.58	0.49	0.12	0.06	0.20	0.92	1.39
3/22/2008	A34-2	WS2-6	5.20	20.3	0.028	0.023	3.38	1.13	1.07	0.07	0.04	0.20	3.67	2.41
3/22/2008	A34-2	WS3-0	6.55	56.6	0.118	0.042	9.08	1.41	2.08	1.21	0.97	0.00	0.84	0.10
3/22/2008	A34-2	WS3-3	6.29	24.3	0.292	0.098				0.17	0.07	0.20	0.39	1.42
3/22/2008	A34-2	WS4-6	6.92	94.8	0.328	0.165	8.49	4.67	1.30	0.28	0.04	0.20	0.72	1.45
3/22/2008	CR7-5C	WS3-3	6.00	16.0	0.128	0.000	1.40	0.38	1.55	0.12	0.04	0.20	0.19	0.73
3/22/2008	CR7-5C	WS3-6	6.02	17.5	0.103	0.048	1.29	0.38	1.55	0.28	0.05	0.20	0.15	0.74
3/22/2008	CR7-5C	WS5-3	6.37	22.0	0.875	0.123	2.52	0.80	1.16	0.23	0.03	0.20	0.48	0.90
3/22/2008	CR11-1	WS3-0	5.64	18.2	0.437	0.093	1.07	0.61	0.96	0.12	0.03	0.20	0.15	0.25
3/22/2008	CR11-1	WS3-3	5.99	18.2	0.043	0.015	1.29	0.61	1.13	0.12	0.04	0.20	0.15	0.29
3/23/2008	A17-2	GRAB 1	7.24	247.0	0.047	0.013	24.74	14.89	0.82	0.02	0.03	0.20	0.59	
3/23/2008	A17-2	GRAB 2	7.21	201.0	0.005	0.015	19.39	11.65	0.86	0.02	0.03	0.18	2.47	
3/23/2008	A17-2	WS1-0	5.91	19.1	0.192	0.045	1.20	0.41	1.89	0.04	0.04	0.14	0.18	
3/23/2008	A17-2	WS1-3	5.97	22.3	0.178	0.057	1.48	0.46	2.99	0.25	0.05	0.19	0.25	
3/23/2008	A17-2	WS1-6	6.28	33.4	0.187	0.140	0.00	0.00	0.00	0.39	0.20	0.18	0.15	
3/23/2008	A17-2	WS3-3	6.60	31.2	0.262	0.213	0.00	0.00	0.00	0.14	0.05	0.18	0.12	
3/23/2008	A34-2	WS3-6	6.55	56.6	0.118	0.042	8.18	1.02	1.58	3.77	3.20	0.20	0.07	
3/23/2008	CR7-5B	WS6-0	6.16	40.3	0.192	1.215	3.66	0.91	2.45	0.26	0.07	0.20	0.35	
3/23/2008	CR7-5C	GRAB 1	6.06	25.9	0.007	0.007	2.10	0.86	0.83	0.04	0.04	0.21	0.28	
3/23/2008	CR7-5C	WS3-0	5.90	18.8	0.303	0.028	1.24	0.63	1.45	0.31	0.09	0.21	0.30	
3/23/2008	CR11-1	GRAB 1	6.23	22.5	0.073	0.062	1.40	0.73	0.96	0.06	0.05	0.21	0.09	
3/23/2008	CR11-1	ST3	6.10	34.2	0.077	0.022	3.28	0.87	4.14	0.09	0.05	0.21	0.42	
3/23/2008	CR11-1	WS1-0	5.71	18.8	0.095	0.092	1.83	0.54	1.11	0.13	0.05	0.21	0.28	
3/23/2008	CR11-1	WS1-3	6.55	95.6	0.187	0.123	1.83	0.68	4.72	5.77	3.82	0.00	6.74	
3/23/2008	CR11-1	WS1-6	5.80	19.5	0.242	0.203	1.88	0.54	1.19	0.63	0.18	0.20	0.40	
3/23/2008	CR11-1	WS2-0	5.52	56.8	0.200	0.077	4.09	1.71	7.14	0.30	0.26	0.20	1.71	
3/23/2008	CR11-1	WS2-3	6.02	28.0	0.155	0.045	1.80	0.68	1.44	0.26	0.15	0.20	1.18	
3/23/2008	CR11-1	WS2-6	6.09	21.7	0.287	0.145	1.51	0.67	1.24	0.10	0.09	0.20	0.13	
3/23/2008	CR11-1	WS3-6	5.87	19.5	0.307	0.083	1.45	0.56	2.13	0.04	0.05	0.21	0.11	
3/23/2008	CR11-3	GRAB 1	6.04	18.0	0.090	0.062	1.75	0.64	0.80	0.04	0.04	0.21	0.07	
3/23/2008	CR11-3	GRAB 2	6.09	26.0	0.002	0.007	2.08	1.03	0.92	0.06	0.09	0.21	0.09	
3/23/2008	CR11-3	GRAB 3	6.41	24.0	0.003	0.013	1.86	0.81	0.84	0.06	0.06	0.21	0.17	
4/12/2008	A34-1	GRAB 1	7.7	43.2	0.003	0.000	2.79	2.09	0.98	0.04	0.03	0.20	2.46	1.84
4/12/2008	A34-1	WS1-0	6	22.1	0.015	0.010	1.62	0.77	1.94	0.17	0.08	0.20	0.42	8.35
4/12/2008	A34-1	WS2-0	5.6	14.2	0.033	0.028	0.27	0.37	1.66	0.16	0.04	0.20	0.28	5.90
4/12/2008	A34-1	WS2-3	5.4	15.7	0.158	0.145	0.43	0.38	1.82	0.15	0.31	0.20	0.51	5.09
4/12/2008	A34-1	WS2-6	5.5	18.3	0.028	0.022	0.49	0.46	2.80	0.06	0.03	0.20	0.23	4.72
4/12/2008	A34-1	WS3-0	5.5	20.4	0.272	0.235	0.92	0.66	0.93	0.27	0.13	0.20	0.25	12.26

Table C.5- Post- harvest water quality parameters and concentration for April 2008

Date	Site	Sampler ID	pH	EC (µS/cm)	TSS (g/L)	TVSS (g/L)	Ca (mg/L)	Mg (mg/L)	K (mg/L)	TP (mg/L)	SRP (mg/L)	NH3-N (mg/L)	NO3 (mg/L)	TN (mg/L)
4/12/2008	A34-1	WS3-3	5.6	23.4	0.013	0.008	1.24	0.71	1.86	0.99	0.53	0.20	0.14	15.00
4/12/2008	A34-1	WS4-0	6.5	22.8	0.343	0.328	1.88	0.62	2.72	0.23	0.49	0.20	0.20	8.96
4/12/2008	A34-1	WS6-0	5.9	20.1	0.322	0.302	0.59	0.61	1.42	0.37	0.05	0.19	4.27	7.04
4/12/2008	A34-1	WS6-6	5.6	15.9	0.107	0.085	0.59	0.53	1.83	0.35	0.05	0.20	0.09	8.86
4/12/2008	A34-1	WS7-6	6.3	23.7	0.005	0.000	1.29	0.92	1.14	0.12	0.06	0.20	0.28	7.45
4/12/2008	A34-1	WS8-6	6.4	24.6	0.063	0.057	1.56	0.97	1.22	0.05	0.04	0.20	0.32	0.95
4/12/2008	A34-1	WS9-0	6.6	37.3	0.073	0.068	3.50	1.38	1.30	0.09	0.06	0.19	0.27	1.84
4/12/2008	A34-1	WS9-6	6.8	38.2	0.097	0.093				0.08	0.03	0.19	0.32	1.87
4/12/2008	A34-1	WS10-0	6.6	18.7	0.303	0.238	1.57	0.77	1.28	0.11	0.05	0.20	0.13	2.34
4/12/2008	A34-2	GRAB 1	6.6	80.6	0.000	0.000	6.90	4.21	1.05	0.19	0.08	0.19	0.51	3.08
4/12/2008	A34-2	WS2-3	6.6	47.9	1.090	1.060	4.42	1.38	1.42	0.11	0.06	0.19	7.89	3.52
4/12/2008	A34-2	WS3-0	5.8	33.2	0.165	0.140	2.37	1.04	1.05	0.15	0.06	0.19	2.76	2.32
4/12/2008	A34-2	WS3-3	6.1	31.0	0.000	0.000	2.06	0.94	0.99	0.08	0.03	0.19	4.69	1.45
4/12/2008	A34-2	WS3-6	6.1	29.3	0.003	0.003	2.06	0.93	4.07	0.14	0.06	0.19	2.60	7.26
4/12/2008	CR7-5B	WS1-0	5.9	20.3	0.362	0.280	1.69	0.42	2.39	0.07	0.04	0.11	4.78	2.08
4/12/2008	CR7-5B	WS1-3	6.2	51.1	0.615	0.480	4.74	1.22	6.52	0.05	0.03	0.00	0.48	1.48
4/12/2008	CR7-5B	WS1-6	5.8	19.5	0.128	0.102	1.79	0.51	1.93	0.06	0.04	0.11	0.21	1.45
4/12/2008	CR7-5B	WS2-6	6.4	30.8	1.673	1.575	4.00	1.01	1.94	0.08	0.04	0.19	0.88	2.09
4/12/2008	CR7-5B	WS6-0	6.5	33.9	0.768	0.745	2.69	0.76	2.62	0.09	0.03	0.20	6.52	2.56
4/12/2008	CR7-5B	WS7-0	6.1	27.7	1.765	1.565	3.21	1.12	2.29	0.06	0.04	0.19	2.99	1.54
4/26/2008	A17-1	ST5	5.7	39.7	0.433	0.433	3.99	1.35	2.89	2.68	0.71	0.20	14.95	
4/26/2008	A17-1	WS1-0	6.1	17.0	0.000	0.000	0.70	0.50	1.49	1.03	0.05	0.20	0.50	
4/26/2008	A17-1	WS2-0	6.2	13.0	0.100	0.100	0.27	0.47	1.59	1.04	0.02	0.20	0.86	
4/26/2008	A17-1	WS2-3	6.4	18.5	0.000	0.000	0.64	0.68	1.66	1.19	0.00	0.19	2.96	
4/26/2008	A17-1	WS3-0	6.2	31.6	0.083	0.083	2.26	1.25	3.13	1.06	0.02	0.16	8.81	
4/26/2008	A17-1	WS3-3	6.3	23.2	0.383	0.367	2.91	0.84	2.82	1.48	0.18	0.09	1.01	
4/26/2008	A17-1	WS3-6	6.4	34.8	0.533	0.500	2.70	0.98	2.60	1.85	0.20	0.08	17.77	
4/26/2008	A17-1	WS4-0	6.1	18.4	0.050	0.033	0.97	0.59	2.11	0.79	0.05	0.17	1.08	
4/26/2008	A17-1	WS4-3	6.1	17.5	0.050	0.033				0.66	0.09	0.19	0.58	
4/26/2008	A17-1	WS4-6	6.4	21.2	0.017	0.017	1.30	0.80	2.08	0.75	0.09	0.18	1.08	
4/26/2008	A17-2	WS1-0	6.8	27.5	0.033	0.033	2.52	0.45	2.98	1.08	0.06	0.16	0.36	
4/26/2008	A17-2	WS5-0	7.1	102.5	0.100	0.067	10.94	5.68	1.78	2.48	0.05	0.20	0.43	
4/26/2008	A17-2	WS5-6	6.6	48.9	0.283	0.200				2.92	0.09	0.17	0.50	
4/26/2008	A34-1	GRAB 1	6.8	96.3	0.000	0.000	8.72	5.76	1.15	1.79	2.44	0.19	0.29	
4/26/2008	A34-1	GRAB 2	6.7	94.6	0.000	0.000	8.34	5.61	1.40	1.05	0.12	0.19	3.83	
4/26/2008	A34-1	WS3-0	6.3	18.8	0.017	0.017	0.92	0.60	0.79	1.04	0.06	0.19	0.21	
4/26/2008	A34-1	WS5-0	6.2	36.7	0.183	0.150	1.29	0.78	0.81	1.61	2.44	0.19	0.14	
4/26/2008	A34-1	WS7-0	7.1	51.4	0.350	0.300	5.06	3.02	0.96	0.80	0.17	0.19	0.29	
4/26/2008	A34-1	WS9-0	6.4	19.5	0.050	0.033	1.08	0.68	1.02	1.00	0.08	0.19	0.14	
4/26/2008	A34-2	WS3-0	6.9	31.5	0.033	0.033	2.37	1.09	1.06	1.44	4.10	0.19	8.45	
4/26/2008	CR7-5C	GRAB 1	6.2	24.6	0.000	0.000	1.33	0.76	0.83	1.36	0.13	0.19	7.65	
4/26/2008	CR7-5C	SPECIAL 1	6.3	20.4	1.433	1.383	2.96	0.68	2.48	0.92	0.25	0.19	2.24	
4/26/2008	CR7-5C	WS1-0	6.6	24.0	0.950	0.950	2.80	0.77	1.23	0.85	0.71	0.19	0.36	
4/26/2008	CR7-5C	WS2-0	6.4	21.6	1.400	1.367	2.69	0.84	1.38	1.85	0.56	0.18	2.53	
4/26/2008	CR7-5C	WS2-3	6.3	20.5	0.817	0.800	2.22	0.72	1.62		0.21	0.19	1.44	

Table C.6- Post- harvest water quality parameters and concentration for March and June 2008

Date	Site	Sampler ID	pH	EC (µS/cm)	TSS (g/L)	TVSS (g/L)	Ca (mg/L)	Mg (mg/L)	K (mg/L)	TP (mg/L)	SRP (mg/L)	NH3-N (mg/L)	NO3 (mg/L)	TN (mg/L)
4/26/2008	CR7-5C	WS2-6	6.3	25.4	0.017	0.017	1.94	0.84	1.09	0.00	0.03	0.20	5.13	
4/26/2008	CR7-5C	WS3-0	6.4	20.4	0.783	0.783	2.44	0.91	1.32	0.04	0.19	0.19	1.08	
4/26/2008	CR7-5C	WS3-0^{+}	6.2	16.5	0.117	0.117	0.72	0.44	1.70	0.05	0.05	0.20	0.43	
4/26/2008	CR7-5C	WS3-3	6.4	27.3	2.100	2.017	4.44	1.29	2.09	0.17	0.75	0.19	2.09	
4/26/2008	CR7-5C	WS3-3^{+}	6.3	16.5	0.067	0.067	0.97	0.46	1.97	0.07	0.12	0.18	0.65	
4/26/2008	CR11-1	WS1-0	6.4	19.0	0.000	0.000	1.50	0.55	1.11	0.00	0.04	0.20	0.00	
4/26/2008	CR11-1	WS1-6	6.3	19.9	0.000	0.000	1.78	0.58	1.27	0.00	0.58	0.20	0.07	
4/26/2008	CR11-1	WS2-0	6.2	19.5	0.017	0.017	1.28	0.63	1.12	0.00	0.95	0.20	0.00	
4/26/2008	CR11-1	WS2-3	6.3	27.4	0.017	0.017	1.33	0.72	1.49	0.00	0.19	0.13	55.69	
4/26/2008	CR11-1	WS2-6	6.4	19.0	0.000	0.000	1.17	0.63	1.12	0.40	0.05	0.19	1.44	
4/26/2008	CR11-1	WS4-0	5.7	18.5	0.017	0.017	0.39	0.62	1.18	0.00	8.54	0.19	0.29	
6/21/2008	A17-1	WS1-0	7.8	58.6	0.015	0.002	1.27	0.56	1.38	0.03	0.04	0.18	1.13	0.35
6/21/2008	A17-1	WS1-0^{+}	6.5	18.3	0.037	0.030	4.53	3.39	1.06	0.04	0.05	0.18	0.56	0.33
6/21/2008	A17-1	WS2-0	6.0	24.0	0.053	0.042	1.33	0.80	1.79	0.21	0.05	0.20	1.52	0.24
6/21/2008	A17-1	WS3-0	9.8	86.7	0.068	0.055	13.76	1.22	3.12	0.61	0.22	0.02	2.68	0.00
6/21/2008	A17-1	WS4-0	7.5	34.7	0.053	0.052	2.00	1.38	2.56	0.08	0.05	0.17	8.11	0.23
6/21/2008	A17-1	WS4-6	6.8	38.1	0.007	0.000	2.53	1.42	2.97	0.03	0.03	0.20	9.03	0.11
6/21/2008	A17-1	WS5-0	6.6	31.1	0.022	0.015	2.21	1.13	2.43	0.02	0.03	0.21	5.57	0.18
6/21/2008	A17-1	WS5-3	6.3	35.2	0.075	0.058	2.21	1.09	2.38	0.04	0.04	0.20	3.41	0.16
6/21/2008	A17-1	WS6-0	6.3	27.6	0.323	0.317	3.23	1.07	2.08	0.03	0.04	0.21	0.70	0.30
6/21/2008	A17-1	WS6-3	6.2	24.5	0.097	0.083	3.16	1.08	2.22	0.06	0.03	0.21	0.48	0.31
6/21/2008	A34-1	GRAB 1	7.3	177.5	0.092	0.080	19.38	12.75	1.43	0.04	0.02	0.21	1.21	0.36
6/21/2008	A34-1	WS1-0	6.4	13.5	0.002	0.000	2.00	0.86	2.43	0.07	0.05	0.21	1.44	0.32
6/21/2008	A34-1	WS2-3	6.6	27.9	0.055	0.045	2.85	1.94	0.86	0.04	0.04	0.21	1.08	0.29
6/21/2008	A34-1	WS3-0	5.7	22.4	0.013	0.008	1.08	0.71	1.11	0.05	0.04	0.21	1.29	0.35
6/21/2008	A34-1	WS3-3	5.9	19.3	0.098	0.080	0.97	0.64	0.75	0.06	0.04	0.21	0.16	0.35
6/21/2008	A34-1	WS4-0	6.7	48.7	0.005	0.000	7.37	0.83	2.56	0.08	0.05	0.21	0.16	0.35
6/21/2008	A34-1	WS4-3	6.4	59.0	0.117	0.103	9.58	0.88	2.86	2.10	1.96	0.21	0.15	0.34
6/21/2008	A34-1	WS6-0	5.7	18.9	0.065	0.055	0.43	0.61	1.03	0.08	0.07	0.21	0.36	0.35
6/21/2008	A34-1	WS6-0^{+}	5.7	14.1	0.027	0.012	1.44	0.81	1.02	0.04	0.03	0.21	0.23	0.36
6/21/2008	A34-1	WS6-3	6.0	18.3	0.038	0.030	1.05	0.74	0.95	0.04	0.03	0.21	0.35	0.34
6/21/2008	A34-1	WS6-6	5.7	20.7	0.155	0.137	2.48	0.79	2.16	0.06	0.04	0.21	0.30	0.31
6/21/2008	A34-1	WS7-0	6.7	32.2	0.007	0.000	3.12	2.04	0.86	0.04	0.03	0.21	0.33	0.33
6/21/2008	A34-1	WS8-0	8.1	87.8	0.025	0.020	8.83	5.77	1.17	0.03	0.02	0.21	0.23	0.35
6/21/2008	A34-1	WS8-3	7.0	115.2	0.118	0.110	11.20	7.43	1.33	0.03	0.02	0.21	0.21	0.35
6/21/2008	A34-1	WS11-3	6.1	12.7	0.060	0.053	1.08	0.26	0.91	0.03	0.03	0.21	0.12	0.32
6/21/2008	A34-1	WS12-0	6.3	19.2	0.145	0.135	1.99	1.19	2.14	1.00	0.87	0.21	0.18	0.32
6/21/2008	A34-2	WS2-0	6.1	26.0	0.193	0.165	2.88	0.90	1.16	0.12	0.07	0.21	0.36	0.33
6/21/2008	A34-2	WS3-0	6.3	31.0	0.077	0.062	2.99	1.14	1.39	0.10	0.05	0.21	0.53	0.30
6/21/2008	A34-2	WS3-3	6.7	25.9	0.002	0.000	2.49	1.07	1.27	0.06	0.03	0.21	0.99	0.31

Table C.7- Post- harvest water quality parameters and concentration for July 2008

Date	Site	Sampler ID	pH	EC (µS/cm)	TSS (g/L)	TVSS (g/L)	Ca (mg/L)	Mg (mg/L)	K (mg/L)	TP (mg/L)	SRP (mg/L)	NH3-N (mg/L)	NO3 (mg/L)	TN (mg/L)
6/21/2008	A34-2	WS4-0	5.8	39.0	0.452	0.430	3.44	1.00	1.50	0.80	0.66	0.21	0.30	0.32
6/21/2008	A34-2	WS4-3	6.2	93.7	0.183	0.163	17.51	1.16	2.33	0.64	0.32	0.21	0.40	0.21
6/21/2008	A34-2	WS5-0	7.1	104.3	0.015	0.007	11.30	6.51	1.43	0.09	0.05	0.21	0.33	0.31
6/21/2008	A34-2	WS5-3	8.5	145.2	0.032	0.027	16.07	9.96	1.43	0.06	0.03	0.21	0.25	0.35
7/26/2008	A34-1	GRAB 1	7.2	118.4	0.125	0.065	10.88	7.23	1.45	0.13	0.07	0.09		0.30
7/26/2008	A34-1	WS1-0	6.2	27.8	0.155	0.093	2.47	1.02	4.41	0.58	0.46	0.13		0.00
7/26/2008	A34-1	WS4-6	6.1	29.3	0.577	0.413	3.73	1.15	3.78	0.18	0.11	0.08		0.43
7/26/2008	A34-1	WS5-0	6.1	65.2	0.327	0.220	2.25	1	1.88	2.41	2.07	0.41		0.30
7/26/2008	A34-1	WS5-6	6.0	33.2	0.048	0.065	3.73	1.52	1.48	0.32	0.17	0.09		0.43

APPENDIX D: NORMAL AND LOGNORMAL DISTRIBUTIONS

Table D.1- Normal and lognormal properties of TSS, TVSS and Calcium

	Pre-harvest		Post-harvest		Pre-harvest		Post-harvest		Pre-harvest		Post-harvest	
Properties	*TSS (g/L) normal output*	*TSS (g/L) lognormal output*	*TSS (g/L) normal output*	*TSS (g/L) lognormal output*	*TVSS (g/L) Normal Output*	*TVSS (g/L) lognormal output*	*TVSS (g/L) Normal Output*	*TVSS (g/L) lognormal output*	*Ca (mg/L) normal output*	*Ca (mg/L) lognormal output*	*Ca (mg/L) normal output*	*Ca (mg/L) lognormal output*
Mean (μ)	0.12	-3.34	0.18	-3.16	0.05	-4.13	0.12	-4.04	4.51	0.70	3.42	0.49
S. Error	0.01	0.06	0.02	0.14	0.01	0.07	0.02	0.16	0.25	0.06	0.30	0.13
Median	0.04	-3.31	0.05	-2.90	0.02	-3.77	0.03	-3.51	2.34	0.85	2.05	0.72
Mode	0.00	-9.21	0.00	-9.21	0.00	-9.21	0.00	-9.21	0.00	-9.21	0.00	-9.21
S. Deviation (σ)	0.35	1.72	0.32	2.20	0.16	1.82	0.28	2.54	7.03	1.83	4.63	1.94
COV	0.13	2.95	0.10	4.86	0.03	3.32	0.08	6.44	49.47	3.35	21.45	3.76
Kurtosis	100.16	2.79	11.47	1.11	229.87	1.83	18.77	-0.13	42.12	15.76	18.94	16.34
Skewness	8.64	-0.91	3.17	-1.00	13.18	-1.07	4.13	-0.72	5.30	-3.29	3.86	-3.65
Range	5.38	10.89	2.10	9.95	3.33	10.41	2.02	9.91	89.84	13.71	34.99	12.77
Minimum	0.00	-9.21	0.00	-9.21	0.00	-9.21	0.00	-9.21	0.00	-9.21	0.00	-9.21
Maximum	5.38	1.68	2.10	0.74	3.33	1.20	2.02	0.70	89.84	4.50	34.99	3.56
Sum	111.69	-3004.81	47.53	-828.01	40.55	-3095.84	31.67	-1063.64	3667.67	571.37	806.57	115.61
Count	899.00	899.00	262.00	262.00	749.00	749.00	263.00	263.00	813.00	813.00	236.00	236.00
C. Level(95.0%)	0.02	0.11	0.04	0.27	0.01	0.13	0.03	0.31	0.48	0.13	0.59	0.25

Table D.2- Normal and lognormal properties of Mg, K and NH3-N

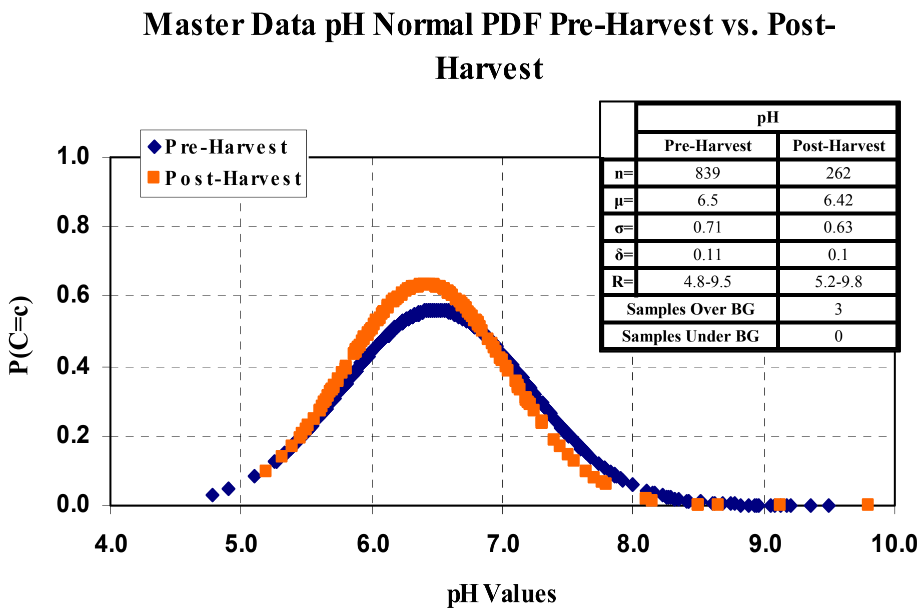
	Pre-harvest		Post-harvest		Pre-harvest		Post-harvest		Pre-harvest		Post-harvest	
Properties	*Mg mg/L) normal output*	*Mg (mg/L) lognormal output*	*Mg mg/L) normal output*	*Mg (mg/L) lognormal output*	*K (mg/L) normal output*	*K (mg/L) lognormal output*	*K (mg/L) normal output*	*K (mg/L) lognormal output*	*NH3-N (mg/L) normal output*	*NH3-N (mg/L) lognormal output*	*NH3-N (mg/L) normal output*	*NH3-N (mg/L) lognormal output*
Mean (μ)	2.06	-0.09	1.67	-0.04	2.32	0.37	1.78	0.209	0.39	-2.50	0.40	-1.70
S. Error	0.13	0.04	0.17	0.08	0.09	0.04	0.17	0.081	0.05	0.08	0.10	0.07
Median	0.75	-0.29	0.87	-0.14	1.53	0.42	1.26	0.229	0.18	-1.71	0.20	-1.62
Mode	0.70	-0.36	0.68	-0.39	1.05	0.05	0.83	-0.186	0.00	-9.21	0.20	-1.61
S. Deviation (σ)	3.82	1.27	2.56	1.24	2.71	1.14	2.57	1.242	1.35	2.33	1.53	1.12
COV	14.63	1.61	6.54	1.54	7.32	1.31	6.63	1.542	1.82	5.42	2.34	1.26
Kurtosis	19.81	7.84	22.77	25.21	28.59	18.04	145.16	40.778	154.49	2.80	81.45	25.89
Skewness	4.08	-0.86	4.38	-3.36	4.23	-2.49	10.90	-5.446	11.22	-1.57	8.91	-2.97
Range	33.85	12.73	20.43	12.23	30.14	12.62	36.70	12.813	22.86	12.34	16.46	12.01
Minimum	0.00	-9.21	0.00	-9.21	0.00	-9.21	0.00	-9.210	0.00	-9.21	0.00	-9.21
Maximum	33.85	3.52	20.43	3.02	30.14	3.41	36.70	3.603	22.86	3.13	16.46	2.80
Sum	1675.70	-69.62	394.33	-9.54	1886.44	299.43	420.59	49.260	313.77	-2013.89	96.17	-414.10
Count	813.00	813.00	236.00	236.00	813.00	813.00	236.00	236.000	807.00	807.00	243.00	243.00
C. Level(95.0%)	0.26	0.09	0.33	0.15904	0.19	0.08	0.33	0.159	0.09	0.16	0.19	0.14

Table D.3- Normal and lognormal properties of NO3, TP and TN

	Pre-harvest		Post-harvest		Pre-harvest		Post-harvest		Pre-harvest		Post-harvest	
Properties	*NO3 mg/L) normal output*	*NO3 (mg/L) lognormal output*	*NO3 mg/L) normal output*	*NO3 (mg/L) lognormal output*	*TP (mg/L) normal output*	*TP (mg/L) lognormal output*	*TP (mg/L) normal output*	*TP (mg/L) lognormal output*	*TN (mg/L) normal output*	*TN (mg/L) lognormal output*	*TN (mg/L) normal output*	*TN (mg/L) lognormal output*
Mean (μ)	0.55	-2.82	1.42	-1.41	0.44	-2.13	0.12	-4.04	1.68	-0.28	1.58	-0.52
S. Error	0.06	0.09	0.30	0.13	0.04	0.07	0.02	0.16	0.09	0.06	0.20	0.14
Median	0.06	-2.81	0.26	-1.35	0.15	-1.90	0.03	-3.51	0.87	-0.14	0.56	-0.58
Mode	0.00	-9.21	0.02	-3.72	0.00	-9.21	0.00	-9.21	0.00	-9.21	0.00	-9.21
S. Deviation (σ)	1.65	2.45	4.56	2.02	1.12	2.00	0.28	2.54	2.46	1.67	2.68	1.91
COV	2.72	6.02	20.82	4.09	1.26	4.02	0.08	6.44	6.08	2.78	7.16	3.66
Kurtosis	35.94	1.43	89.05	2.44	128.35	3.88	18.77	-0.13	18.09	11.81	15.00	11.45
Skewness	5.54	-0.77	8.37	-0.62	9.31	-1.47	4.13	-0.72	3.78	-2.54	3.55	-2.74
Range	15.40	11.94	55.69	13.23	19.60	12.19	2.02	9.91	20.95	12.25	19.00	12.15
Minimum	0.00	-9.21	0.00	-9.21	0.00	-9.21	0.00	-9.21	0.00	-9.21	0.00	-9.21
Maximum	15.40	2.73	55.69	4.02	19.60	2.98	2.02	0.70	20.95	3.04	19.00	2.94
Sum	447.46	-2318.99	335.60	-334.19	338.96	-1650.10	31.67	-1063.64	1300.66	-219.37	296.48	-98.62
Count	821.00	821.00	237.00	237.00	774.00	774.00	263.00	263.00	774.00	774.00	188.00	188.00
C. Level(95.0%)	0.11	0.17	0.58	0.26	0.08	0.14	0.03	0.31	0.17	0.12	0.38	0.28

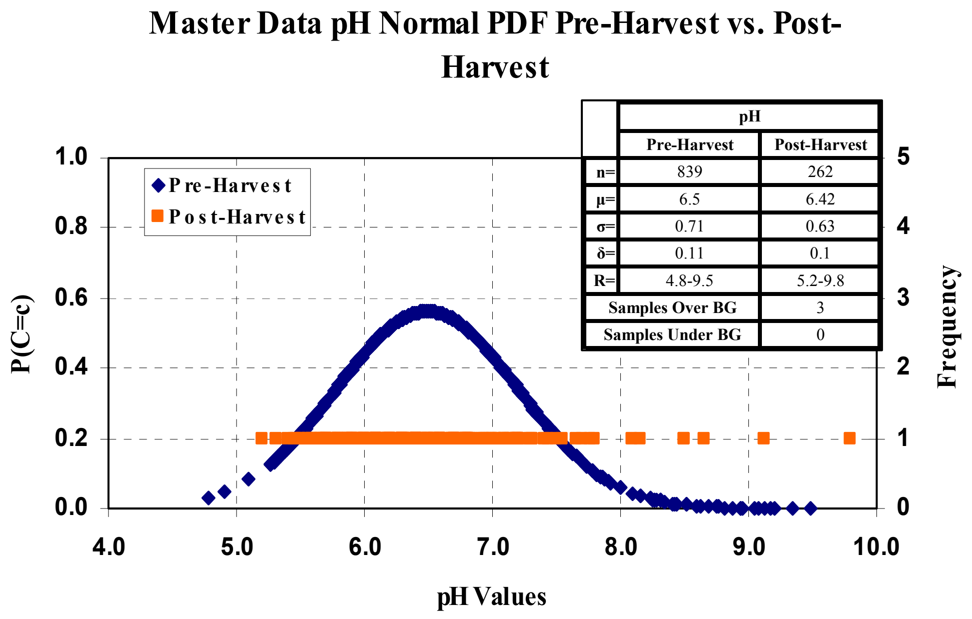
Table D.4- Normal and lognormal properties of pH, EC and SRP

	Pre-harvest		Post-harvest		Pre-harvest		Post-harvest		Pre-harvest		Post-harvest	
Properties	*pH mg/L) normal output*	*pH (mg/L) lognormal output*	*pH mg/L) normal output*	*pH (mg/L) lognormal output*	*EC (mg/L) normal output*	*EC (mg/L) lognormal output*	*EC (mg/L) normal output*	*EC (mg/L) lognormal output*	*SRP (mg/L) normal output*	*SRP (mg/L) lognormal output*	*SRP (mg/L) normal output*	*SRP (mg/L) lognormal output*
Mean (μ)	6.49	1.87	6.42	1.85	50.92	3.44	41.40	3.45	0.19	-3.40	0.28	-3.05
S. Error	0.02	0.00	0.04	0.01	2.22	0.04	3.12	0.04	0.02	0.08	0.05	0.12
Median	6.35	1.85	6.32	1.84	28.70	3.36	28.30	3.34	0.04	-3.22	0.04	-3.22
Mode	6.32	1.84	6.30	1.84	19.80	2.99	19.50	2.97	0.00	-9.21	0.04	-3.22
S. Deviation (σ)	0.71	0.10	0.63	0.09	64.19	1.23	50.43	0.66	0.54	2.35	0.86	1.85
COV	0.50	0.01	0.39	0.01	4120.77	1.51	2543.10	0.43	0.29	5.54	0.73	3.43
Kurtosis	2.25	1.19	4.93	2.58	20.83	26.39	65.34	2.39	79.37	1.13	41.68	2.57
Skewness	1.21	0.80	1.57	1.05	3.86	-3.67	6.87	0.85	7.75	-1.00	5.74	-0.34
Range	4.71	0.69	4.60	0.63	670.00	12.72	599.62	4.93	7.46	11.22	8.54	11.36
Minimum	4.78	1.56	5.20	1.65	0.00	-6.21	4.38	1.48	0.00	-9.21	0.00	-9.21
Maximum	9.49	2.25	9.80	2.28	670.00	6.51	604.00	6.40	7.46	2.01	8.54	2.14
Sum	5448.72	1565.04	1680.89	485.84	42723.55	2889.03	10847	903.48	157.79	-2775.74	68.05	-750.27
Count	839.00	839.00	262.00	262.00	839.00	839.00	262.00	262.00	817.00	817.00	246.00	246.00
C. Level(95.0%)	0.05	0.01	0.08	0.01	4.35	0.08	6.13	0.08	0.04	0.16	0.11	0.23



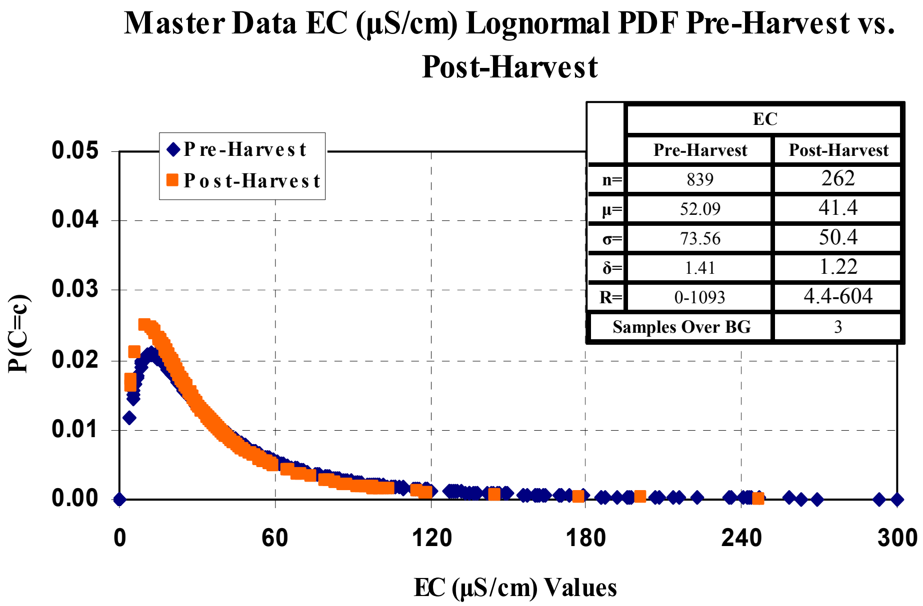
	pH	
	Pre-Harvest	Post-Harvest
n=	839	262
μ=	6.5	6.42
σ=	0.71	0.63
δ=	0.11	0.1
R=	4.8-9.5	5.2-9.8
Samples Over BG	3	
Samples Under BG	0	

Figure D.1- Pre-and post-harvest pH lognormal distribution



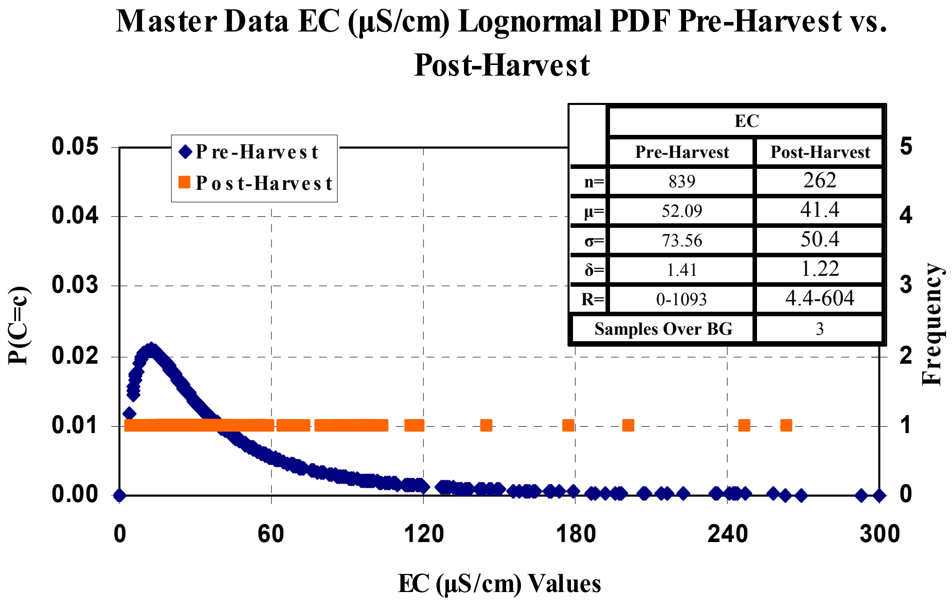
	pH	
	Pre-Harvest	Post-Harvest
n=	839	262
μ=	6.5	6.42
σ=	0.71	0.63
δ=	0.11	0.1
R=	4.8-9.5	5.2-9.8
Samples Over BG	3	
Samples Under BG	0	

Figure D.2- Pre-harvest pH lognormal distribution with individual post harvest samples



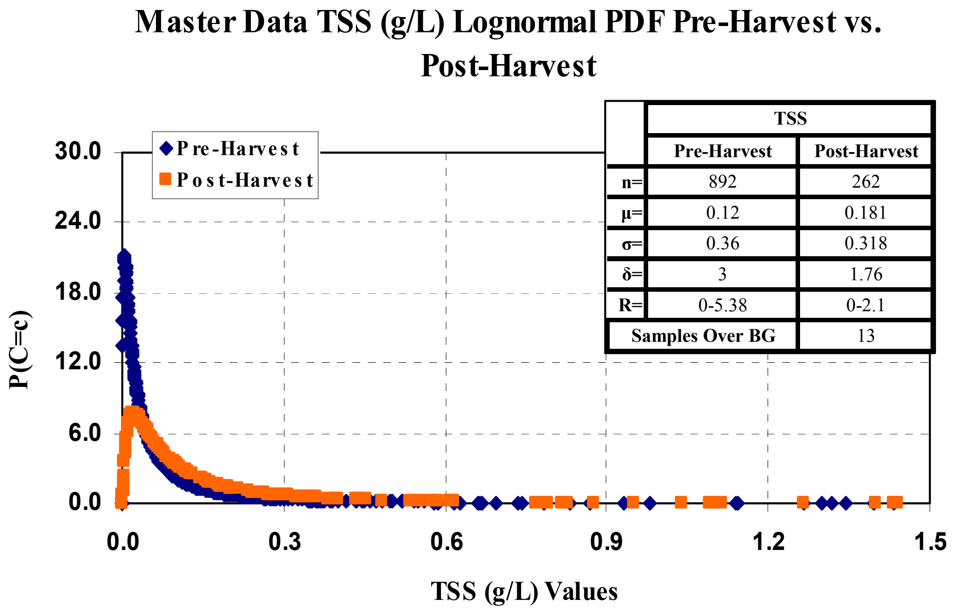
	EC	
	Pre-Harvest	Post-Harvest
n=	839	262
µ=	52.09	41.4
σ=	73.56	50.4
δ=	1.41	1.22
R=	0-1093	4.4-604
Samples Over BG		3

Figure D.3- Pre-and post-harvest EC lognormal distribution



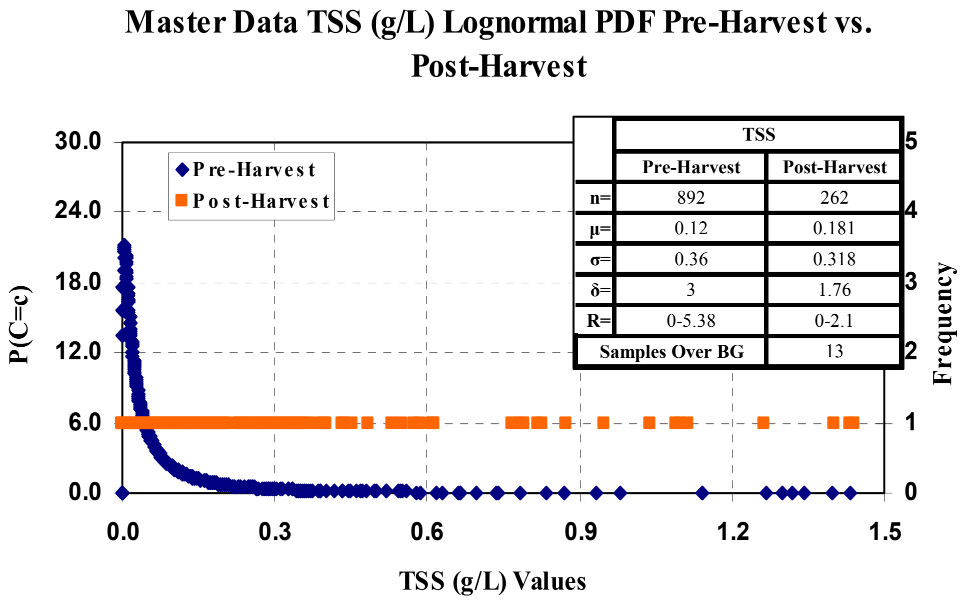
	EC	
	Pre-Harvest	Post-Harvest
n=	839	262
µ=	52.09	41.4
σ=	73.56	50.4
δ=	1.41	1.22
R=	0-1093	4.4-604
Samples Over BG		3

Figure D.4- Pre-harvest EC lognormal distribution with individual post harvest samples


Master Data TSS (g/L) Lognormal PDF Pre-Harvest vs. Post-Harvest

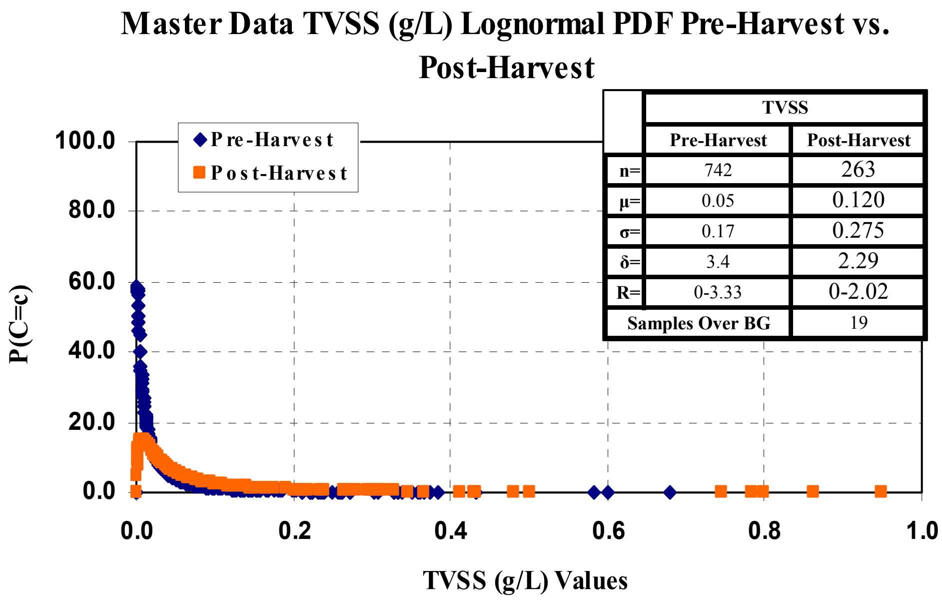
	TSS	
	Pre-Harvest	Post-Harvest
n=	892	262
μ=	0.12	0.181
σ=	0.36	0.318
δ=	3	1.76
R=	0-5.38	0-2.1
Samples Over BG		13

Figure D.5- Pre-and post-harvest TSS lognormal distribution


Master Data TSS (g/L) Lognormal PDF Pre-Harvest vs. Post-Harvest

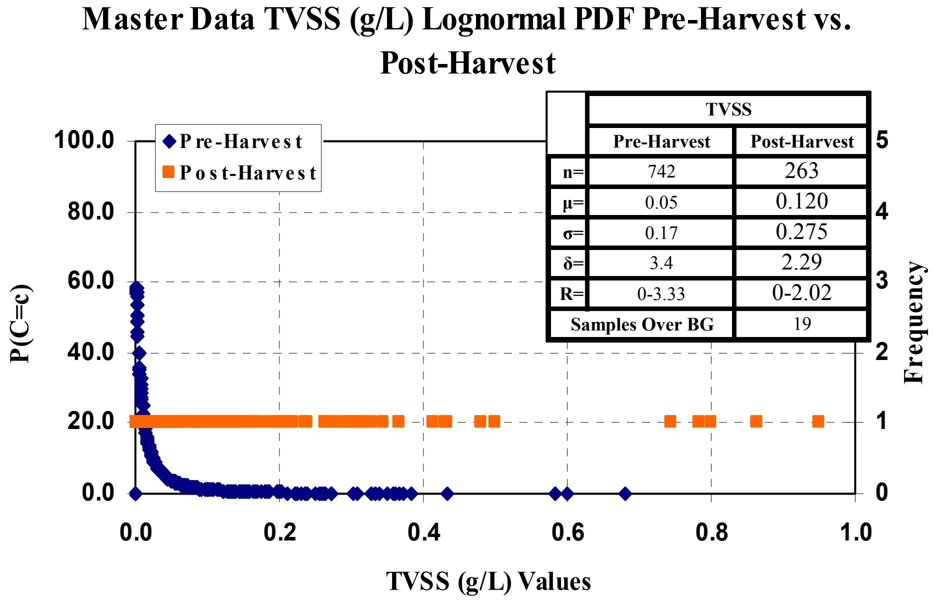
	TSS	
	Pre-Harvest	Post-Harvest
n=	892	262
μ=	0.12	0.181
σ=	0.36	0.318
δ=	3	1.76
R=	0-5.38	0-2.1
Samples Over BG		13

Figure D.6- Pre-harvest TSS lognormal distribution with individual post harvest samples



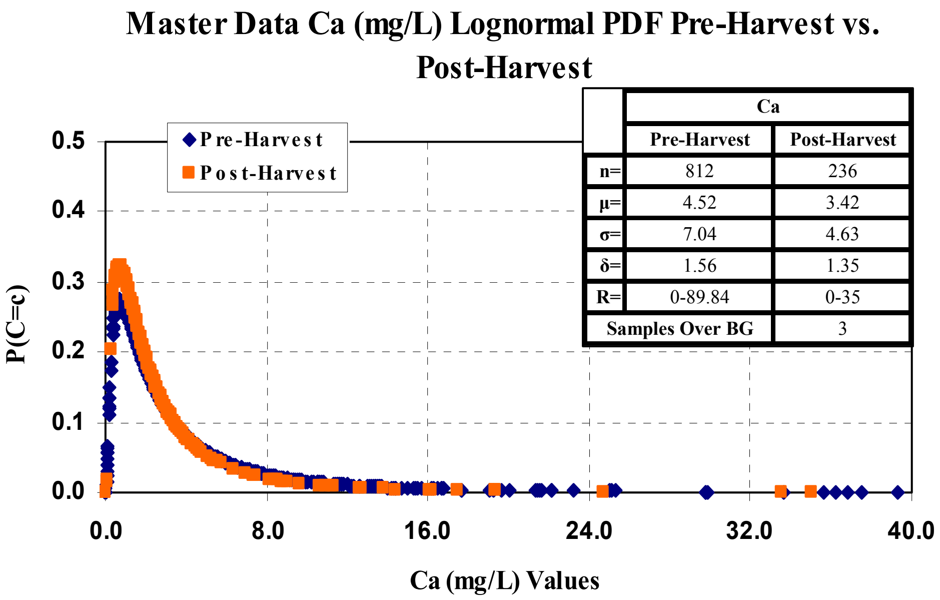
	TVSS	
	Pre-Harvest	Post-Harvest
n=	742	263
μ=	0.05	0.120
σ=	0.17	0.275
δ=	3.4	2.29
R=	0-3.33	0-2.02
Samples Over BG		19

Figure D.7- Pre-and post-harvest TVSS lognormal distribution



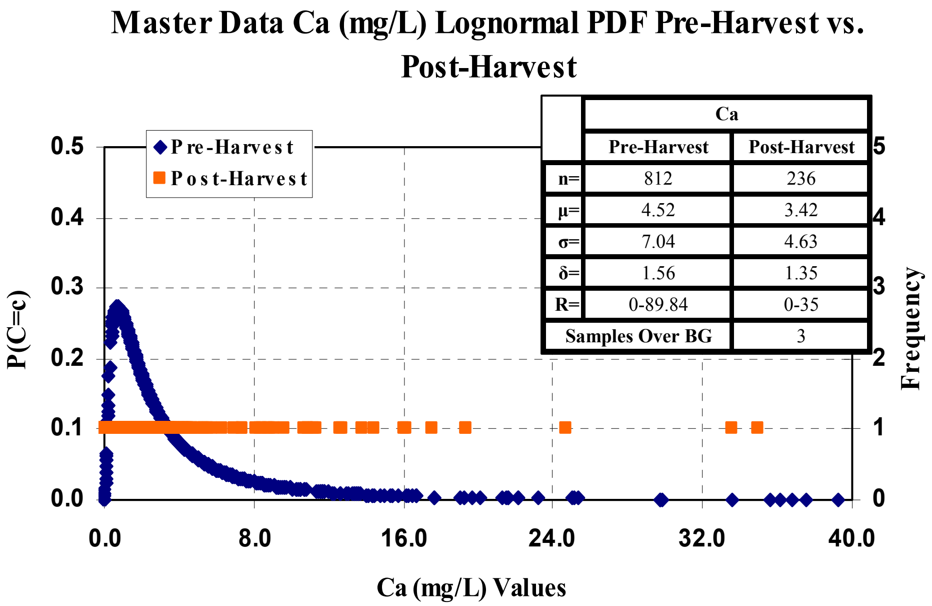
	TVSS	
	Pre-Harvest	Post-Harvest
n=	742	263
μ=	0.05	0.120
σ=	0.17	0.275
δ=	3.4	2.29
R=	0-3.33	0-2.02
Samples Over BG		19

Figure D.8- Pre-harvest TVSS lognormal distribution with individual post harvest samples



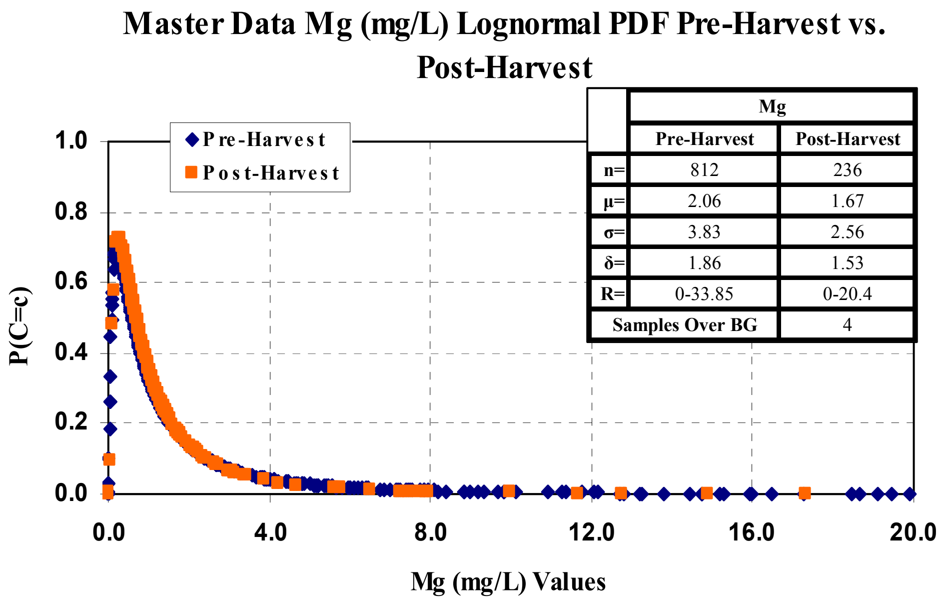
	Ca	
	Pre-Harvest	Post-Harvest
n=	812	236
μ=	4.52	3.42
σ=	7.04	4.63
δ=	1.56	1.35
R=	0-89.84	0-35
Samples Over BG		3

Figure D.9- Pre-and post-harvest Ca lognormal distribution



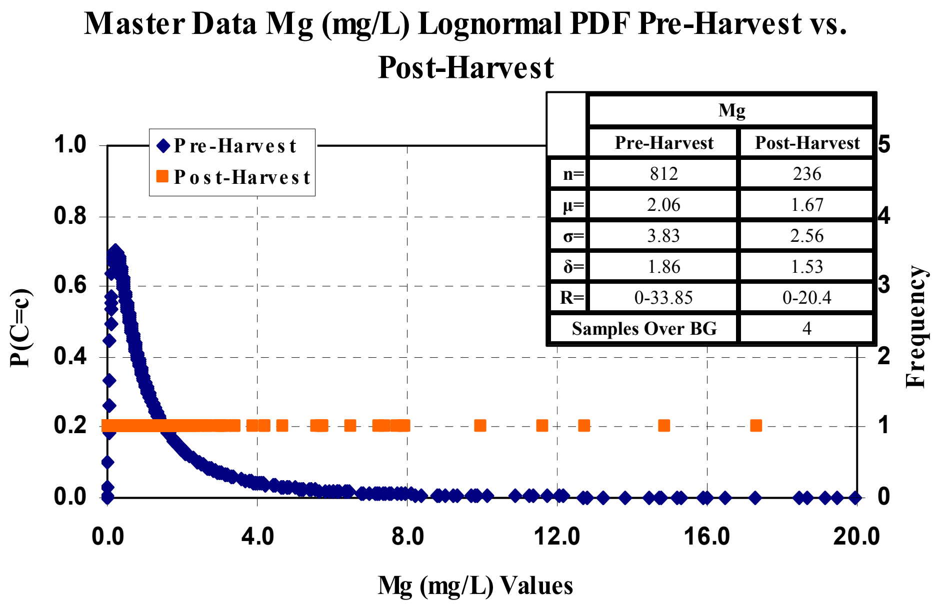
	Ca	
	Pre-Harvest	Post-Harvest
n=	812	236
μ=	4.52	3.42
σ=	7.04	4.63
δ=	1.56	1.35
R=	0-89.84	0-35
Samples Over BG		3

Figure D.10- Pre-harvest Ca lognormal distribution with individual post harvest samples



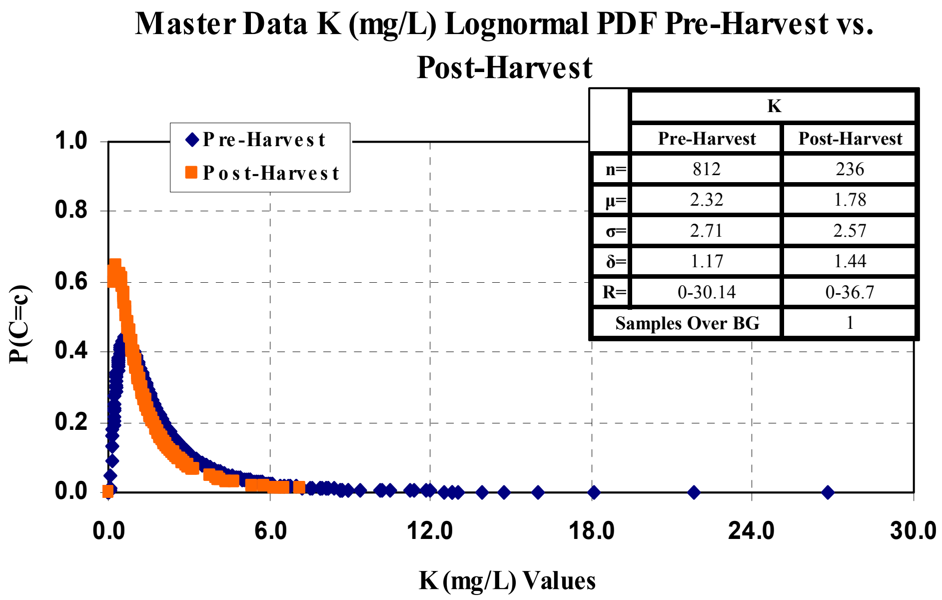
	Mg	
	Pre-Harvest	Post-Harvest
n=	812	236
μ=	2.06	1.67
σ=	3.83	2.56
δ=	1.86	1.53
R=	0-33.85	0-20.4
Samples Over BG		4

Figure D.11- Pre-and post-harvest Mg lognormal distribution



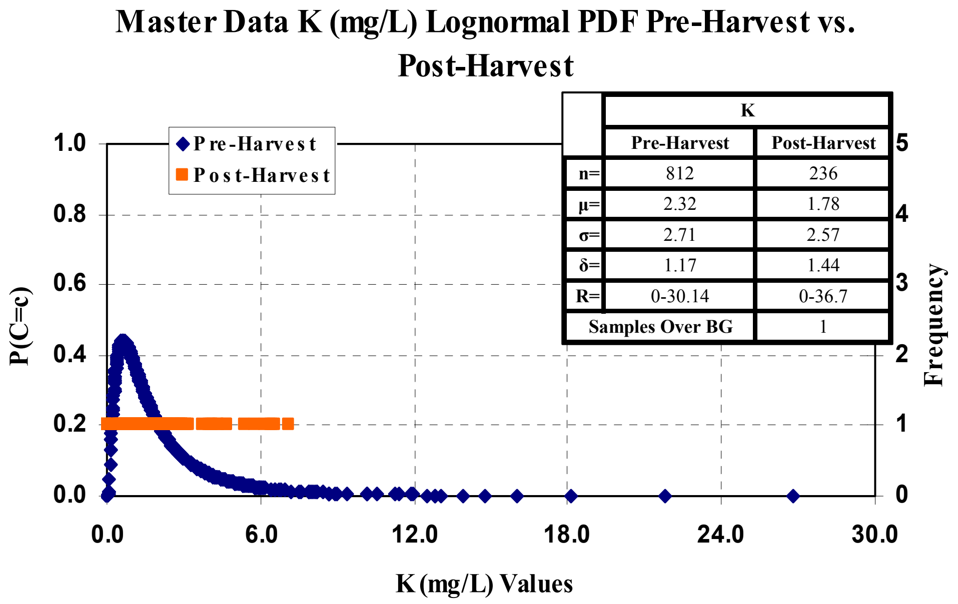
	Mg	
	Pre-Harvest	Post-Harvest
n=	812	236
μ=	2.06	1.67
σ=	3.83	2.56
δ=	1.86	1.53
R=	0-33.85	0-20.4
Samples Over BG		4

Figure D.12- Pre-harvest Mg lognormal distribution with individual post harvest samples



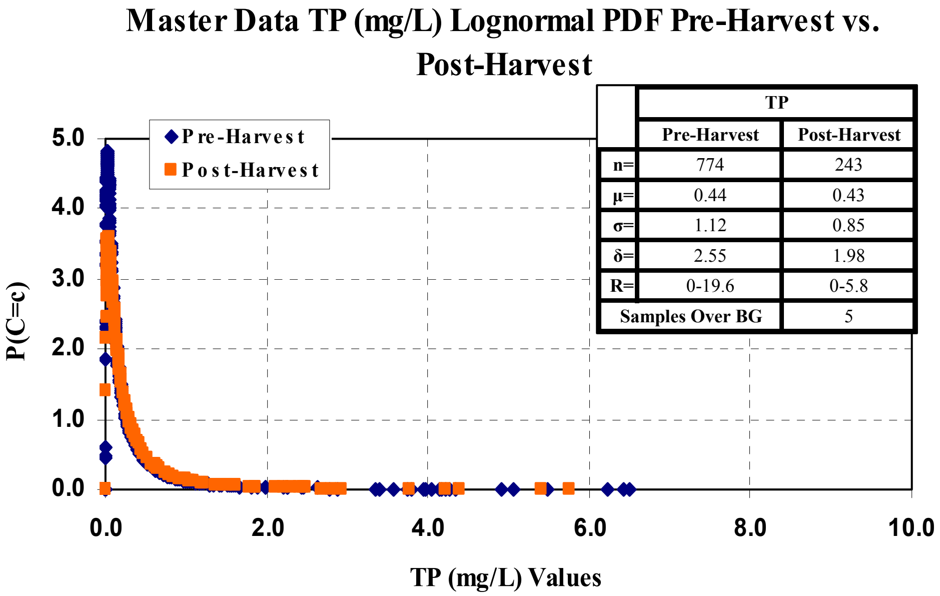
	K	
	Pre-Harvest	Post-Harvest
n=	812	236
μ=	2.32	1.78
σ=	2.71	2.57
δ=	1.17	1.44
R=	0-30.14	0-36.7
Samples Over BG		1

Figure D.13- Pre-and post-harvest K lognormal distribution



	K	
	Pre-Harvest	Post-Harvest
n=	812	236
μ=	2.32	1.78
σ=	2.71	2.57
δ=	1.17	1.44
R=	0-30.14	0-36.7
Samples Over BG		1

Figure D.14- Pre-harvest K lognormal distribution with individual post harvest samples



	TP	
	Pre-Harvest	Post-Harvest
n=	774	243
μ=	0.44	0.43
σ=	1.12	0.85
δ=	2.55	1.98
R=	0-19.6	0-5.8
Samples Over BG		5

Figure D.15- Pre-and post-harvest TP lognormal distribution

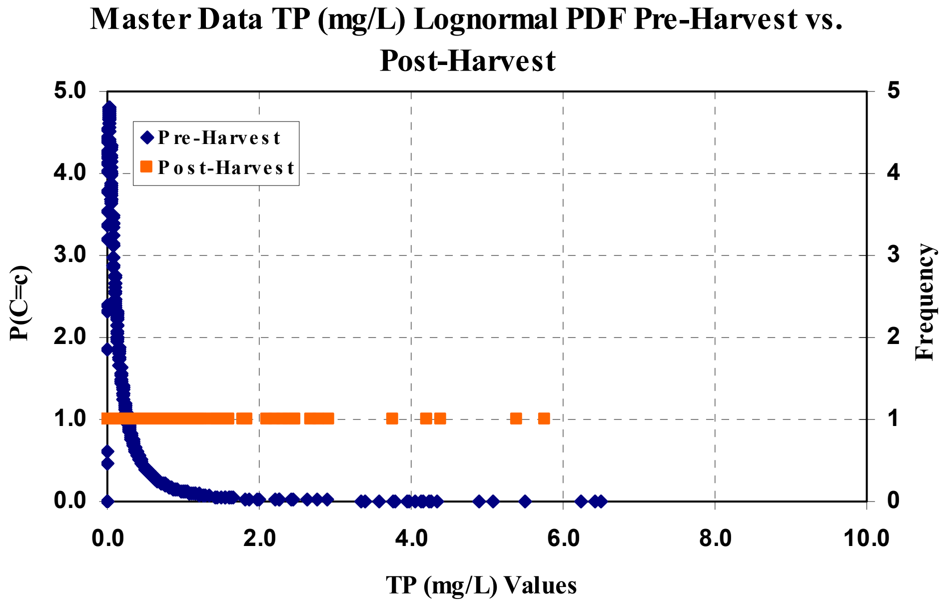
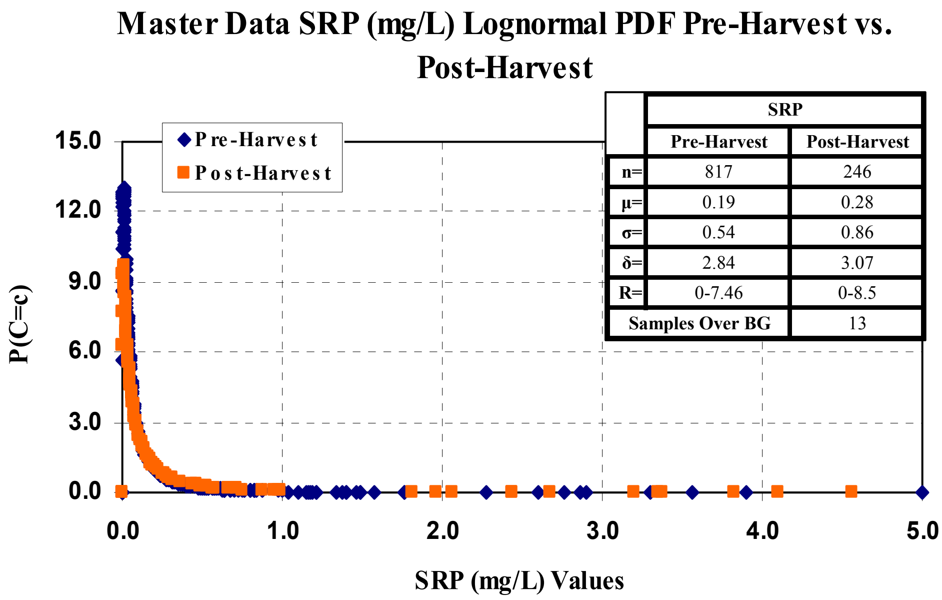
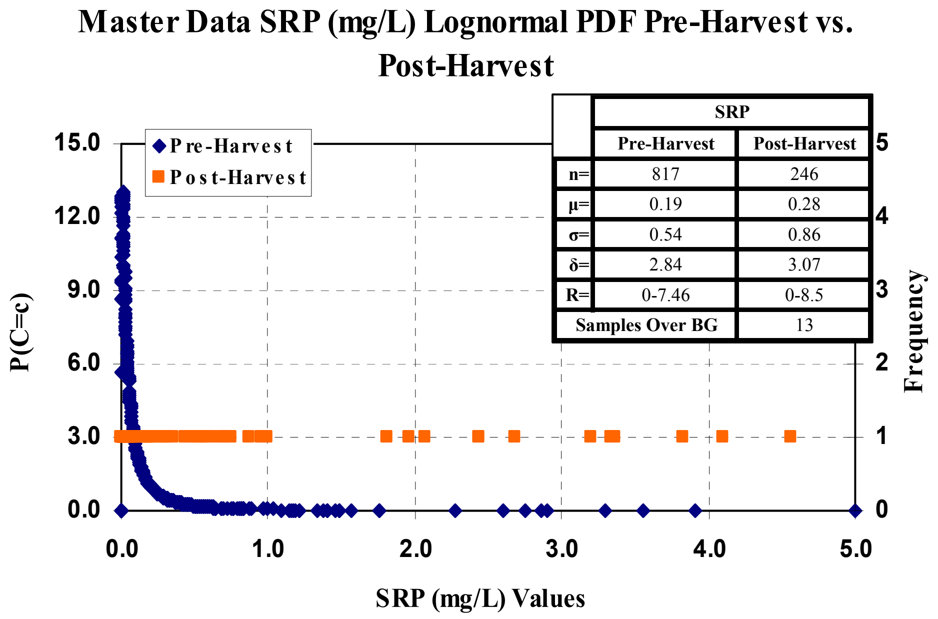


Figure D.16- Pre-harvest TP lognormal distribution with individual post harvest samples



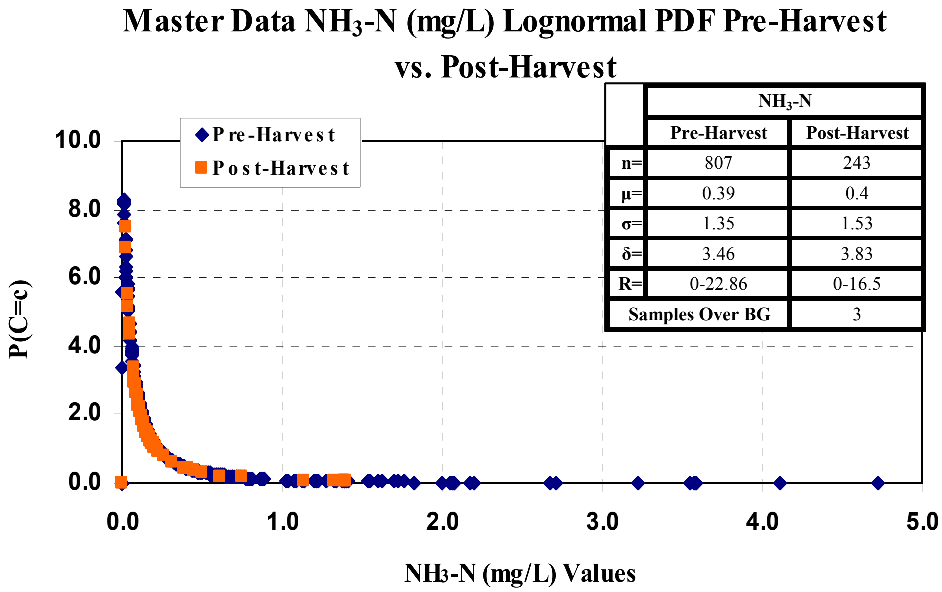
	SRP	
	Pre-Harvest	Post-Harvest
n=	817	246
μ=	0.19	0.28
σ=	0.54	0.86
δ=	2.84	3.07
R=	0-7.46	0-8.5
Samples Over BG		13

Figure D.17- Pre-and post-harvest SRP lognormal distribution



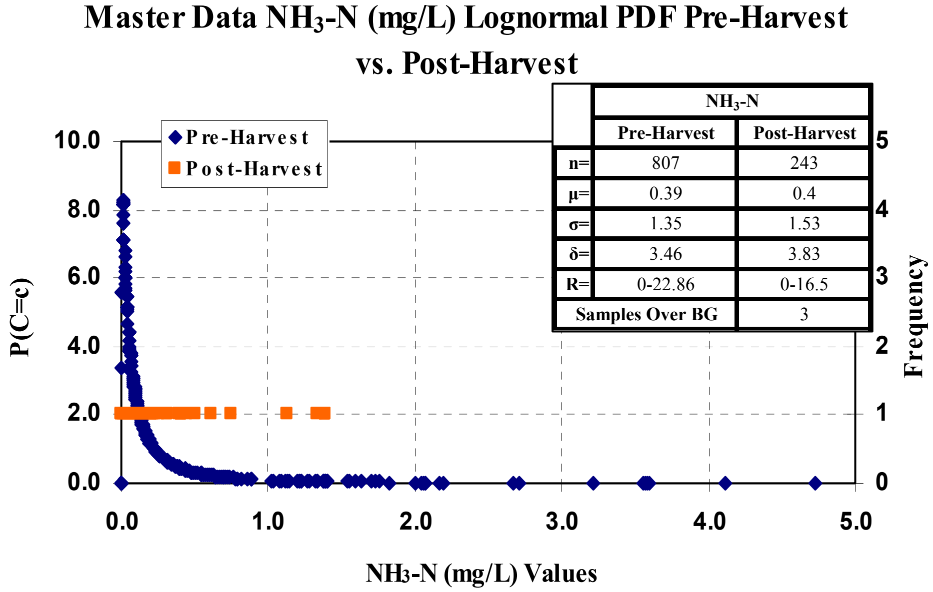
	SRP	
	Pre-Harvest	Post-Harvest
n=	817	246
μ=	0.19	0.28
σ=	0.54	0.86
δ=	2.84	3.07
R=	0-7.46	0-8.5
Samples Over BG		13

Figure D.18- Pre-harvest SRP lognormal distribution with individual post harvest samples



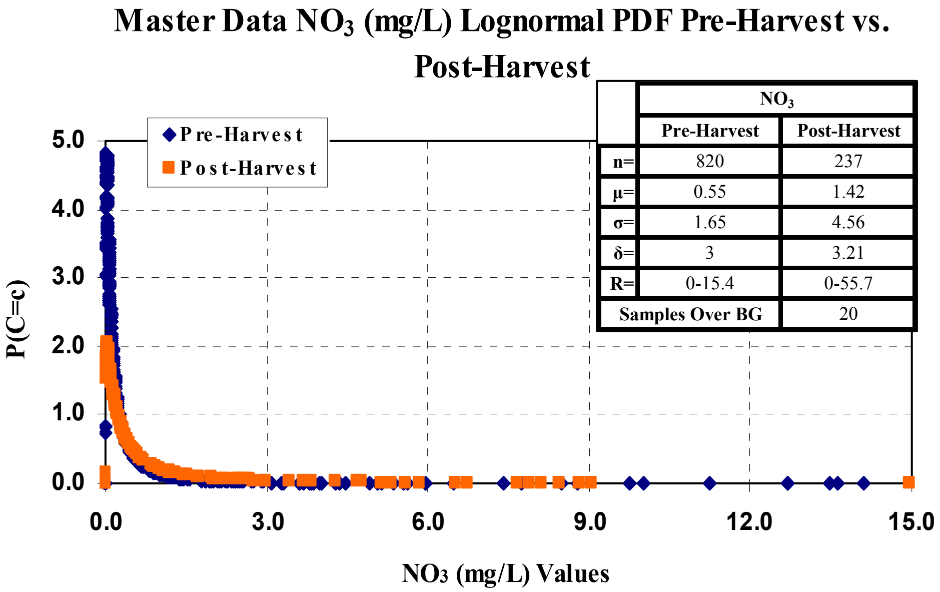
	NH$_3$-N	
	Pre-Harvest	**Post-Harvest**
n=	807	243
μ=	0.39	0.4
σ=	1.35	1.53
δ=	3.46	3.83
R=	0-22.86	0-16.5
Samples Over BG		3

Figure D.19- Pre-and post-harvest NH3-N lognormal distribution



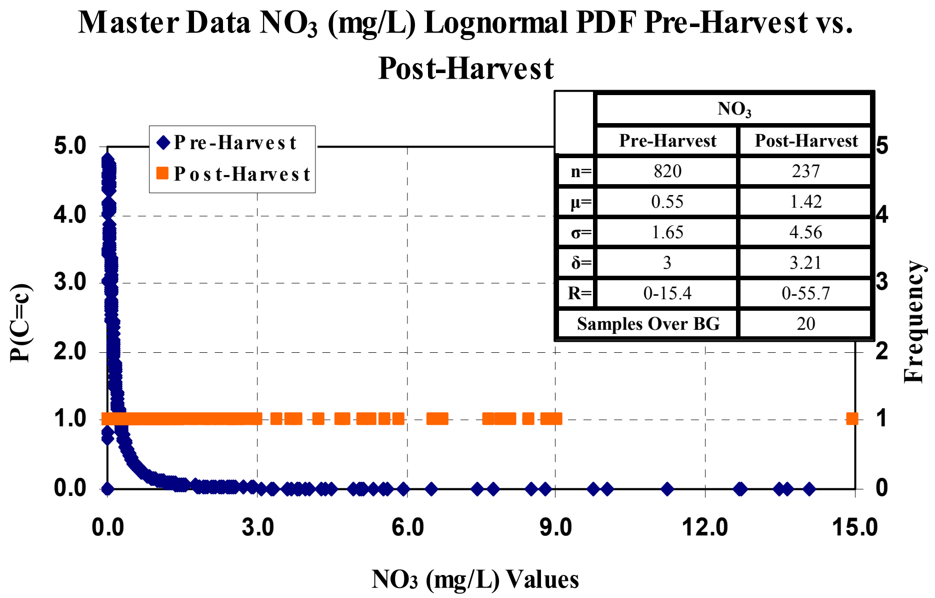
	NH$_3$-N	
	Pre-Harvest	**Post-Harvest**
n=	807	243
μ=	0.39	0.4
σ=	1.35	1.53
δ=	3.46	3.83
R=	0-22.86	0-16.5
Samples Over BG		3

Figure D.20- Pre-harvest NH3-N lognormal distribution with individual post harvest samples


Master Data NO_3 (mg/L) Lognormal PDF Pre-Harvest vs. Post-Harvest

	NO_3	
	Pre-Harvest	Post-Harvest
n=	820	237
μ=	0.55	1.42
σ=	1.65	4.56
δ=	3	3.21
R=	0-15.4	0-55.7
Samples Over BG		20

Figure D.21- Pre-and post-harvest NO3 lognormal distribution


Master Data NO_3 (mg/L) Lognormal PDF Pre-Harvest vs. Post-Harvest

	NO_3	
	Pre-Harvest	Post-Harvest
n=	820	237
μ=	0.55	1.42
σ=	1.65	4.56
δ=	3	3.21
R=	0-15.4	0-55.7
Samples Over BG		20

Figure D.22- Pre-harvest NO3 lognormal distribution with individual post harvest samples

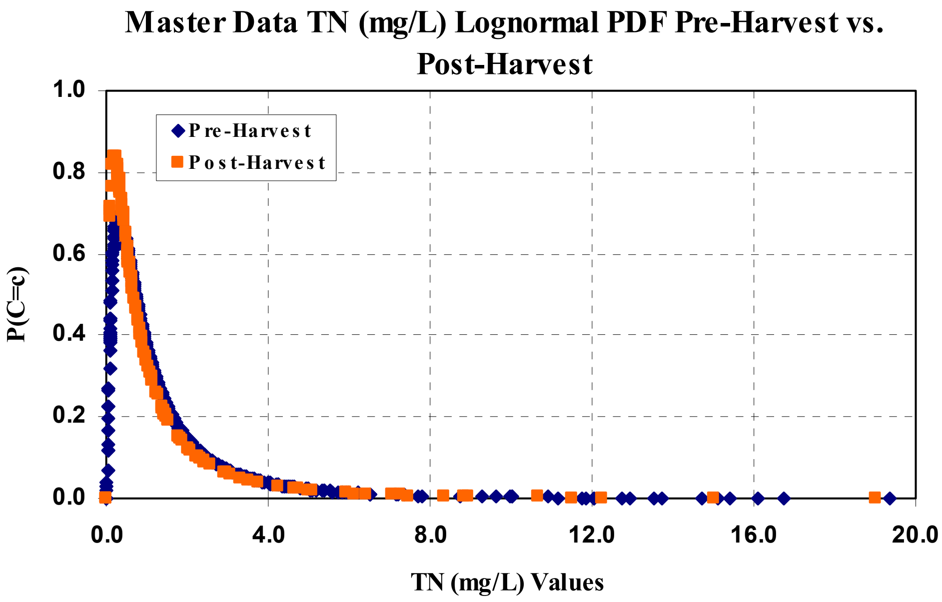


Figure D.23- Pre-and post-harvest TN lognormal distribution

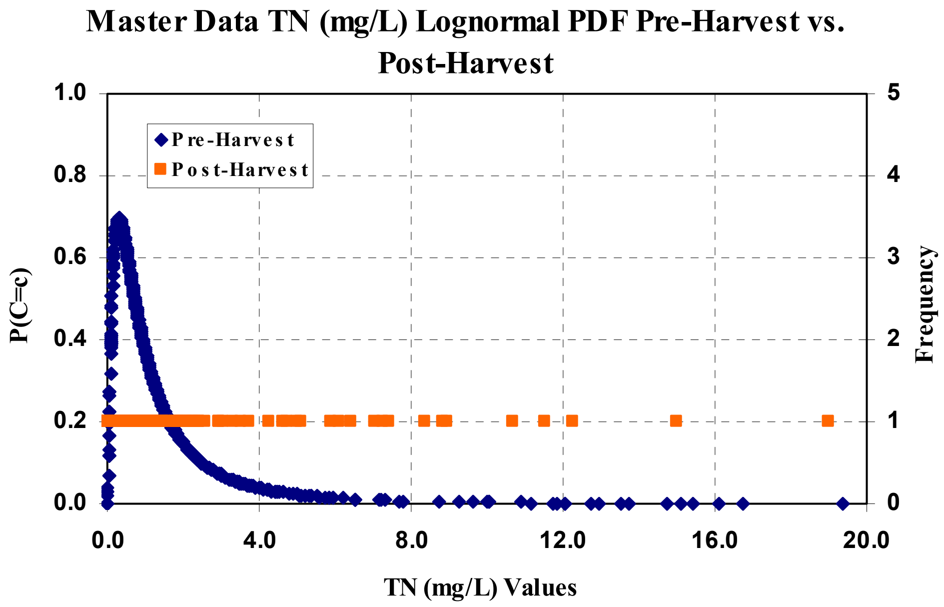


Figure D.24- Pre-harvest TN lognormal distribution with individual post harvest samples

APPENDIX E: BEST FIT OF NORMAL AND LOGNORMAL DISTRIBUTION

Table E. 1- Anova analysis summery for TSS and TVSS

TSS (g/L)							
PRE-HARVEST	*Groups*	*Count*	*Sum*	*Average*	*Variance*		
SUMMARY	Concentration	900.00	111.69	0.12	0.13		
	Theo. Lognormal	900.00	107.89	0.12	0.07		
ANOVA	*Source of Variation*	*SS*	*df*	*MS*	*F*	*P-value*	*F crit*
	Between Groups	0.01	1.00	0.01	0.08	0.77	3.85
	Within Groups	171.09	1798.00	0.10			
	Total	171.10	1799.00				
TSS (g/L)							
POST-HARVEST	*Groups*	*Count*	*Sum*	*Average*	*Variance*		
SUMMARY	Concentration	262	47.53	0.18	0.10		
	Theo. Lognormal	262	45.72	0.17	0.06		
ANOVA	*Source of Variation*	*SS*	*df*	*MS*	*F*	*P-value*	*F crit*
	Between Groups	0.01	1.00	0.01	0.08	0.78	3.86
	Within Groups	41.44	522.00	0.08			
	Total	41.44	523.00				
TVSS (g/L)							
PRE-HARVEST	*Groups*	*Count*	*Sum*	*Average*	*Variance*		
SUMMARY	Concentration	749.00	40.55	0.05	0.03		
	Theo. Lognormal	749.00	38.78	0.05	0.01		
	Source of Variation	*SS*	*df*	*MS*	*F*	*P-value*	*F crit*
ANOVA	Between Groups	0.00	1.00	0.00	0.10	0.75	3.85
	Within Groups	30.17	1496.00	0.02			
	Total	30.17	1497.00				
TVSS (g/L)							
POST-HARVEST	*Groups*	*Count*	*Sum*	*Average*	*Variance*		
SUMMARY	Concentration	263.00	31.67	0.12	0.08		
	Theo. Lognormal	263.00	29.98	0.11	0.03		
	Source of Variation	*SS*	*df*	*MS*	*F*	*P-value*	*F crit*
ANOVA	Between Groups	0.01	1.00	0.01	0.10	0.75	3.86
	Within Groups	28.93	524.00	0.06			
	Total	28.93	525.00				

Table E. 2- Anova analysis summery for pH and EC

pH PRE-HARVEST	*Groups*	*Count*	*Sum*	*Average*	*Variance*		
SUMMARY	Concentration	839.00	4275.01	5.10	722.27		
	Theo. Lognormal	839.00	5448.72	6.49	0.50		
ANOVA	*Source of Variation*	*SS*	*df*	*MS*	*F*	*P-value*	*F crit*
	Between Groups	820.97	1.00	820.97	2.27	0.13	2.71
	Within Groups	605683.93	1676.00	361.39			
	Total	606504.90	1677.00				
pH POST-HARVEST	*Groups*	*Count*	*Sum*	*Average*	*Variance*		
SUMMARY	Concentration	262.00	1061.08	4.05	313.70		
	Theo. Lognormal	262.00	1680.89	6.42	0.39		
ANOVA	*Source of Variation*	*SS*	*df*	*MS*	*F*	*P-value*	*F crit*
	Between Groups	733.15	1.00	733.15	4.67	0.03	3.86
	Within Groups	81977.37	522.00	157.04			
	Total	82710.52	523.00				
EC PRE-HARVEST	*Groups*	*Count*	*Sum*	*Average*	*Variance*		
SUMMARY	Concentration	839.00	42723.55	50.92	4120.77		
	Theo. Lognormal	839.00	42184.29	50.28	4016.87		
	Source of Variation	*SS*	*df*	*MS*	*F*	*P-value*	*F crit*
ANOVA	Between Groups	173.30	1.00	173.30	0.04	0.84	3.85
	Within Groups	6819342.35	1676.00	4068.82			
	Total	6819515.65	1677.00				
EC POST-HARVEST	*Groups*	*Count*	*Sum*	*Average*	*Variance*		
SUMMARY	Concentration	262.00	1061.08	4.05	313.70		
	Theo. Lognormal	262.00	1680.89	6.42	0.39		
	Source of Variation	*SS*	*df*	*MS*	*F*	*P-value*	*F crit*
ANOVA	Between Groups	172.41	1.00	172.41	0.07	0.79	3.86
	Within Groups	1254276.56	522.00	2402.83			
	Total	1254448.97	523.00				

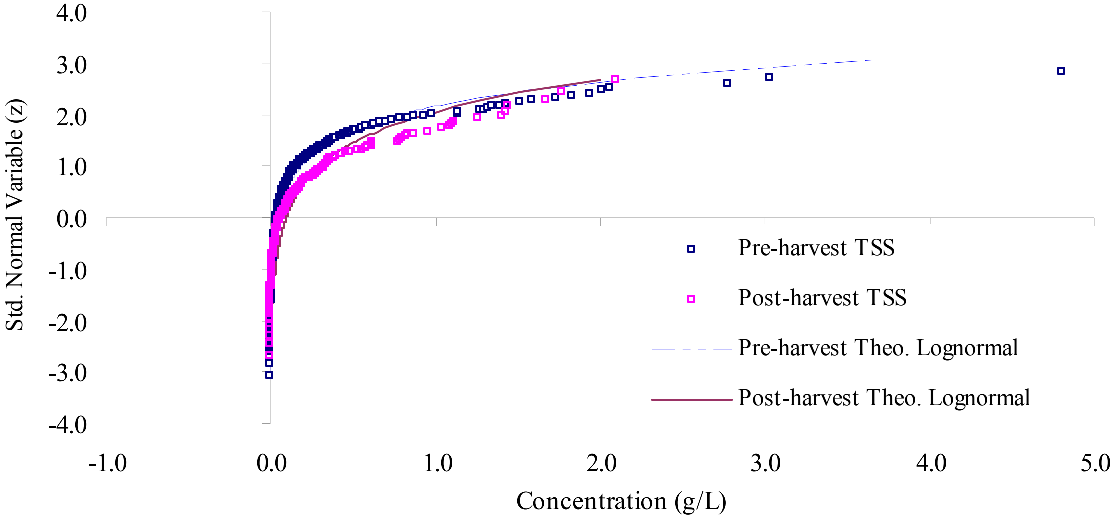


Figure E. 1- Pre-and Post-harvest TSS theoretical lognormal and best fit concentration

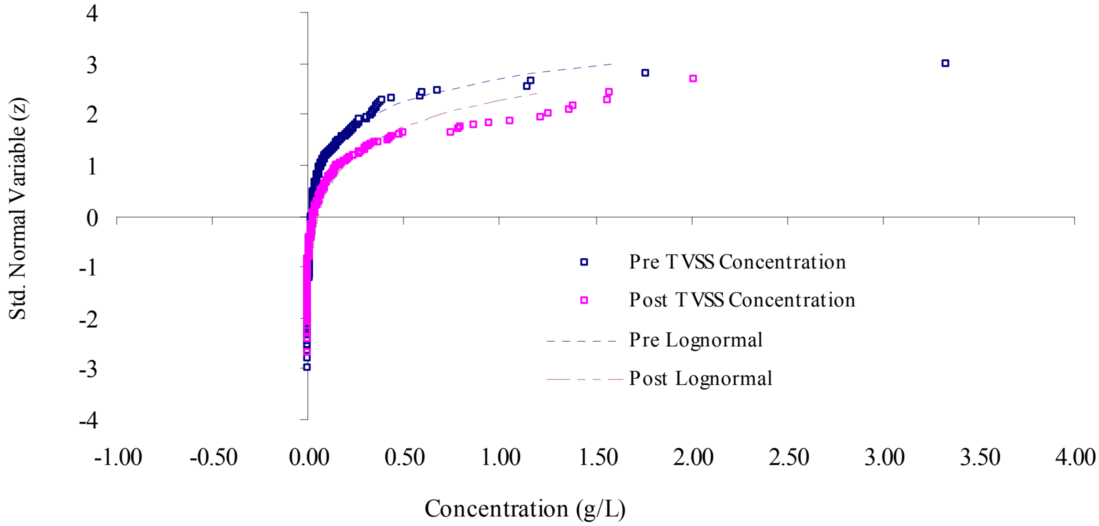


Figure E. 2- Pre-and Post-harvest TVSS theoretical lognormal and best fit concentration

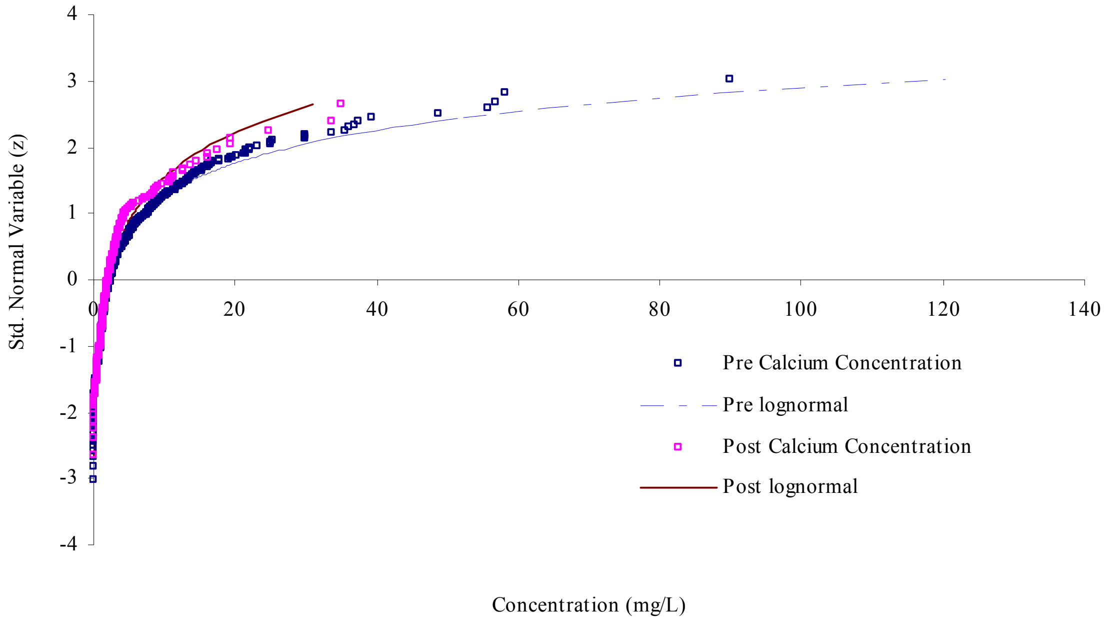


Figure E. 3- Pre-and Post-harvest Ca theoretical lognormal and best fit concentration

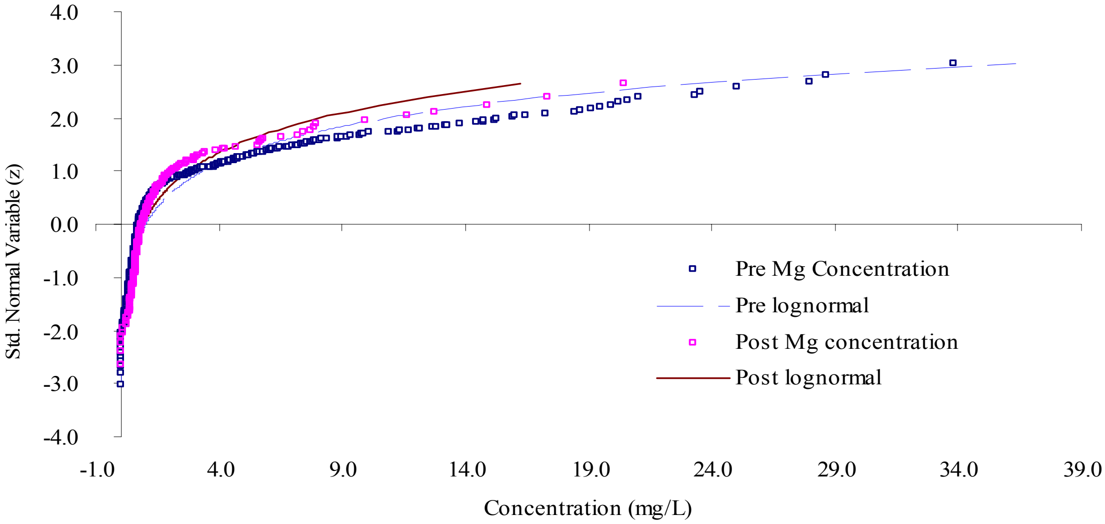


Figure E. 4- Pre-and Post-harvest Mg theoretical lognormal and best fit concentration

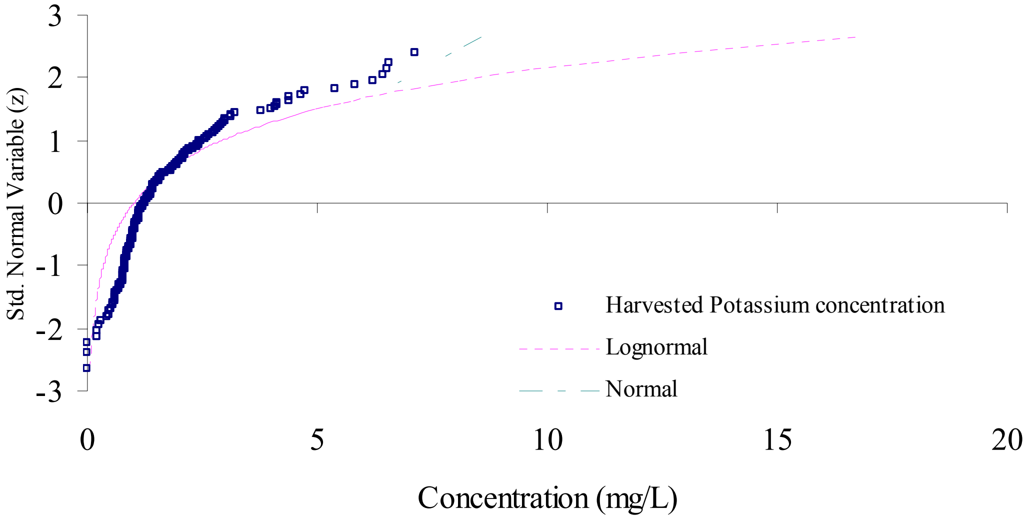


Figure E. 5- Post-harvest K theoretical lognormal and best fit concentration

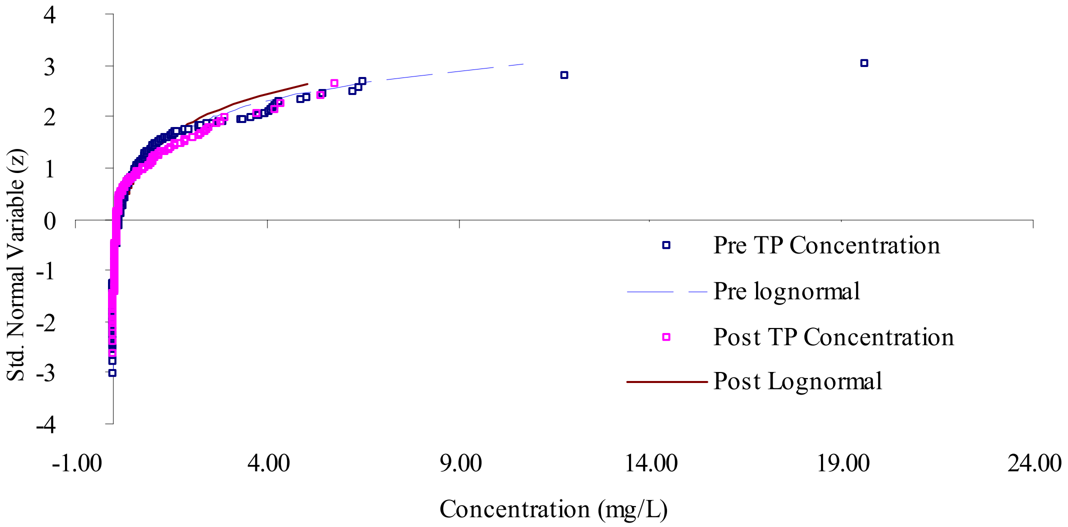


Figure E. 6- Pre-and Post-harvest TP theoretical lognormal and best fit concentration

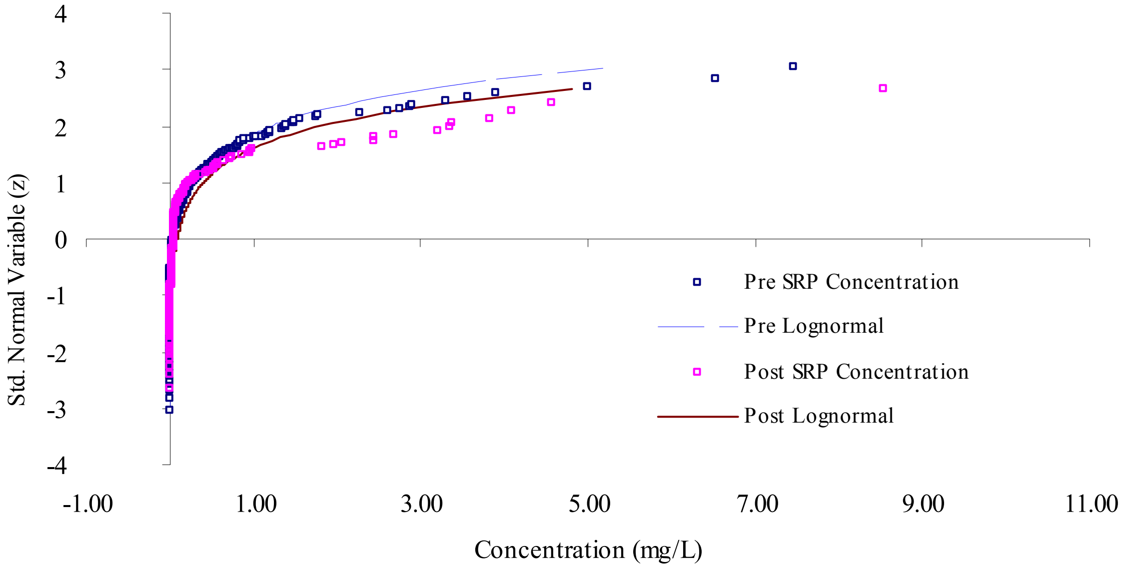


Figure E. 7- Pre-and Post-harvest SRP theoretical lognormal and best fit concentration

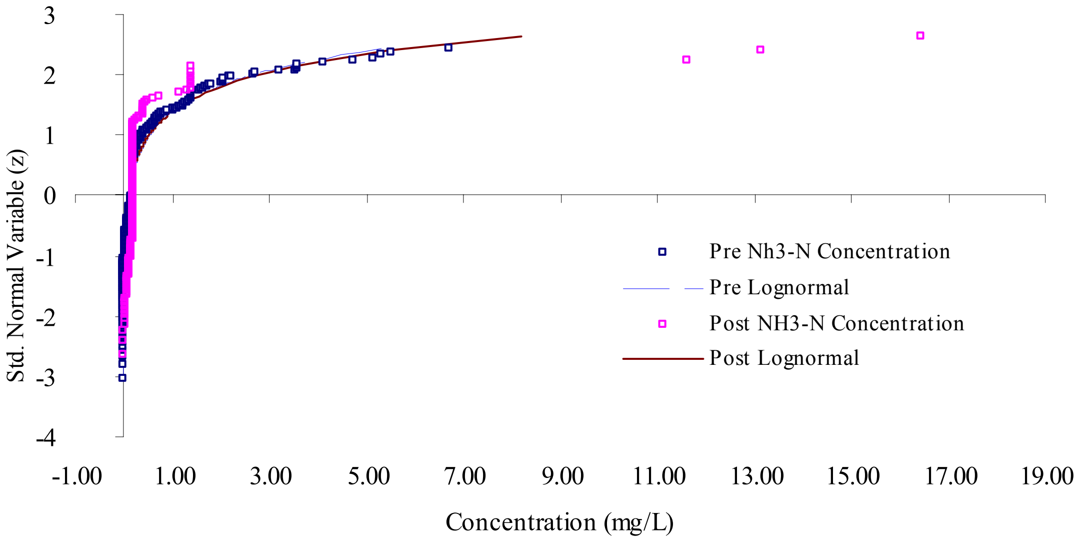


Figure E. 8- Pre-and Post-harvest NH_3-N theoretical lognormal and best fit concentration

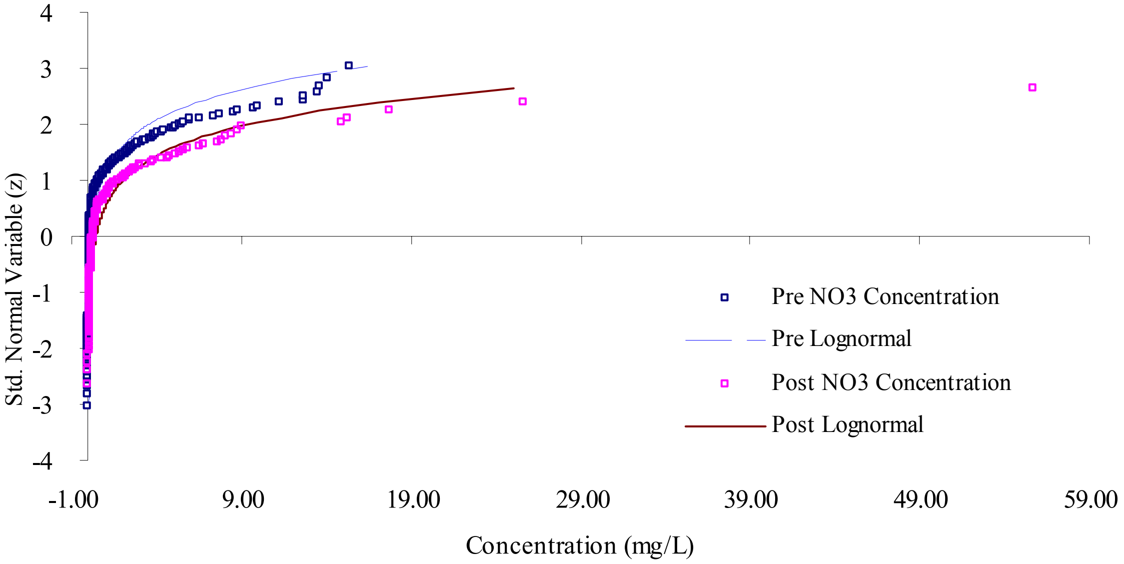


Figure E. 9- Pre-and Post-harvest NO_3 theoretical lognormal and best fit concentration

TN

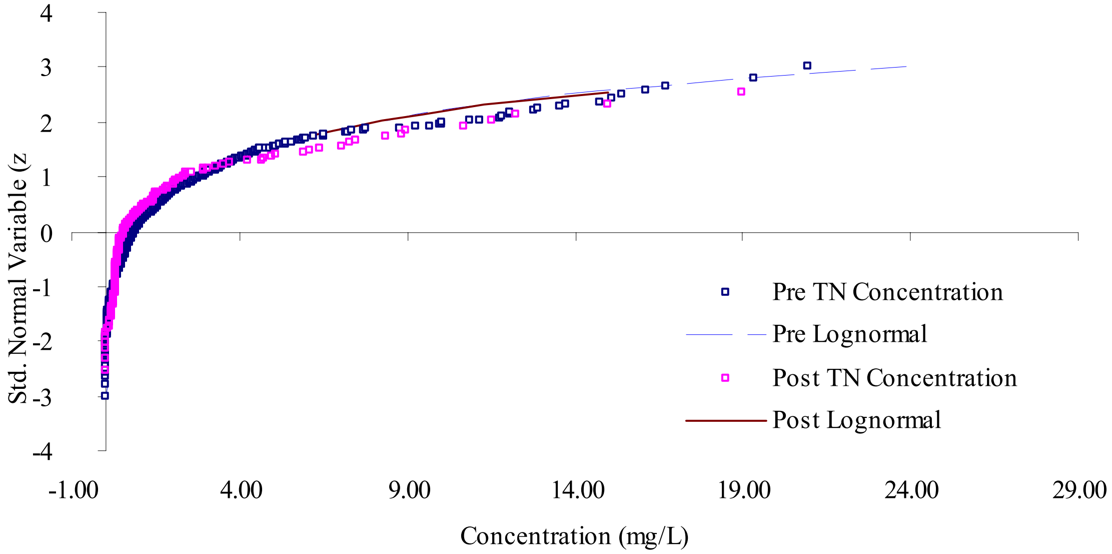


Figure E. 10- Pre-and Post-harvest TN theoretical lognormal and best fit concentration

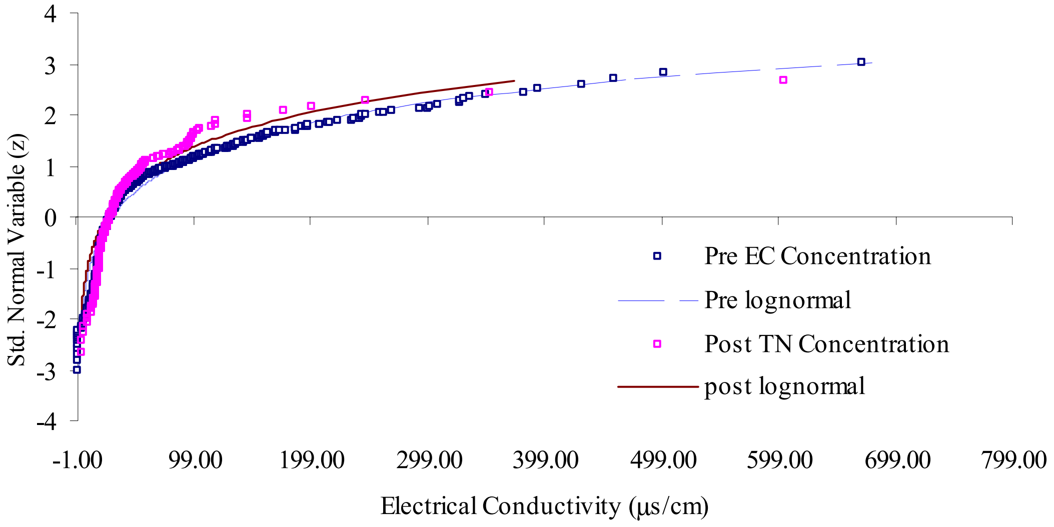


Figure E. 11- Pre-and Post-harvest EC theoretical lognormal and best fit concentration

APPENDIX F: BOX PLOTS OF ALL PARAMETERS

Table F. 1- Pre-and post harvest box plot properties of minerals (mg/L)

Statistic	Unharvested Ca	Harvested Ca	Unharvested Mg	Harvested Mg	Unharvested K	Harvested K
q1	1.290	1.280	0.520	0.638	0.89	0.94
5%	0.202	0.353	0.216	0.370	0.28	0.5775
median	2.340	2.048	0.750	0.873	1.525	1.2575
95%	14.802	11.630	8.900	5.954	6.742	4.2
q3	5.000	3.446	1.480	1.455	2.74	1.99

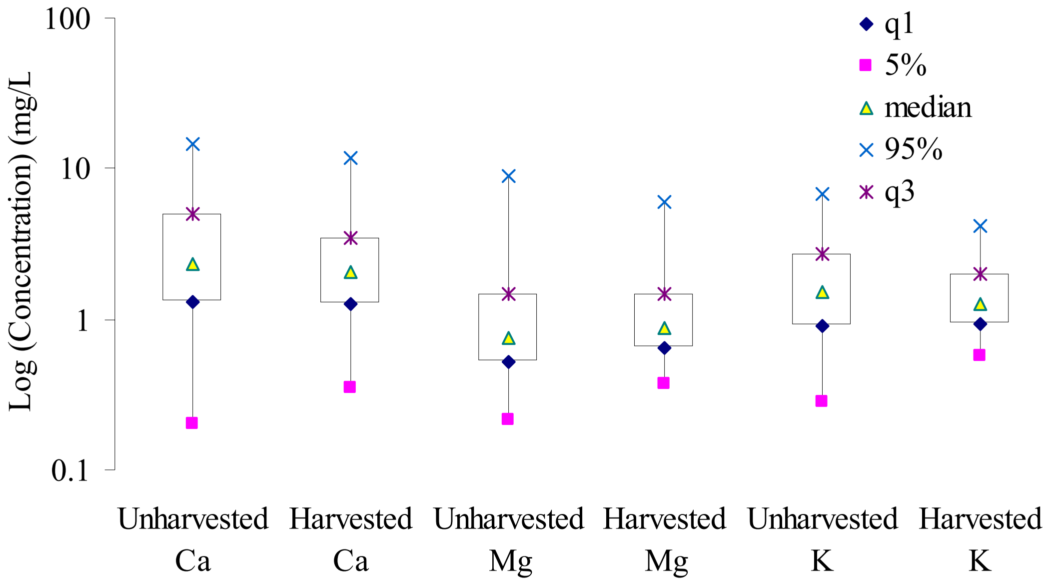


Figure F. 1- Pre-and post harvest box plot for Ca, Mg and K

Table F. 2- Pre-and post harvest box plot properties for total and soluble reactive phosphorous (mg/L)

Statistic	Unharvested TP	Harvested TP	Unharvested SRP	Harvested SRP
q1	0.050	0.053	0.010	0.021
5%	0.010	0.013	0.000	0.007
median	0.150	0.113	0.040	0.040
95%	1.560	2.201	0.801	1.612
q3	0.370	0.334	0.150	0.090

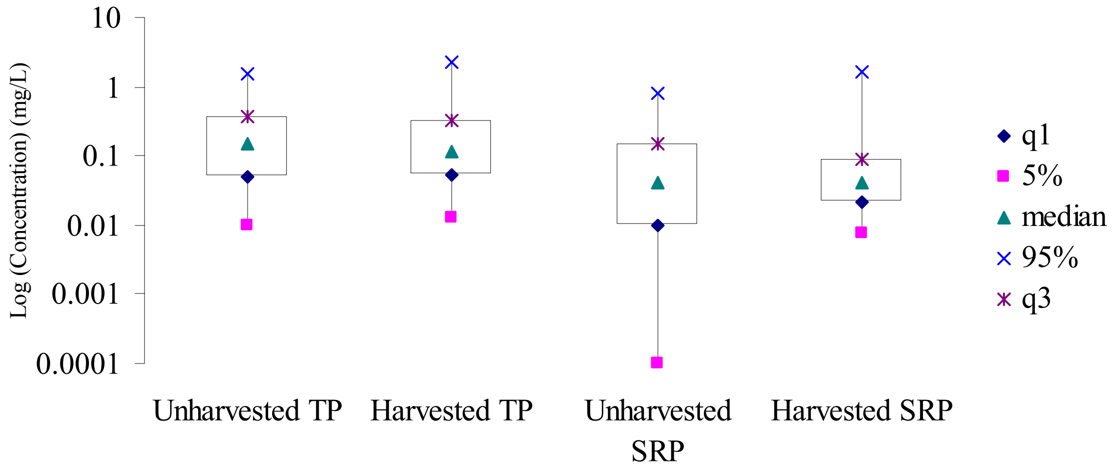


Figure F. 2- Pre-and post harvest box plot for total and soluble reactive phosphorous

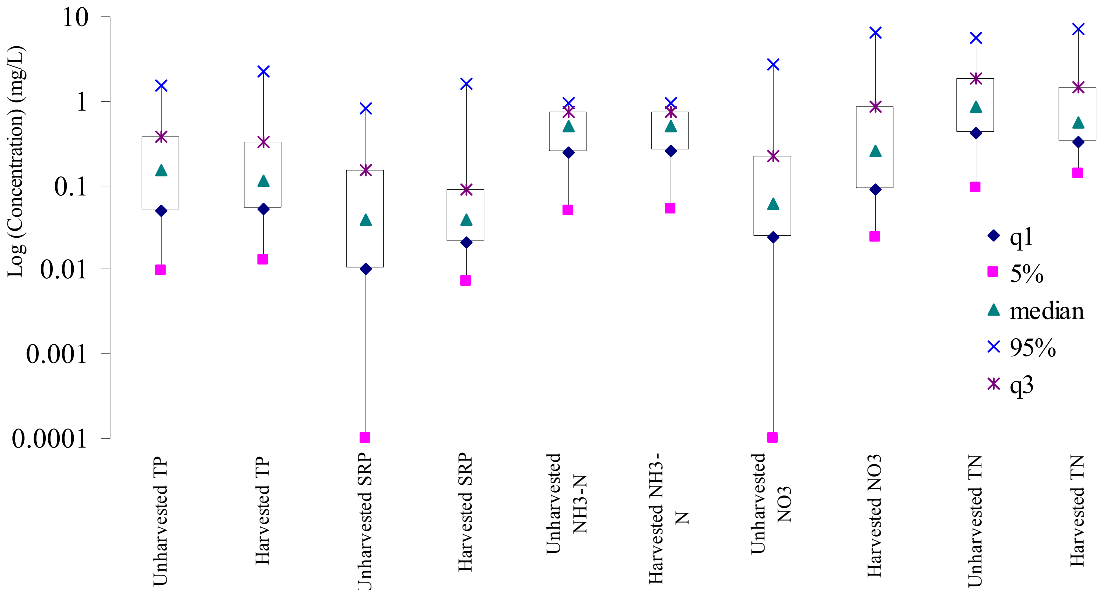


Figure F. 3- Pre-and post harvest box plot of nutrients

Table F. 3- Pre-and post harvest box plot properties of nutrients (mg/L)

Statistic	Unharvested NH3-N	Harvested NH3-N	Unharvested NO3	Harvested NO3	Unharvested TN	Harvested TN
q1	0.040	0.180	0.024	0.090	0.410	0.333
5%	0.000	0.071	0.000	0.024	0.095	0.141
median	0.180	0.198	0.060	0.260	0.865	0.561
95%	1.390	0.607	2.730	6.564	5.553	7.185
q3	0.210	0.207	0.223	0.840	1.890	1.487

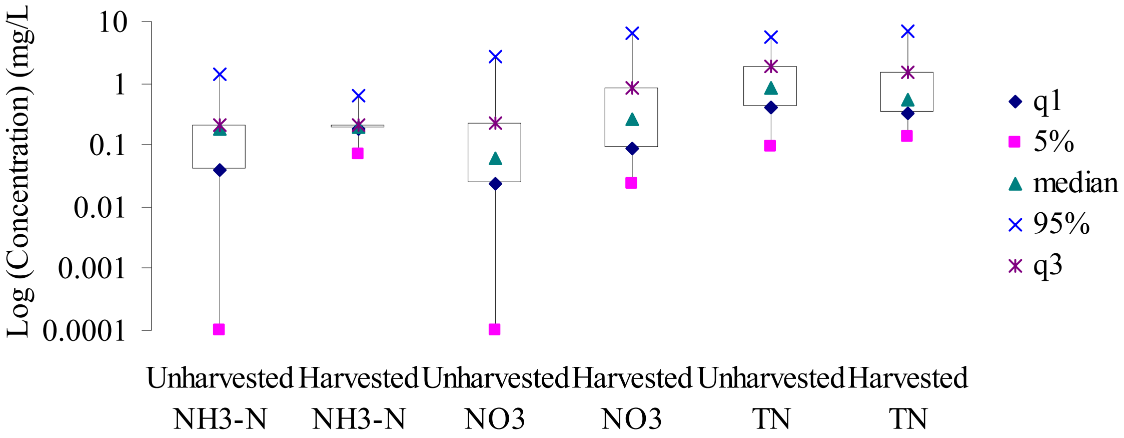


Figure F. 4- Pre-and post harvest box plot for nitrogen minerals

APPENDIX G: DISCRETE ANALYSIS OF HISTOGRAMS

Table G. 1- Percent exceedance of TSS, TVSS, Ca, Mg., K, TP from various concentration intervals from discrete analysis of histograms

Parameter	Concentration Interval	Exceedance	% Exceedance
TSS (g/L)	sum .1-.4 (intersection)	0.097	9.70
	sum 50th% >0.037	0.089	8.93
	sum 75th% >0.092	0.143	14.34
	sum 95th% >0.459	0.054	5.35
	sum .2-.5 (MDC)	0.055	5.47
	sum >.5	0.051	5.10
TVSS (g/L)	sum .05-.5 (intersection)	0.043	4.34
	sum .2-.5 (MDC)	0.044	4.41
	sum >.5	0.040	4.01
	sum 50th% >0.055	0.180	18.05
	sum 75th% >0.192	0.084	8.42
	sum 95th% >0.828	0.033	3.27
Ca (mg/L)	sum 6-16 (intersection)	-0.108	-10.82
	sum 50th% >2.34	-0.060	-5.99
	sum 75th% >5.0	-0.109	-10.86
	sum 95th% >14.8	-0.018	-1.78
	sum EPA >82	-0.001	-0.12
Mg (mg/L)	sum 1-16 (intersection)	0.005	0.52
	sum 50th% >0.75	0.129	12.90
	sum 75th% >1.48	0.023	2.33
	sum 95th% >8.9	-0.027	-2.75
	sum EPA >76	0.000	0.00
K (mg/L)	sum 2-7 (intersection)	0.030	3.03
	sum 50th% >1.525	-0.139	-13.87
	sum 75th% >2.740	-0.130	-12.98
	sum 95th% >6.742	-0.038	-3.84
	sum MDC .1-5	0.005	0.45
	sum MDC >5	-0.067	-6.70
TP (mg/L)	sum .4-1.2 (intersection)	-0.147	-14.67
	sum 50th% >0.15	-0.116	-11.62
	sum 75th% >0.37	-0.138	-13.83
	sum 95th% >1.56	0.027	2.65
	sum MDC >0.5	-0.076	-7.65
	sum >0.5	0.006	0.57

Table G. 2- Percent exceedance of STP, NH3-N, NO3, TN, SPT, ph and EC from various concentration intervals from discrete analysis of histograms

Parameter	Concentration Interval	Exceedance	% Exceedance
SRP (mg/L)	sum .04-.08 (intersection)	0.158	15.82
	sum 50th% >0.04	-0.001	-0.10
	sum 75th% >0.15	-0.065	-6.49
	sum 95th% >0.801	0.019	1.89
	sum EPA >4	0.000	0.00
NH3-N (mg/L)	sum .2-.5 (intersection)	0.340	34.01
	sum 50th% >0.18	0.296	29.64
	sum 75th% >0.21	0.231	23.11
	sum 95th% >1.39	-0.016	-1.62
	sum MDC 0.1-32	0.260	26.01
	>32	0	0.00
NO3- (mg/L)	sum .2-.7 (intersection)	0.229	22.90
	sum 50th% >0.06	0.199	19.90
	sum 75th% >0.223	0.289	28.92
	sum 95th% >2.73	0.060	5.98
	sum MDC 0.02-.06	-0.233	-23.30
	>.06	0.290	29.04
TN (mg/L)	sum 1-4.5 (intersection)	-0.202	-20.21
	sum 50th% >0.865	-0.117	-11.70
	sum 75th% >1.89	-0.053	-5.25
	sum 95th% >5.55	0.024	2.41
	sum EPA >35	0.000	0.00
pH	sum 6.5-9.3 (intersection)	-0.050	-5.04
	sum 50th% >6.350	-0.049	-4.90
	sum 75th% >6.810	-0.072	-7.23
	sum 95th% >7.851	-0.025	-2.52
	sum MDC 6-9	-0.019	-1.90
	sum >9	-0.004	-0.43
EC (µs/cm)	sum 30-60 (intersection)	0.105	10.53
	sum 50th% >28.7	-0.006	-0.58
	sum 75th% >50.75	-0.052	-5.18
	sum 95th% >164.5	-0.031	-3.10
	sum MDC 5-150	0.050	4.96
	sum >150	-0.042	-4.17

Table G. 3- Pre-and post TVSS relative frequencies and differences of concentration

Concentration Interval	*Unharvested relative frequency*	*Harvested relative frequency*	*difference*
0.00	0.06	0.13	0.06
0.03	0.48	0.34	-0.14
0.05	0.24	0.14	-0.10
0.08	0.07	0.09	0.02
0.10	0.04	0.07	0.03
0.13	0.02	0.04	0.02
0.15	0.02	0.04	0.02
0.18	0.01	0.01	0.00
0.20	0.01	0.01	0.00
0.23	0.01	0.02	0.00
0.25	0.01	0.01	0.00
0.28	0.01	0.01	0.00
0.30	0.00	0.01	0.01
0.33	0.00	0.01	0.01
0.35	0.01	0.01	0.00
0.38	0.01	0.00	0.00
0.40	0.00	0.00	0.00
0.43	0.00	0.00	0.00
0.45	0.00	0.01	0.01
0.48	0.00	0.00	0.00
0.50	0.00	0.01	0.01
> .5	0.01	0.05	0.04

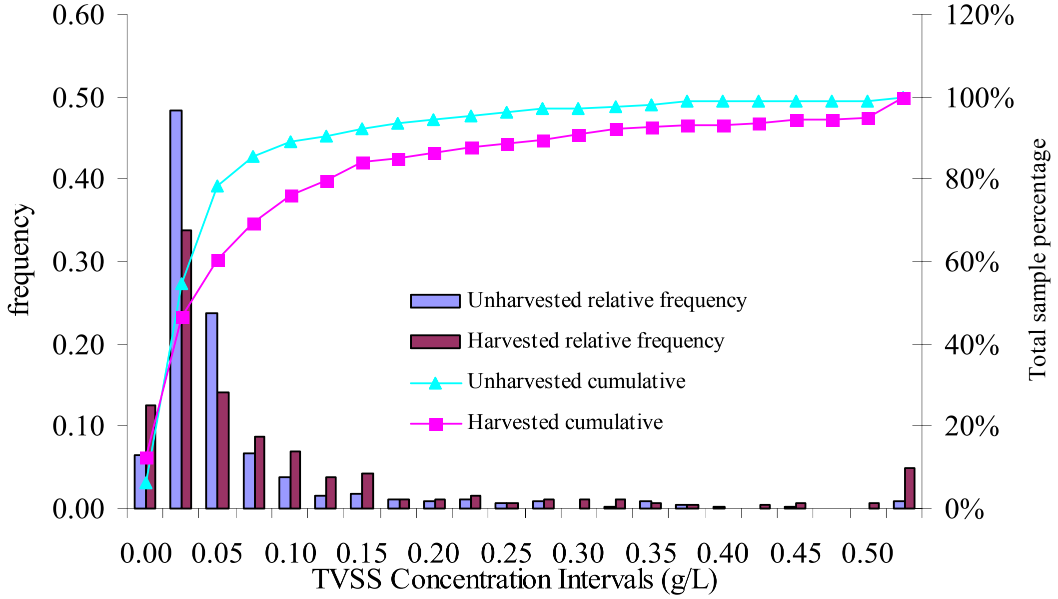


Figure G. 1- Pre-and post-harvest TVSS histograms and cumulative distribution

Table G. 4- Pre-and post Ca relative frequencies and differences of concentration

Concentration Interval	*Unharvested relative frequency*	*Harvested relative frequency*	*difference*
0	0.021	0.030	0.009
2	0.421	0.462	0.041
4	0.253	0.322	0.069
6	0.108	0.068	-0.040
8	0.054	0.017	-0.037
10	0.041	0.030	-0.011
12	0.025	0.021	-0.003
14	0.021	0.013	-0.008
16	0.012	0.004	-0.008
18	0.010	0.013	0.003
20	0.004	0.008	0.005
>20	0.031	0.013	-0.018

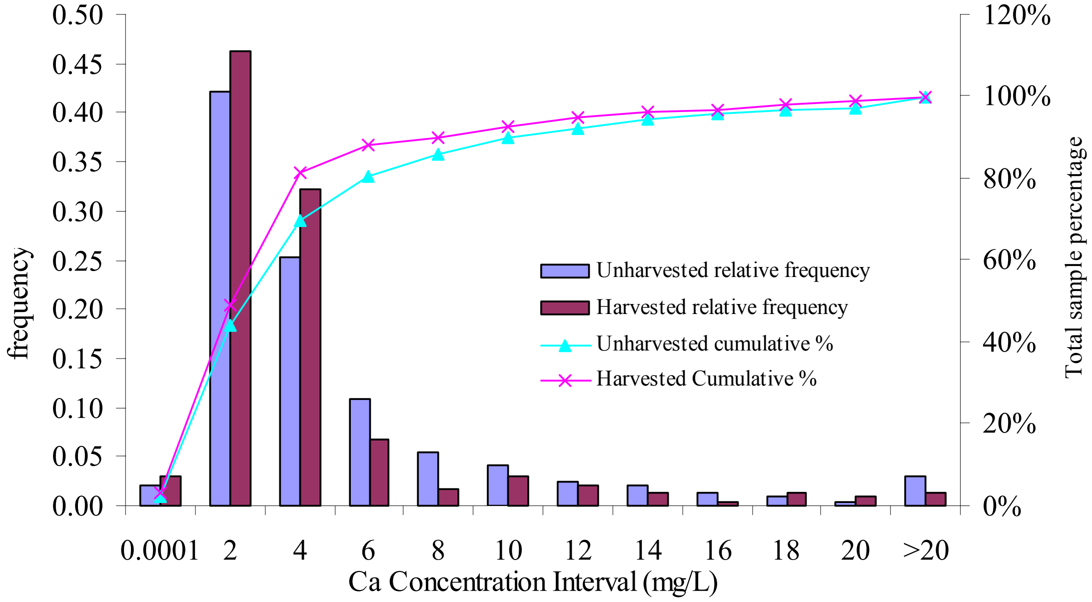


Figure G. 2- Pre-and post-harvest Ca histograms and cumulative distribution

Table G. 5- Pre-and post Mg relative frequencies and differences of concentration

Concentration Interval	*Unharvested relative frequency*	*Harvested relative frequency*	*difference*
0.0001	0.002	0.008	0.006
1	0.632	0.551	-0.081
2	0.173	0.275	0.102
3	0.037	0.059	0.022
4	0.027	0.025	-0.002
5	0.027	0.013	-0.014
6	0.017	0.017	0.000
7	0.014	0.004	-0.009
8	0.014	0.021	0.008
9	0.007	0.000	-0.007
10	0.006	0.004	-0.002
11	0.002	0.000	-0.002
12	0.004	0.004	0.001
13	0.005	0.004	-0.001
14	0.004	0.000	-0.004
15	0.004	0.004	0.001
16	0.005	0.000	-0.005
17	0.001	0.000	-0.001
18	0.001	0.004	0.003
19	0.002	0.000	-0.002
20	0.004	0.000	-0.004
>20	0.011	0.004	-0.007

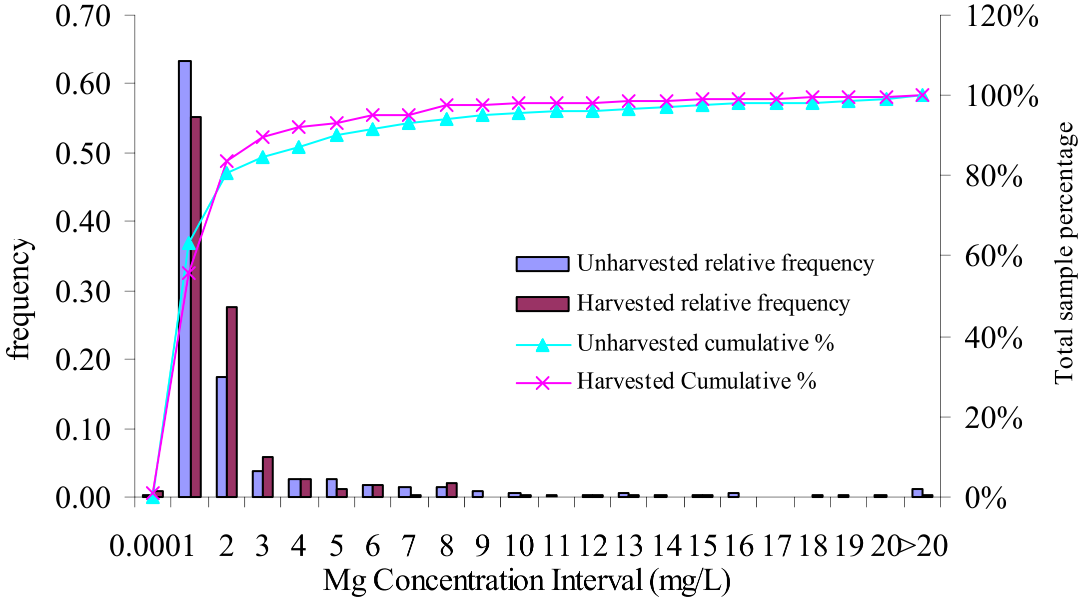


Figure G. 3- Pre-and post-harvest Mg histograms and cumulative distribution

Table G. 6- Pre-and post K relative frequencies and differences of concentration

Concentration Interval	*Unharvested relative frequency*	*Harvested relative frequency*	*difference*
0.0001	0.004	0.013	0.009
1	0.299	0.297	-0.002
2	0.336	0.445	0.109
3	0.141	0.161	0.020
4	0.076	0.021	-0.055
5	0.043	0.030	-0.013
6	0.037	0.008	-0.028
7	0.018	0.017	-0.002
8	0.009	0.004	-0.004
9	0.014	0.000	-0.014
10	0.001	0.000	-0.001
11	0.004	0.000	-0.004
12	0.005	0.000	-0.005
13	0.004	0.000	-0.004
14	0.002	0.000	-0.002
15	0.001	0.000	-0.001
16	0.001	0.000	-0.001
17	0.000	0.000	0.000
18	0.000	0.000	0.000
19	0.001	0.000	-0.001
20	0.000	0.000	0.000
>20	0.004	0.004	0.001

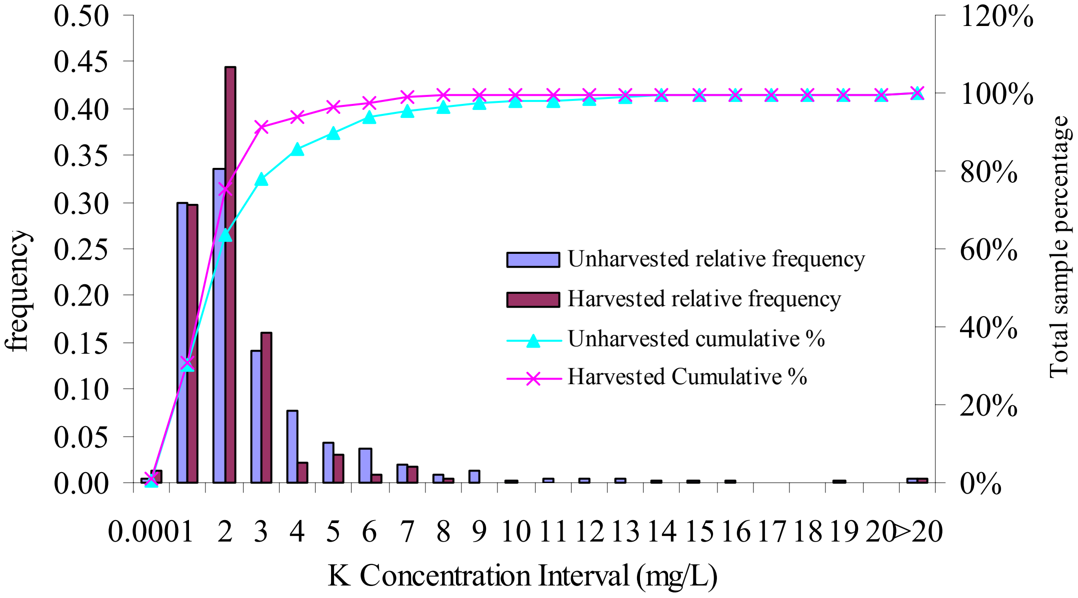


Figure G. 4- Pre-and post-harvest K histograms and cumulative distribution

Table G. 7- Pre-and post TP relative frequencies and differences of concentration

Concentration Interval	*Unharvested relative frequency*	*Harvested relative frequency*	*difference*
0.0001	0.04	0.03	-0.01
0.2	0.54	0.65	0.12
0.4	0.19	0.09	-0.10
0.6	0.06	0.03	-0.04
0.8	0.05	0.04	-0.01
1	0.03	0.02	-0.01
1.2	0.02	0.04	0.02
1.4	0.01	0.01	0.00
1.6	0.01	0.01	0.00
1.8	0.00	0.01	0.01
2	0.01	0.01	0.00
2.2	0.00	0.00	0.00
2.4	0.01	0.01	0.00
2.6	0.00	0.01	0.01
2.8	0.00	0.01	0.01
3	0.00	0.00	0.00
3.2	0.00	0.00	0.00
3.4	0.00	0.00	0.00
3.6	0.00	0.00	0.00
3.8	0.00	0.00	0.00
4	0.00	0.00	0.00
4.2	0.00	0.00	0.00
4.4	0.00	0.01	0.00
4.6	0.00	0.00	0.00
4.8	0.00	0.00	0.00
5	0.00	0.00	0.00
>5	0.01	0.01	0.00

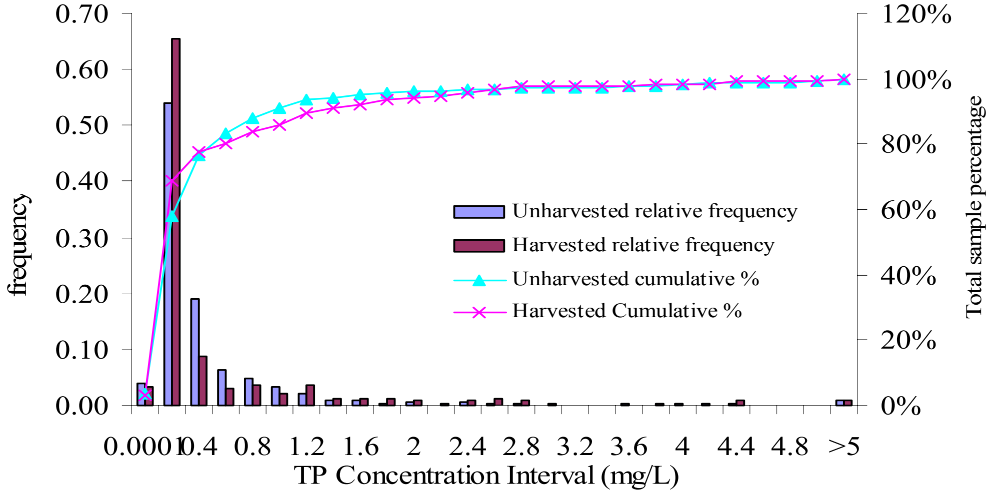


Figure G. 5- Pre-and post-harvest TP histograms and cumulative distribution

Table G. 8- Pre-and post SRP relative frequencies and differences of concentration

Concentration Interval	*Unharvested relative frequency*	*Harvested relative frequency*	*difference*
0.0001	0.092	0.028	-0.064
0.2	0.695	0.809	0.114
0.4	0.095	0.041	-0.054
0.6	0.043	0.037	-0.006
0.8	0.019	0.016	-0.003
1	0.015	0.016	0.002
1.2	0.007	0.000	-0.007
1.4	0.007	0.000	-0.007
1.6	0.005	0.000	-0.005
1.8	0.002	0.000	-0.002
2	0.000	0.008	0.008
2.2	0.000	0.004	0.004
2.4	0.001	0.000	-0.001
2.6	0.000	0.008	0.008
2.8	0.002	0.004	0.002
3	0.002	0.000	-0.002
3.2	0.000	0.000	0.000
3.4	0.001	0.012	0.011
3.6	0.001	0.000	-0.001
3.8	0.000	0.000	0.000
4	0.001	0.004	0.003
4.2	0.000	0.004	0.004
4.4	0.000	0.000	0.000
4.6	0.000	0.004	0.004
4.8	0.000	0.000	0.000
5	0.001	0.000	-0.001
>5	0.002	0.004	0.002

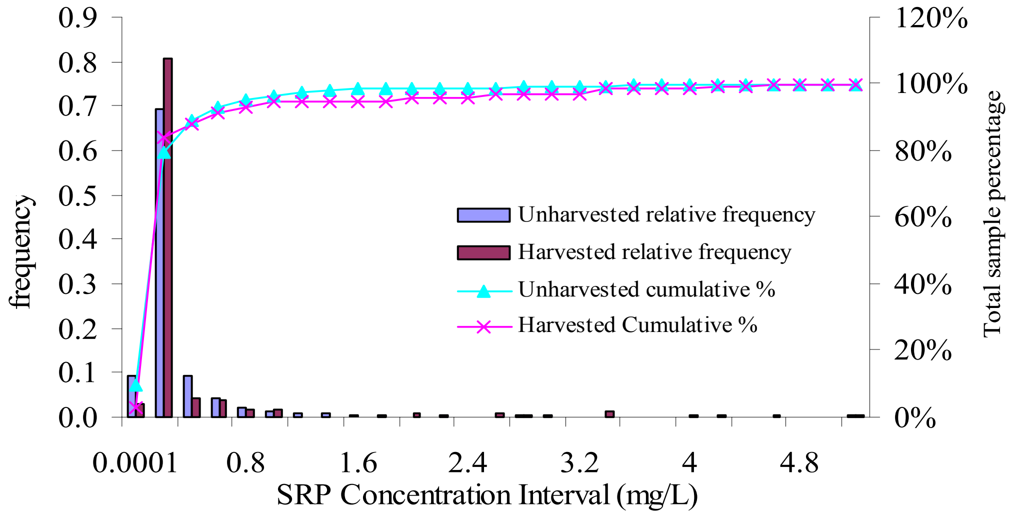


Figure G. 6- Pre-and post-harvest SRP histograms and cumulative distribution

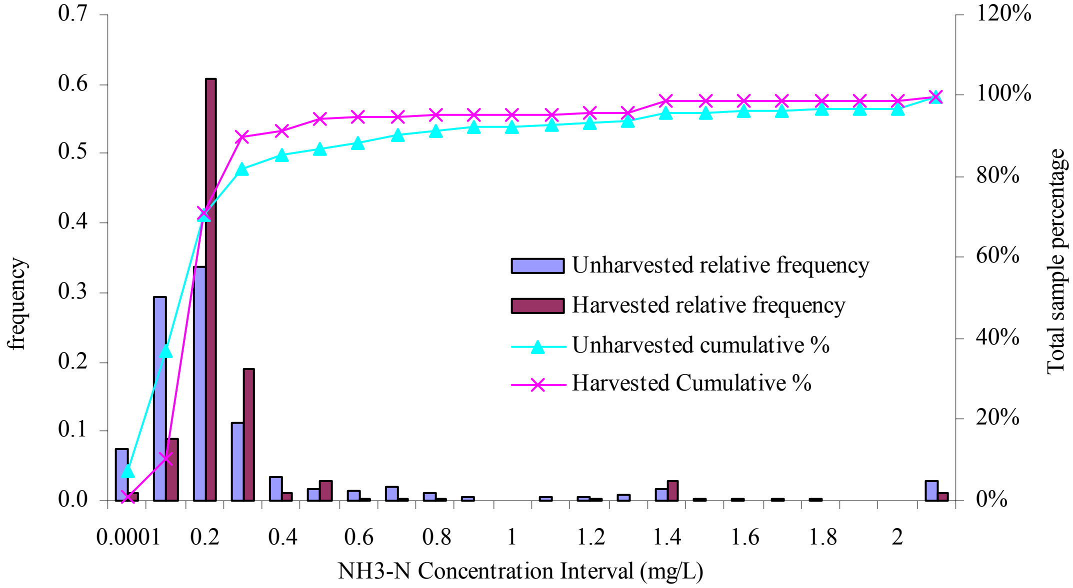


Figure G. 7- Pre-and post-harvest NH_3-N histograms and cumulative distribution

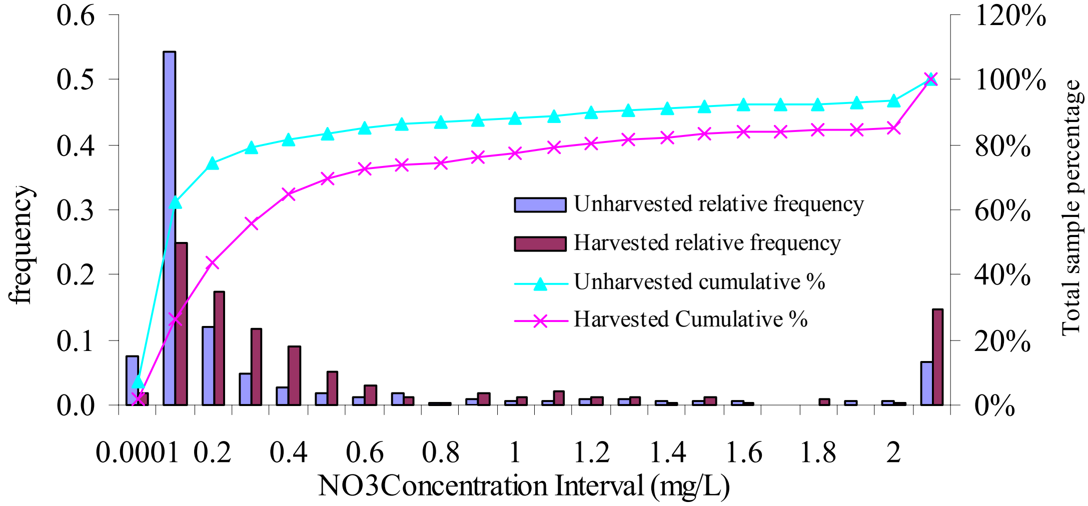


Figure G. 8- Pre-and post-harvest N_O3 histograms and cumulative distribution

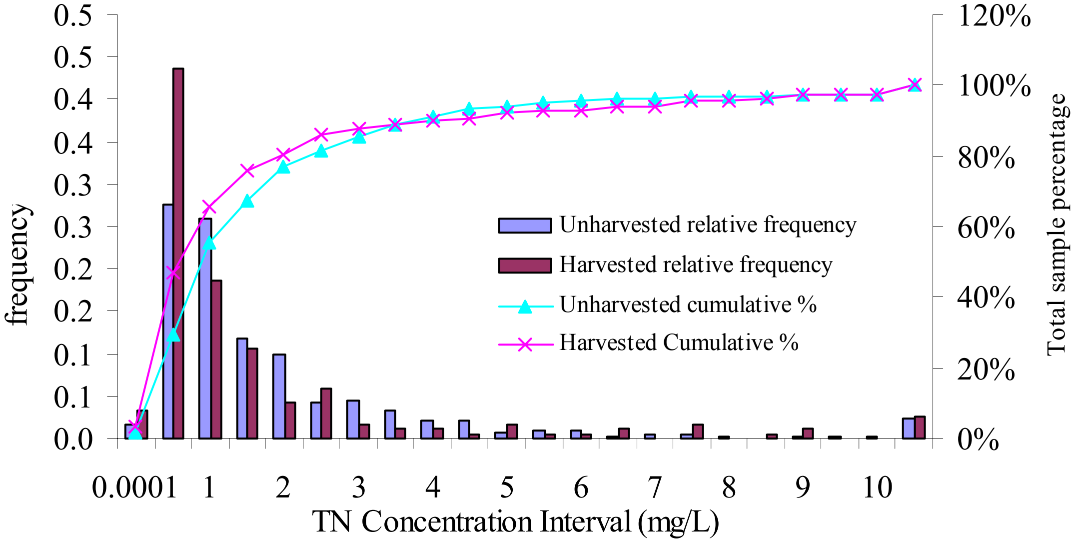


Figure G. 9- Pre-and post-harvest TN histograms and cumulative distribution

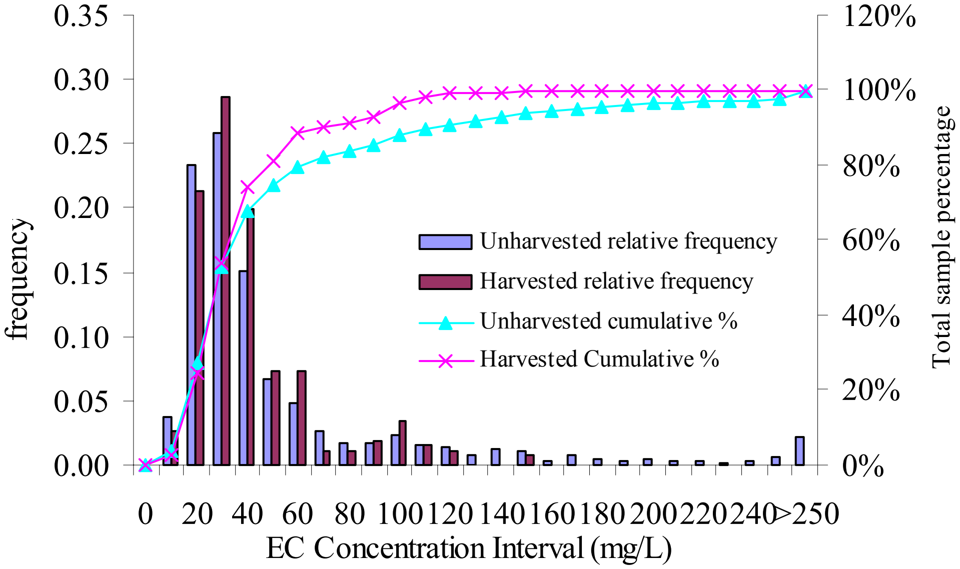


Figure G. 10- Pre-and post-harvest EC histograms and cumulative distribution

APPENDIX H: PROBABILIY OF EXCEEDANCE (PoE)

Table H. 1- An example (TSS) of formulae used to calculate area exceedance (PoE)

Properties	**Pre Harvest**	**Post Harvest**
	TSS	**TSS**
	(g/l)	**(g/l)**
Count, n =	895	253
Mean, μ =	0.129	0.187
Std Dev, σ =	0.381	0.340
c.o.v., δ =	2.96	1.82
Max =	5.38	2.30
Min =	0	0
Xi, ξ =	1.509	1.208
Lambda, λ=	-3.1863	-2.4053

Exceedance = (Cum Area @ x = 2.0 - Cum Area @ x = xintercept)Post Harvest - (Cum Area @ x = 2.0 - Cum Area @ x = xintercept)Pre Harvest

Exceedance =	0.2400
Exceedance (%) =	24.00

24 percent of the post-harvest values can be expected to exceed the pre-harvest values.

$$f_X\left(x\right) = \frac{1}{\zeta x\sqrt{2\pi}} e^{-0.5\left(\frac{\ln x - \lambda}{\zeta}\right)^2}$$

$$\boxed{\zeta = \sqrt{\ln\left(1 + \frac{\sigma^2}{\mu^2}\right)}}$$

$$\lambda = \ln\mu - 0.5\zeta^2$$

Table H. 2- An example (TSS) calculation of Probability of Exceedance (PoE)

Counter	TSS (g/L) After 06	TSS (g/L) Before 06	Ex TSS	LND (cum)	Lognormal Incre	Fc (C)before	Area Incre, before	Area Cum, before	Fc (c)after	Area Incre, after	Area Cum, after	Fc (c)after-Fc(c)before
1	0.11	0.006	0.001	0.03	0.03	17.17	0.02	0.02	2.98	0.00	0.00	-14.19
2	0.002	0.009	0.005	0.11	0.08	22.93	0.09	0.11	9.03	0.04	0.04	-13.90
3	0.014	0.027	0.010	0.19	0.08	18.49	0.09	0.20	9.98	0.05	0.09	-8.51
4	0.025	0.006	0.015	0.26	0.08	14.82	0.07	0.28	9.52	0.05	0.14	-5.30
5	0.081	0.360	0.020	0.33	0.07	12.14	0.06	0.34	8.78	0.04	0.18	-3.36
6	0.178	0.254	0.025	0.39	0.06	10.15	0.05	0.39	8.03	0.04	0.22	-2.12
7	0.073	0.001	0.030	0.44	0.05	8.63	0.04	0.43	7.33	0.04	0.26	-1.30
8	0.042	0.001	0.035	0.49	0.05	7.44	0.04	0.47	6.71	0.03	0.29	-0.74
9	0.007	0.023	0.040	0.53	0.04	6.49	0.03	0.50	6.15	0.03	0.32	-0.34
10	0.031	0.228	0.045	0.57	0.04	5.72	0.03	0.53	5.66	0.03	0.35	-0.06
11	0.135	0.064	0.050	0.60	0.03	5.08	0.03	0.55	5.23	0.03	0.38	0.14
12	0.008	0.011	0.055	0.63	0.03	4.55	0.02	0.58	4.84	0.02	0.40	0.29
13	0.051	0.010	0.060	0.65	0.03	4.10	0.02	0.60	4.50	0.02	0.42	0.40
14	0.254	0.001	0.065	0.68	0.02	3.71	0.02	0.62	4.19	0.02	0.44	0.48
15	0.016	0.002	0.070	0.70	0.02	3.38	0.02	0.63	3.91	0.02	0.46	0.53
16	0.169	0.020	0.075	0.72	0.02	3.08	0.02	0.65	3.66	0.02	0.48	0.57
17	0.032	0.064	0.080	0.74	0.02	2.83	0.01	0.66	3.43	0.02	0.50	0.60
18	0.042	0.048	0.085	0.75	0.02	2.61	0.01	0.67	3.23	0.02	0.51	0.62
19	0.023	0.012	0.090	0.77	0.01	2.41	0.01	0.69	3.04	0.02	0.53	0.63
20	0.256	0.026	0.095	0.78	0.01	2.23	0.01	0.70	2.87	0.01	0.54	0.64
21	0.186	0.002	0.100	0.79	0.01	2.07	0.01	0.71	2.71	0.01	0.56	0.64
22	0.018	0.198	0.105	0.80	0.01	1.93	0.01	0.72	2.57	0.01	0.57	0.63
23	0.082	0.010	0.110	0.81	0.01	1.80	0.01	0.73	2.43	0.01	0.58	0.63
24	0.047	0.020	0.115	0.82	0.01	1.69	0.01	0.74	2.31	0.01	0.59	0.62
25	0.389	0.662	0.120	#NUM!	#NUM!	1.58	0.01	0.74	2.20	0.01	0.61	0.61

Table H. 3- Probability of Exceedance (PoE) for all water quality parameters for all categories

Comparison/Grouping	TSS (g/L)	TVSS (g/L)	Ca (mg/L)	Mg (mg/L)	NO3- (mg/L)	SRP (mg/L)	NH3-N (mg/L)	TN (mg/L)	TP (mg/L)	pH	E. Cond. (µs/cm)	K (mg/L)
All Sites	0.24	0.29	0.00	0.01	0.22	0.08	0.00	0.00	0.00	0.00	0.00	0.00
Harvested Sites (Before vs After 2006)	0.25	0.28	0.16	0.13	0.37	0.11	0.00	0.00	0.00	0.00	0.00	0.01
Angeline CA	0.18	0.18	0.02	0.02	0.00	0.10	0.00	0.00	0.00	0.00	0.00	0.00
Current River CA	0.40	0.50	0.11	0.14	0.32	0.14	0.22	0.00	0.00	0.00	0.00	0.04
Control Sites (Before vs After Dec. 2006)	0.21	0.15	0.11	0.17	0.00	0.28	0.00	0.00	0.00	0.00	0.00	0.00
Harvested vs Control Sites (After Dec. 2006)	0.25	0.13	0.00	0.00	0.12	0.02	0.08	0.06	0.14	0.32	0.00	0.00
Harvest vs Control Sites (Before Dec. 2006)	0.05	0.03	0.00	0.00	0.00	0.00	0.02	0.01	0.00	0.00	0.00	0.00

Table H. 4- Probability of Exceedance (PoE) for all water quality parameters due to timber harvest effects only

Parameters	PoE Harvest Sites (A)	PoE Control Sites (B)	Difference (A)-(B)	% PoE	Remarks
	(Before vs After Dec. 2006) Eliminates geology, soil, aspect as well as size and area of sites but includes precipitation variation and treatments	(Before vs After Dec. 2006) Eliminates harvest effects soil type, geology, slope and aspect as well as size and area of site but Includes leaf on/off and Precipitation	(PoE w/out Background Variation) Eliminates background PoE but includes site differences, aspect and slope, size as well as soil and geology		
TSS (g/L)	0.25	0.21	0.04	4.06	Very Low
TVSS (g/L)	0.28	0.15	0.13	13.20	Low
Ca (mg/L)	0.16	0.11	0.05	5.49	Very Low
Mg (mg/L)	0.13	0.17	-0.04	-3.70	No effect
NO3-(mg/L)	0.37	0.28	0.09	9.21	Low
SRP (mg/L)	0.11	0.00	0.11	11.49	Low
NH3-N (mg/L)	0.00	0.00	0.00	0.00	No effect
TN (mg/L)	0.00	0.00	0.00	0.00	No effect
TP (mg/L)	0.00	0.00	0.00	0.00	No effect
pH	0.00	0.00	0.00	0.00	No effect
Cond. (µs/cm)	0.00	0.00	0.00	0.00	No effect
K (mg/L)	0.01	0.00	0.01	0.65	Very Low

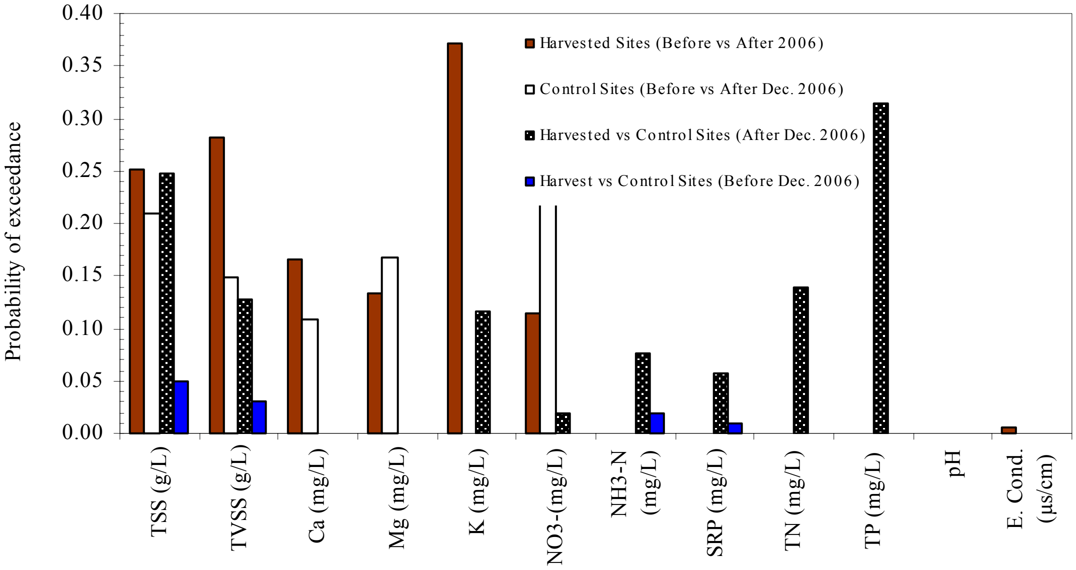


Figure H. 1- Probability of Exceedance (PoE) for all water quality parameters inclusive precipitation, leaf on/off as well as harvesting effects

APPENDIX I: TIME VARIATION OF CONCENTRATION

Table I. 1- Normal and lognormal properties of timber harvest water quality parameters

Parameter	Property	Unharvested	Harvested	Parameter	Property	Unharvested	Harvested
TVSS	normal mean	0.05	0.12	NH3-N	normal mean	0.39	0.40
	normal std deviation	0.16	0.28		normal std. deviation	1.35	1.53
	lognormal mean	-4.13	-4.04		lognormal mean	-2.50	-1.70
	lognormal std deviation	1.82	2.54		lognormal std. deviation	2.33	1.12
Ca	normal mean	4.51	3.42	NO3	normal mean	0.55	1.42
	normal std deviation	7.03	4.63		normal std. deviation	1.65	4.56
	lognormal mean	0.70	0.49		lognormal mean	-2.82	-1.41
	lognormal std deviation	1.83	1.94		lognormal std. deviation	2.45	2.02
Mg	normal mean	2.06	1.67	TN	normal mean	0.00	0.00
	normal std deviation	3.82	2.56		normal std. deviation	0.00	0.00
	lognormal mean	-0.09	-0.04		lognormal mean	0.00	0.00
	lognormal std deviation	1.27	1.24		lognormal std. deviation	0.00	0.00
K	normal mean	2.32	1.78	pH	normal mean	6.49	6.42
	normal std deviation	2.71	2.57		normal std. deviation	0.71	0.63
	lognormal mean	0.37	0.21		lognormal mean	1.87	1.85
	lognormal std deviation	1.14	1.24		lognormal std. deviation	0.10	0.09
TP	normal mean	0.44	0.43	EC	normal mean	50.92	41.40
	normal std. deviation	1.12	0.85		normal std. deviation	64.19	50.43
	lognormal mean	-2.13	-2.15		lognormal mean	3.44	3.45
	lognormal std. deviation	2.00	1.92		lognormal std. deviation	1.23	0.66
SRP	normal mean	0.19	0.28				
	normal std. deviation	0.54	0.86				
	lognormal mean	-3.40	-3.05				
	lognormal std. deviation	2.35	1.85				

Table I. 2- Pre-harvest mean, max and min concentration for water quality parameters with sample data

Parameters	Properties	Oct '04	Dec '04	Jan '05	Jan '05	Feb '05	Apr '05	May '05	Jun '05	Jul '05	Aug '05	Sep '05	Nov '05
TSS (g/L)	Max	0.11	0.11	0.18	0.52	1.14	0.55	0.32	0.93	0.05	0.26	0.29	0.98
	Min	0.05	0.002	0.01	0.01	0.02	0.00	0.00	0.01	0.00	0.00	0.00	0.00
	Mean	0.077	0.04	0.05	0.08	0.26	0.13	0.04	0.15	0.01	0.05	0.07	0.09
TVSS (g/L)	Max								0.36	0.02	0.20	0.17	0.26
	Min								0.00	0.00	0.00	0.00	0.00
	Mean								0.06	0.01	0.02	0.03	0.04
Ca (mg/L)	Max	9.30	17.70	10.50	12.00	11.40	9.90	14.00			10.23	12.62	19.65
	Min	7.60	0.50	0.10	0.40	0.80	2.90	1.30			0.71	1.01	0.04
	Mean	8.47	4.12	2.50	2.24	4.00	5.19	6.03			3.46	4.21	3.27
Mg (mg/L)	Max	0.90	6.20	13.20	9.20	4.20	15.20	28.00			4.41	6.32	9.83
	Min	0.40	0.20	0.10	0.20	0.20	0.50	0.70			0.18	0.22	0.01
	Mean	0.73	1.70	2.20	1.38	1.48	2.99	3.75			0.81	1.03	1.38
K (mg/L)	Max	3.46	6.41	3.97	8.67	0.50	2.00	15.98			11.39	18.10	6.08
	Min	3.19	0.41	0.00	0.03	0.04	0.28	0.47			0.42	0.93	0.02
	Mean	3.31	1.70	0.69	0.85	0.32	1.13	6.55			2.62	4.03	1.85
TP (mg/L)	Max	0.45	0.61	0.57	1.56	0.73	2.22	1.61			3.35	0.90	1.42
	Min	0.01	0.01	0.01	0.01	0.02	0.05	0.03			0.05	0.05	0.01
	Mean	0.16	0.13	0.08	0.20	0.27	0.64	0.56			0.41	0.30	0.24
SRP (mg/L)	Max	0.45	0.04	0.30	1.37	0.21	0.82	1.21			1.76	1.49	1.19
	Min	0.01	0.00	0.00	0.00	0.00	0.00	0.01			0.01	0.02	0.00
	Mean	0.16	0.02	0.04	0.07	0.03	0.18	0.38			0.22	0.26	0.13
NH3-N (mg/L)	Max	1.02	0.17	0.29	1.55	0.59	1.23	3.59			2.17	2.07	1.41
	Min	0.00	0.02	0.00	0.00	0.01	0.00	0.00			0.00	0.00	0.00
	Mean	0.35	0.06	0.03	0.08	0.13	0.14	0.82			0.28	0.37	0.12
NO3 (mg/L)	Max	0.08	0.04	2.13	2.33	1.85	1.42	0.97			3.70	1.38	0.68
	Min	0.05	0.02	0.00	0.00	0.00	0.00	0.00			0.00	0.02	0.00
	Mean	0.07	0.03	0.13	0.10	0.12	0.16	0.10			0.29	0.47	0.04
TN (mg/L)	Max	1.10	2.98	3.87	6.50	2.93	3.35	10.04			7.71	3.74	7.79
	Min	0.75	0.04	0.04	0.02	0.06	0.14	0.12			0.13	0.45	0.14
	Mean	0.96	1.19	0.58	1.02	0.59	1.01	2.46			2.15	1.69	1.45
pH	Max	6.56	8.00	7.85	8.93	8.52	9.21	8.31			6.70	6.88	9.49
	Min	6.12	6.32	5.47	5.43	5.61	5.76	6.07			5.33	5.85	4.90
	Mean	6.37	7.23	7.00	6.70	7.03	7.03	6.73			6.03	6.41	6.47
EC (µs/cm)	Max	70.80	244.00	236.00	127.30	196.10	223.00	432.00			103.50	57.60	169.90
	Min	49.80	12.11	4.16	5.78	4.22	11.07	23.00			10.42	6.48	14.74
	Mean	57.68	76.75	46.41	32.51	57.52	70.45	113.51			29.88	22.94	38.87

Table I. 3- Pre-harvest mean, max and min concentration for water quality parameters with sample data

Parameters	Properties	Mar '06	May '06	Jul '06	Oct '06	Nov '06	Dec '06	Dec '06	Jan '07	Mar '07	May '07	Sep '07	Mar '08	Mar '08
TSS (g/L)	Max	1.94	3.04	0.79	4.80	1.83	1.40	0.87	0.46	0.66	5.38	0.03	0.23	1.58
	Min	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
	Mean	0.11	0.16	0.12	0.23	0.15	0.10	0.12	0.08	0.07	0.39	0.01	0.09	0.29
TVSS (g/L)	Max	1.77	0.33	0.68	0.37	0.34	0.26	0.24	0.33	0.15	0.58	0.01	0.21	3.33
	Min	0.00	0.02	0.00	0.03	0.00	0.00	0.02	0.00	0.00	0.00	0.00	0.01	0.00
	Mean	0.04	0.05	0.06	0.09	0.06	0.04	0.07	0.06	0.02	0.04	0.01	0.06	0.26
Ca (mg/L)	Max	22.15	89.84	21.32	21.57	29.87	21.46	4.72	5.45	36.84	58.18	4.12	16.43	37.53
	Min	0.06	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	1.65	1.09	0.70
	Mean	3.67	5.44	4.37	3.75	5.05	4.67	1.96	1.59	5.00	10.65	3.21	5.49	8.06
Mg (mg/L)	Max	12.69	18.45	23.34	13.82	6.99	28.67	2.00	3.17	23.52	33.85	1.63	8.82	21.00
	Min	0.01	0.05	0.00	0.07	0.04	0.09	0.08	0.15	0.00	0.45	0.67	0.45	0.23
	Mean	1.57	2.02	3.22	1.48	1.41	2.68	0.71	0.85	3.19	5.57	1.27	2.28	3.59
K (mg/L)	Max	21.78	26.77	8.69	30.14	11.87	8.71	7.61	3.05	2.02	3.16	3.76	3.62	4.74
	Min	0.33	0.19	0.00	0.69	1.35	0.18	0.52	0.17	0.00	0.03	1.68	0.71	0.64
	Mean	2.00	2.33	2.78	5.53	5.69	2.52	2.60	1.29	0.97	1.13	2.29	1.62	1.72
TP (mg/L)	Max	1.56	6.51	2.43	19.60	0.29	6.43	4.05	1.30	0.80	11.77	0.57	1.67	3.58
	Min	0.00	0.00	0.01	0.25	0.16	0.00	0.03	0.05	0.00	0.00	0.13	0.07	0.02
	Mean	0.10	0.39	0.65	2.94	0.28	0.35	0.64	0.23	0.08	1.25	0.34	0.35	0.37
SRP (mg/L)	Max	2.76	7.46	1.34	5.00	2.60	6.53	1.15	0.59	0.81	0.04	0.52	1.40	3.30
	Min	0.00	0.00	0.00	0.00	0.02	0.00	0.00	0.00	0.00	0.01	0.06	0.03	0.06
	Mean	0.12	0.25	0.32	0.47	0.33	0.35	0.14	0.08	0.06	0.01	0.32	0.28	0.35
NH3-N (mg/L)	Max	22.86	7.08	0.22	1.08	0.21	1.41	17.07	1.39	1.76	0.20	0.39	0.21	0.21
	Min	0.08	0.00	0.00	0.01	0.06	0.01	0.00	0.03	0.00	0.01	0.08	0.18	0.18
	Mean	1.11	0.38	0.12	0.21	0.19	0.63	1.58	0.28	0.24	0.18	0.15	0.20	0.20
NO3 (mg/L)	Max	8.78	13.47	0.92	11.24	3.83	8.50	15.40	0.69	5.08	0.05	0.20	3.27	14.09
	Min	0.00	0.00	0.03	0.02	0.01	0.00	0.04	0.06	0.00	0.02	0.08	0.07	0.10
	Mean	0.53	0.76	0.25	1.61	0.87	0.42	1.38	0.12	0.35	0.03	0.13	0.41	3.21
TN (mg/L)	Max	15.42	7.15	1.43	16.11	13.53	19.36	16.74	20.95	7.23	0.92	0.53	7.34	0.70
	Min	0.02	0.02	0.11	0.98	0.59	0.27	0.20	0.24	0.22	0.16	0.23	0.15	0.00
	Mean	3.64	0.87	0.51	6.28	2.93	2.15	2.73	4.35	1.15	0.56	0.38	1.23	0.25
pH	Max	8.28	9.35	8.82	7.59	7.32	9.12	6.45	8.94	8.25	7.50	6.80	7.51	9.05
	Min	5.27	4.78	5.51	5.58	5.99	5.47	5.32	5.48	5.10	5.52	5.80	5.77	5.38
	Mean	6.41	6.38	6.57	6.28	6.50	6.89	5.98	6.70	6.16	6.58	6.48	6.42	6.58
EC (µs/cm)	Max	247.00	300.00	243.00	216.00	155.80	335.00	105.20	72.80	394.00	670.00	75.60	33.30	328.00
	Min	8.71	8.48	19.20	13.67	11.86	11.21	11.38	5.50	5.19	18.19	23.00	0.00	13.00
	Mean	46.08	43.73	74.51	57.06	51.65	59.43	31.51	27.61	54.11	122.69	38.56	5.20	71.16

Table I. 4- Post-harvest mean, max and min concentration for water quality parameters with sample data

Parameters	Properties	Dec '06	Jan '07	Mar '07	May '07	Jun '07	Jul '07	Sep '07	Mar '08	Mar '08	Apr '08	Apr '08	Jun '08	Jul '08
TSS (g/L)	Max	0.61	0.35	1.44	0.55	0.61	1.04	1.12	1.27	0.31	1.77	2.10	0.45	0.58
	Min	0.00	0.00	0.00	0.00	0.01	0.01	0.00	0.02	0.00	0.00	0.00	0.00	0.05
	Mean	0.11	0.06	0.15	0.06	0.108	0.15	0.25	0.29	0.15	0.32	0.29	0.08	0.25
TVSS (g/L)	Max	0.27	0.06	0.11	0.06	0.27	0.35	0.21	1.26	1.22	1.58	2.02	0.43	0.41
	Min	0.00	0.00	0.00	0.00	0.00	0.03	0.00	0.00	0.01	0.00	0.00	0.00	0.07
	Mean	0.04	0.02	0.02	0.01	0.052	0.10	0.07	0.14	0.12	0.29	0.28	0.07	0.17
Ca (mg/L)	Max	1.19	34.99	16.14	12.73		3.58	6.35	33.57	24.74	6.90	10.94	19.38	10.88
	Min	0.00	0.00	0.52	0.00		0.06	1.87	1.07	0.00	0.27	0.27	0.43	2.25
	Mean	0.54	5.87	3.99	3.10		1.11	3.90	4.23	3.94	2.19	2.56	5.08	4.61
Mg (mg/L)	Max	1.00	4.22	17.32	7.96		1.06	1.86	20.43	14.89	4.21	5.76	12.75	7.23
	Min	0.10	0.03	0.58	0.01		0.22	0.64	0.38	0.00	0.37	0.44	0.26	1.00
	Mean	0.51	1.55	2.85	2.08		0.57	1.23	1.97	1.83	0.99	1.25	2.22	2.38
K (mg/L)	Max	4.13	36.70	2.74	1.99		3.20	6.57	6.43	7.14	6.52	3.13	3.12	4.41
	Min	0.21	0.21	0.29	0.00		0.68	1.12	0.49	0.00	0.93	0.79	0.75	1.45
	Mean	1.25	4.47	1.01	0.96		1.63	4.21	1.46	1.80	1.97	1.63	1.70	2.60
TP (mg/L)	Max	2.79	0.94	0.58	4.38		2.31	2.46	5.40	5.77	0.99	2.92	2.10	2.41
	Min	0.01	0.04	0.01	0.02		0.05	0.09	0.00	0.02	0.04	0.00	0.02	0.13
	Mean	0.28	0.30	0.10	0.28		0.48	0.57	0.51	0.58	0.17	0.96	0.21	0.72
SRP (mg/L)	Max	3.34	0.36	0.58	0.02		0.52	2.68	4.56	3.82	0.53	8.54	1.96	2.07
	Min	0.00	0.00	0.00	0.01		0.03	0.05	0.03	0.03	0.03	0.00	0.02	0.07
	Mean	0.32	0.07	0.07	0.01		0.08	0.59	0.39	0.39	0.10	0.68	0.15	0.58
NH3-N (mg/L)	Max	1.39	0.17	0.75	0.20		16.46	0.41	0.21	0.21	0.20	0.20	0.21	0.41
	Min	0.19	0.02	0.04	0.12		0.21	0.08	0.00	0.00	0.00	0.08	0.02	0.08
	Mean	1.02	0.10	0.23	0.19		3.28	0.16	0.18	0.19	0.18	0.18	0.20	0.16
NO3 (mg/L)	Max	5.31	0.38	1.28	0.03		0.23	2.24	25.64	6.74	7.89	55.69	9.03	
	Min	0.00	0.07	0.01	0.02		0.00	0.12	0.07	0.07	0.09	0.00	0.12	
	Mean	0.56	0.18	0.16	0.02		0.16	1.03	2.02	0.73	1.71	4.04	1.34	
TN (mg/L)	Max	19.00	2.04	6.10	0.58		10.67	0.62	11.53		15.00		0.36	0.43
	Min	0.31	0.24	0.20	0.00		0.23	0.11	0.10		0.95		0.00	0.00
	Mean	2.73	1.06	1.63	0.39		1.67	0.35	1.93		4.67		0.29	0.29
pH	Max	7.20	9.13	8.50	7.19	7.20	7.77	7.20	7.40	7.24	7.70	7.10	9.80	7.18
	Min	5.56	5.75	5.47	5.69	5.56	5.32	5.90	5.20	5.52	5.40	5.70	5.70	6.00
	Mean	6.16	7.29	6.76	6.51	6.335	6.03	6.51	6.31	6.20	6.16	6.38	6.63	6.33
EC (µs/cm)	Max	100.30	604.00	145.20	83.40	100.30	41.90	118.10	352.00	247.00	80.60	102.50	177.50	118.40
	Min	6.10	4.38	16.25	19.00	6.10	9.74	28.50	16.00	18.00	14.20	13.00	12.65	27.80
	Mean	35.18	80.58	44.44	39.00	46.840	20.93	49.57	43.78	49.10	29.38	30.64	47.01	54.78

Table I. 5- Slope and R2 for all water quality parameter for both pre-and post-harvest samples

Parameter	Property	Unharvested	Harvested	Year 2007	Year 2008
TSS	R²	0.1027	0.3249	0.4498	0.0674
	Slope (m)	0.0039	0.0138	0.0205	-0.0132
TVSS	R²	0.1639	0.5147	0.4151	0.0000008
	Slope (m)	0.0042	0.0172	0.0097	0.00004
Ca	R²	0.0316	0.0642	0.0018	0.0694
	Slope (m)	0.0561	0.1114	0.0453	0.1625
Mg	R²	0.0989	0.0625	0.00002	0.1171
	Slope (m)	0.0561	0.0509	-0.0023	0.1
K	R²	0.0002	0.0011	0.0417	0.4576
	Slope (m)	-0.0031	-0.0105	0.1782	0.1448
TP	R²	0.0391	0.2369	0.4924	0.0177
	Slope (m)	0.0174	0.0342	0.0626	0.0215
SRP	R²	0.1144	0.229	0.1013	0.0363
	Slope (m)	0.0067	0.0316	0.0384	0.0232
NH3-N	R²	0.0167	0.0636	0.0488	0.0424
	Slope (m)	0.007	-0.0634	0.1474	-0.0014
NO3	R²	0.2162	0.4782	0.0929	0.0595
	Slope (m)	0.0496	0.2476	0.0618	0.1931
TN	R²	0.0108	0.0135	0.4487	0.338
	Slope (m)	0.0225	-0.0535	-0.3236	-0.9292
pH	R²	0.1705	0.1107	0.1216	0.2577
	Slope (m)	-0.0195	-0.0268	-0.0677	0.0454
EC	R²	0.007	0.0246	0.097	0.0674
	Slope (m)	-0.3341	-0.5876	-2.6332	1.4277

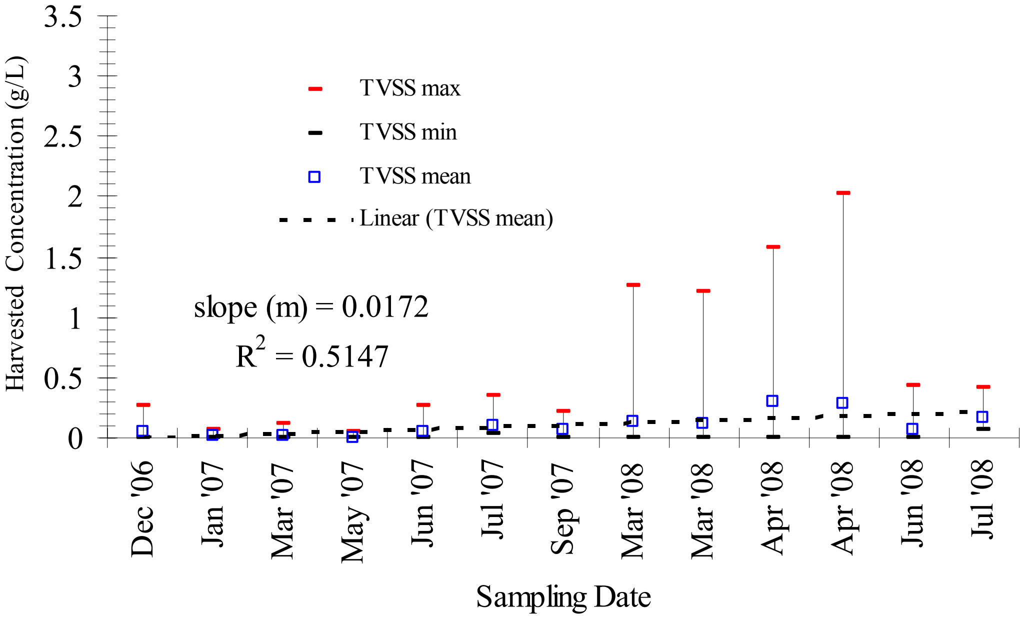


Figure I. 1- Post harvest TVSS mean, max , min and linear fit for year 2007 and 2008

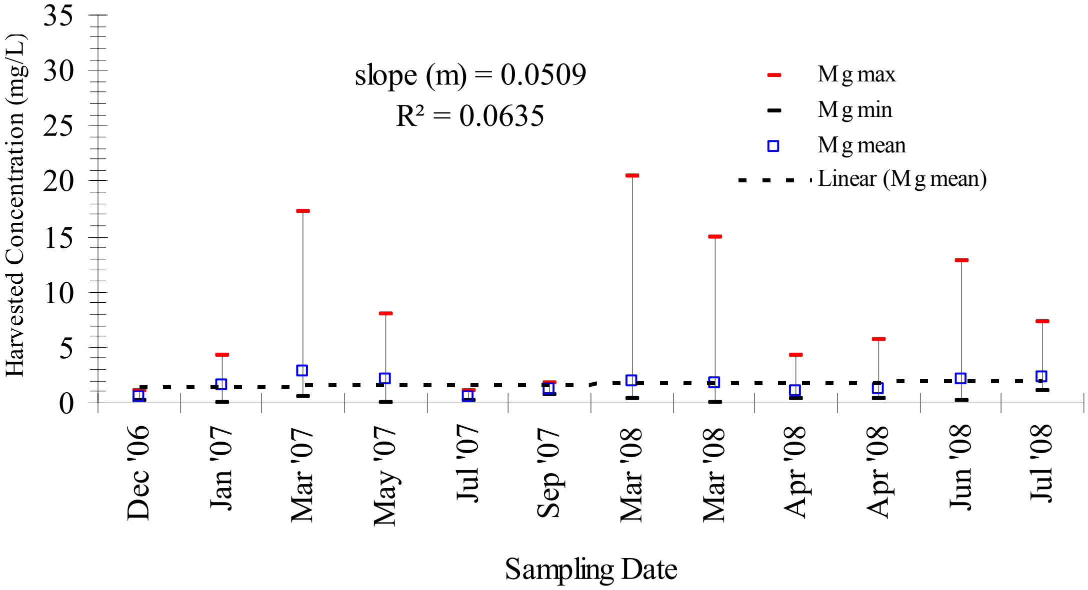


Figure I. 2- Post harvest Mg mean, max , min and linear fit for year 2007 and 2008

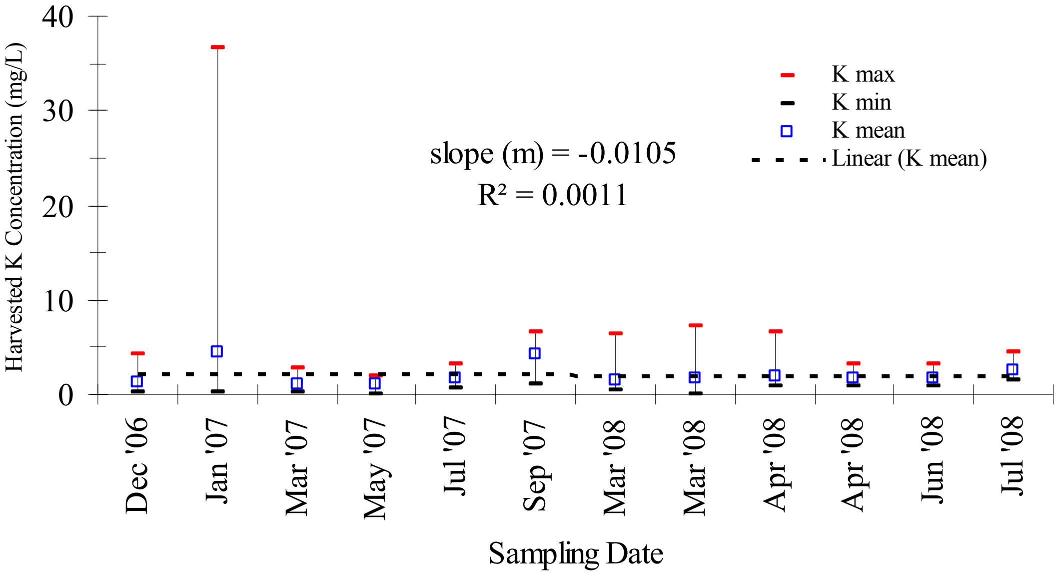


Figure I. 3- Post harvest K mean, max , min and linear fit for year 2007 and 2008

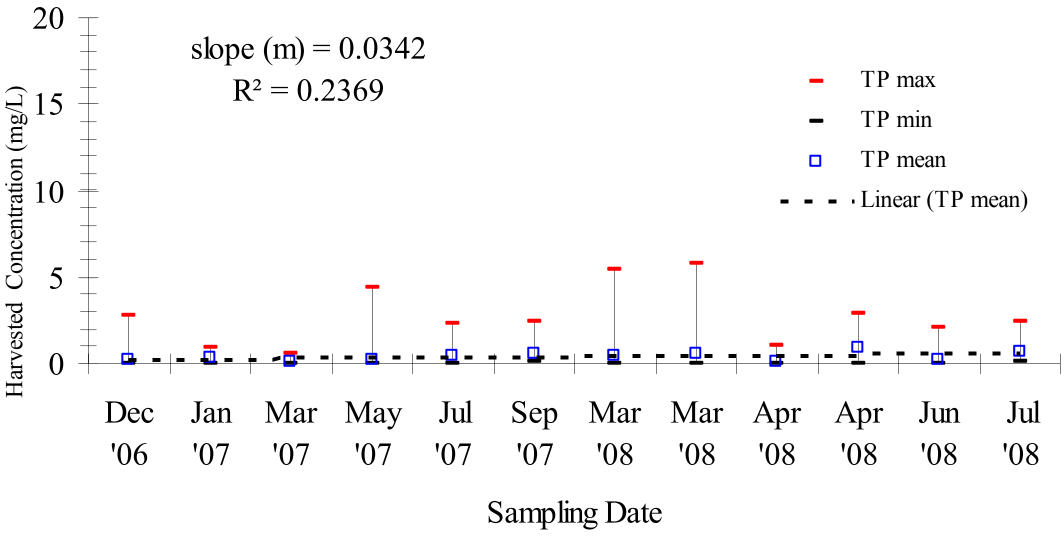


Figure I. 4- Post harvest TP mean, max , min and linear fit for year 2007 and 2008

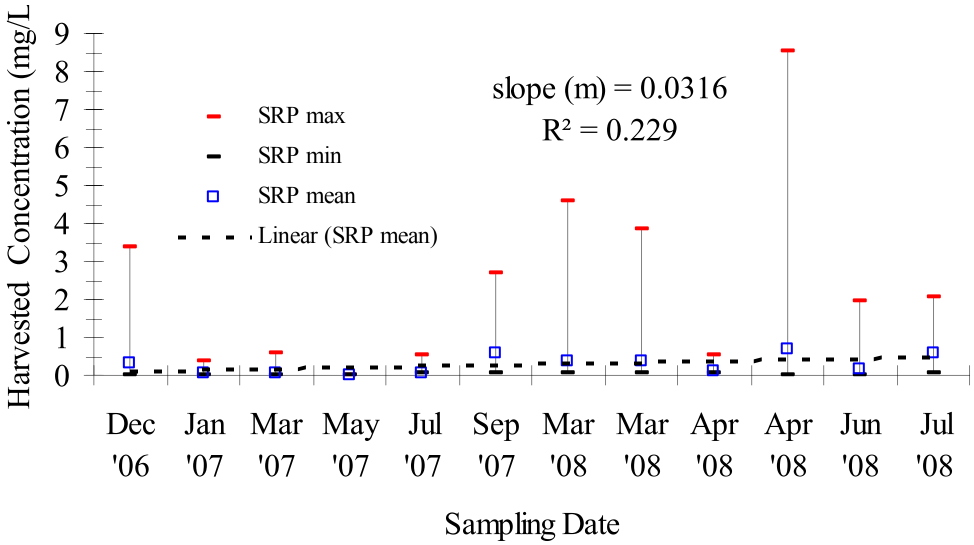


Figure I. 5- Post harvest SRP mean, max , min and linear fit for year 2007 and 2008

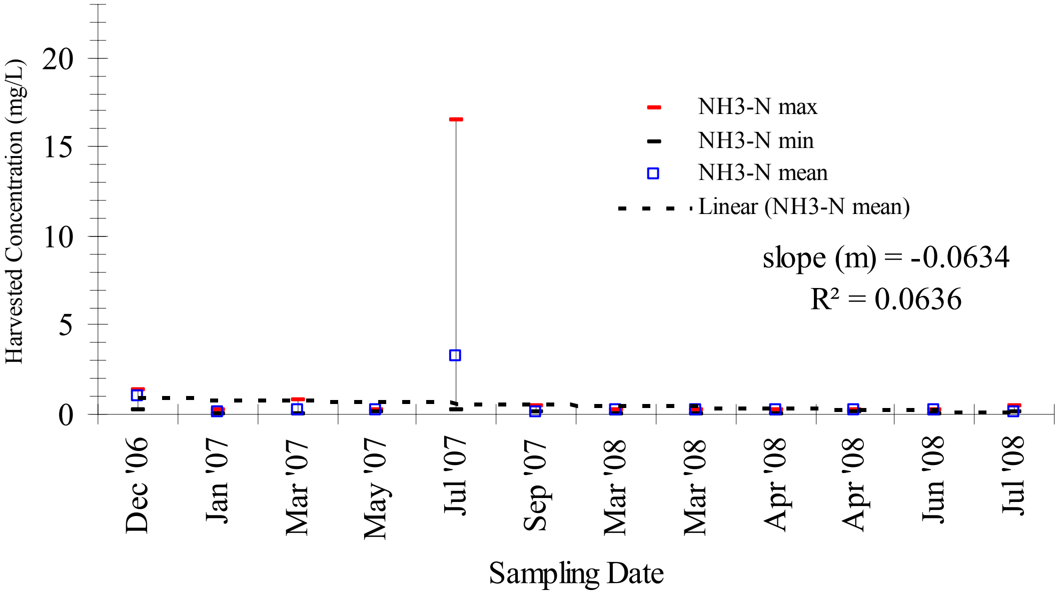


Figure I. 6- Post harvest NH_3-N mean, max , min and linear fit for year 2007 and 2008

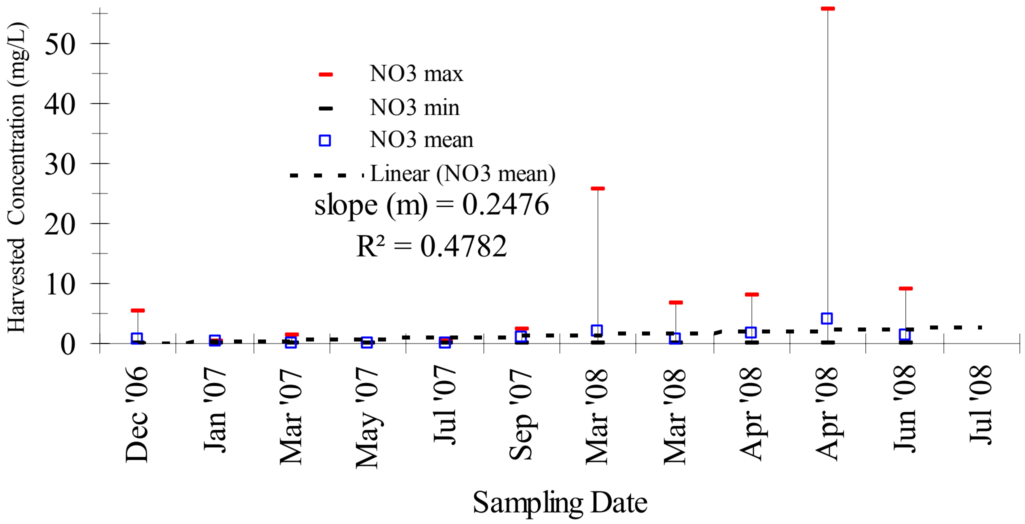


Figure I. 7- Post harvest NO_3 mean, max , min and linear fit for year 2007 and 2008

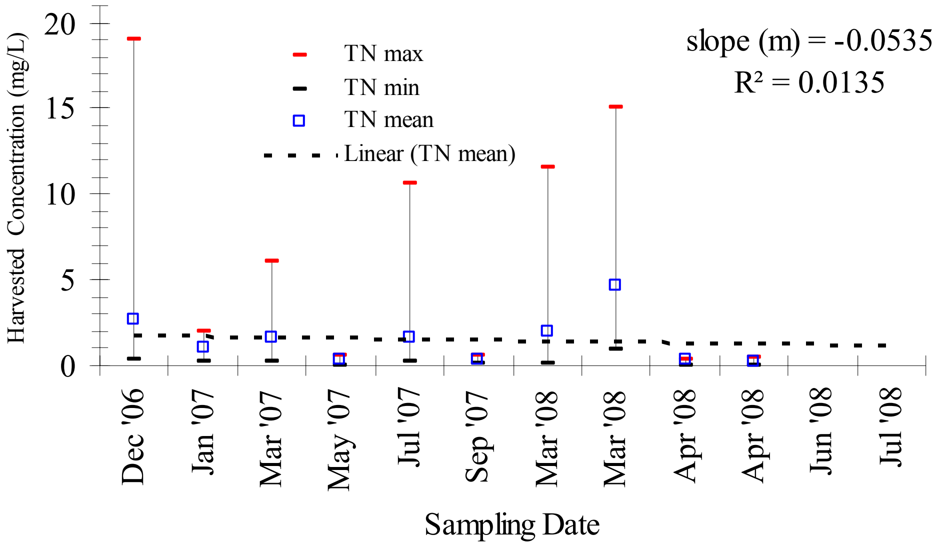


Figure I. 8- Post harvest TN mean, max , min and linear fit for year 2007 and 2008

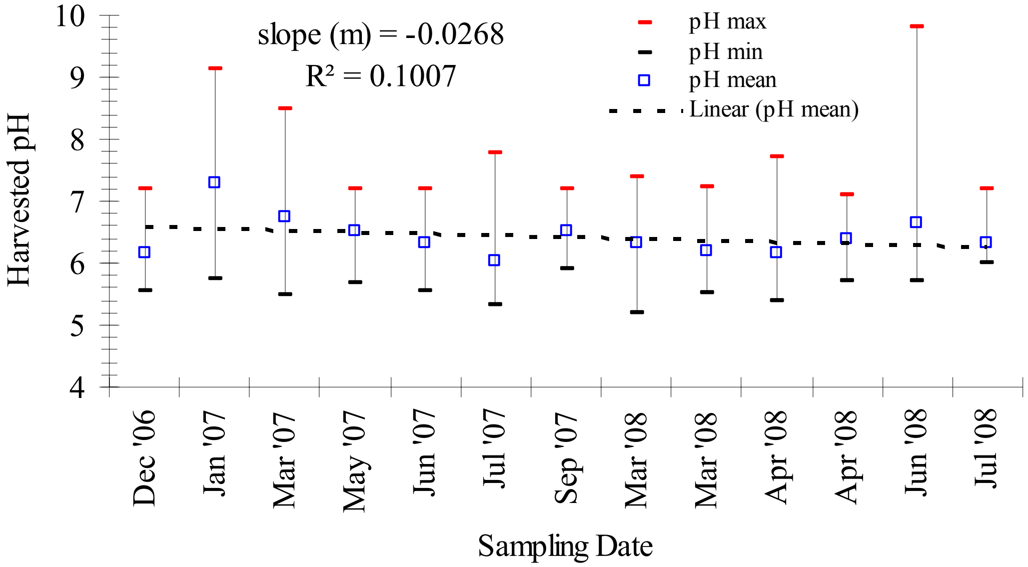


Figure I. 9- Post harvest pH mean, max , min and linear fit for year 2007 and 2008

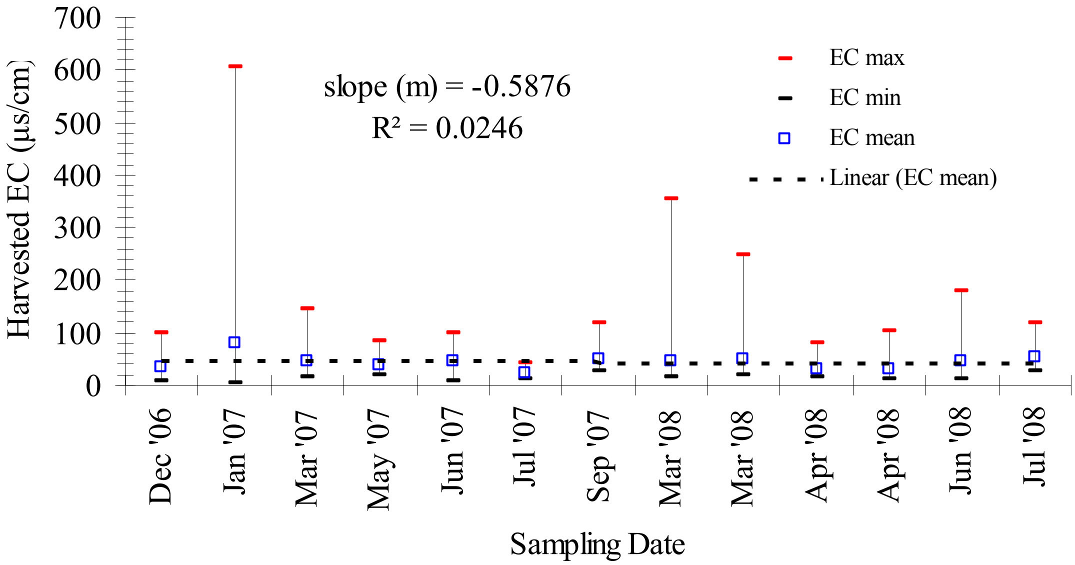


Figure I. 10- Post harvest EC mean, max , min and linear fit for year 2007 and 2008

APPENDIX J: TIME VARIATION OF CONCENTRATION OVER THE LOCATION OF IN-STREAM SAMPLER

Table J.1- A34-1 pre-harvest in-stream sampler mean, max and min for all parameters

Sampler	Properties	pH	EC (µS/cm)	TSS (g/L)	TVSS (g/L)	Ca (mg/L)	Mg (mg/L)	K (mg/L)	TP (mg/L)	SRP (mg/L)	NH3-N(mg/L)	NO3 (mg/L)	TN (mg/L)
WS-1	Mean	6.05	29.90	0.02	0.01	1.99	0.72	1.73	0.37	0.58	0.24	0.17	1.47
	Min	5.51	20.70	0.01	0.00	1.35	0.70	0.76	0.12	0.00	0.00	0.01	0.06
	Max	6.58	36.90	0.04	0.03	3.00	0.78	2.81	0.56	2.76	0.76	0.40	2.95
WS-2	Mean	5.19	20.87	0.02	0.03	0.72	0.57	1.42	0.03	0.03	0.12	0.10	4.17
	Min	4.78	19.30	0.01	0.01	0.38	0.53	0.92	0.00	0.00	0.01	0.04	0.56
	Max	5.88	23.50	0.04	0.04	1.14	0.65	1.97	0.06	0.06	0.20	0.21	7.79
WS-3	Mean	6.19	57.15	0.03	0.04	6.67	1.13	3.76	0.47	0.42	0.53	0.06	0.72
	Min	5.56	26.40	0.01	0.04	1.14	0.75	1.71	0.04	0.01	0.48	0.00	0.70
	Max	6.82	87.90	0.04	0.04	12.20	1.50	5.80	0.91	0.82	0.57	0.13	0.73
WS-4	Mean	6.39	29.90	0.04	0.03	1.86	0.76	1.08	0.15	0.04	0.24	0.13	1.34
	Min	5.84	10.82	0.00	0.01	0.00	0.16	0.15	0.00	0.00	0.00	0.01	0.04
	Max	7.02	56.40	0.12	0.06	2.96	1.40	2.38	0.73	0.21	1.54	0.37	5.10
WS-5	Mean	6.10	27.07	0.03	0.02	1.61	0.73	1.06	0.10	0.02	0.12	0.03	0.75
	Min	5.61	20.80	0.01	0.01	0.92	0.57	0.20	0.01	0.00	0.02	0.00	0.16
	Max	6.51	40.60	0.05	0.05	2.34	0.90	1.63	0.23	0.08	0.20	0.07	2.00
WS-6	Mean	5.61	15.20	0.02	0.03	1.57	0.86	0.56	0.07	0.01	0.06	0.02	0.44
	Min	5.32	10.32	0.01	0.02	0.70	0.56	0.23	0.00	0.00	0.00	0.00	0.10
	Max	6.22	18.62	0.03	0.04	2.98	1.69	1.04	0.25	0.02	0.20	0.04	0.70
WS-7	Mean	6.75	29.07	0.03	0.02	1.71	1.18	0.57	0.22	0.01	0.06	0.09	0.98
	Min	6.13	21.40	0.01	0.01	1.10	0.78	0.23	0.02	0.00	0.00	0.00	0.07
	Max	7.34	47.30	0.09	0.03	2.97	1.80	1.46	0.51	0.02	0.24	0.69	4.92
WS-8	Mean	6.79	27.93	0.06	0.02	2.19	1.59	0.73	0.06	0.01	0.09	0.62	0.60
	Min	6.28	21.90	0.00	0.00	1.10	0.67	0.28	0.00	0.00	0.00	0.00	0.04
	Max	7.19	36.30	0.56	0.03	7.18	4.12	1.94	0.26	0.07	0.45	7.75	2.66
WS-9	Mean	6.60	32.86	0.15	0.02	2.33	1.12	1.10	0.18	0.23	0.58	0.02	0.69
	Min	5.98	21.70	0.01	0.00	1.63	0.82	0.34	0.01	0.00	0.00	0.00	0.11
	Max	6.95	56.00	0.52	0.03	4.07	1.40	3.47	0.77	1.46	3.59	0.05	3.03
WS-10	Mean	6.35	23.68	0.07	0.04	6.87	3.76	0.38	0.11	0.07	0.14	0.33	1.43
	Min	5.64	16.87	0.03	0.04	0.06	0.01	0.09	0.01	0.00	0.00	0.00	0.08
	Max	6.60	45.70	0.12	0.05	35.64	18.45	0.81	0.22	0.21	0.80	1.85	3.66

Table J.2- A34-1 post-harvest in-stream sampler mean, max and min for all parameters

Sampler	Properties	pH	EC (µS/cm)	TSS (g/L)	TVSS (g/L)	Ca (mg/L)	Mg (mg/L)	K (mg/L)	TP (mg/L)	SRP (mg/L)	NH3-N(mg/L)	NO3 (mg/L)	TN (mg/L)
WS1	Mean	6.11	22.92	0.18	0.06	1.85	0.89	2.07	0.20	0.09	0.38	0.42	2.55
	Min	5.56	6.10	0.00	0.00	0.00	0.13	0.25	0.02	0.00	0.13	0.01	0.00
	Max	6.65	43.50	0.59	0.31	3.32	1.73	4.41	0.58	0.46	1.38	1.44	8.35
WS2	Mean	6.10	22.38	0.26	0.10	0.98	0.75	1.86	0.08	0.07	0.34	0.36	2.86
	Min	5.40	14.20	0.03	0.01	0.27	0.37	0.60	0.02	0.02	0.20	0.03	0.29
	Max	6.60	30.40	0.83	0.27	2.85	1.94	4.13	0.16	0.31	1.33	1.08	5.90
WS3	Mean	6.00	34.34	0.06	0.04	1.16	0.60	0.99	0.39	0.21	0.31	1.62	3.70
	Min	5.50	18.80	0.01	0.00	0.00	0.10	0.21	0.02	0.01	0.19	0.02	0.00
	Max	6.82	98.20	0.27	0.24	3.65	0.73	1.86	1.52	0.99	1.39	15.28	15.00
WS4	Mean	6.22	33.18	0.16	0.11	3.83	0.80	2.21	0.43	0.42	0.38	0.10	1.91
	Min	5.89	21.00	0.00	0.00	0.84	0.58	1.00	0.01	0.02	0.08	0.02	0.34
	Max	6.70	59.00	0.58	0.41	9.58	1.15	3.78	2.10	1.96	1.39	0.20	8.96
WS5	Mean	6.29	38.44	0.21	0.11	2.29	1.06	1.36	0.90	0.96	0.21	0.42	0.84
	Min	6.00	28.30	0.05	0.04	1.29	0.75	0.81	0.07	0.05	0.09	0.14	0.30
	Max	6.77	65.20	0.33	0.22	3.73	1.52	1.88	2.41	2.44	0.41	0.68	1.77
WS6	Mean	6.01	16.27	0.08	0.06	1.15	0.84	1.11	0.12	0.05	0.20	0.60	2.07
	Min	5.60	4.38	0.00	0.00	0.00	0.03	0.21	0.01	0.00	0.14	0.02	0.31
	Max	8.50	20.70	0.32	0.30	4.32	3.14	2.16	0.37	0.20	0.26	4.27	8.86
WS7	Mean	6.68	35.57	0.10	0.04	3.44	2.23	0.94	0.16	0.03	0.16	0.31	1.23
	Min	5.88	23.70	0.00	0.00	1.29	0.92	0.60	0.02	0.00	0.02	0.02	0.25
	Max	7.31	54.60	0.48	0.30	12.62	7.87	1.36	0.80	0.17	0.21	1.28	7.45
WS8	Mean	6.92	65.09	0.16	0.03	3.12	2.22	1.04	0.25	0.23	0.33	0.54	2.25
	Min	6.19	4.65	0.00	0.00	0.48	0.69	0.45	0.00	0.00	0.04	0.01	0.24
	Max	8.66	352.00	1.44	0.11	11.20	7.43	2.79	2.79	3.34	1.39	5.31	19.00
WS9	Mean	6.60	31.67	0.07	0.06	2.29	1.03	1.16	0.39	0.06	0.19	0.24	1.85
	Min	6.40	19.50	0.05	0.03	1.08	0.68	1.02	0.08	0.03	0.19	0.14	1.84
	Max	6.80	38.20	0.10	0.09	3.50	1.38	1.30	1.00	0.08	0.19	0.32	1.87

Table J.3- A34-2 pre-harvest in-stream sampler mean, max and min for all parameters

Sampler	Properties	pH	EC (µs/cm)	TSS (g/L)	TVSS (g/L)	Ca (mg/L)	Mg (mg/L)	K (mg/L)	TP (mg/L)	SRP (mg/L)	NH3-N(mg/L)	NO3 (mg/L)	TN (mg/L)
WS2	Mean	6.25	58.10	0.05	0.03	2.33	0.87	1.78	0.21	0.16	3.82	0.11	3.33
	Min	5.89	20.70	0.03	0.01	1.40	0.60	0.38	0.01	0.01	0.01	0.04	0.13
	Max	6.74	197.80	0.11	0.12	4.12	1.44	5.19	0.55	0.84	22.86	0.27	12.76
WS3	Mean	6.27	38.63	0.06	0.01	5.06	2.60	0.44	0.54	0.03	0.11	0.06	2.05
	Min	6.06	18.90	0.04	0.00	2.40	0.70	0.30	0.02	0.02	0.03	0.01	0.03
	Max	6.48	68.30	0.10	0.01	7.72	4.49	0.58	1.56	0.05	0.23	0.15	5.85
WS4	Mean	6.06	24.25	0.10	0.03	1.83	1.53	1.77	0.26	0.15	1.01	0.04	0.54
	Min	5.29	18.61	0.03	0.02	0.06	0.60	0.21	0.01	0.01	0.01	0.01	0.06
	Max	7.32	30.70	0.23	0.04	6.20	4.80	5.80	0.75	0.68	5.29	0.09	1.23
WS5	Mean	6.93	60.34	0.06	0.05	6.91	3.89	2.08	0.33	0.15	0.12	0.05	1.48
	Min	6.02	24.00	0.01	0.00	5.00	2.76	0.86	0.01	0.01	0.00	0.01	0.10
	Max	8.93	97.90	0.17	0.11	9.61	5.20	4.50	0.61	0.53	0.25	0.08	3.26
WS6	Mean	7.29	73.23	0.06	0.07	6.31	3.44	1.15	0.05	0.01	0.07	0.12	1.02
	Min	6.18	26.40	0.02	0.02	1.95	0.86	0.17	0.01	0.01	0.00	0.00	0.02
	Max	8.62	106.20	0.20	0.14	11.63	5.00	2.90	0.15	0.02	0.30	0.62	2.93
WS7	Mean	8.37	116.20	0.04	0.03	10.56	6.40	0.74	0.19	0.02	0.13	0.03	1.30
	Min	7.29	72.80	0.02	0.02	1.40	0.68	0.51	0.02	0.01	0.01	0.02	0.29
	Max	9.35	161.90	0.07	0.04	15.73	11.75	0.90	0.33	0.05	0.19	0.04	2.31

Table J.4- A34-2 post-harvest in-stream sampler mean, max and min for all parameters

Sampler	Properties	pH	EC (µs/cm)	TSS (g/L)	TVSS (g/L)	Ca (mg/L)	Mg (mg/L)	K (mg/L)	TP (mg/L)	SRP (mg/L)	NH3-N(mg/L)	NO3 (mg/L)	TN (mg/L)
WS1	Mean	6.67	140.92	0.11	0.04	10.77	1.71	11.34	1.59	1.62	0.17	0.46	2.73
	Min	5.78	17.09	0.01	0.00	1.58	0.59	0.94	0.00	0.01	0.11	0.16	0.78
	Max	7.55	604.00	0.35	0.06	34.99	4.22	36.70	5.40	4.56	0.20	0.92	4.99
WS2	Mean	6.24	56.54	0.23	0.20	4.81	1.94	1.00	0.14	0.04	0.27	1.86	1.31
	Min	5.20	20.30	0.01	0.00	1.50	0.58	0.49	0.07	0.01	0.19	0.02	0.33
	Max	7.21	145.20	1.09	1.06	16.14	7.71	1.42	0.26	0.07	0.51	7.89	3.52
WS3	Mean	6.56	35.13	0.09	0.04	3.95	1.07	1.82	0.70	0.81	0.17	1.96	1.74
	Min	5.80	24.30	0.00	0.00	2.06	0.31	0.75	0.06	0.03	0.00	0.07	0.10
	Max	8.15	56.60	0.29	0.14	9.08	1.80	4.07	3.77	4.10	0.21	8.45	7.26
WS4	Mean	6.20	60.92	0.20	0.13	6.79	2.01	1.57	0.47	0.27	0.18	0.30	0.60
	Min	5.75	18.90	0.01	0.00	0.59	0.60	0.29	0.04	0.00	0.09	0.02	0.21
	Max	6.92	94.80	0.45	0.43	17.51	4.67	2.74	0.80	0.66	0.21	0.72	1.45
WS5	Mean	7.64	95.40	0.04	0.03	12.67	6.51	1.34	0.08	0.05	0.16	0.23	0.72
	Min	6.43	55.90	0.00	0.00	10.65	3.07	1.15	0.06	0.03	0.05	0.12	0.31
	Max	9.13	145.20	0.17	0.11	16.07	9.96	1.43	0.09	0.06	0.21	0.33	1.50
WS6	Mean	6.91	80.90	0.12	0.09								
	Min	6.82	70.20	0.03	0.05								
	Max	6.99	91.60	0.20	0.14								

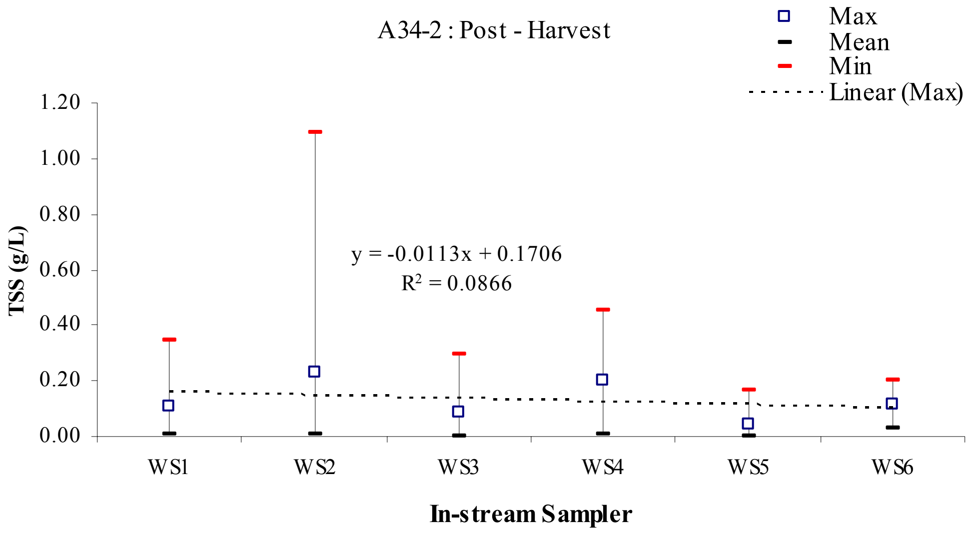


Figure J.1- A34-2 (TSS) post-harvest in-stream sampler mean, max and min and linear fit

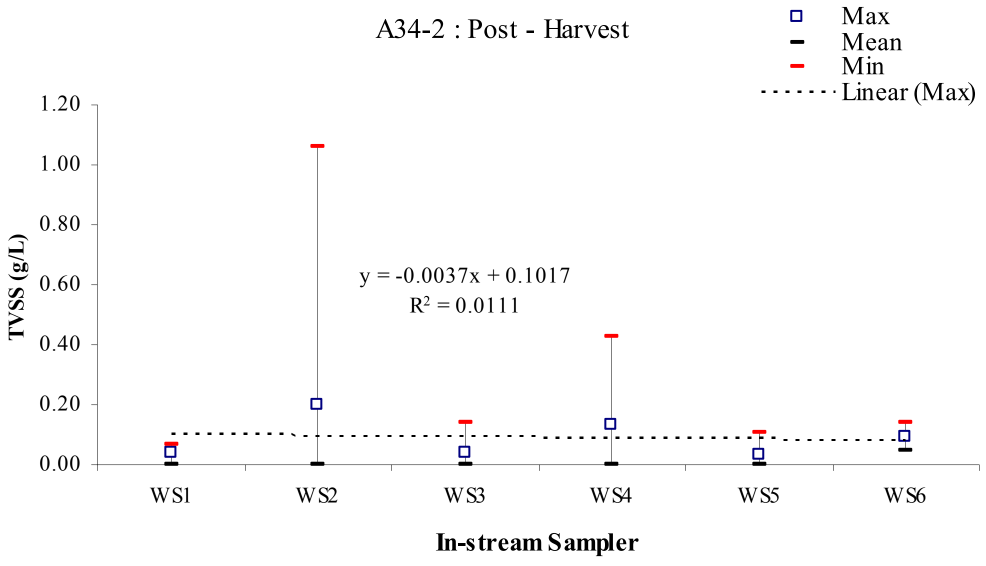


Figure J.2- A34-2 (TVSS) post-harvest in-stream sampler mean, max and min and linear fit

Table J.5- A17-1 pre-harvest in-stream sampler mean, max and min for all parameters

Sampler	Properties	pH	EC (µs/cm)	TSS (g/L)	TVSS (g/L)	Ca (mg/L)	Mg (mg/L)	K (mg/L)	TP (mg/L)	SRP (mg/L)	NH3-N(mg/L)	NO3 (mg/L)	TN (mg/L)
WS1	Mean	6.16	27.05	0.03	0.02	1.85	0.63	2.25	0.24	0.05	1.33	0.04	1.71
	Min	5.33	16.87	0.00	0.00	0.06	0.01	0.02	0.00	0.01	0.00	0.00	0.35
	Max	6.78	72.10	0.08	0.07	6.74	1.79	12.49	1.63	0.17	7.08	0.16	6.50
WS2	Mean	6.09	33.70	0.08	0.05	2.47	1.35	1.07	0.21	0.19	0.84	0.55	0.70
	Min	5.61	17.31	0.00	0.00	0.19	0.39	0.75	0.01	0.00	0.00	0.00	0.10
	Max	6.67	83.70	0.23	0.22	4.65	3.16	1.59	0.66	1.16	4.11	3.86	1.71
WS3	Mean	5.95	21.72	0.07	0.02	1.47	0.61	1.52	0.42	0.30	1.02	0.08	1.76
	Min	5.47	15.66	0.02	0.01	0.97	0.33	0.29	0.02	0.00	0.02	0.00	0.18
	Max	6.62	28.40	0.15	0.03	1.98	0.88	4.24	1.04	1.49	5.15	0.39	3.74
WS4	Mean	6.04	23.13	0.07	0.02	1.15	0.63	1.86	0.33	0.02	0.27	0.25	1.63
	Min	5.54	14.02	0.01	0.00	0.11	0.36	0.81	0.01	0.00	0.12	0.01	0.24
	Max	6.74	47.80	0.18	0.08	2.44	1.06	3.53	2.45	0.08	0.81	2.40	10.90
WS5	Mean	6.11	23.60	0.07	0.04	1.44	0.69	1.46	0.22	0.14	0.44	0.36	1.38
	Min	5.46	15.85	0.00	0.00	0.39	0.49	0.87	0.00	0.00	0.00	0.00	0.11
	Max	7.46	40.00	0.20	0.14	2.51	0.95	3.45	0.73	0.81	1.38	2.74	5.19

Table J.6- A17-1 post-harvest in-stream sampler mean, max and min for all parameters

Sampler	Properties	pH	EC (µs/cm)	TSS (g/L)	TVSS (g/L)	Ca (mg/L)	Mg (mg/L)	K (mg/L)	TP (mg/L)	SRP (mg/L)	NH3-N(mg/L)	NO3 (mg/L)	TN (mg/L)
WS1	Mean	6.57	28.09	0.02	0.02	1.99	1.27	1.25	0.31	0.05	0.19	0.63	0.60
	Min	5.87	17.00	0.00	0.00	0.70	0.50	1.05	0.03	0.04	0.18	0.35	0.33
	Max	7.80	58.60	0.04	0.03	4.53	3.39	1.49	1.03	0.06	0.20	1.13	1.13
WS2	Mean	6.13	27.35	0.46	0.42	0.95	0.70	1.65	1.14	0.61	0.15	5.21	3.62
	Min	5.88	13.00	0.00	0.00	0.27	0.47	1.57	0.07	0.00	0.02	0.07	0.24
	Max	6.40	68.90	1.27	1.26	1.57	0.84	1.79	4.21	3.37	0.20	25.64	11.53
WS3	Mean	7.18	44.08	0.27	0.25	5.41	1.07	2.92	1.25	0.16	0.09	7.57	0.00
	Min	6.20	23.20	0.07	0.05	2.26	0.84	2.60	0.61	0.02	0.02	1.01	0.00
	Max	9.80	86.70	0.53	0.50	13.76	1.25	3.13	1.85	0.22	0.16	17.77	0.00
WS4	Mean	6.58	25.98	0.04	0.03	1.70	1.05	2.43	0.46	0.06	0.18	3.98	0.17
	Min	6.10	17.50	0.01	0.00	0.97	0.59	2.08	0.03	0.03	0.17	0.58	0.11
	Max	7.50	38.10	0.05	0.05	2.53	1.42	2.97	0.79	0.09	0.20	9.03	0.23
WS5	Mean	6.45	33.15	0.05	0.04	2.21	1.11	2.41	0.03	0.03	0.21	4.49	0.17
	Min	6.30	31.10	0.02	0.01	2.21	1.09	2.38	0.02	0.03	0.20	3.41	0.16
	Max	6.60	35.20	0.07	0.06	2.21	1.13	2.43	0.04	0.04	0.21	5.57	0.18
WS6	Mean	6.25	26.05	0.21	0.20	3.20	1.08	2.15	0.05	0.03	0.21	0.59	0.30
	Min	6.20	24.50	0.10	0.08	3.16	1.07	2.08	0.03	0.03	0.21	0.48	0.30
	Max	6.30	27.60	0.32	0.32	3.23	1.08	2.22	0.06	0.04	0.21	0.70	0.31

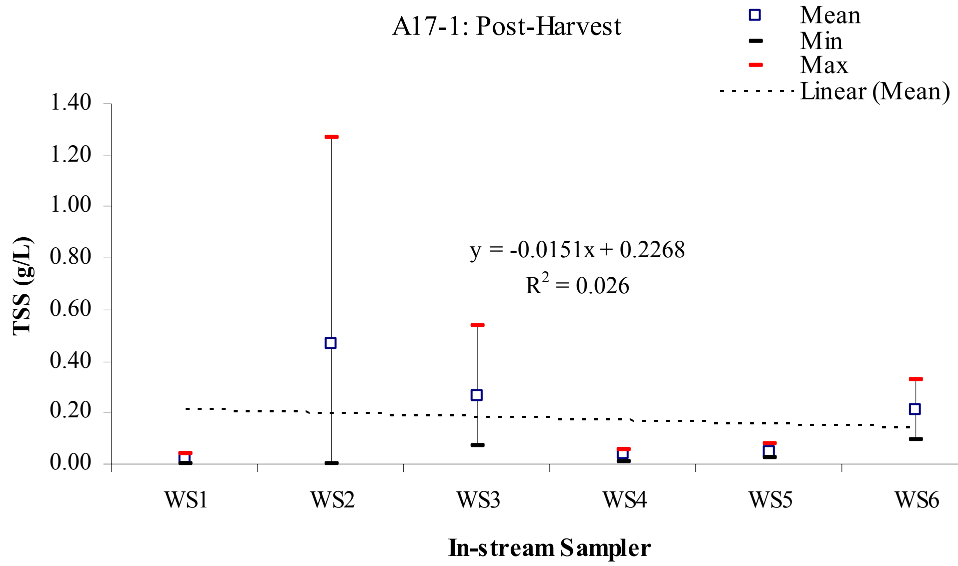


Figure J.3- A17-1 (TSS) post-harvest in-stream sampler mean, max and min and linear fit

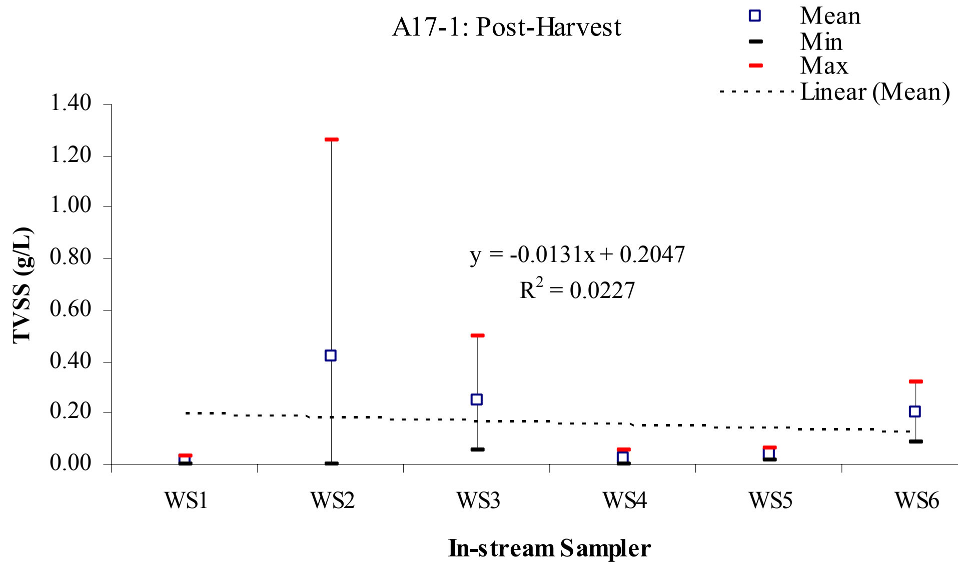


Figure J.4- A17-1 (TVSS) post-harvest in-stream sampler mean, max and min and linear fit

Table J.7- CR7-5B pre-harvest in-stream sampler mean, max and min for all parameters

Sampler	Properties	pH	EC (µs/cm)	TSS (g/L)	TVSS (g/L)	Ca (mg/L)	Mg (mg/L)	K (mg/L)	TP (mg/L)	SRP (mg/L)	NH3-N(mg/L)	NO3 (mg/L)	TN (mg/L)
WS1	Mean	6.28	34.39	0.08	0.02	2.32	0.98	1.21	0.72	0.23	2.89	2.73	3.81
	Min	5.94	5.50	0.00	0.00	0.39	0.15	0.17	0.01	0.00	0.03	0.02	0.25
	Max	6.53	105.20	0.33	0.05	7.59	3.15	3.45	3.97	1.15	17.07	15.40	16.74
WS2	Mean	6.19	19.39	0.40	0.04	1.55	0.56	1.24	0.09	0.03	0.13	0.06	1.20
	Min	5.87	16.35	0.01	0.00	1.20	0.49	0.89	0.05	0.01	0.04	0.01	0.25
	Max	6.68	23.20	1.14	0.07	2.08	0.70	1.99	0.16	0.04	0.23	0.15	2.97
WS3	Mean	6.03	18.86	0.27	0.04	2.55	1.00	1.35	0.09	0.04	0.12	0.08	1.23
	Min	5.50	12.65	0.01	0.00	0.25	0.25	0.89	0.05	0.01	0.03	0.01	0.25
	Max	6.68	23.20	1.14	0.07	13.70	5.45	1.99	0.16	0.25	0.23	0.18	2.97
WS4	Mean	6.46	23.23	0.15	0.07	2.21	0.93	1.45	0.11	0.08	0.12	0.30	1.34
	Min	6.24	11.72	0.06	0.00	0.90	0.30	0.33	0.00	0.03	0.03	0.01	0.08
	Max	6.73	35.80	0.38	0.14	4.95	2.46	3.43	0.29	0.19	0.26	1.30	2.41
WS5	Mean	6.35	62.24	0.68	0.14	3.68	1.09	2.99	0.23	0.09	0.43	1.92	2.73
	Min	5.95	12.74	0.04	0.01	0.64	0.26	1.03	0.00	0.00	0.03	0.00	0.33
	Max	6.92	300.00	2.02	0.33	9.31	2.96	7.88	1.20	0.24	1.21	12.69	7.15
WS6	Mean	6.45	29.02	0.67	0.43	3.45	0.75	1.69	0.18	0.16	0.10	0.33	1.03
	Min	6.26	18.28	0.08	0.04	2.02	0.43	1.23	0.00	0.02	0.00	0.00	0.18
	Max	6.80	40.50	1.34	1.77	4.61	1.34	1.95	0.47	0.45	0.20	1.57	2.04

Table J.8- CR7-5B post-harvest in-stream sampler mean, max and min for all parameters

Sampler	Properties	pH	EC (µs/cm)	TSS (g/L)	TVSS (g/L)	Ca (mg/L)	Mg (mg/L)	K (mg/L)	TP (mg/L)	SRP (mg/L)	NH3-N(mg/L)	NO3 (mg/L)	TN (mg/L)
WS1	Mean	5.95	29.13	0.28	0.22	2.49	0.72	3.21	0.07	0.04	0.13	1.39	1.54
	Min	5.80	19.50	0.01	0.03	1.69	0.42	1.93	0.05	0.03	0.00	0.10	1.14
	Max	6.20	51.10	0.62	0.48	4.74	1.22	6.52	0.10	0.04	0.31	4.78	2.08
WS3	Mean	6.06	20.27	1.36	0.94	2.40	0.77	1.49	0.10	0.06	0.66	0.56	1.78
	Min	5.72	9.74	1.04	0.30	0.80	0.52	1.03	0.08	0.04	0.19	0.23	1.46
	Max	6.40	30.80	1.67	1.58	4.00	1.01	1.94	0.11	0.07	1.13	0.88	2.09
WS5	Mean	6.29	25.90	0.26	0.01	1.93	0.76	1.74	1.98	0.01	0.19	0.02	0.45
	Min	6.05	23.10	0.10	0.00	1.29	0.76	1.38	0.34	0.01	0.17	0.02	0.25
	Max	6.53	28.30	0.55	0.03	2.30	0.77	1.99	4.38	0.02	0.19	0.03	0.58
WS6	Mean	6.33	37.10	0.48	0.98	3.18	0.83	2.54	0.18	0.05	0.20	3.44	2.56
	Min	6.16	33.90	0.19	0.75	2.69	0.76	2.45	0.09	0.03	0.20	0.35	2.56
	Max	6.50	40.30	0.77	1.22	3.66	0.91	2.62	0.26	0.07	0.20	6.52	2.56

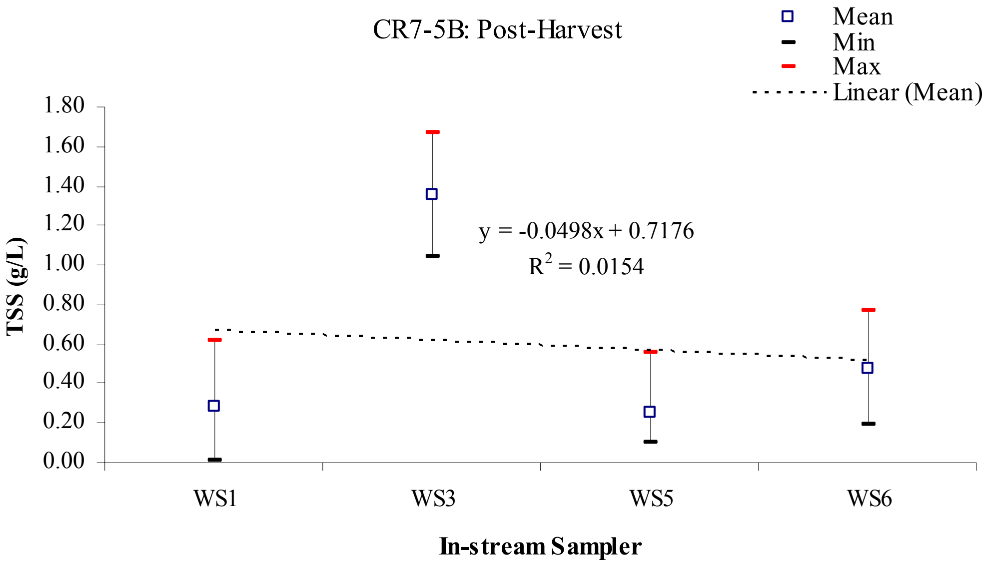


Figure J.5- CR7-5B (TSS) post-harvest in-stream sampler mean, max and min and linear fit

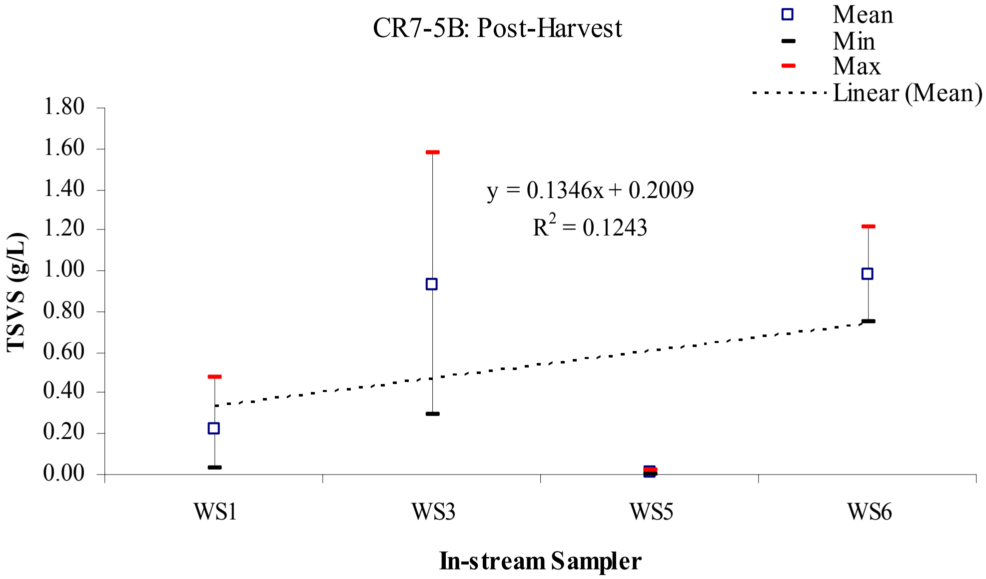


Figure J.6- CR7-5B (TVSS) post-harvest in-stream sampler mean, max and min and linear fit

Table J.9- CR7-5C pre-harvest in-stream sampler mean, max and min for all parameters

Sampler	Properties	pH	EC (µS/cm)	TSS (g/L)	TVSS (g/L)	Ca (mg/L)	Mg (mg/L)	K (mg/L)	TP (mg/L)	SRP (mg/L)	NH3-N(mg/L)	NO3 (mg/L)	TN (mg/L)
WS1	Mean	6.20	21.92	0.08	0.02	1.87	0.46	0.91	0.20	0.02	0.34	0.13	1.80
	Min	5.90	5.78	0.00	0.00	0.60	0.20	0.05	0.00	0.01	0.03	0.01	0.93
	Max	6.66	30.80	0.30	0.03	2.37	0.61	1.44	0.33	0.04	1.21	0.47	2.48
WS2	Mean	6.35	31.05	0.28	0.06	2.14	0.66	1.67	0.29	0.15	0.08	0.05	1.07
	Min	6.07	17.30	0.02	0.01	0.88	0.50	0.83	0.01	0.01	0.01	0.00	0.02
	Max	6.90	92.10	1.94	0.27	4.44	1.30	4.75	0.72	0.64	0.18	0.13	3.43
WS3	Mean	6.28	46.81	0.22	0.10	5.59	1.06	3.02	1.01	0.54	2.05	0.57	3.88
	Min	5.80	19.50	0.00	0.00	1.01	0.52	1.15	0.01	0.01	0.08	0.01	0.63
	Max	7.32	155.50	0.67	0.34	29.87	2.74	6.58	4.05	2.60	17.07	2.91	13.72
WS4	Mean	6.03	21.60	0.16	0.05	1.52	0.55	1.18	0.12	0.03	0.21	0.09	0.97
	Min	5.71	15.99	0.01	0.00	1.00	0.41	0.52	0.00	0.00	0.02	0.03	0.20
	Max	6.20	35.90	0.87	0.15	2.42	0.66	1.88	0.21	0.07	0.63	0.18	2.38
WS5	Mean	6.36	19.63	0.14	0.04	1.12	0.49	2.25	0.15	0.06	0.13	0.05	1.05
	Min	5.84	11.86	0.01	0.01	0.00	0.04	0.61	0.02	0.00	0.03	0.00	0.16
	Max	6.82	28.50	0.66	0.16	1.68	0.70	6.01	0.40	0.18	0.30	0.13	2.75

Table J.10- CR7-5C post-harvest in-stream sampler mean, max and min for all parameters

Sampler	Properties	pH	EC (µS/cm)	TSS (g/L)	TVSS (g/L)	Ca (mg/L)	Mg (mg/L)	K (mg/L)	TP (mg/L)	SRP (mg/L)	NH3-N(mg/L)	NO3 (mg/L)	TN (mg/L)
WS1	Mean	6.60	39.20	0.33	0.32	2.72	0.73	2.34	0.36	0.29	0.14	0.62	0.35
	Min	6.50	24.00	0.00	0.00	1.87	0.64	1.12	0.10	0.05	0.08	0.20	0.13
	Max	6.70	65.10	0.95	0.95	3.50	0.77	4.66	0.85	0.71	0.19	1.31	0.58
WS2	Mean	6.42	25.28	0.34	0.31	2.90	1.05	2.58	0.92	0.35	0.20	1.72	0.47
	Min	5.90	13.74	0.01	0.02	1.18	0.65	0.68	0.00	0.03	0.11	0.12	0.23
	Max	7.77	44.20	1.40	1.37	5.54	1.86	6.57	2.31	1.82	0.41	5.13	1.11
WS3	Mean	6.10	27.12	0.44	0.31	2.21	0.76	2.71	0.40	0.22	2.63	0.48	2.25
	Min	5.32	16.00	0.04	0.00	0.38	0.22	1.32	0.04	0.04	0.13	0.00	0.34
	Max	6.50	54.10	2.10	2.02	6.35	1.77	6.21	2.21	0.75	16.46	2.09	10.67
WS4	Mean	6.24	23.42	0.04	0.04	1.82	0.77	2.29	0.10	0.07	0.33	0.64	0.56
	Min	6.08	17.47	0.02	0.01	0.80	0.50	1.05	0.07	0.03	0.08	0.17	0.19
	Max	6.60	34.60	0.07	0.06	4.31	1.37	4.38	0.15	0.16	0.62	2.02	1.08
WS5	Mean	6.34	40.97	0.38	0.11	1.95	0.78	1.83	0.64	0.62	2.55	0.55	0.96
	Min	5.62	16.84	0.00	0.00	0.27	0.40	0.94	0.05	0.03	0.09	0.14	0.11
	Max	7.20	118.10	0.88	0.19	3.50	1.35	2.92	2.46	2.68	11.62	1.75	2.04

Table J.11- CR11-1 pre-harvest in-stream sampler mean, max and min for all parameters

Sampler	Properties	pH	EC (µs/cm)	TSS (g/L)	TVSS (g/L)	Ca (mg/L)	Mg (mg/L)	K (mg/L)	TP (mg/L)	SRP (mg/L)	NH3-N(mg/L)	NO3 (mg/L)	TN (mg/L)
WS2	Mean	6.91	22.86	0.04	0.03	1.51	0.67	1.47	0.26	0.04	0.12	0.04	0.97
	Min	6.08	18.10	0.01	0.01	0.97	0.53	0.50	0.11	0.01	0.01	0.00	0.20
	Max	8.94	36.30	0.09	0.05	3.51	0.80	3.97	0.57	0.09	0.20	0.08	1.87
WS3	Mean	6.18	18.17	0.04	0.02	0.74	0.57	0.76	1.96	0.20	0.14	0.04	0.61
	Min	6.03	6.94	0.03	0.00	0.10	0.30	0.12	0.03	0.00	0.03	0.01	0.09
	Max	6.31	25.10	0.06	0.03	1.32	0.76	1.21	5.07	0.74	0.20	0.08	0.91
WS4	Mean	7.30	16.93	0.03	0.00	1.05	0.60	0.60	0.13	0.02	0.03	0.01	0.92
	Min	7.20	16.30	0.01	0.00	1.00	0.50	0.44	0.03	0.01	0.02	0.00	0.15
	Max	7.39	17.55	0.04	0.00	1.10	0.70	0.76	0.23	0.03	0.03	0.02	1.68
WS5	Mean	6.83	21.40	0.09	0.03	1.34	0.58	0.70	0.06	0.06	0.13	0.02	0.32
	Min	6.22	14.15	0.01	0.03	0.80	0.40	0.35	0.01	0.01	0.01	0.01	0.17
	Max	7.41	34.40	0.30	0.03	2.30	0.72	1.08	0.13	0.13	0.19	0.04	0.45

Table J.12- CR11-1 post-harvest in-stream sampler mean, max and min for all parameters

Sampler	Properties	pH	EC (µs/cm)	TSS (g/L)	TVSS (g/L)	Ca (mg/L)	Mg (mg/L)	K (mg/L)	TP (mg/L)	SRP (mg/L)	NH3-N(mg/L)	NO3 (mg/L)	TN (mg/L)
WS1	Mean	6.15	34.56	0.10	0.08	1.76	0.58	1.88	1.30	0.93	0.16	1.50	
	Min	5.71	18.80	0.00	0.00	1.50	0.54	1.11	0.00	0.04	0.00	0.00	
	Max	6.55	95.60	0.24	0.20	1.88	0.68	4.72	5.77	3.82	0.21	6.74	
WS2	Mean	6.09	28.73	0.11	0.05	1.86	0.84	2.26	0.17	0.28	0.19	10.03	
	Min	5.52	19.00	0.00	0.00	1.17	0.63	1.12	0.00	0.05	0.13	0.00	
	Max	6.40	56.80	0.29	0.14	4.09	1.71	7.14	0.40	0.95	0.20	55.69	
WS3	Mean	5.83	18.63	0.26	0.06	1.27	0.59	1.41	0.09	0.04	0.20	0.14	0.27
	Min	5.64	18.20	0.04	0.01	1.07	0.56	0.96	0.04	0.03	0.20	0.11	0.25
	Max	5.99	19.50	0.44	0.09	1.45	0.61	2.13	0.12	0.05	0.21	0.15	0.29

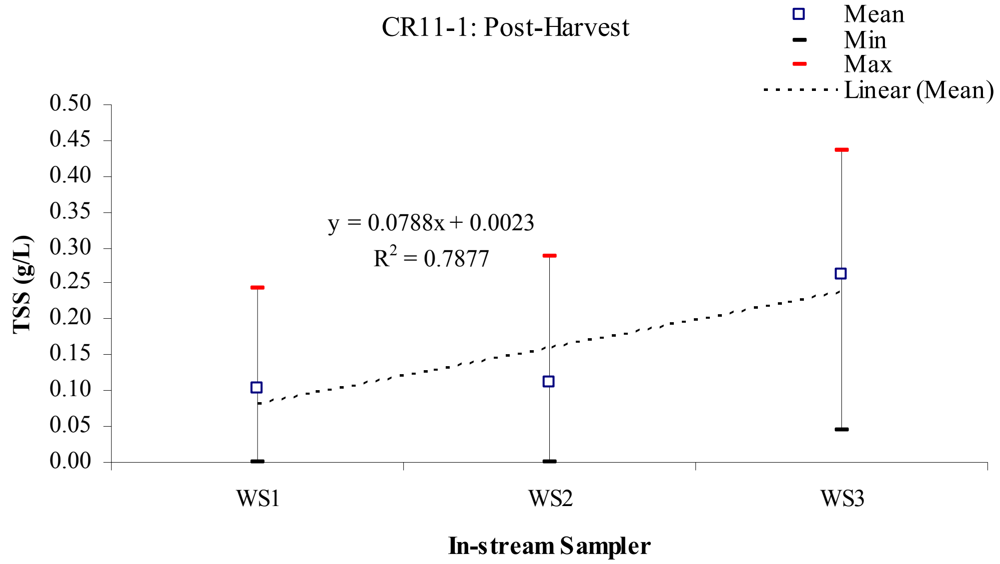


Figure J.7- CR11-1 (TSS) post-harvest in-stream sampler mean, max and min and linear fit

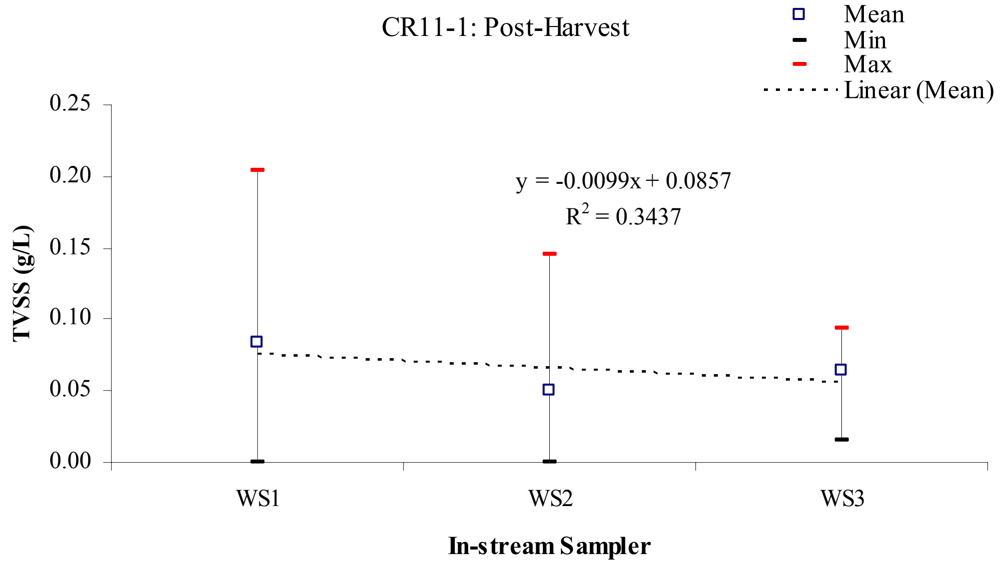


Figure J.8- CR11-1 (TVSS) post-harvest in-stream sampler mean, max and min and linear fit

VITA

Amod K. Koirala, son of Dhurba Bahadur Koirala and Shobha Devi Kshetri (Koirala), was borne on January 16, 1974 in Govindpur-3, Siraha, Nepal. He received the Bachelor of Science degree from Tribhuwan University, Pokhara, Nepal. He worked for about four years in the Department of Soil & Water Conservation, Kathmandu.

He joined the Department of Civil & Environmental Engineering, University of Missouri-Columbia in July 2004 and finished his Master's degree in Civil Engineering in August 2006. He continued his Ph.D. degree in the department and is graduating with his doctoral degree in Civil Engineering specializing in Geotechnical Engineering in December 2009. He is married to Susma Koirala and they are the parents of Alija Shreya Koirala who was borne in November 2002.