SECTION 319 NONPOINT SOURCE POLLUTION CONTROL PROGRAM

EDUCATION/TRAINING/DEMONSTRATION PROJECT

FINAL REPORT

FDEP Contract #GO217

Reducing Nonpoint Source Loss of Nitrate within the Santa Fe Basin: Efficacy of Container Nursery BMPs and Denitrification Wall

by

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EXECUTIVE SUMMARY

PROJECT TITLE Reducing Nonpoint Source Loss of Nitrate within the Santa Fe Basin: Efficacy of Container Nursery BMPs and Denitrification Wall

PROJECT START DATE 4-4-2007 PROJECT COMPLETION DATE 10-1-2011

FUNDING:

Grant Work Plan Budget - Funds

EPA Section 319

FY03	$159,482
FY08	**$145,644**
TOTAL	$259,917

Matching Funds

FY03	$55,170
FY08	**$32,396**
TOTAL	$87,566

Total Budget

FY03	$214,652
FY08	**$178,040**
TOTAL	$392,692

Actual Project Costs - EPA Section 319 Funds

FY03	$114,273
FY08	**$128,634.85**
Total	$242,907.85

Matching Funds

FY03	$50,012.99
FY08	**$39,692.73**
TOTAL	$89,705.72

Budget Revisions

FY03	$45,509
FY08	**$0**
TOTAL	$45,509

Total Project

FY03	$164,285.99
FY08	**$168,327.58**
Project	$332,613.57

SUMMARY OF ACCOMPLISHMENTS

There were four principal objectives of this project: 1) to evaluate the overall efficacy of existing Container Nursery BMP's to reduce downstream nitrate loading, 2) to optimize irrigation practices as a means to reduce nitrate losses from containers, 3) to evaluate the efficacy of denitrification walls to reduce downstream nitrate loads in shallow groundwater and 4) to communicate findings to stakeholders associated with the container nursery industry.

The project was conducted at a medium size (160 acre) container nursery in North Central Florida in the headwaters of a tributary within the Santa Fe River Watershed. Approximately 10 acres of the nursery are allocated to overhead irrigation and the remaining acreage is irrigated using microjet irrigation. All fertilizer is slow release and applied on the surface of containers, not mixed into the soil-less media. Surficial soils in the area are well drained but underlain by a thick clay aquatard. Surficial groundwater perched on top of the clay moves laterally until coming to the surface along an escarpment and forming the headwaters of a tributary that flows to the Santa Fe River. Prior to BMP implementation, excess irrigation in the nursery resulted in nitrogen leaching from the containers, vertical movement through the surficial sands and eventual migration to the tributary. As a result, nitrogen levels and flow rates in the tributary headwaters averaged 7.6 ± 0.9 mg L^{-1}, had an average discharge of 16.8 L s^{-1} and an annual total nitrogen load of 4,206 kg.

PreBMP irrigation practices consisted of a one-time 40-45 minute application of water to containers. However, due to the low water holding capacity of the soil-less media used, monitoring data indicated that of the 22.9 ± 2.42 L day^{-1} applied, 17.8 ± 2.81 L day^{-1} (87.2 ± 12.8%) were lost to leaching. This included a loss of total nitrogen averaging 26.0 ± 14.5 mg L^{-1} of which 17.5 ± 11.0 mg L^{-1} was in the form of nitrate nitrogen. By changing irrigation practices from a single event to multiple smaller events ("cyclical irrigation"), a significant reduction in overall volume applied and water lost to leaching occurred. Using a 6 minute irrigation duration applied three times per day, the total irrigation volume was reduced by 63% to 8.4 ± 3.74 L day^{-1}, and total leached volume was reduced by 71%. This translated into a reduction in total nitrogen leached of 78.8% or a decrease from 454 ± 251 mg N $container^{-1}$ day^{-1} under preBMP conditions to 96.2 ±78.0 mg N $container^{-1}$ day^{-1} under postBMP conditions. Unfortunately, other irrigation infrastructure limitations did not allow this short duration irrigation regime to continue beyond the monitoring period and a 10 min x 10 min x 5 minute cyclical regime is now being used by the nursery to balance infrastructure limitations while minimizing leaching losses.

Although presently not a BMP within the Container Nursery BMP manual, site geological conditions and movement of groundwater first vertically and then horizontally at the nursery required an innovative means to intercept and treat nitrate rich groundwater at the edge of the field. After identifying an edge of the field where groundwater was focused along a subsurface valley in the clay aquatard, a 55m long, 1.8 m deep and 1.5 m wide denitrification wall was installed. The denitrification wall media consisted of a 50:50 mix of pine sawdust and uncoated builder's sand. Three groundwater well monitoring transects with wells upstream, within and downstream of the wall were used to evaluate groundwater treatment potential of the wall. A surface water monitoring station downstream of the wall was used to evaluate treatment efficacy of the wall on the tributary. Average nitrate-nitrogen concentrations upstream and downstream of the wall showed a 77% reduction in concentration from 6.2 ± 0.65 to 1.6 ± 0.40 mg L^{-1}. However, downstream well values may be somewhat elevated due to groundwater short circuiting around the ends of the wall. Nitrate concentrations within two of the three groundwater wells inside the wall were undetectable indicating a 100% reduction in nitrate only halfway through the flowpath and the third well showed an 88% reduction with only half of the flow path through the wall completed. These reduction rates indicate that actual nitrate removal for groundwater passing through the wall is likely 100%. Based on groundwater flow rates and nitrate concentration among the three well transects, a range of nitrate removal between 3.0-5.2 g-N m^{-3} d^{-1} is occurring within the wall. Nitrate reductions in the surface tributary immediately downstream from the wall showed a 65% reduction in nitrogen load one year after the wall was installed changing from 1.46 ± 0.32 kg day^{-1} to 0.52 ± 0.26 kg day^{-1}, an average load reduction of approximately 340 ± 130 kg of N per year. Using a mass balance of carbon along with stoichiometry for reactions associated with denitrification, the wall is estimated to maintain a high level of denitrification for at least 23 ± 5.9 years. The cost of materials and construction of this wall were approximately $20,000 of which native soils could have been substituted for builders sands lowering the cost. Assuming a conservative 15 year life-span and stable nitrate removal rates measured one year after installation, the N removal cost over the 15-year period would be $0.79 kg-$N^{-1}$ or $0.36 lb N^{-1}

Overall nitrogen reductions in the main tributary resulting from implementation of the Container Nursery BMPs, denitrification wall and tailwater pond showed a significant decrease in nitrogen concentration, flow rates and load. Total nitrogen concentrations decreased from 7.6 $\pm$ 0.9 mg L^{-1} preBMP to 5.5 $\pm$ 0.7 mg L^{-1} postBMP. Average flows decreased from 16.8 L s^{-1} preBMP to 8.44 L s^{-1} postBMP. Total nitrogen load decreased from 4,206 kg yr^{-1} to 1,525 kg yr^{-1} post BMP. In addition, the trend in tributary nitrogen concentration at the end of the monitoring period was still decreasing and had not leveled off indicating that the full extent of nitrogen reductions due to implementation of BMPs may not yet been fully realized. Therefore a period of future monitoring at this site would be warranted to fully quantify reductions in nitrogen load resulting from BMPs and other nitrogen load reduction practices implemented in the watershed.

A field day to discuss Container Nursery BMP’s, demonstrate various practices evaluated as part of this study and share our findings with stakeholders was conducted on June 19, 2012. Thirteen (13) individuals from nurseries in the region participated. A program flyer, participant sign-up sheet and handout provided at the event can be found in section 9.1 Appendix A. Participants indicated that they had a better understanding of the effectiveness of various BMPs and a broader understanding of the connectivity between nursery operations and the natural environment as a result of the field day event.

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9.0 APPENDICIES

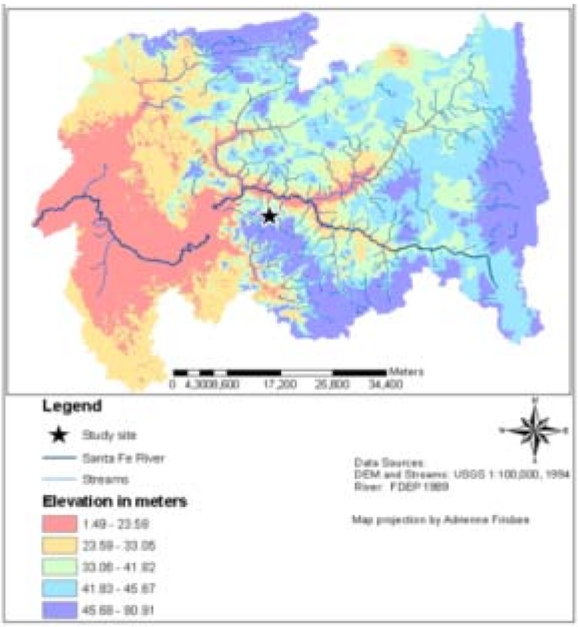
1.0 INTRODUCTION

Excess nutrient loads from anthropogenic activities have become a significant area of research and regulatory activity as the negative effects of excess nutrients in aquatic ecosystems become increasingly realized. Although phosphorus is typically the nutrient of greater concern in freshwater systems due to its often limiting condition, nitrogen can also be an issue especially in marine and groundwater associated systems. In the State of Florida, numeric nutrient criteria for Total Nitrogen and Nitrate-Nitrogen are soon to be adopted into state rule or imposed on the state by federal rule. These criteria will establish thresholds for nutrients that are expected to protect the designated use of a water body. As such, managing nutrient loads from point and nonpoint sources using various Best Management Practices (BMPs) will become even more critical and common place in an effort to keep receiving water body nutrient levels below the protective threshold or to reduce loads in already impacted watersheds.

In the case of agricultural nonpoint source loads, commodity specific BMPs offer agricultural operations an important tool to reduce nutrient loss to the extent economically practicable. Although load reductions associated with BMP implementation may not reduce loads to the total extent required to be protective of a waterbody, they are the first step in an overall treatment train designed to reduce loads. To facilitate the adoption of appropriate agricultural BMPs for specific agricultural commodities, the Florida Department of Agriculture and Consumer Services (FDACS) has taken the lead in developing BMP Manuals for most of the prominent agricultural commodities in Florida. During the BMP Manual development process stakeholder input is often solicited with final approval being granted by the Florida Department of Environmental Protection (FDEP). Once a commodity BMP manual has been developed and adopted, commodities can implement practices on a voluntary basis if their operation is not within an impaired watershed for nutrients; however, if their operation is within the watershed of an impaired waterbody they are required to either adopt recommended BMP’s through a Notice of Intent (NOI) and maintain appropriate record keeping to be granted a presumption of compliance, or they need to monitor water quality discharges from there site to show their operation is in compliance. Understanding how effective implementation of BMP’s are to reduce nutrient loads for a particular commodity in a particular region of the state is critical so that accurate estimates in load reduction as a result of BMP implementation can be accounted for.

To this end an evaluation of the load reduction potential resulting from implementation of the Container Nursery Best Management Practices Manual (FDACS 2007) was conducted at a nursery within the nitrogen impaired Santa Fe River Watershed (HUC 03110206) in North Central Florida (FDEP 2008). In addition to evaluation of the overall effectiveness of BMP’s outlined in the manual, irrigation practices and tailwater recovery from an area of overhead irrigation were studied in more detail. There was also a detailed investigation conducted on an innovative subsurface edge of field management practices referred to as a denitrification wall that has the potential to significantly reduce surficial groundwater nitrate loads. This report summarizes findings from those investigations.

The container nursery where this study took place occurs at the headwaters of a tributary that discharges into the middle reach of the Santa Fe River. The nursery is located at the edge of the south side escarpment into the Santa Fe River valley (Figure 1-1). Baseflow in the tributary flowing from the nursery is principally sourced from groundwater seeps that occur along the escarpment where the surface of the Hawthorne Formation (a low hydraulic permeability geological aquatard) becomes exposed.


Meters
0 4,300 8,600 17,200 25,800 34,400
Legend
★ Study site
Santa Fe River
Streams
Elevation in meters
1.49 - 23.58
23.59 - 33.05
33.06 - 41.82
41.83 - 45.67
45.68 - 90.91
Data Sources:
DEM and Streams: USGS 1:100,000, 1994
River: FDEP 1989
Map projection by Adrienne Frisbee

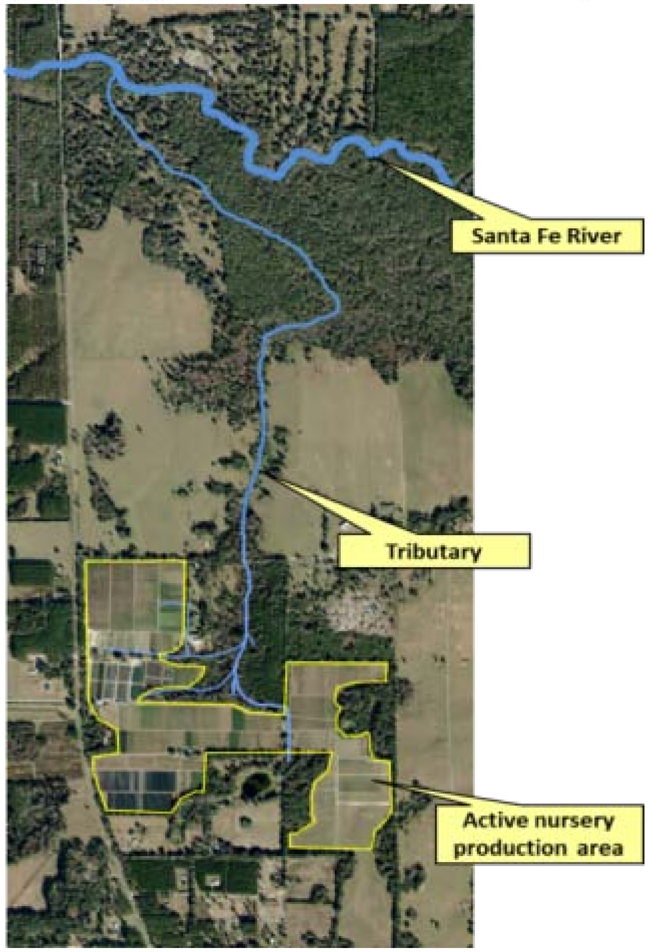

Santa Fe River
Tributary
Active nursery production area

Figure 1-1. Location of study site within the Santa Fe River Watershed (left) and 3/18/2011 aerial view of tributary watershed with nursery located in the headwaters and discharge to the Santa Fe River (right).

Overlying the Hawthorne Formation in much of the nursery are well-drained sands approximately 10-15 feet thick. Rainfall and excess irrigation within the nursery first infiltrate rapidly through the sands, but downward infiltration becomes impeded by the low permeability Hawthorne Formation resulting in a saturated groundwater table which then flows laterally toward the escarpment.

There is little visual evidence (erosion, gullies, sediment deposition etc.) within most of the nursery that there is any regular surface runoff with the exception of an overhead irrigation area to be discussed later suggesting most of the rainfall within the nursery that contributes to tributary flows is vectored first through groundwater. Rainfall that falls within the higher sloped areas of the escarpment where overlying sands have already eroded and the Hawthorne Formation is near the surface appear to have a high level of runoff and direct contribution to tributary flows.

Vegetation in these high slope areas of the headwaters are for the most part undisturbed and densely vegetated with native hardwood species. Once seepage water has coalesced into the subtributarys or the main tributary it travels for 1.8 km behind several rural properties and through the University of Florida Santa Fe River Beef Research Unit (SFRBRU) property before entering the Santa Fe River Floodplain. Once in the floodplain the tributary flows another 1.6 km before it reaches the main channel of the Santa Fe River 3.4 km from the headwater seeps.

Previous research conducted in 2005 on the tributary as it flows through the SFRBRU (Frisbee 2007) indicated high levels of nitrate-nitrogen + nitrite-nitrogen (NOx-N) coming from sources upstream of the SFRBRU where NOx-N concentrations of 5.53 ± 0.567 mg L^{-1} were measured as the tributary flowed onto the SFRBRU property. These level decreased 29.0 ± 15.9% as the water flowed through the SFRBRU and an additional 50.1 % as it flowed through the Santa Fe River floodplain before entering the main river channel. A comparison of monthly average NOx-N concentrations along this tributary (4.86 + 0.855 mg L^{-1}) with another tributary on the SFRBRU in the next valley to the east (0.027 + 0.026 mg L^{-1}) indicated significantly different NOx-N concentrations.

The most apparent difference in the two tributaries was the difference in headwater land use, one with mostly nursery, the other had pasture, hay operation, silviculture and natural areas. The other difference was in baseflow where the tributary dominated by the nursery had a continuous baseflow year round while the other tributary had continuous baseflow only during the wet season and the rest of the year it was intermittent or dry. A one-time grab sample survey of surface waters and seeps around the escarpment below the nursery conducted in January of 2006 confirmed elevated levels of nitrates originating from the groundwater adjacent to the nursery site (Figure 1-2).

This report summarizes findings from an evaluation of several BMPs and denitrification wall technology implemented at the nursery to reduce these loads and to demonstrate these practices for other nursery operations in North Florida.

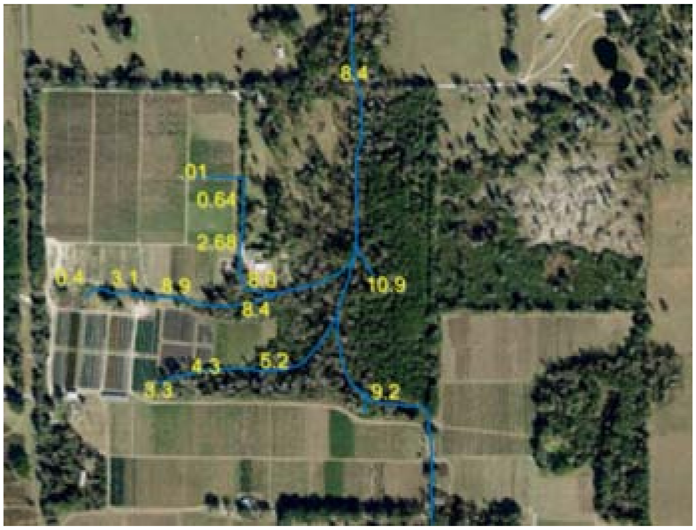


Figure 1-2. Surface water Nitrate-Nitrogen concentrations (mg L-1) collected in January 2006 from subtributaries and seeps of the tributary headwater that ultimately discharges to the Santa Fe River.

2.0 PROJECT GOALS, OBJECTIVES, AND ACTIVITIES

The overall goal for this project was to quantify nitrogen load reduction potential of various Best Management Practices and other edge of field nitrogen load reduction techniques. Quantification of the efficacy of these practices under specific production systems, climate conditions and soils/geology provides a more accurate estimate for load reduction potential associated with load allocation and TMDL implementation.

Within this overall goal there were four principal objectives of this project: 1) to evaluate the overall efficacy of existing Container Nursery BMP’s to reduce downstream nitrate loading, 2) to optimize irrigation practices as a means to reduce nitrogen losses from containers, 3) to evaluate the efficacy of a denitrification walls to reduce downstream nitrogen loads in shallow groundwater and 4) to communicate findings to stakeholders associated with the container nursery industry.

Activities associated with implementation of project objects included establishment of a monitoring network at different spatial scales to evaluate Container Nursery BMP’s at the watershed scale, denitrification wall efficacy at the groundwater and subtributary scale, container leaching studies at the plant container scale. PreBMP baseline monitoring was conducted at each scale to quantify nitrogen loads prior to BMP/denitrification wall implementation. Once the preBMP monitoring period was complete the nursery implemented feasible and appropriate BMP's by signing the Notice of Intent (NOI) to implement. Various changes in irrigation cycles were explored with the nursery owner and a "postBMP" regime was agreed upon and evaluated. A denitrification wall was constructed and groundwater and surface waters immediately downstream from the wall were evaluated. Activities associated with communicating findings to stakeholders consisted of presentations along with an on-site field day to demonstrate the various practices implemented.

2.1 PLANNED AND ACTUAL MILESTONES, PRODUCTS, AND COMPLETION DATES

This project had an original start date of April 2007 with original task timeline outlined in Table 2.0. However, due to matching funds for this project not being made available this effort was essentially in limbo for one year. During the second year of the project, a funding match became available, but only for six months before it was again withdrawn due to agency funding constraints. These early funding limitations were addressed by additional support from the Florida Department of Environmental Protection (FDEP) beginning in April of 2009. At that time the project was extended to October 2011, and task timelines reset to a start date to April 4, 2009 (Table 2.1).

Table 2.0. Original task timeline and deliverable dates referenced to an April 4, 2007 start time.

Task	Activity	Start	Complete
1	Implement groundwater monitoring wells and surface water monitoring stations	Month 1	Month 3
2	Design of controlled drainage, in-ditch denitrification, and denitrification wall	Month 1	Month 3
3	Construct controlled drainage, and in-ditch denitrification	Month 4	Month 5
4	Construct denitrification wall	Month 4	Month 4
5	Evaluate effectiveness of controlled drainage and in-stream denitrification	Month 5	Month 22
6	Evaluate effectiveness of denitrification wall	Month 5	Month 22
7	Evaluate cumulative effect on tributary water quality	Month 3	Month 22
8	Demonstration/education and training	Month 12	Month 22
9	Draft and final report	Month 22	Month 24

Table 2.1 New project timeline and deliverable dates referenced to April 4, 2009 start time.

Task	**Activity**	**Start**	**Complete**
1	Implement groundwater monitoring wells and surface water monitoring stations	Month 1	Month 3
2	Design of controlled drainage, in-ditch denitrification, and denitrification wall	Month 1	Month 1
3	Construct controlled drainage, and in-ditch denitrification	Month 2	Month 3

4	Construct denitrification wall	Month 3	Month 3
5	Evaluate effectiveness of controlled drainage and in-stream denitrification	Month 4	Month 30
6	Evaluate effectiveness of denitrification wall	Month 4	Month 30
7	Evaluate cumulative effect on tributary water quality	Month 1	Month 30
8	Irrigation optimization and controller feedback mechanisms	Month 1	Month 30
9	Demonstration/education and training	Month 12	Month 36
10	Draft and final report	Month 30	Month 36

Generally all project deliverable deadlines were met with the exception of Task 9, Demonstration/education and training and Task 10, Draft and final report deadlines. Delays in implementation of these tasks were mainly the result of project personnel and did not have anything to do with design flaws or monitoring infrastructure problems.

2.2 EVALUATION OF GOAL ACHIEVEMENT

This project has achieved multiple objectives that are relevant to the State of Florida's efforts to quantify the efficacy of BMPs, evaluate new technologies for nutrient load reduction and to educate stakeholders about implementation of these practices to minimize nonpoint source pollution. Specifically, this study successfully quantified the water conservation and reduced nutrient loss benefits of cyclical irrigation practices. Although the specific frequency and duration of a cyclical irrigation regime will be influenced in part by infrastructure limitations, the directional improvements resulting from this refinement in any irrigation system are clearly evident. This study successfully demonstrated a denitrification wall which clearly showed the nitrate reduction potential of this technology and how with proper site selection a very high level of treatment can be achieved at a very low amortized cost. This project also evaluated the overall nutrient load reduction potential of implementing applicable Container Nursery BMPs and although the full extent of load reduction achieved by BMP implementation does not yet appear to be fully realized based on the continued downward trend of nitrogen loads, significant reduction potential has been demonstrated.

2.3 SUPPLEMENTAL INFORMATION

This project is part of a larger demonstration effort to increase awareness and verify efficacy of Container Nursery BMPs. Container nurseries are a significant agricultural commodity in the State of Florida which can be a source of concentrated nutrient loads. Similar to other agricultural commodities, the container nursery industry has a suite of specific BMPs that have been tailored to their production system. A copy of the Container Nursery BMP manual can be found at http://bmp.ifas.ufl.edu/nurseries.shtml . This project has helped to quantify the potential reductions in nutrient loads that might be expected by implementing BMP's in this industry as well as increasing awareness of these BMPs among industry stakeholders.

The location of the project site is also located within the Santa Fe River watershed which has been verified a nitrate impaired. Load reduction strategies associated with this project have resulted in direct reductions from this tributary to the Santa Fe River as well as increased awareness of this issue to other regional stakeholders.

3.0 LONG TERM RESULTS IN TERMS OF BEHAVIOR MODIFICATION, STREAM/LAKE QUALITY, GROUNDWATER, AND/OR WATERSHED PROTECTION CHANGES

PostBMP and denitrification wall implementation monitoring indicates that significant reductions in nitrogen concentration and load have occurred in the tributary that discharges to the Santa Fe River. Specifically total nitrogen concentrations decreased from 7.6 ± 0.9 mg L^{-1} preBMP to 5.5 ± 0.7 mg L^{-1} postBMP, average flows decreased from 16.8 L s^{-1} preBMP to 8.44 L s^{-1} postBMP, and total nitrogen load decreased from 4,206 kg yr^{-1} to 1,525 kg yr^{-1} post BMP.

Although the specific cyclical irrigation regime evaluated during this project is not presently being implemented by the nursery owner due to infrastructure limitations, the concept of cyclical irrigation as a BMP compared to one time application for the benefits of water conservation and reduced nutrient leaching has been fully adopted by the grower and he is constantly adjusting his system to optimize water delivery and reduce nutrient losses. The nursery has also become much more aware of the connectivity between his nursery and downstream aquatic systems and often seeks advice when considering changes in irrigation, fertilizer or stormwater management. His experience and increased awareness of BMPs as well as demonstration of those BMPs evaluated in this study were presented to stakeholders during the field day with expectations of their similar adoption of practices into production systems.

4.0 BEST MANAGEMENT PRACTICES (BMPS) DEVELOPED AND/OR REVISED (FOR DEMONSTRAION PROJECTS)

Multiple BMPs were implemented as part of this project and were evaluated at different spatial scales. For this summary they will be broken down into four sections 4.1)BMPs associated with Notice of Intent, 4.2)Cyclical Irrigation Study, 4.3)Denitrification Wall and 4.4) Intercept Berm, conveyence Swale and Tailwater Pond.

4.1 BMPS ASSOCIATED WITH NOTICE OF INTENT

Prior to signing the NOI in November of 2006, the nursery indicated it was already implementing 128 of 153 candidate BMPs applicable to the operation (BMP checklist for the nursery was recreated from original NOI and is provided on Disk 1). Seven BMPs were planned for implementation in 2007 and 18 practices were deemed technically not feasible, economically not feasible, or that alternative measures were being used. Of the planned BMP's to be implemented in 2007, all were implemented with the exception of 1.D.1 Substrate Storage Area, which is and never was directly applicable relative to its primary purpose to protect substrate media that is premixed with fertilizer. The nursery does not premix fertilize in its media and instead applies all fertilizer as a top dress to the container.

For the purposes of this assessment we believe that of the "alternative measures being used" and one previously thought "not applicable" practice, BMPs listed in Table 4-0 were implemented to varying degrees in the nursery in conjunction with this monitoring effort. Therefore, any changes in nutrient load over the monitoring period are most likely the result of reductions related to implementation of these practices. Although alternative irrigation practices were being investigated as early as fall 2008, the earliest full implementation of these practices is considered to be January 1, 2009 with other practices implemented later in 2009 as indicated in table 4-1.

Table 4-1. List of candidate BMP's implemented in conjunction with this project and having an initiation date of January 1, 2009. Each practice is followed by a brief description of the practice as implemented in the nursery

1.B.1 Retain rainwater – intercept berm, swale and tailwater pond described in section 3.0. Practice implemented by October 1, 2009.

1.B.5 Buffers used – enhanced 25' undisturbed buffer or natural forested buffer around tributaries. Practice mostly implemented by January 1, 2009 and fully implemented by October 1, 2009.

1.D.2 Runoff captured – intercept berm, swale and tailwater pond described in section 2.0. Practice implemented October 1, 2009.

2.C.5 Minimize off-site nutrient loss – intercept berm, swale and tailwater pond described in section 2.0 and denitrificatoin wall described in section 4. Practice implemented October 1, 2009.

3.C.1 Fertilizer Rate – approximate 20% reduction in application of fertilizer to 15 and 30 gal nursery stock on microirigation. Practice implemented October 1, 2009.

6.A.5 Cyclic irrigation – applied to all nursery irrigation as described in section 2. Practice implemented January 1, 2009.

8.B.1 Water retained – intercept berm, swale and tailwater pond described in section 2.0. Practice implemented October 1, 2009

4.2 CYCLICAL IRRIGATION STUDY

During earlier investigations on the main tributary downstream from the nursery in 2005, it was evident that differences in baseflow between wet season and dry season were far less in that tributary than in another larger tributary in the valley directly to the east which went dry during several periods in the late spring of that year. At that time it was hypothesized that the persistent baseflow in the tributary during the dry season may be the result of excess irrigation from the nursery. For this reason a significant focus in this investigation was placed on evaluating irrigation practices and determining if alternative BMPs were possible to implement.

Although the majority of the container stock in the nursery by number of containers can be found in the 10 acres of overhead irrigation in the center of the nursery, most of the nursery area is under multi-zoned microirrigation (Figure 4.0). In the microirrigation area, 15 and 30 gallon containers are placed partially in the ground and irrigated with one 0.75 L min^{-1} emitter each. Prior to the summer of 2008, irrigation was applied once per day for 40-45 minutes providing an estimated volume of 30-33 L continaer^{-1} day^{-1}. Irrigation was applied daily between March and September. During the months of October through February irrigation frequency was phased back to every other day with duration of 20 min day^{-1} resulting in an estimated average application of 7.5 L continer^{-1} day^{-1}.

Figure 4.0 Areas of the nursery that are irrigated using overhead irrigation (red) and those areas using microirrigation (yellow). Inset photos are representative of the two irrigation practices as seen on the ground.

Container media used by the nursery is referred to as a “soil-less” media and is composed principally of ground pine bark with a blend of peat added to the mix. At the time of our investigation the peat content in the mix was 5%. One of the values of the “soil-less” mix is the low weight of containers due to the low particle density of the pine bark. However, due to the relatively large particle size of the ground pine bark, large pores are present in the media profile and preferential flow paths can develop. As a result of the media texture, providing a well wetted container during an irrigation event while minimizing discharge from the bottom of the container can be challenging.

Due to the well-drained surficial sands at the nursery and the fact that the containers are partially buried for stability, there was little visual evidence of over irrigation. However, after double potting several 15 gal nursery containers with a container that had no drainage holes allowing it to capture any water that flowed through the inner container during an irrigation cycle, it became clear that a significant amount of irrigation water was flowing through the container media during the one time application event.

It was decided that by distributing the number of irrigation events throughout the day instead of applying the full volume of water at one time, less overall water could be applied while improving the amount of water that was retained in the pot and ultimately available to the plant. After multiple combinations of duration and frequency were tried by the nursery, they settled on a 6 minute irrigation event duration applied 3 times per day.

This irrigation regime continued until some of the piping infrastructure began to fail (ruptured pipes) likely due to the rapid cycling of the valves and the distance between some of the pumps and irrigation zones. Part of the nursery’s solution was to install variable speed pumps to allow ramping up and down of pressure prior to valves opening and closing which decreases sudden changes in pressure within the piping infrastructure. However, the volume discharged by the emitter at the beginning and end of each irrigation event as pressure is ramped up and down is also decreased and therefore the duration of each irrigation event must be increased to provide for the same amount of water pre installation of the variable speed pumps. Assessment of the postBMP condition for this study was based on the 6 min duration x 3 application regime prior to variable speed pumps being installed in the system.

4.3 DENITRIFICATION WALL

Denitrification is a microbial process that mitigates nitrate-N pollution by reducing nitrate-nitrogen to N_2 or N_2O in hypoxic conditions utilizing an electron donor such as organic carbon. Several techniques have been utilized to increase the denitrification rate in agricultural effluent by adding a C amendment such as woodchips or sawdust. These include ‘denitrification beds’ and ‘denitrification walls’, both of which are termed denitrification bioreactors. Denitrification walls are traditional permeable reactive barriers (PRBs) inserted vertically into the ground to intercept groundwater flow. Denitrification is stimulated in these PRBs by adding an organic carbon amendment such as sawdust or woodchips to stimulate the denitrification process and reduce effluent nitrate-nitrogen concentrations.

Scaling-up denitrification walls for widespread application to reduce groundwater nitrate-nitrogen requires efficiently maximizing treatment area and volume. When denitrification walls are installed in aquifers with low porewater velocities, volumetric treatment rates are low and nitrogen limiting conditions are more likely to occur in a fraction of the groundwater flow-length within the wall. One technique to increase treatment efficiency is to deploy denitrification walls to target zones of high porewater velocities, such as adjacent to a ditch or in riparian areas where groundwater discharges to surface water. This will reduce the occurrence of N-limiting conditions and allow for high volumetric treatment rates and greater reductions in nitrate-nitrogen loading rates.

In this study, this concept was evaluated by the construction of a relatively large denitrification wall (168 m^3) approximately 14 m upgradient from a subtributary, which begins as a significant seepage discharge (Figure 4-1). The lowest depth of the wall was installed a few inches into the clay-rich aquatard to prevent groundwater bypass below the wall. The shallowest depth was 1.8 m above that at a height which for two years had been the highest water table measured within an adjacent well.

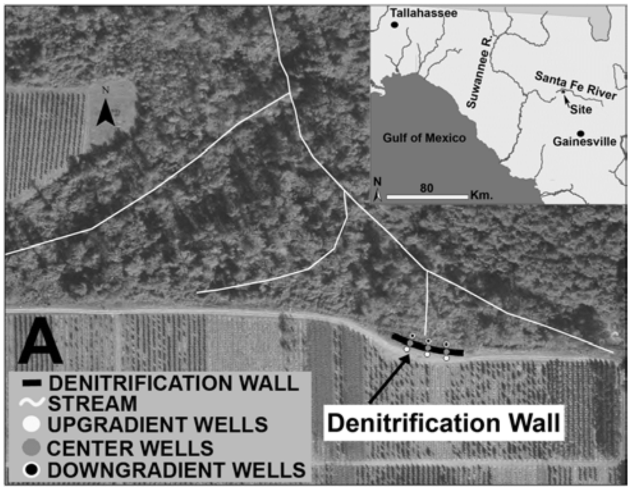


Figure 4-1. Location of the denitrificaiton wall relative to the rest of the nursery and tributary watershed.

The denitrification wall was constructed on September 30th, 2009. A washed and sieved quartz sand (Edgar Minerals, Inc., Edgar, Florida) was mixed with pine sawdust in a 1:1

ratio by volume (Figure 4-2). The sand and sawdust were mixed above ground, and then as soil and groundwater were excavated along the trench, the sand-sawdust media was rapidly placed in the excavated pit (Figure 4-3). The C content of the final sand-sawdust mixture was 7.4±0.7%. After construction, four subsamples were collected of the final mixture within the trench. The final dimensions of the wall were 55 m long, 1.7 m wide and 1.8 m deep (168 m^3) (Figure 4-4). After sand:sawdust media was installed, spoil material was used to backfill the remaining trench with minimal evidence of the subsurface wall remaining except for monitoring wells.(Figure 4-5)

Figure 4-2. Sawdust and sieved quartz sand stockpiled in preparation for mixing and additional to denitrification wall trench. Image in upper left is photo of 50:50 sand sawdust after mixing.

Figure 4-3. Excavation of denitrification wall trench (left) and backfilling with 50:50 sand:sawdust media (right)

Figure 4-4. Denitrification wall trench excavation and backfill with sand:sawdust media completed. Topsoil was later backfilled on top of the denitrification wall media.

Figure 4-5. Completed denitrification wall with groundwater well transects the only evidence remaining of subsurface wall below. Flow is from foreground to tree line in background.

4.4 INTERCEPT BERM, CONVEYANCE SWALE AND TAILWATER POND

As indicated in section 4.2, the majority of the nursery area is under microirrigation and only about 10 acres are under overhead irrigation. In addition, evidence of surface runoff is mostly absent throughout the nursery area mainly due to the well-drained surface soils; however, where there is evidence of regular surface runoff is in the area of overhead irrigation. This is likely facilitated by ground cloth used to suppress weeds, which although pervious, can reduces infiltration rates and will result in runoff during higher intensity rainfall events or when antecedent soil moisture conditions reduce infiltration capacity. Evidence from this study suggests that rainfall intensities over 0.25 in hr^{-1} are likely to result in runoff from the overhead irrigation area at this nursery.

PreBMP overhead irrigation was applied once daily for 45 minutes during the months of March through September. During the months of October through February irrigation frequency was cut back to every other day. Estimated irrigation rate per container (total irrigation volume/number of containers was 1.15 gal $container^{-1}$ day^{-1} (March-September) and 0.56 gal $container^{-1}$ day^{-1} October-February). PostBMP changes in overhead irrigation frequency and duration were implemented at the same time that changes in microirrigation frequency were conducted. Frequency and duration of postBMP overhead irrigation was similar to that of microirrigation evolving through several iterations in frequency and duration with the present cycle being 20 min and 10 min cycle applied daily or every other day depending on time of year.

Although these changes in irrigation event duration by distributing irrigation over several events will reduce the likelihood of irrigation related runoff, rainfall related runoff either independently or in conjunction with irrigation still pose a potential source of discharge to the tributary. In most cases runoff from the overhead irrigation area is directed through a vegetated buffer before it enters one of two subtributaries that border the area to the north and southeast (Figure 4-6). One exception to the buffer is a point of concentrated flows along the north side of the overhead irrigation area where an erosion gully was evident in 2006 and surface runoff from the overhead irrigation area was directly discharging to the subtributary (Figure 4-7).

In addition to runoff related concerns in the overhead irrigation area, a grow-out area to the east of the overhead irrigation area had poorly drained soils and in depressions where containers were typically placed to help stabilize the plants, water stayed saturated for extended periods of time. This area also had considerable runoff especially during storm events (Figure 4-8). The reason for the poor drainage and runoff was that this area was near the edge of the escarpment and surficial sands that provide good drainage in the rest of the nursery had eroded away and the underlying high clay content soils were closer to the surface. Since this area already had marginal production potential, an opportunity arose to use it to capture runoff from the overhead irrigation area and provide additional treatment before it was discharged to the tributary.

Although the area is relatively small and the slope of the area limited the extent to which a tailwater pond could reasonably be constructed, it was decided that interception of direct flows into the tributaries was critical to reducing storm event loads. Therefore, intercept berms and swales were constructed adjacent to the two subtributaries that would direct runoff to a tailwater pond for detention and treatment (Figure 4-9). In addition to pond treatment a seepage slope/wetland was added where pond water was discharged. Essentially this area was a vegetated filter strip but by regulating the release of water from the pond the area would maintain a saturated condition and facilitate nitrate-nitrogen removal through denitrification.

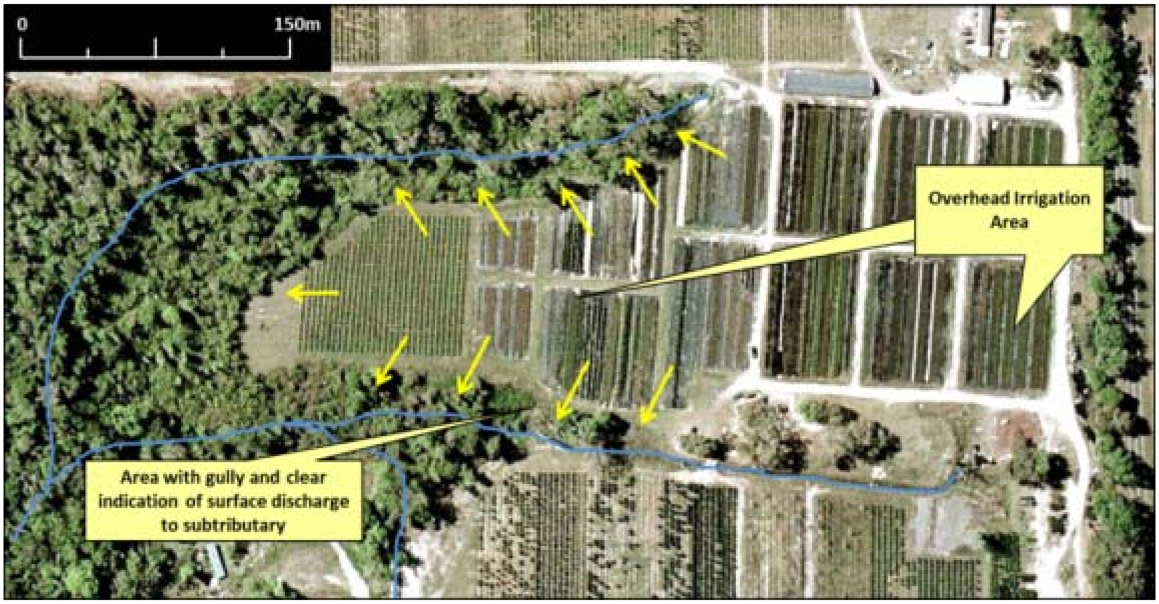


Figure 4-6. A 2006 aerial image of the nursery indicating the area of overhead irrigation where south in the image is to the top and north is to the bottom. Two subtributaries bracket much of the overhead irrigation area with flow vectors from the eastern portion of the area noted with yellow arrows through vegetated buffers before reaching the subtributary. An area where runoff from the overhead irrigation area discharges directly into the subtributary is noted.

Figure 4-7. Area of erosion and gully formation in the vegetated buffer to the northeast of the overhead irrigation area where surface runoff from overhead irrigation area (in background) was directly entering subtributary (in foreground).

Figure 4-8. Area where well-drained surficial sands that occur in much of the rest of the nursery were absent and lower permeability clay soils are near the surface. The area already had poor production due to almost continuously saturated soils. The area was converted into a tailwater detention and treatment area as part of the BMP implementation effort.

The surface area of the tailwater pond when full is 1,346 m^2 and holds 360 m^3 of water before overtopping at the spillway at a depth of 0.67 m. Once overtopped, discharge from the spillway travels 30 m across a vegetated filter strip and then an additional 40 m through a natural forested buffer before entering the tributary. Water detained by the tailwater pond is discharged at an average rate of 10 m^3 day^{-1} to a diffuser that distributes the discharge along a 35 m diffuser pipe and allows the water to seep across a 25 m long 500 m^2 area that is expected to further lower nitrate nitrogen levels. In addition, repair of the washed out vegetated buffer to the northeast of the overhead irrigation area and enhancement of vegetated buffers in areas not protected by the berm/swale were conducted.

Tailwater pond, intercept berm and swale practices as well as repair and enhancement of the vegetated buffer were completed by early October 2009 after which overland flows from the eastern half of the overhead irrigation area were intercepted by the berm and conveyed to the tailwater pond by the swale. The diffuser pipe and seepage area were not completed until March 2010 (Figure 4-10).

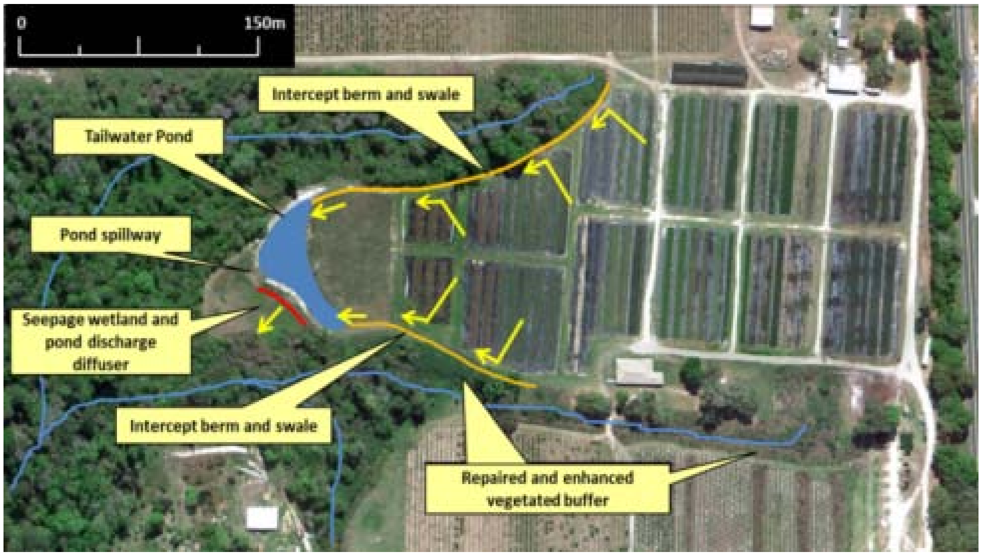


Figure 4-9. BMP modifications to surface discharge from overhead irrigation area. Post implementation, overland flow is intercepted by intercept berms and direct via a swale to a tailwater pond. Water detained in pond is released at a controlled rate to a seepage wetland and eventually flows back to the tributary.

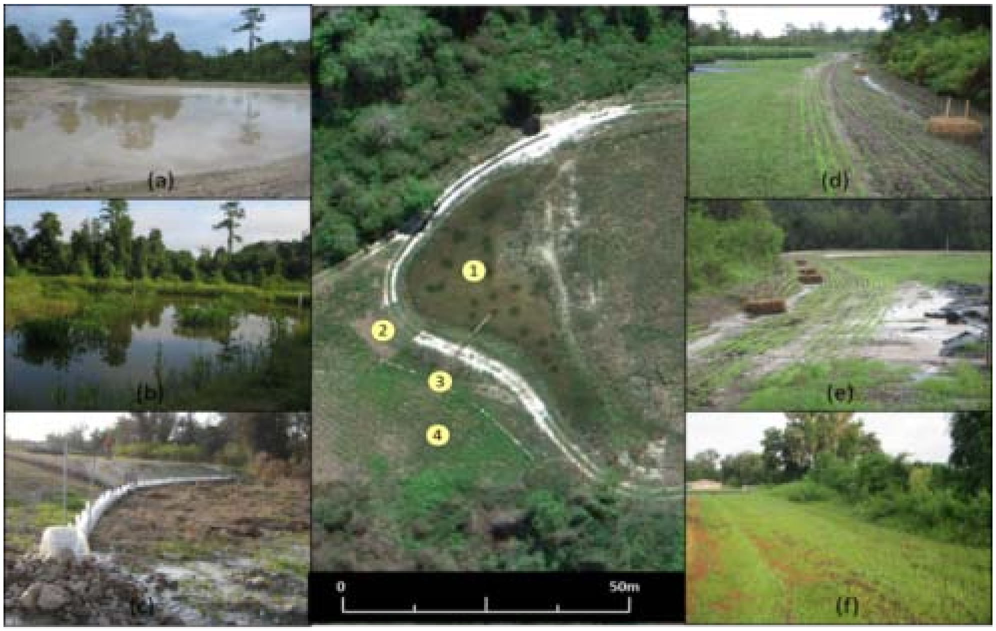


Figure 4.10. Images of BMP and other practices integrated into the overhead irrigation area to intercept and treat overland flows previously being discharged directly to the tributary or via vegetated buffers. Center image shows 1) tailwater pond, 2) spillway, 3) pond discharge diffuser pipe and 4) seepage slope/wetland area. Images starting in upper left show a) pond shortly after construction after first rainfall event (10/16/09), b) tailwater pond nine months after construction (7/26/10), c) tailwater pond discharge diffuser, d and e) intercept berm and swale on south and north side of overhead irrigation area shortly after construction (10/16/09) and f) north side berm and swale nine months after construction (7/26/10).

5.0 MONITORING RESULTS FOR DEMONSTRATION PROJECTS

Results of the demonstration projects will be discussion under their most appropriate subsections with a discussion of cyclical irrigation practices covered under section 5.1, effects of the denitrification wall and overall BMP implementation on surface waters discussed under section 5.2 and the effects of the denitrification wall demonstration on groundwater discussed under section 5.3. A more detailed discussion of all of these results can be found in Appendix A under technical report.

5.1 BMP EFFECTIVENESS EVALUATIONS

To assess the effectiveness of changes in irrigation practices, mainly from a single application to a cyclical application, three 24 hr irrigation events were monitored during the preBMP period (prior to 1/1/2009) and three events were monitored during the postBMP period (after 1/1/2009). During preBMP sampling 20, 15 gal containers were monitored, 10 each from two different irrigation zones. During the postBMP sampling 10, 15 gal containers were monitored, 5 each from two different irrigation zones. During monitoring events, growing containers were placed inside another container that did not have any drainage holes. After 24hrs, the container with plant and media were taken out of the outer container and allowed to completely drain. After all freewater had drained from the growing container into the capture container, the capture container and water were weighed and then preweighted container weight was subtracted to determine the flow-through water volume. Any flow-through water in the bottom of the container was then mixed and samples were collected and filtered for NO_x-N analysis or unfiltered for TP and TKN analysis. All samples were acidified with H_2SO_4, placed on wet ice and transported to the laboratory where they were analyzed in a NELAC certified laboratory.

In addition to planted containers, a second set of containers were deployed to collect irrigation water directly from the emitter. For this purpose the emitter from an adjacent container was pulled out and placed to direct any irrigation water into an empty container. After 24 hrs the container and water were weighted. This volume was used to estimate the inflow irrigation volume to the planted container that was being monitored. By pairing inflow volume from an adjacent emitter with flow-through volume of the planted container we believe the percent flow through volumes are more accurate than overall averages due to variability in emitter flow rate along each row. However, there are some instances where the percent flow-through volume is greater than 100% which reflects the variability between adjacent microirrigation emitters

Measured microirrigation volume applied prior to cyclical BMP implementation averaged 22.9 ± 2.42 L day^{-1} for the three 24 hour events sampled. After the new cyclical irrigation regime was applied, daily application volume decreased to 8.40 ± 3.74 L day^{-1} . As a result, the PostBMP irrigation regime reduced average flow-through volume in the container from 17.8 ± 2.81 L day^{-1} to 5.13 ± 2.67 L day^{-1} (Figure 5-0).

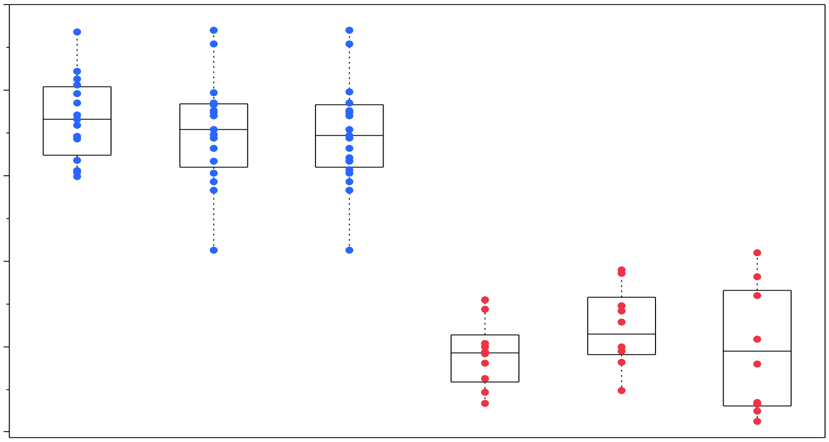


Figure 5-0. Flow-through irrigation volume collected during three sampling periods before cyclical BMPs were implemented (blue) and after cyclical application and lower volumes were implemented (red).

In addition to changes in irrigation regime pre vs. post BMP, a 20% reduction in the amount of slow release fertilizer applied to 15 gal containers was also implemented. Fertilizer applications were applied as a top dressing to containers by the nursery in February and August, with the August application applied prior to irrigation sampling events in this study.

Total nitrogen concentrations leached from the container under the preBMP irrigation and fertilizer regime averaged 26.0 ± 14.5 mg L^{-1} and postBMP averaged 22.2 ± 21.1 mg L^{-1}, a reduction of 14.6 % (figure 5-1). Approximately 67% of the TN concentration under preBMP conditions and 68% of the TN concentration under postBMP conditions was the result of Nitrate-nitrogen.

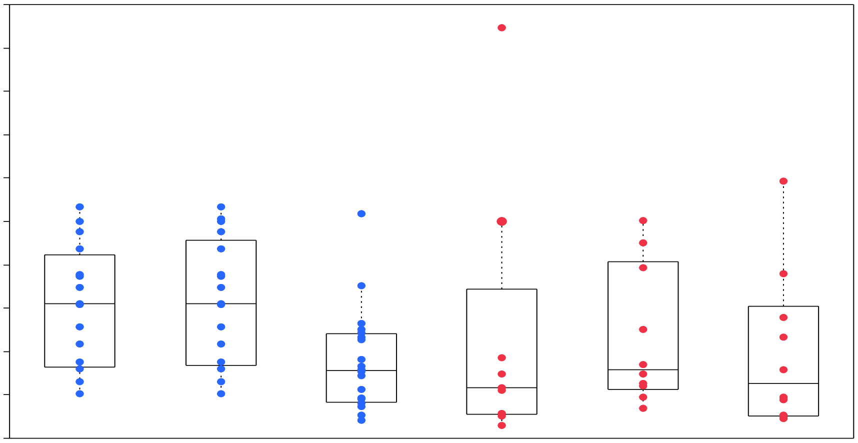


Figure 5-1. Total Nitrogen concentrations in irrigation flow through water under preBMP (blue) and postBMP (red) irrigation regimes and fertilizer application rate.

When combining reductions in irrigation flow-through volume and nutrient concentrations we can determine overall nutrient load reductions as a result of the preBMP vs. postBMP irrigation regime. Overall nitrogen loads at the container scale were reduced by 78.8% as a result of integrating cyclical irrigation practices, reduced irrigation volume and reduced fertilizer application rate with loads decreasing from 454 ± 251 mg container^{-1} day^{-1} under preBMP conditions to 96.2 ±78.0 mg container^{-1} day^{-1} under postBMP conditions (Figure 5-2). A summary of reductions in container flow-through volume, container flow-through nutrient concentration and container flow-through loads preBMP vs. postBMP is provided in Table 5-0

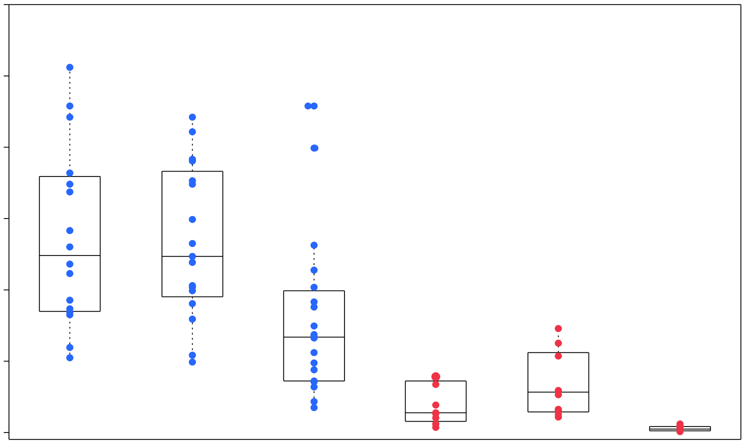


Figure 5-2. Total Nitrogen loads in irrigation flow through water from 15 gal containers under preBMP (blue) and postBMP (red) irrigation regimes and fertilizer application rate.

Table 5-1. Summary table of PreBMP and Post BMP flow-through volume, nutrient concentration and loads.

	30 min x 1 application	6 min x 3 applications	% reduction
Irrigation applied	22.9 ± 2.42	8.40 ± 3.74	63.3
Flow-through, L	17.8 ± 2.81	5.13 ± 2.67	71.2
Flow-through, % of irrigatic	87.2 ± 12.8	59.4 ± 17.8	31.9
Flow-through concentration			
TP, mg L^{-1}	4.63 ± 3.77	4.14 ± 4.09	10.6
NOx-N, mg L^{-1}	17.5 ± 11.9	15.1 ± 17.4	13.7
TKN, mg L^{-1}	8.46 ± 5.04	7.06 ± 7.84	16.5
TN, mg L^{-1}	26.0 ± 14.5	22.2 ± 21.1	14.6
Flow-through mass			
TP, mg day^{-1}	80.2 ± 65.3	29.0 ± 40.0	63.8
NOx-N, mg day^{-1}	306 ± 207	57.6 ± 46.7	81.2
TKN, mg day^{-1}	148 ± 82.1	38.6 ± 41.1	73.9
TN, mg day^{-1}	454 ± 251	96.2 ± 78.0	78.8

5.2 Surface Water Improvements

5.2.1 Surface Water Improvements Resulting from Denitrification Wall

To determine the influence of the denitrification wall at the watershed scale, surface water discharge, stream N concentration and N loads were monitored before and after wall installation in two catchments, which drain almost entirely from the property. Surface water monitoring was conducted within a ‘treatment’ tributary that was affected by denitrification wall installation and a ‘control’ watershed with similar land-use, climate, hydrology, fertilizer applications and N concentration that should not be affected by the wall (Figure 5-3).

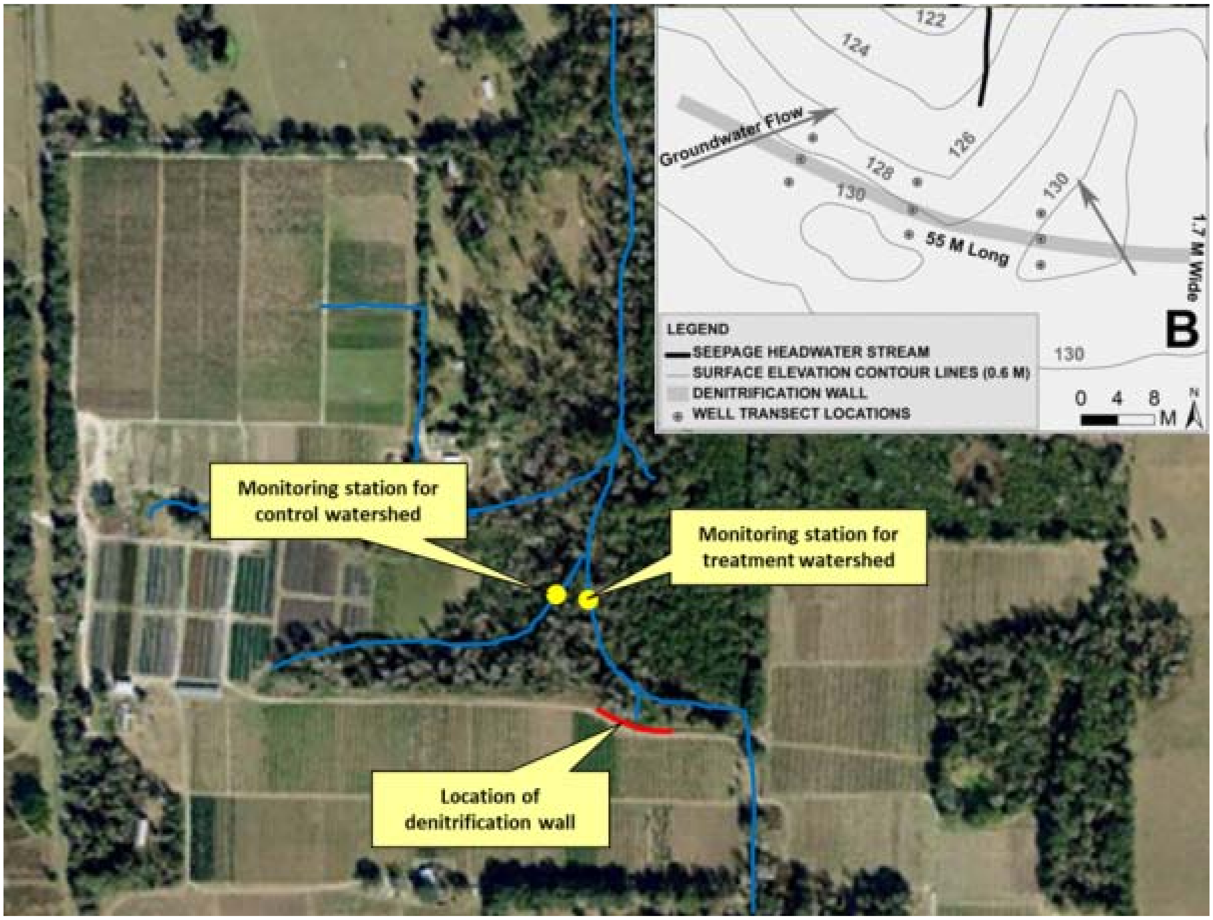


Figure 5-3. Aerial image of nursery indicating the location of the denitrification wall and treatment and control watershed monitoring stations. Inset image in upper right (B) is a scaled drawing delineating the denitrification wall location and the receiving seepage headwaters stream.

To measure discharge within the treatment and control catchments, stream flows were controlled by installing weirs spanning the entire stream bank width. The weirs were a compound v-notch design, where baseflow discharged through a v-notch and short duration high flow events discharged through the v-notch and a larger compound rectangular weir (Figure 5-4). The water head above the bottom of the stream bank was measured every second and reported as a 5 minute average with pressure transducers (Instrumentation Northwest Inc., Kirkland, Washington) and recorded in dataloggers (Campbell Scientific, Logan, Utah). Discharge was calculated from head measurements with equations programmed in to the datalogger. The discharge equations and weir installation design all proceeded following standard protocols outlined in USBR (2001).

Figure 5-4 Compound weirs used to monitor the treatment watershed (left) and the control watershed (right)

The relationship between stage and discharge for the v-notch portion of these weirs was determined using the Kindsvater-Shen equation as described in USBR (2001).

In this equation, was the discharge through the v-notch weir [L^3 T^{-1}], was the v-notch angle (90°), was the gravitational acceleration constant [L T^2], was the effective coefficient of discharge reported in Kulin et al. (1975), which was a function of v-notch angle only ( ), and was the effective head [L] calculated from the following equation.

For this equation, was the head above the bottom of the v-notch [L], and was a constant reported in Kulin et al. (1975), which is a function of v-notch angle only ( ). Flows through the rectangular portion of the weir were calculated using the Kindsvater-Carter equation (Kindsvater and Carter, 1959; USBR, 2001).

The variable, was the discharge through the rectangular portion of the weir only excluding the v-notch flows [L^3 T^{-1}], was the effective coefficient of discharge, which is a function of constant weir geometry and the measured head above the rectangular notch ( ), was the effective weir length and was the effective head. The effective coefficient of discharge was calculated using the following equation from USBR (2001).

—

In this effective coefficient of discharge equation, was the head value above the bottom of the rectangular notch as measured by the transducer, was the distance from the stream bottom to the bottom of the rectangular notch, was an equation coefficient and was an equation constant. The equation coefficient ( ) and equation constant ( ) are based on empirical relationships as a function of weir crest length ( ) divided by the stream bank width (USBR, 2001). The effective weir length was calculated with the following equation.

The variable, was the weir crest length [L], was a correction factor reported in USBR (2001). The effective head was quantified with an equation of the following form.

In this equation, was a correction factor reported in USBR (2001). When water was discharging through the larger rectangular portion of the weir, flows through the v-notch were calculated as a fully contracted orifice flow using a standard orifice flow equation (USBR, 2001).

In this equation, was the effective coefficient of discharge which was determined empirically from site calibration as recommended in USBR (2001), was the surface area of the v-notch orifice, and was the head of water above the midpoint of the v-notch orifice. When water was flowing through the v-notch portion alone, the discharge was calculated as only. When the stream was discharging through the v-notch and rectangular portion of the weir, the discharge was calculated as + .

Based on these discharge measurements, discharge-weighted water samples were collected in an autosampler (Teledyne ISCO, Inc., Lincoln, Nebraska) at programmed stream discharge volumes into pre-acidified bottles. Samples were removed from the autosampler weekly, filtered if applicable, refrigerated and analyzed within 28 days. For the first 163 days of sampling, approximately 15-20 flow-weighted samples per week were collected depending on discharge. These high-frequency flow-weighted samples were composited in to 5 sample increments for an N-load reporting frequency of 3-4 times per week. For the remainder of the monitoring, flow-weighted samples were collected at the same frequency and resolution but composited in to one weekly sample, which gave the exact same weekly average load as the previous method. Stream discharge, N concentration and N load were monitored for approximately 62 days before wall installation and for approximately 448 days after wall installation. In addition to the flow-weighted samples, grab samples were collected (*n*=34) beginning in October, 2008 for 290 days before monitoring of the discharge sampling station began (August, 2009). This extended the N concentration record before the wall was installed to 352 days. Grab samples were also collected one month before installation (*n*=5) and for five months after installation (*n*=24) in the stream, immediately at the seepage headwaters which was located 14 m from the denitrification wall. Grab samples were carefully collected from the middle of the water column, minimizing sediment disturbance and were immediately filtered if applicable and refrigerated.

Flow-weighted and grab samples were analyzed for nitrate and total Kjeldahl N (TKN). Unfiltered samples were digested with a block digestion and subsequently analyzed colorimetrically for TKN on an autoanalyzer (Seal Analytical, West Sussex, UK). Nitrate samples were prepared by filtering through a 0.45 μm membrane filter (Pall Corporation, Port Washington, NY) and then analyzed colorimetrically after reduction in a cadmium column on an autoanalyzer (Seal Analytical, West Sussex, UK). Nitrogen load was calculated by multiplying the sum of nitrate and TKN (Total N) measured from the water sample [$M\ L^{-3}$] by the discharge between samples [$L^3\ T^{-1}$]. Statistically significant differences in N concentration and load in the two streams before and after denitrification wall installation were determined with a t-test. A change point analysis was done on N concentration and load to determine statistically significant changes in these values at an alpha level of 0.05 with the Change-Point Analyzer© software (Taylor Enterprises, Inc.).

Rainfall was measured with a tipping bucket and potential evapotranspiration was determined using the REF-ET software (Allen, 1999) as a turfgrass reference with the Penman-Monteith equation based on on-site measurements for solar radiation, air temperature and wind combined with a relative humidity probe (Campbell Scientific, Logan, Utah).

The treatment stream receiving discharges from the denitrification wall and an adjacent control stream (Figure 5-5) were monitored before and after wall installation to detect and quantify changes in N concentration and load due solely to the wall installation. While no two watersheds are exactly the same in hydrology or N concentration, these two watersheds are sufficiently similar to merit comparison. The two streams discharged from immediately adjacent watersheds whose major headwaters are separated by less than 500 m As such they both shared very similar climates. Both watersheds were almost entirely under the same land-use (container-plant nursery) and fertilizer was applied at the same time of year to both watersheds. Most significantly, before the wall was installed, the relationship in discharge and N concentration between the two streams was strongly correlated justifying their comparison (Figure 5-6).

All results are reported as total N ± 1 standard deviation, which was the sum of measured nitrate and TKN. TKN only averaged 0.7±0.4 and 0.8±0.4 mg L^{-1} in the control and treatment streams respectively and this concentration did not significantly change after the wall was installed. Before the denitrification wall was installed, total N concentrations were stable in both the treatment and control streams and no significant change points occurred (Figure 5-7). After the wall was installed, the N concentration in the treatment stream immediately diverged from the control stream, and the first change point occurred in the treatment stream 2 days after the wall was installed. Due to the fact that the detention time of the denitrification wall in groundwater was reported in as 1.7 – 1.9 days, this was strong confirmation of the denitrification wall's immediate impact. Subsequent change points occurred when the concentration appeared to partially rebound higher and then stabilized at an intermediate concentration over the duration of the study. This was plausibly due to an initially high concentration of soluble and labile C sources when the wall was first installed, which instigated elevated N removal rates. After these labile C sources were depleted, the N removal rates appeared to have stabilized at a new equilibrium, utilizing consistent C sources.

Long-term studies of denitrification walls have indicated that N removal rates stabilized after one year of operation and were predictive of long-term rates (Robertson et al., 2000; Schipper and Vojvodic-Vukovic, 2001; Jaynes et al., 2008, Schipper et al., 2010b). Removing this period of

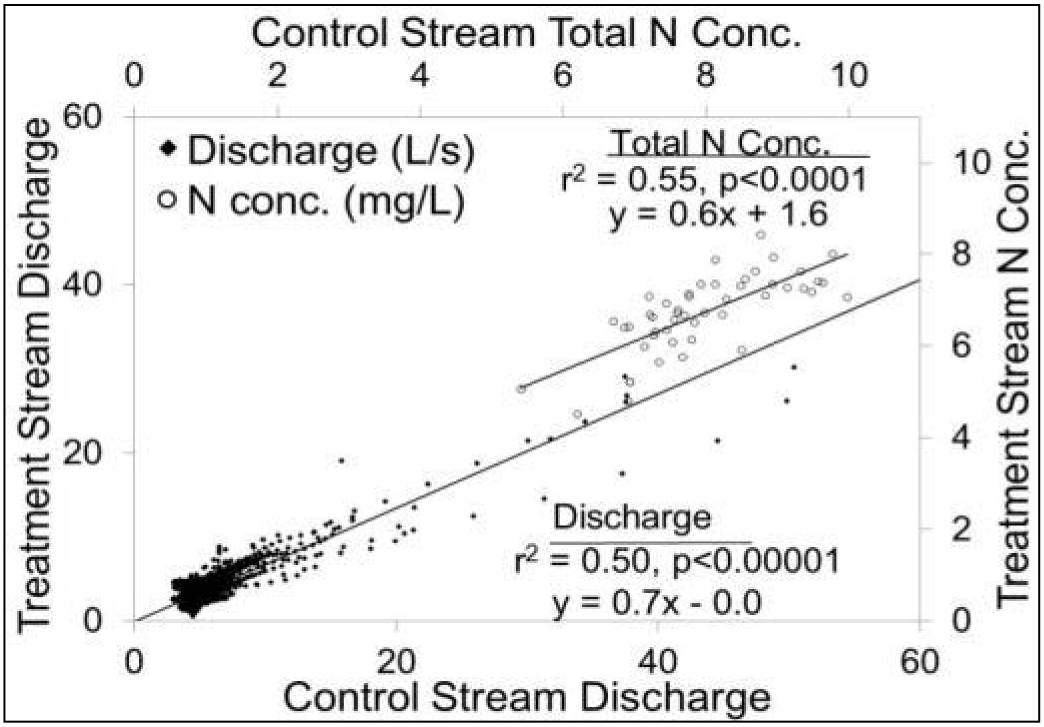


Figure 5-5. The correlation between discharge and N concentration between the control and treatment stream. The correlation between discharge and nitrogen concentration between the two streams was strongly significant, justifying their comparison.

temporarily high N reductions, the total N concentration significantly declined from 6.7±1.2 mg L^{-1} in the 352 days before wall installation to 3.9±0.78 mg L^{-1} in the period after the last change point only. The concentrations observed in the treatment stream after wall installation had no significant overlap with concentrations measured before wall installation across the range of discharges (Figure 5-8). This indicated that the concentration reduction in the treatment stream was robust and exhibited stationarity across a variety of discharges. Additionally, the relatively even N concentration across a range of stream discharges indicated that the wall was not strongly affected by corresponding increases in groundwater discharges and subsequent decreases in detention time (Figure 5-8). This conclusion was strengthened by the fact that in section 4.2 we found that all nitrate traveling through the denitrification wall was removed long before discharging from the denitrification wall.

No change points were detected and no subsequent decline was apparent in the control watershed, which significantly increased from 7.4 ± 0.91 mg L^{-1} (n=70) before construction to 7.9 ± 0.78 mg L^{-1} (n=109) after construction (Figure 5-7). The concentration measured in the

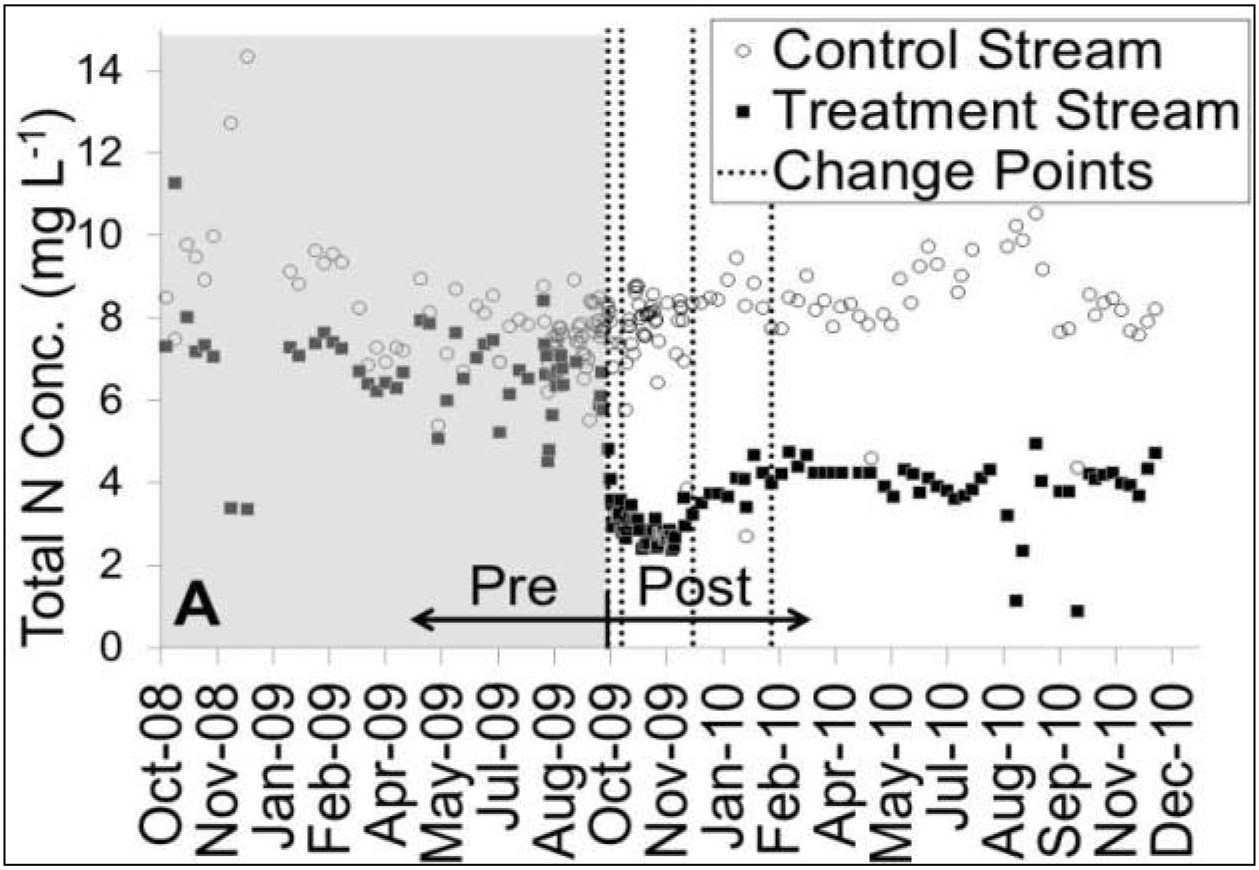


Fig 5-6 Total Nitrogen concentrations in the control and treatment stream before (Pre) and after (Post) wall installation with significant change points indicated

control stream before and after wall installation strongly overlapped across the range of discharges measured (Figure 5-8). Lastly, the N concentration relationship between the control and treatment streams had measurably shifted, thus confirming the response in the treatment stream only (Figure 5-9).

Corresponding to the N concentration reductions, the N load significantly declined in the treatment stream. Before wall installation, the daily total N loading rate within the treatment stream was 1.5 ± 0.32 kg day^{-1} (*n*=20) (Figure 5-10). Similarly to N concentration, the initial two-month decline in loading rate was quite high and significantly decreased to 0.39 ± 0.51 kg day^{-1} (n=70). Mass loads of any constituent are very strongly driven by discharge. It was therefore difficult to extrapolate the impact of the denitrification wall on N loading beyond the initial period after construction because seasonal shifts in precipitation and evapotranspiration over longer time frames modified discharge and thus stream N load (Figure 5-11).

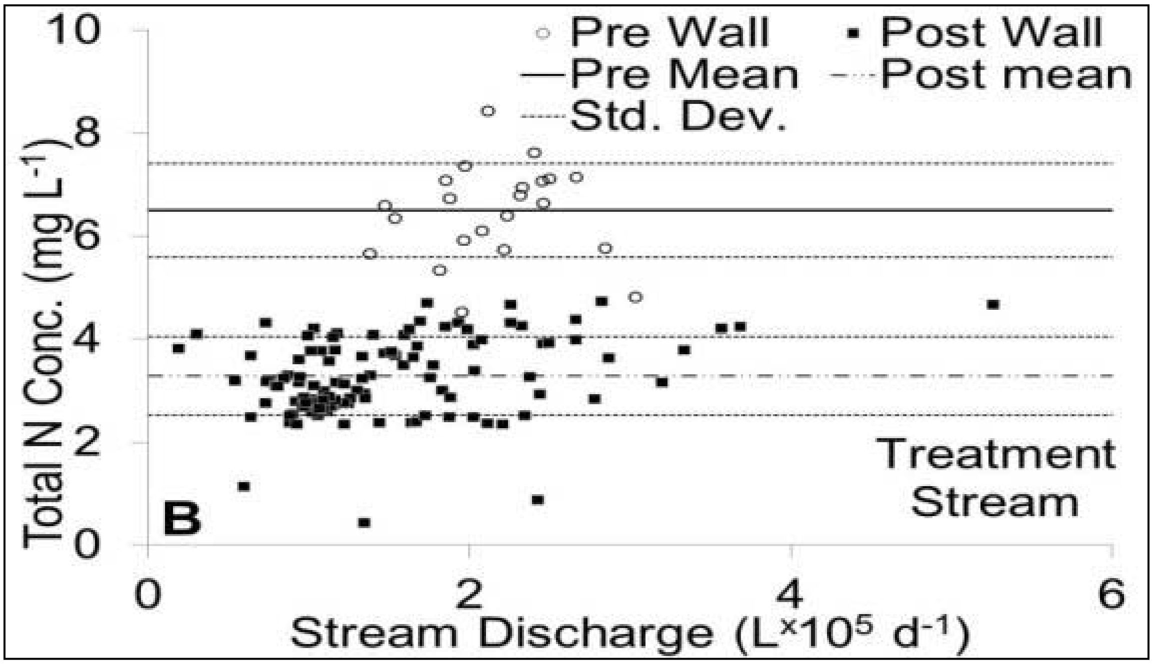


Figure 5-7 Total Nitrogen concentrations across the range of discharges measured for the treatment stream.

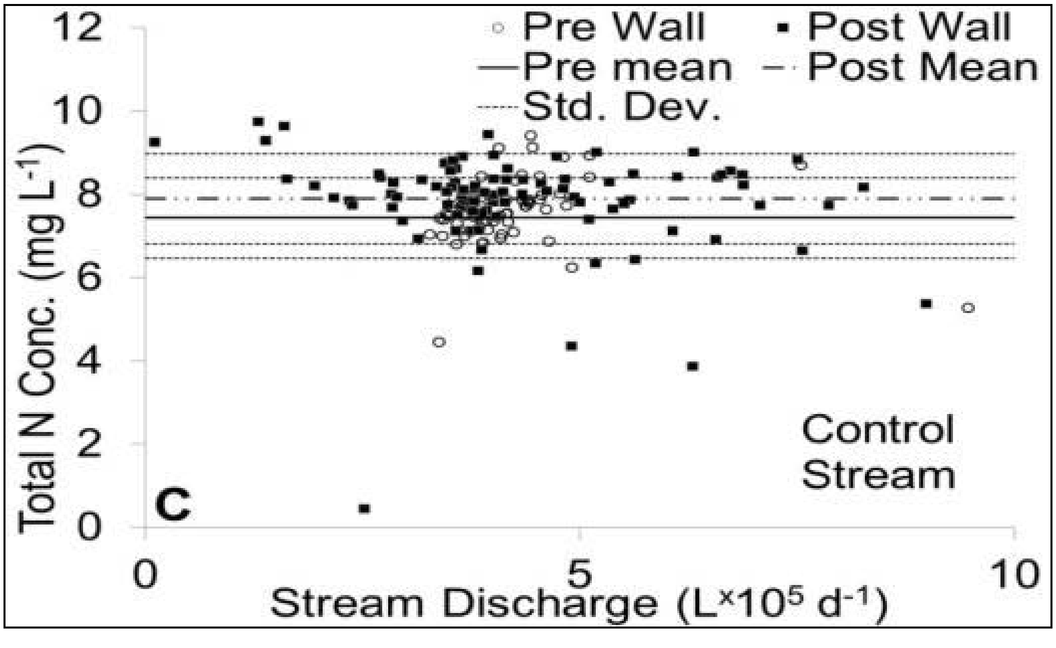


Figure 5-8 Total Nitrogen concentrations across the range of discharges measured for the control stream.

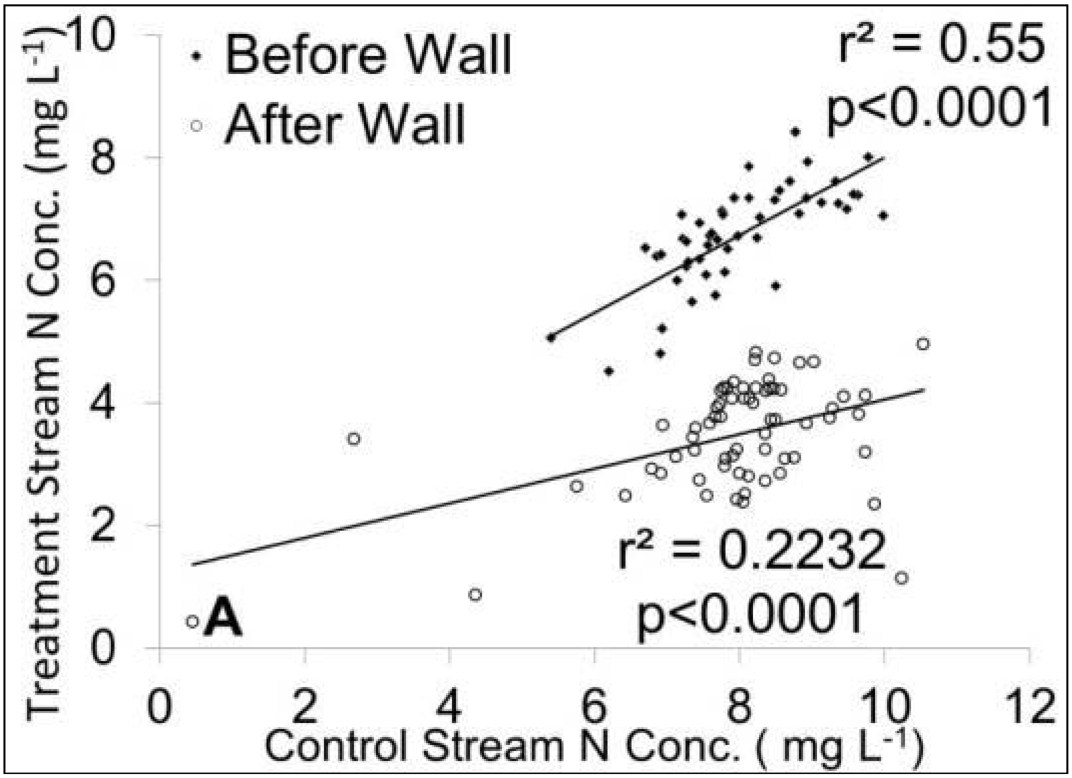


Figure 5-9. Total Nitrogen concentration correlations between the Control and Treatment stream before (Pre) and after (Post) wall installation.

Unfortunately as the change point analysis of N concentration revealed, the initial N reductions were temporarily elevated and after three months they stabilized at a new equilibrium. An analysis of the climatically similar periods before and immediately after the wall was installed would likely yield artificially high estimates of long-term load reduction. Nitrogen loading rate over the entire 15 month monitoring period after wall installation was significantly decreased to 0.82 ± 1.59 kg day^{-1} (n=119). Much of the higher N load during this period was driven by the regular, seasonal shifts in evapotranspiration between the hot summers in Florida when stream discharge is generally low and the periods of lower evapotranspiration which increases discharges in winter (Figure 5-11). Additionally, N loading increased during the winter months, largely due to a 50-year storm in January (Figure 5-11). Although the consistent decline in N concentration (Figure 5-6) which occurred across the range of discharges measured (Figure 5-7), indicated that N loads would have been significantly higher regardless of discharge had the wall not been installed. While these seasonal shifts are a normal part of the hydrology that the denitrification wall will experience, specifically quantifying an N load reduction was made difficult with such a short record, especially with incomplete overlap in seasons from sampling periods before and after wall installation.

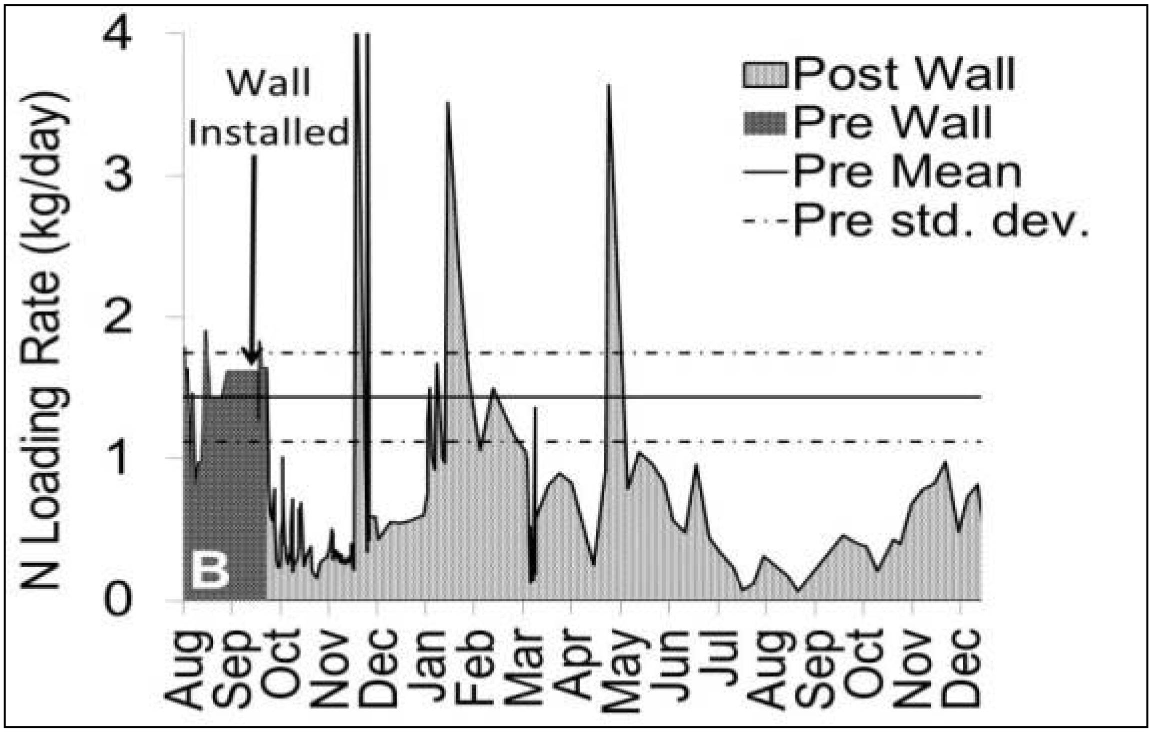


Figure 5-10 Nitrogen load in the treatment stream before and after wall installation

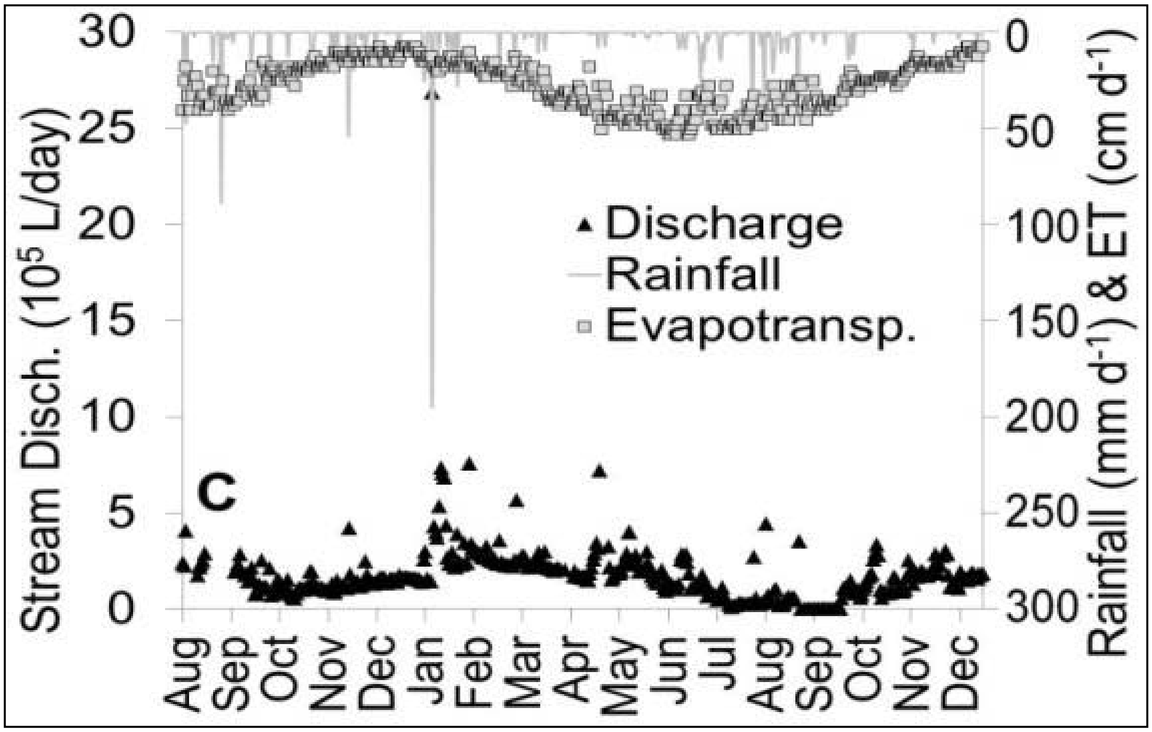


Figure 5-11 Watershed rainfall, evapotranspiration and stream discharge of the treatment stream during the period of record.

One method for discerning long-term rate reductions was to compare the same seasons before and after wall installation, when hydrology was comparable. During a subsequent summer/fall period one year after wall installation, when there was no significant difference in rainfall, evapotranspiration or discharge from the previous year, the total N loading rate in the treatment watershed was 0.52 ± 0.26 kg day^{-1} (n=15). Comparing this stabilized N loading rate a year after construction to the same time of year before wall construction (1.46 ± 0.32 kg day^{-1}), indicates a significant cumulative N load reduction of 65% for an average load reduction of approximately 340 ± 130 kg of N per year at least during this time of year.

5.2.2 Surface Water Improvmenets Resulting from Implementation of Container Nursery BMPs Including Denitrification Wall

To determine the influence of best management practices at the watershed scale surface water discharge, stream N concentration and N loads were monitored from October, 2008 to July 2011. To measure discharges, stream flows were controlled by installing a weir spanning the entire width of the stream bank. The weir located at the “SW1 sampling station” (Figure 5-12) is a compound rectangular weir (Figure 5-13).

Figure 5-13. Location of main monitoring station (SW1) used to assess overall efficacy of BMP implementation.

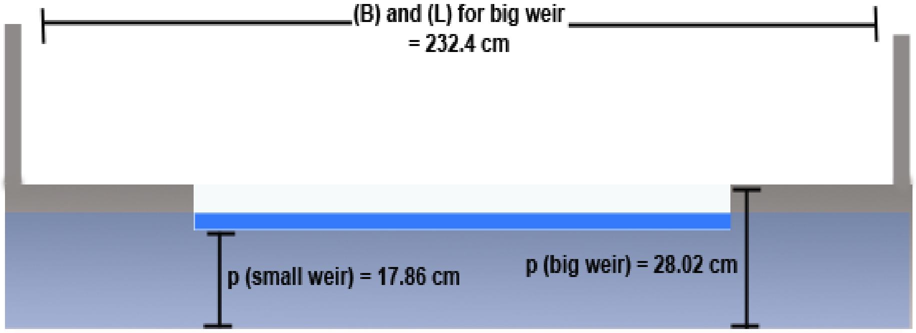


Figure 5-12. Two photos of the SW1 wier at baseflow (left) and moderate stormflow (right). Diagram (bottom) showing the dimensions of the weir at the SW1

For this weir, the Kindsvater and Carter (1959) equation was used to calculate discharge based on the stage measured. The Kindsvater and Carter equation is shown in Equation [1]:

$$Q = C_e L_e h_{1e}^{3/2} \qquad [1]$$

Where

Q = Discharge (ft^3/s)

L_e = Effective weir length (ft).

h_{1e} = Effective head (ft).

C_e = effective coefficient of discharge ($ft^{1/2}/s$).

The effective weir length (L_e) was calculated utilizing Equation [2].

$$L_e = L + k_b \qquad [2]$$

Where

L = Weir crest length (ft)

k_b = a correction factor equal to 0.01 ft for the small weir and 0 ft for the big weir.

The effective head (h_{1e}) was calculated with Equation [3].

$$h_{1e} = h_1 + k_h \qquad [3]$$

Where

h_1 = The head value measured from the top of the weir (ft)

k_h = A correction factor with a value of 0.003 ft.

The effective coefficient of discharge was calculated based on Equation [4].

$$Ce = C_1(h_1/p) + C_2 \qquad [4]$$

Where

h_1 = The head value measured from the top of the weir (ft).

p = The distance from the stream bottom to the bottom of the weir (ft). The value is 0.586 ft for the small weir and 0.919 ft for the big weir.

C_1 = Equation coefficient (A function of the weir crest length (L) and the Bank Width (B) shown below).

C_2 = Equation constant (A function of the weir crest length (L) and the Bank Width (B) shown below).

The coefficient (C_1) and the constant (C_2) are measured based on published empirical relationships. These coefficients are a function of the ratio of the weir crest length (L) divided by the bank width (B). For the smaller rectangular portion of the weir the ratio is 0.53 and for the larger rectangular portion of the compound weir the L/B ratio is 1.0. The C_1 and C_2 values used for the small weir are thus 0.0612 and 3.173 respectively and for the big weir the C_1 and C_2 values used are 0.4 and 3.22 respectively.

When the water is flowing through the smaller rectangle, the discharge is calculated normally. When the water is flowing through the larger weir and the smaller weir at the same time, the larger weir is treated as if it were a single weir and the discharge through the smaller weir is calculated as a fully-contracted orifice flow utilizing the equation shown in Equation [5].

$$Q = C_e A (2gh)^{1/2} \qquad [5]$$

Where

Q = Discharge through the orifice (ft^3/s)

C_e = Effective coefficient of discharge equal to 0.61 for a fully contracted weir.

A = Surface area of orifice. Equal to 1.33 ft^2.

g = Acceleration due to gravity (ft/s^2)

h = Head of water from the midpoint of the orifice (ft).

The stage discharge relationship for SW1 developed from these equations is shown in Figure 5-13.

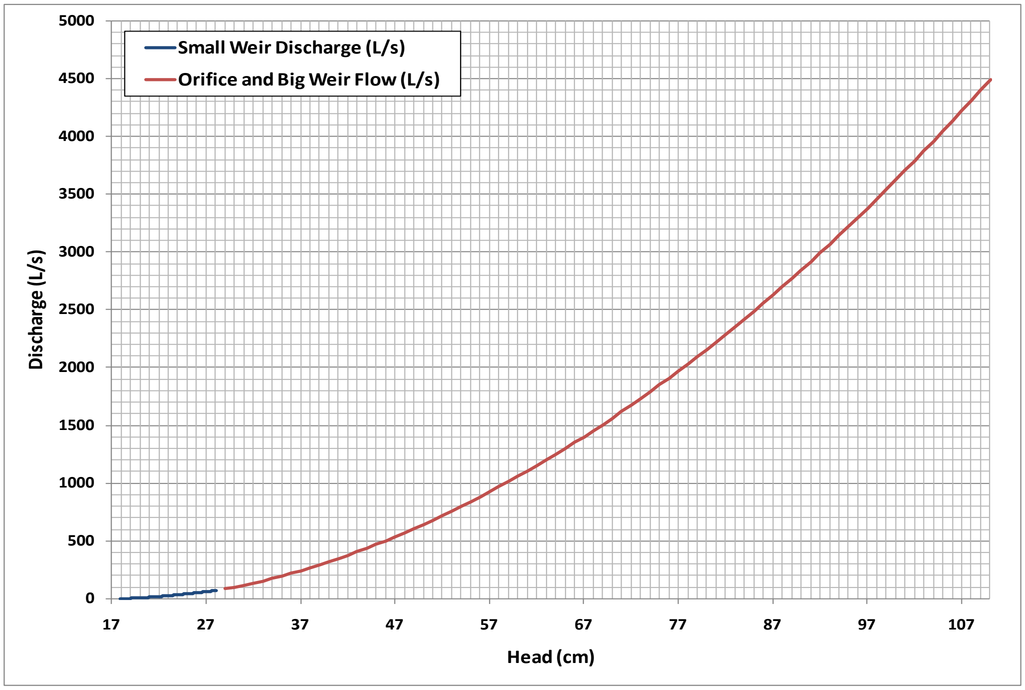


Figure 5-13 – The stage-discharge relationship for the SW1 weir. The flow through the lower rectangular weir (small weir) and the combination of orifice flow and upper rectangular weir (big weir) are indicated.

Based on these discharge measurements, discharge-weighted water samples were collected in an autosampler (Teledyne ISCO, Inc., Lincoln, Nebraska) at programmed stream discharge volumes into pre-acidified bottles. Samples were removed from the autosampler weekly, filtered if applicable, refrigerated and analyzed within 28 days. For the first 638 days of sampling, approximately 28 flow-weighted samples per week were collected depending on discharge. These high-frequency flow-weighted samples were composited in to 5 sample increments for an N-load reporting frequency of 7 times per week. For the remainder of the monitoring (385 days), flow-weighted samples were collected at the same frequency and resolution but composited in to one weekly sample, which gave the exact same weekly average load as the previous method. In addition to the flow-weighted samples, grab samples were collected (*n*=19) beginning in May, 2004 and ending in October, 2007. Grab samples were carefully collected from the middle of the water column, minimizing sediment disturbance and were immediately filtered if applicable and refrigerated.

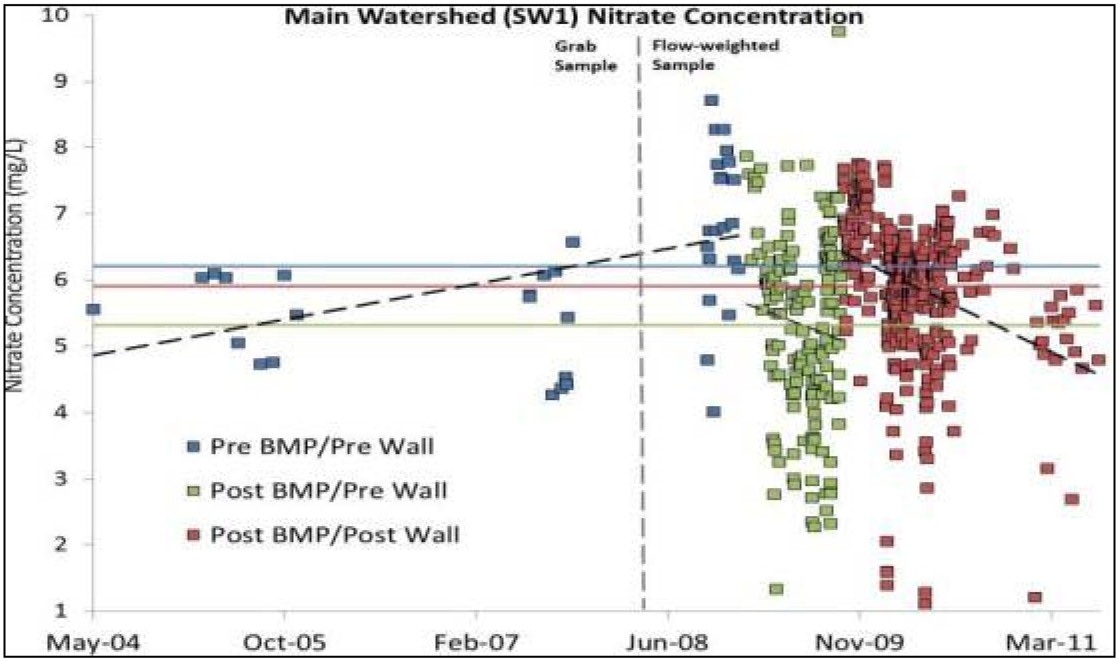
Flow-weighted and grab samples were analyzed for nitrate and flow-weighted samples were additionally analyzed for total Kjeldahl N (TKN). Unfiltered samples were digested with a block digestion and subsequently analyzed colorimetrically for TKN on an autoanalyzer (Seal Analytical, West Sussex, UK). Nitrate samples were prepared by filtering through a 0.45 μm membrane filter (Pall Corporation, Port Washington, NY) and then analyzed colorimetrically after reduction in a cadmium column on an autoanalyzer (Seal Analytical, West Sussex, UK). Nitrogen load was calculated by multiplying the sum of nitrate and TKN (Total N) measured from the water sample [$M\ L^{-3}$] by the discharge between samples [$L^3\ T^{-1}$].

Rainfall was measured with a tipping bucket and potential evapotranspiration was determined using the REF-ET software (Allen, 1999) as a turfgrass reference with the Penman-Monteith equation based on on-site measurements for solar radiation, air temperature and wind combined with a relative humidity probe (Campbell Scientific, Logan, Utah).

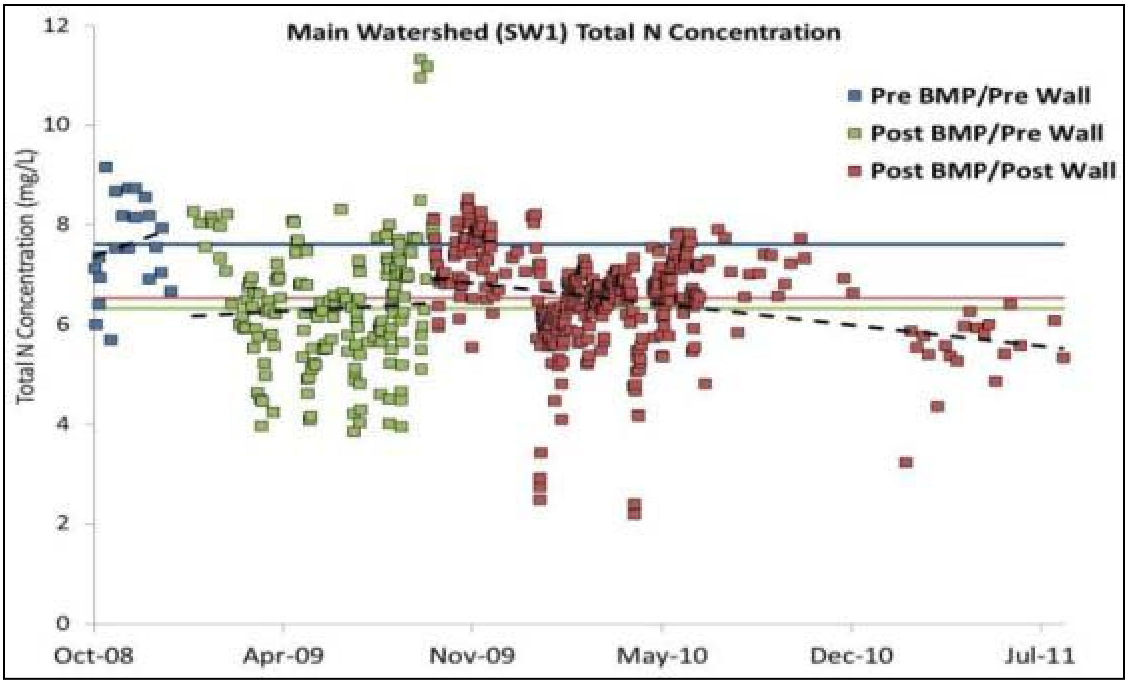
Prior to BMP implementation, the nitrate concentration was steadily increasing within the watershed (Figure 5-14). Declining trends in nitrate concentration occurred after BMP implementation. Total nitrogen was only analyzed on flow-weighted samples beginning in October 2008. Total N was increasing before BMP implementation and average concentrations decreased after BMP implementation.

Based on N concentrations towards the end of the sampling period in 2011, it is clear that the total N and nitrate-N concentrations continue to decline. It is possible that further reductions will be observed in nitrogen concentration over longer time periods after BMP implementation. Because much of the surface soils of the property are well-drained, much of the high nitrogen waters which are leaching below the containers, enters a pool of shallow groundwater. This shallow groundwater slowly discharges to surface waters. Therefore, it is likely that there will be a delay in N reductions within stream discharges after BMP implementation.

Based on measurements in a series of periphery groundwater wells, the average time for groundwater under the nursery to completely discharge to surface waters (assuming plug flow) ranges from approximately 380-870 days (Figure 5-15). Although a plug-flow assumption is overly simplistic and results in shorter time than what would actually occur with mixed exchange, these values illustrate the point that nitrogen concentrations being monitored at SW1



(A)



(B)

Figure 5-5. Nitrate-Nitrogen (A) and Total Nitrogen (B) concentration over time at the main watershed sampling station (SW1). Shown in the figure are averages before and after BMP implementation and denitrification wall installation, as well as period averages (horizontal colored lines) and period trendlines (black dashed lines).

do not yet fully reflect the nutrient load reductions that have likely resulted from BMP implementation.

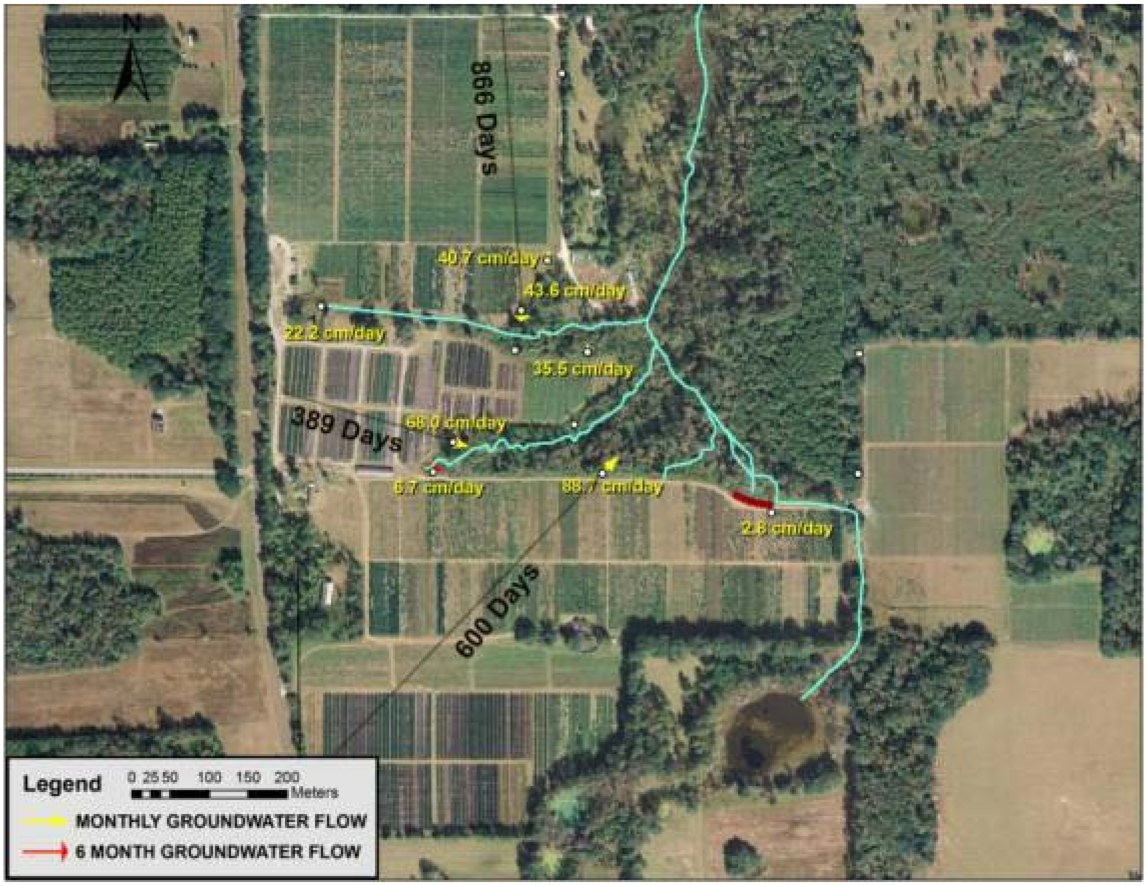


Figure 5-15 – Groundwater velocities and directions measured at a series of periphery wells at the property. Average time for a groundwater pool to discharge to surface waters based on these measurements is delineated in the figure. These estimates rely on an assumption of plug-flow in groundwater.

Stream baseflow at the main watershed sampling station (SW1) was estimated as the 30 day running 10th percentile of discharge values. Stream baseflow and actual discharge declined throughout the period of sampling corresponding to the time period of irrigation reductions and other best management practices on the property (Figure 5-16). It is clear that corresponding to this reduction in discharge, was a reduction in rainfall.

Average annual rainfall for the two years with full annual records (2009, 2010) was 1386 and 827 mm respectively. As a result of the combined effects of reduced rainfall and best management practice implementation, the average discharge declined through the sampling

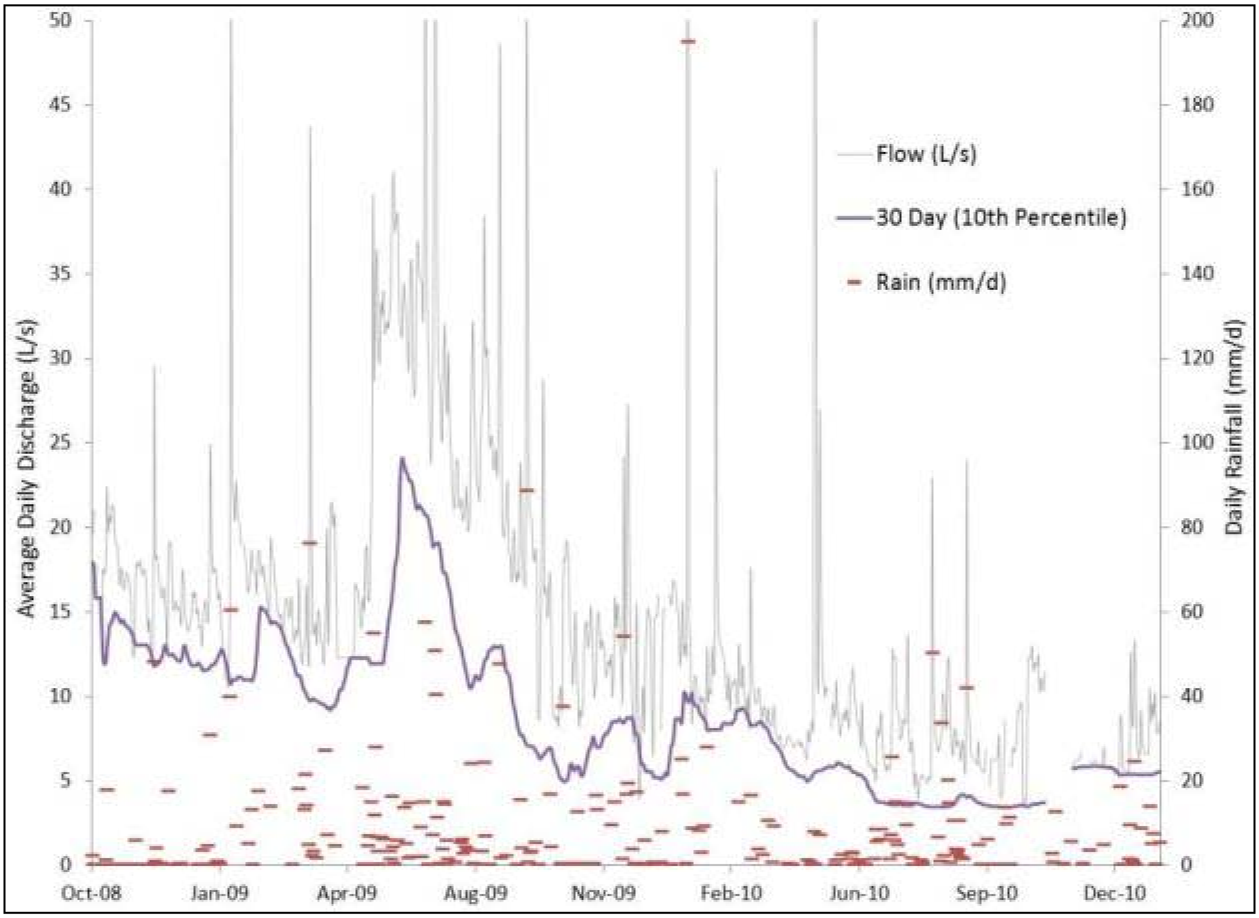


Figure 5-16 – Rainfall, stream discharge, and an estimate of baseflow based on the 30 day 10th percentile of discharges measured at the main watershed sampling station.

period from 19.8 in 2009 to 10.0 L s^{-1} in 2010 respectively (Table 5-2). Discharge during the first 7 months in July were even lower averaging 8.44 L s^{-1}. To parse the influence of rainfall vs. BMPs on stream discharge, a relationship was developed between rainfall event discharge and total event runoff discharge.

Table 5-2 – Summary discharge, nitrogen concentration and load data for the main watershed.

Year	TN Conc (mg/L)	Discharge Ave. (L/s)	Annual TN Load Estimate (kg)	Total Rain (mm)	Rain Rate (mm/d)	Ave Rain intensity (mm/min)	Net Storm Runoff (m3)	Net Storm Runoff Load (kg)	Baseflow (10th Percentile) (L/s)
2008*	7.6 ± 0.9	16.8	4206		1.3	0.05	1674		13.2 ± 1.2
2009	6.6 ± 1.2	19.8	4294	1386	3.8	0.17	27005	173.3	11.3 ± 4.3
2010	6.4 ± 0.9	10.0	2097	827	2.3	0.21	26197	162.8	5.57 ± 1.9
2011*	5.5 ± 0.7	8.44	1525		3.2	0.11	1170		5.41 ± 0.05

**2008 and 2011 were only sampled for approximately 3 and 7 months respectively. As such, total rainfall is not indicated, although the rainfall rate is indicated. Additionally, the annual TN load is estimated by extrapolating existing data collection to the entire year.*

To estimate this relationship, an iterative process was used to calculate the volume above the preceding baseflow discharges as delineated in Figure 5-17. Utilizing this methodology, a storm began when at least 0.5 mm of rain had fallen. Storm event runoff ended when no new rainfall had occurred for 30 minutes and the stream discharge was within 1.5 L s^{-1} of the preceding baseflow discharge. Based on these calculations, a relationship was developed between total event rainfall and total event runoff discharges for the entire watershed (Figure 5-18).

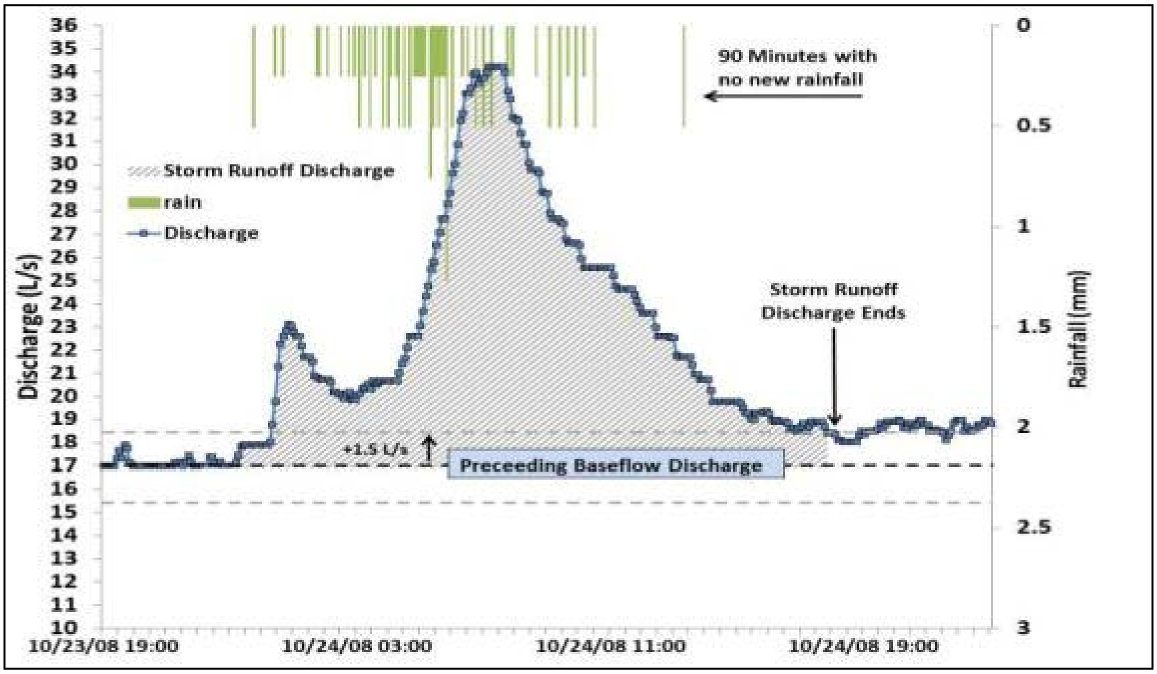


Figure 5-17. Diagram of the methodology used to quantify storm runoff discharge volume. This was determined as the volume above the preceding baseflow discharge. The beginning of the storm was demarcated when greater than 0.5 mm of rainfall had occurred. The storm discharges was determined to end when no new rainfall had occurred for 30 minutes and the discharge had returned to within 1.5 L s-1 of the preceding baseflow discharge.

Based on this relationship, the total storm runoff volume in 2009 was 27,005 m^3 and 26,197 m^3 in 2010 (Table 5-2). Although there was a large divergence in total rainfall between these two time periods, these values of total storm runoff are remarkably similar. This is possibly a result of the greater average storm intensity in 2010 (0.21) as compared to 2009 (0.17). Much of the increase in storm intensity in 2010 was driven by one event in January, which deposited over 7 inches of rain in under two hours. This generated a significant amount of surface runoff volume. These results indicate that storm runoff doesn’t likely explain the decline in average discharge and baseflow over the period of monitoring, particularly between 2009 and 2010.

Corresponding to the reductions in nitrogen concentration and tributary discharge, the N load has decreased during the duration of the sampling period (Table 5-2). Because the total N concentration has only declined slightly, a large proportion of the load reduction is due to discharge reductions. Discharge reductions are expected given the irrigation reductions and the subsequent decline in leaching volume. The N load attributed to storm runoff discharge can be quantified by incorporating flow-weighted TN concentrations in to the rainfall-discharge relationship shown in Figure 5-8. The TN load as a function of total event rainfall is shown in Figure 5-19. For the two years, when samples were collected for the full year (2009 and 2010), the TN load attributed to storm runoff discharge was 173.3 and 162.8 kg respectively. Although significant, these loads are less than 10% of the total nitrogen load measured at SW1. Therefore, the reduction in TN loads over time can't be attributed solely to differences in precipitation alone.

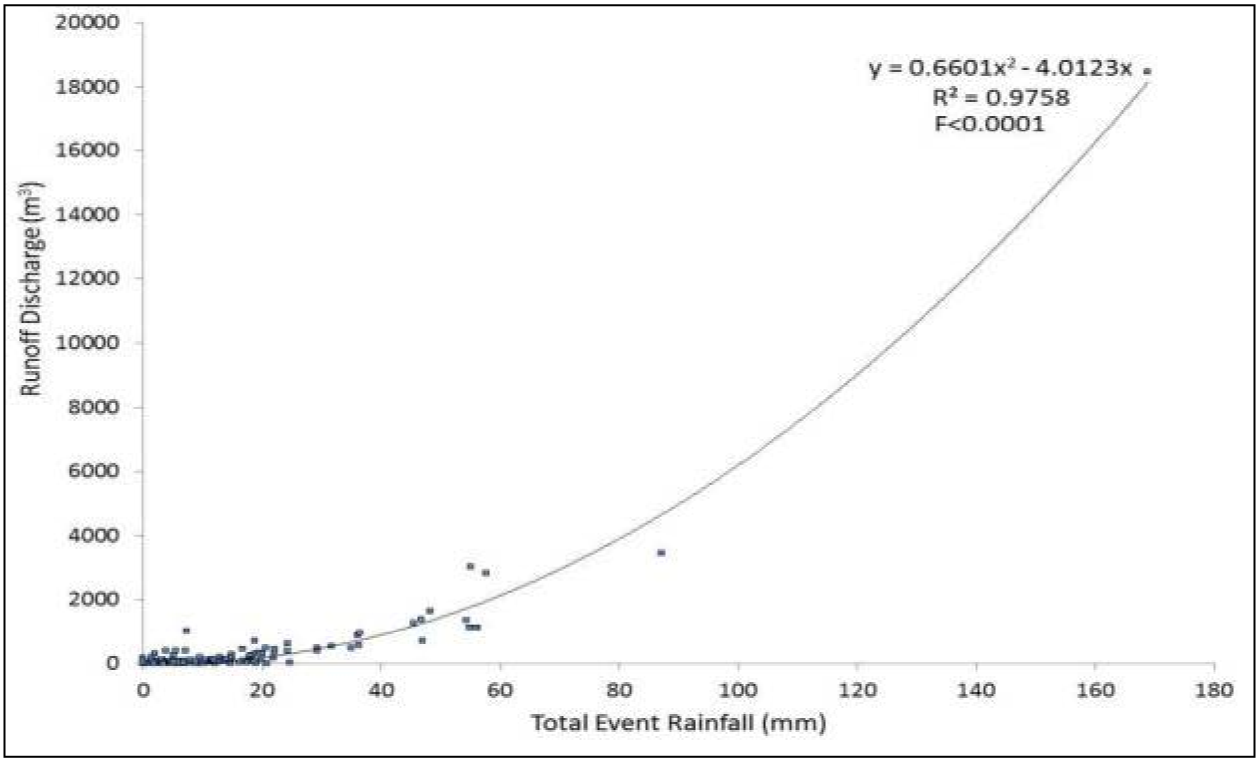


Figure 5-18 – Total runoff discharge as a function of total event rainfall (n=328).

Although this is counter to many watershed nutrient loading situations we believe that the weighting of load toward baseflow vs. storm flow is due to the well-drained surfical soils under much of the nursery allowing a large fraction of rainfall not to runoff and instead recharge the surficial groundwater, and secondly that although irrigation loading to groundwater has been significantly reduce through cyclical irrigation practices, there is still a large contribution of excess irrigation to baseflow in the tributary.

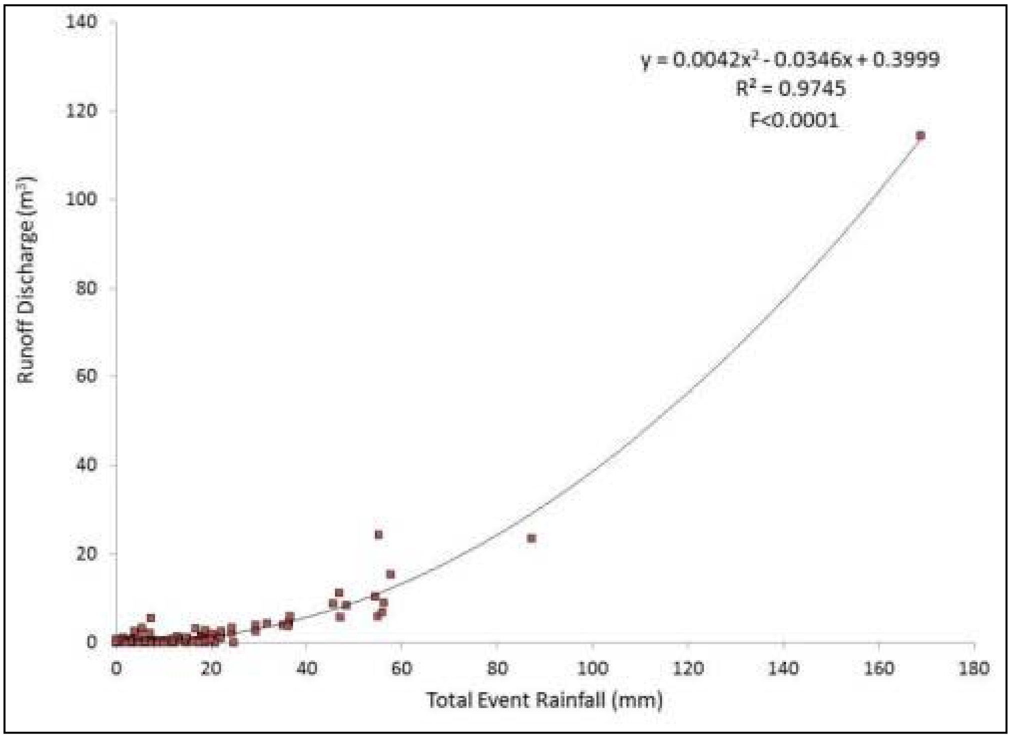


Figure 5-19 – The relationship between total event rainfall and total runoff discharge.

One method to determine discharge-independent reductions in N load, is to correlate discharge volume to N load during the two time periods when load reductions are expected as a result of BMPs. Due to the limitations in the length of the preBMP dataset, these discharge-load relationships were graphed for two time periods (2008-2009 and 2010-2011). This analysis was done for baseflow conditions only (Discharge<16 L/s) as that is when it is expected that implementation of BMPs is likely to have the greatest influence in this system (Figure 5-20). Due to the wide range of discharges, the log of the discharge and load values are graphed and a power law best fit line was displayed (Figure 5-21). Based on this analysis, it is clear that for a given discharge the total N load has decreased and the overall centroid of sample loads has shifted to lower discharge volume and loads indicating a reduction in both volume and concentration.

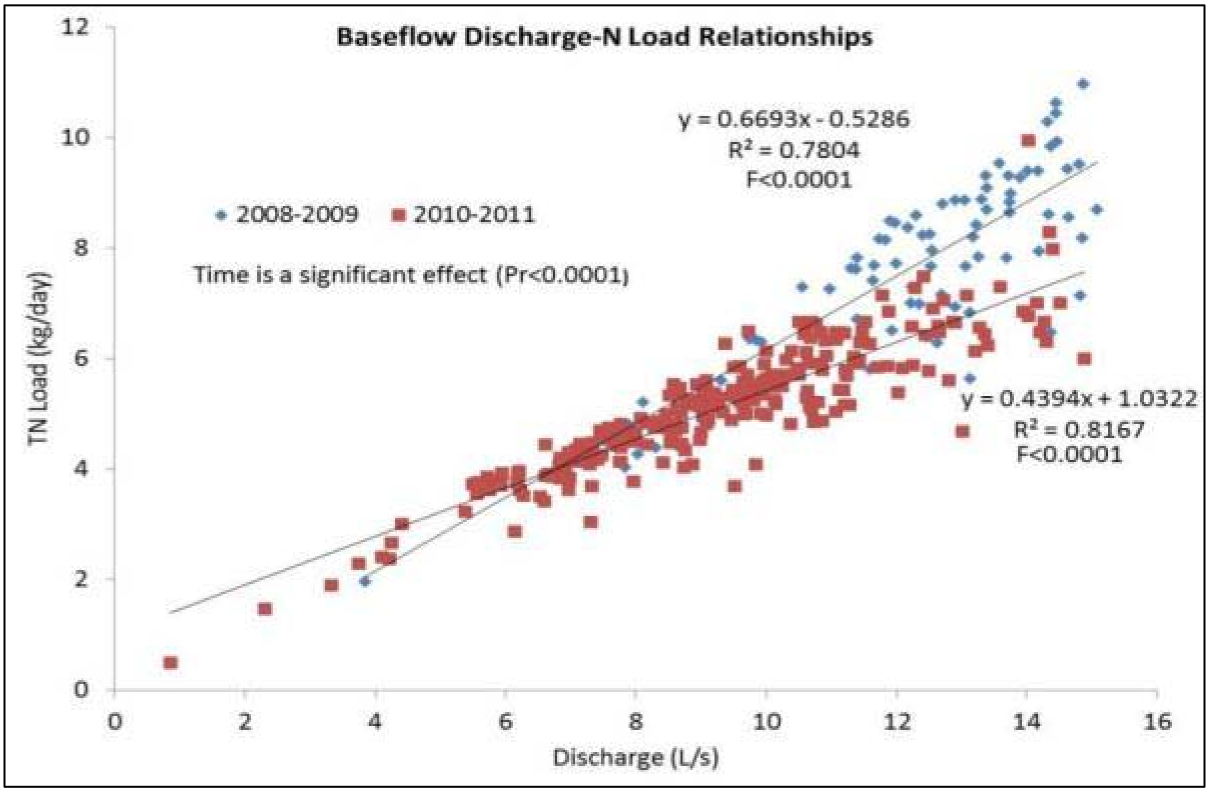


Figure 5-20. Baseflow only discharge correlated to total N load for two time periods (2008-2009 and 2010-2011).

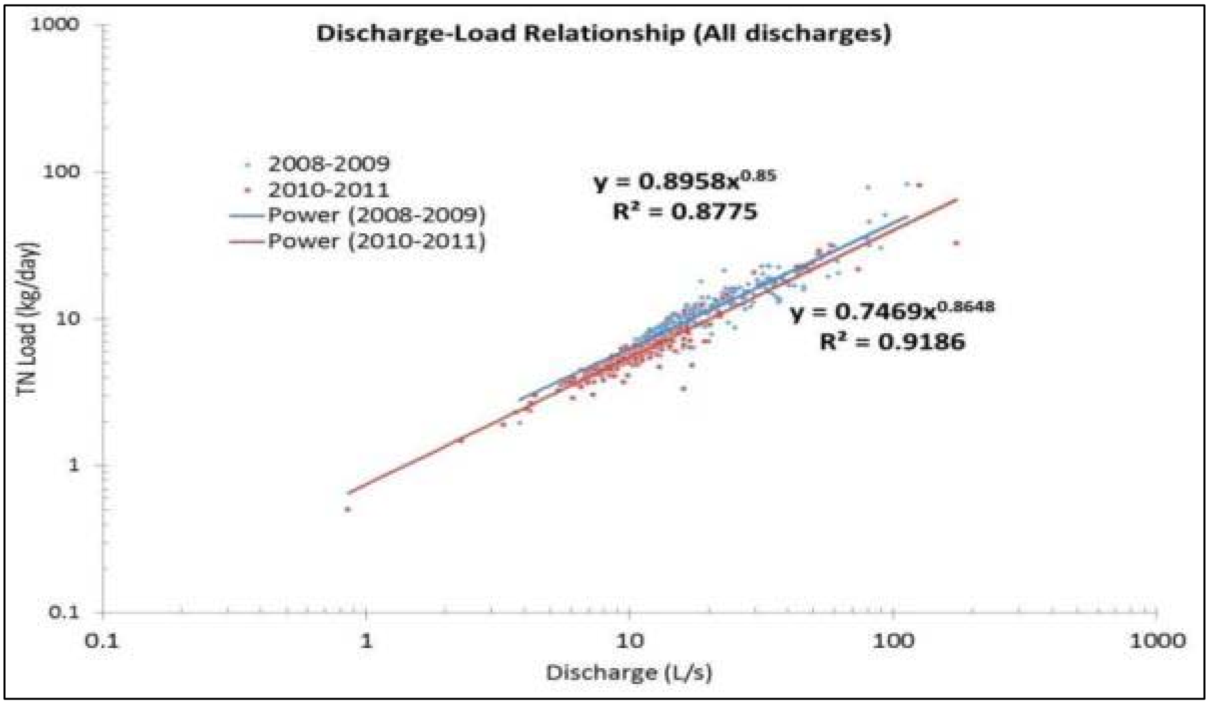


Figure 5-21 – Log/log correlation of baseflow only discharge to total N load for two time periods (2008-2009 and 2010-2011). Full range of discharges fit with a power law relationship.

5.3 GROUNDWATER IMPROVEMENTS

Monitoring wells were used to evaluate the efficacy of the denitrification wall to reduce groundwater nitrogen loads. Well's were installed to the bottom of the denitrification wall in three parallel transects according to USEPA guidelines (USEPA, 2008) (Figure 5-22). Wells were placed upgradient, within (center), and downgradient of the wall in three transects to monitor nitrate-N, total Kjeldahl N (TKN), and dissolved organic C loading.

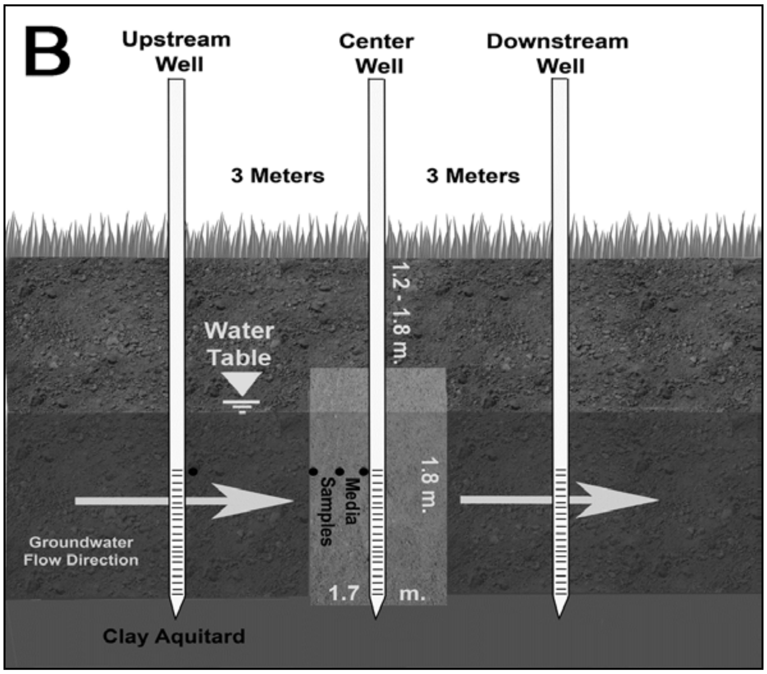


Figure 5-22 Completed denitrification wall with groundwater well transects evident (A). Cross-section diagram of the denitrification wall delineating the well transects and the media sampling transect(B).

Water samples were collected within each well weekly for 20 weeks and then monthly thereafter for 660 days after construction after purging two well volumes using a submersible pump (Mini Typhoon$^{®}$ DTW, Proactive Environmental Products, Bradenton, FL). Samples were collected and either filtered through a 0.45 µm membrane filter (Pall Corporation, Port Washington, NY), then acidified or unfiltered and acidified directly, stored on ice and transported to the laboratory. Unfiltered samples were digested using a block digester and analyzed colorimetrically for TKN (EPA Method 351.2) on an autoanalyzer (Seal Analytical, West Sussex, UK). Filtered samples were analyzed for nitrate-nitrite colorimetrically (EPA Method 353.2) after cadmium reduction on an autoanalyzer (Seal Analytical, West Sussex, UK). Total organic C (TOC) was determined using EPA Method 415.1, after combustion as non-purgable organic C on an infrared gas analyzer (Shimadzu Corp, Kyoto, Japan). Dissolved oxygen was measured directly in the wells by slowly raising and lowering a YSI multi-probe (556 MPS, YSI Incorporated, Yellow Springs, Ohio) throughout the groundwater column.

Effective porosity of the denitrification wall was determined in triplicate as the fraction of saturated water volume drained at field capacity (33 kPa) (Ahuja et al., 1984; Timlin et al., 1999) in a laboratory study using recreated cores of sand and sawdust in the same ratios and same bulk density as the wall. Cores were vacuum saturated in tempe cells

(Soil Moisture Equipment Co., Santa Barbara, CA), then allowed to drain to a porous surface for 72 hours. This field capacity measure of effective porosity has been determined as a better predictor of the mobile groundwater volume in wall media than total porosity (Barkle et al., 2008).

The focusing of groundwater through permeable reactive barriers (PRBs) has been hampered in other applications by decreases in hydraulic conductivity due to construction, thus instigating bypass flow (Barkle et al., 2008; Schipper, 2004). The hydraulic conductivity (K_{sat}) was therefore determined in all nine wells using the Hvorslev slug-test method as described in the following equation (Fetter, 2001).

In this equation, is the saturated hydraulic conductivity [L T^{-1}], is the well casing radius [L], is the length of the well screen [L], is the borehole radius, and is the time it takes for the water level to fall to 37% of initial head change.

Porewater velocity and direction were measured periodically in wells at 0.4, 0.8 and 1.2 m. from the bottom of the denitrification wall using a heat-pulse flowmeter (GeoFlo Model 40, Kerfoot Technologies, Mashpee, MA). The direction and velocity readings of the flowmeter are calibrated by pumping a known velocity and direction in a tank containing the well screen surrounded by the same standard sand filter pack used in the field well installation. This procedure yielded an r^2 for velocity of 0.999 and a standard deviation for direction of ± 2 degrees around the true value. Heat-pulse groundwater flowmeters have been field-verified as accurate representations of porewater velocity and direction as compared to piezometer gradients with average velocity uncertainties of only 0.02 – 0.04 m d^{-1} and direction uncertainties of 4.9 – 7.4 degrees (Alden and Munster, 1997).

Water level elevations and temperature were measured hourly over 462 days by pressure transducers placed in the wells (Global Water. Gold River, CA). To provide a confirmation on the flowmeter results and a more continuous measurement of groundwater mobility, porewater velocities were determined using Darcy’s law based on measured head gradients from transducers, K_{sat}, and effective porosity.

Nitrate-N removal rates within the wells were determined as daily mass nitrate-N loss per volume of reactor media using the following equation (Schipper and Vojvodic-Vukovic 2000).

In this equation, is the nitrate-N mass removal rate per volume of wall [g-N m^{-3} d^{-1}], is the porewater velocity [L T^{-1}], is the cross-sectional area conducting ground water [L^2], calculated as , where is effective porosity [L^3 L^{-3}], is the decrease in nitrate-N N concentration [M L^{-3}] and is the media volume of wall the nitrate-N travels through [L^3] (L^2 x the travel distance within the wall). Porewater velocity ( ) and media volume ( ) were determined from velocity and directional readings measured with the groundwater flowmeter.

The saturated hydraulic conductivity (K_{sat}) of the denitrification wall averaged 1.2 x 10^{-2} ± 3.4 x 10^{-4} cm s^{-1}, which was greater than the K_{sat} of the surrounding soils which averaged 7.0 x 10^{-3} ± 5.4 x 10^{-3} cm s^{-1}. The effective porosity of the wall media was 50.0 ± 5.3% (n=3) of the total volume.

The porewater velocity and direction was measured with the heat-pulse groundwater flowmeter in May and July, 2010 (Figure 5-23). In general the groundwater travelled perpendicularly through the denitrification wall with a curvature towards the main surface water discharge. In both May and July the average porewater velocity was 1.7 m day^{-1} (Table 5-3), which is much faster than velocities for other walls (0.007-0.47 m day^{-1}) (Schipper and Vojvodic-Vukovic, 2000; Schipper et al., 2005; Robertson and Cherry, 1995). The average detention time (1.8 days), based on the projected flowpaths through the wall (not wall width), is at the lower end of the range of values reported in previous studies (1-10 days) (Schipper and Vojvodic-Vukovic, 2001; Schipper et al., 2005) and (10-13 days) (Robertson et al., 2000). Based on these flowmeter measurements and determinations of effective porosity, the wall treats approximately 84 m^3 d^{-1}. Utilizing the Darcy equation from measurements of effective porosity, K_{sat}, and head gradients yields a volumetric treatment rate of 100 ± 28 m^3 d^{-1}, which overlaps the direct measurements taken with the flowmeter.

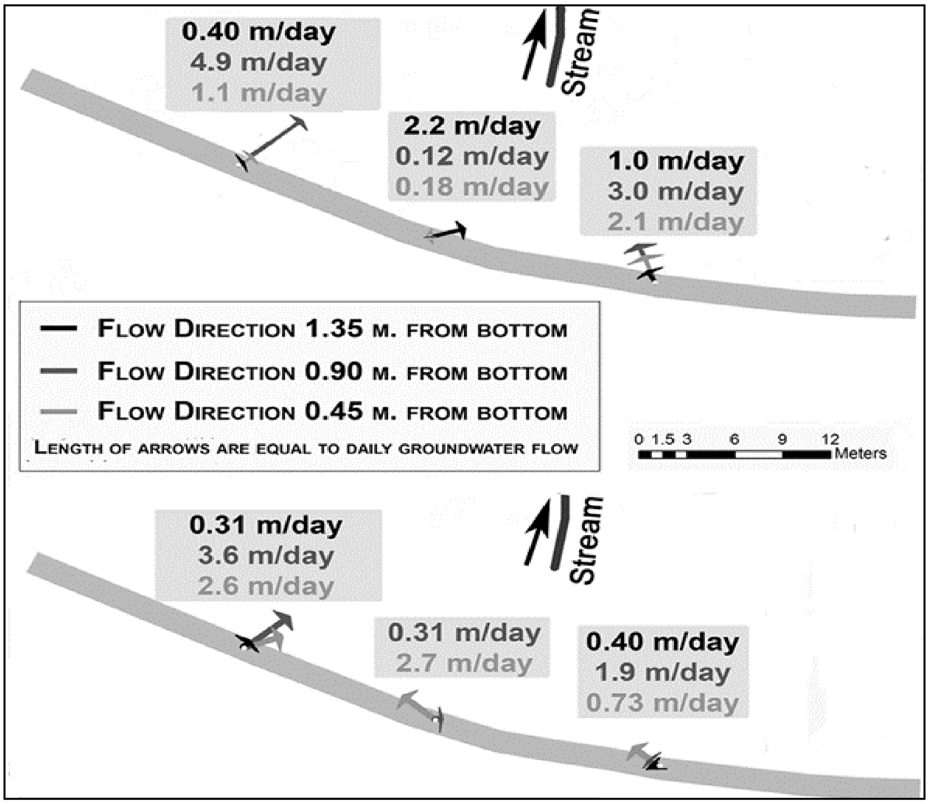


Figure 5-23 Porewater velocities and directions measured using a heat-pulse flowmeter; May 13, 2010 (top) and July 13, 2010 (bottom).

Table 5-3. Groundwater velocity, flow length and detention time within the denitrification wall wells for Transects 1 - 3 (T1 - T3).

		May	
	Velocity (m/day)	Flow-length (m)	Detention Time (days)
T1	2.1	1.9	0.9
T2	0.9	2.8	3.1
T3	2.1	2.1	1.0
Ave	1.7 ± 0.7	2.3 ± 0.5	1.7 ± 1.2

		July	
	Velocity (m/day)	Flow-length (m)	Detention Time (days)
T1	1.3	3.0	2.3
T2	1.5	3.6	2.4
T3	2.2	2.1	1.0
Ave	1.7 ± 0.5	2.9 ± 0.8	1.9 ± 0.8

Over the 660 days of sampling, average nitrate-N concentration significantly decreased from 6.2 ± 0.65 to 1.6 ± 0.40 g m^{-3} (*n* = 30) between the upgradient and downgradient well transects for a 77% average reduction. The nitrate-N reduction between the upgradient and the well within the wall (center) was much greater (Figure 5-24 and 5-25), with reductions in transects 1, 2 of 100±1.6%, and 100±0.43% and 75±9.7% reductions in Transect 3 which had the highest influent nitrate-N concentration (9.3 ± 1.2 g m^{-3}) and shortest detention time (0.5 days) (Average reduction = 88%). The 88% reduction in nitrate-N concentration measured in well transects in half the wall flow-distance, indicates the strong possibility that all nitrate-N traveling the width of the wall is lost. The increase in nitrate-N concentration between wells within the wall (0.8 ± 0.26) and downgradient wells (1.6± 0.40 g m^{-3}) can likely be attributed to groundwater bypassing the edge of the wall for the following reason. The two transects at the ends of the wall had an average nitrate-N increase of (1.2 ± 0.8 g m^{-3}), while the center transect had no increase (~0 g m^{-3}). Therefore it is likely that higher nitrate-N concentrations in the outer two transects downgradient of the wall may be attributed to groundwater bypassing the wall.

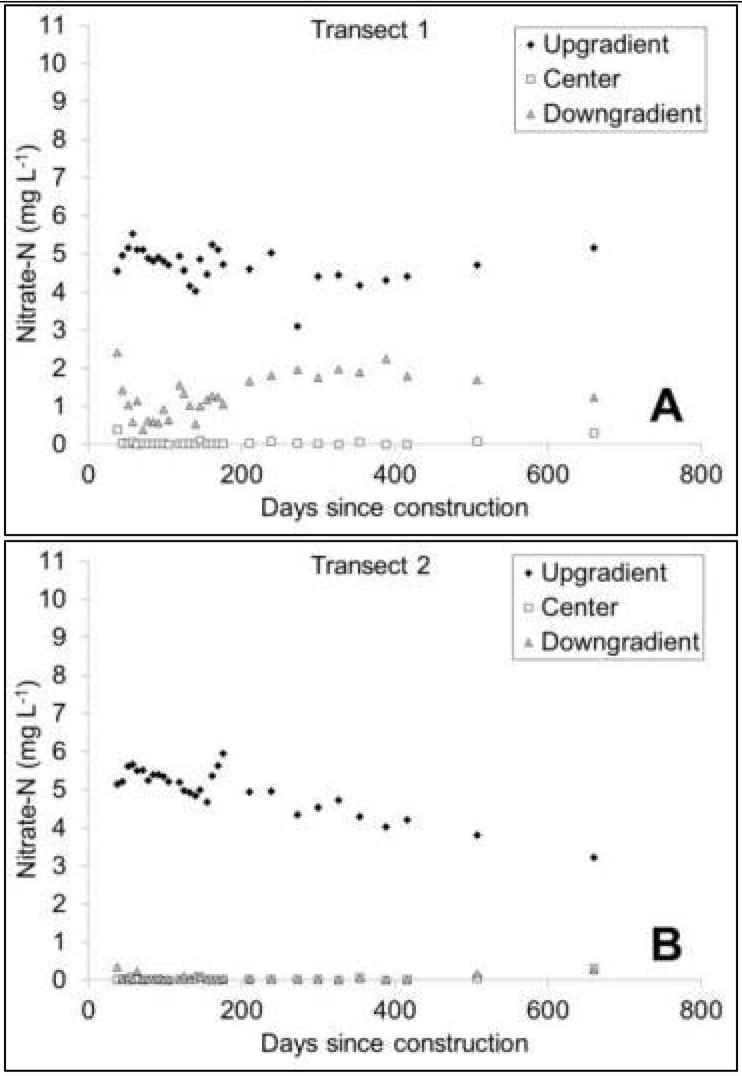
Over the study duration, temperature (Table 5-4) was not correlated with nitrate-N reductions between the upgradient and center wells. Nitrate-N reductions tended to be higher the first few months after wall installation, even with low groundwater temperatures. This is possibly due to the confounding effect of elevated concentrations of bioavailable and soluble carbon during this initial start-up period causing temporarily elevated nitrate-N reduction rates.

The mass nitrate-N removal rates per volume of reactor media, averaged 3.4 g-N m^{-3} d^{-1} in May 2010 and 3.0 g-N m^{-3} d^{-1} in July 2010, 225 and 286 days after installation when porewater velocity and direction were directly measured. The nitrate-N removal rate of transect 3 (Ave = 5.2 g-N $m^{-3}day^{-1}$) where some nitrate-N is still present in the center well is likely more representative of actual rates without nitrate limitation. These values are at the upper end of the range of reported nitrate-N removal rates for other sand-sawdust denitrification walls (0.014 – 5 g-N m^{-3} d^{-1} (Robertson et al., 2008 (assuming a 50% effective porosity); Schipper et al., 2010). This high denitrification rate is possibly due to elevated groundwater temperature (Table 5-5; average of 19 ± 2.7^{o} C) and greater C additions (average total C = 7.4±0.7%) than some other studies

Table 5-4. Groundwater temperatures within the denitrification wall (2009-2010).

	Nov	Dec	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct

Temp (°C)	20	18	16	15	15	17	19	20	21	22	22	22



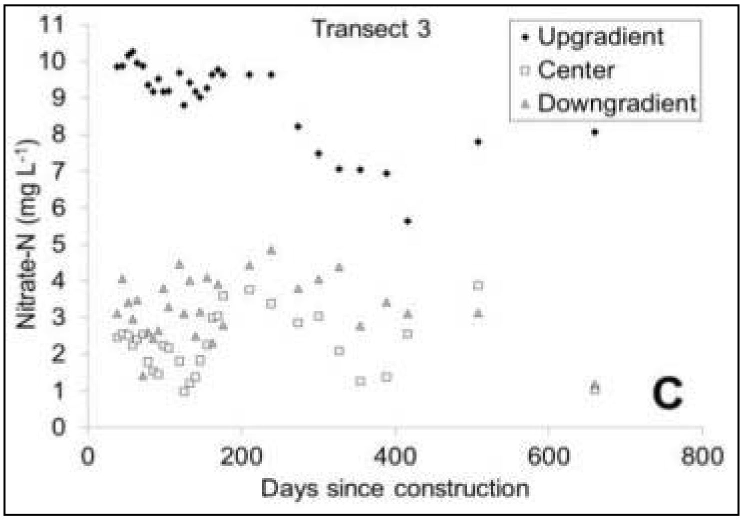
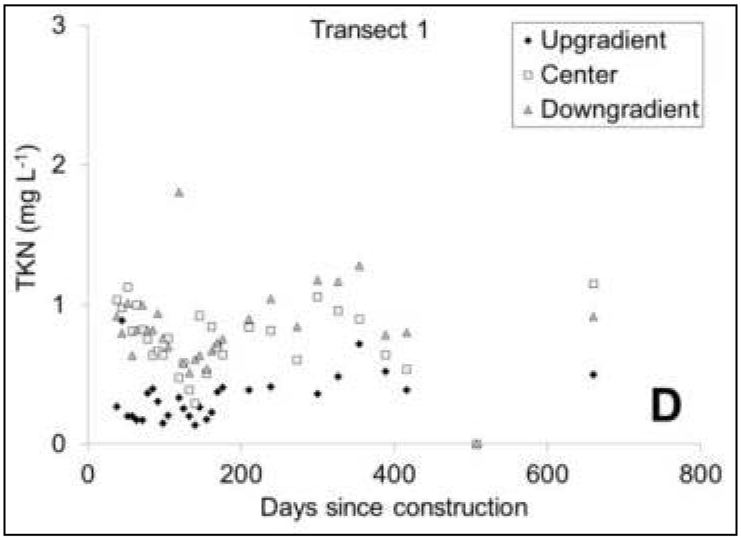
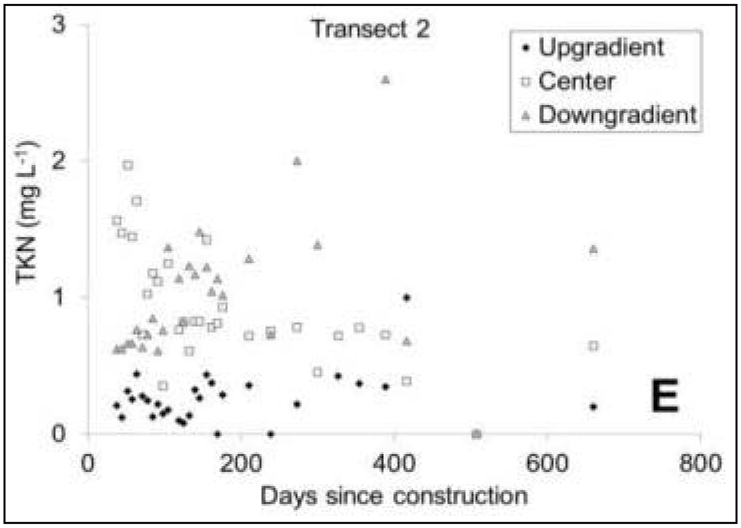


Figure 5-24. Temporal trends in Nitrate-Nitrogen concentration along each of the three groundwater transects through the denitrification wall.


Transect 1
• Upgradient
□ Center
▲ Downgradient
TKN (mg L^{-1})
0
1
2
3
0
200
400
600
800
Days since construction
D


Transect 2
• Upgradient
□ Center
▲ Downgradient
TKN (mg L^{-1})
0
1
2
3
0
200
400
600
800
Days since construction
E

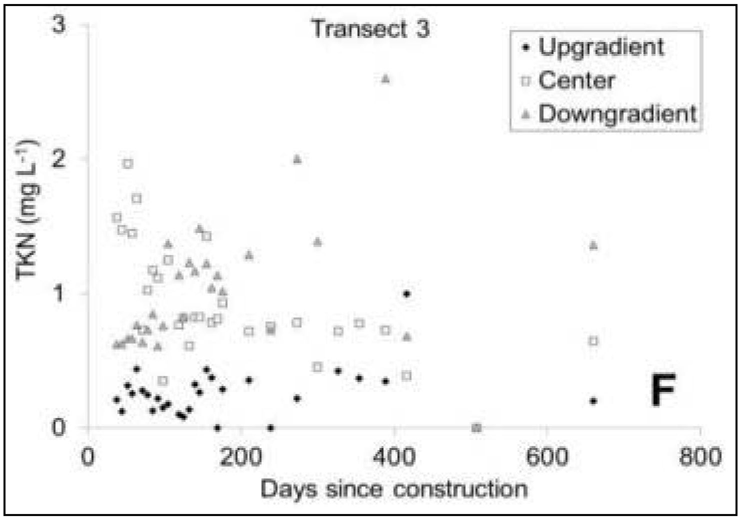

Transect 3
• Upgradient
□ Center
▲ Downgradient
TKN (mg L^{-1})
0
1
2
3
0
200
400
600
800
Days since construction
F

Figure 5-25. Temporal trends in Nitrate-Nitrogen concentration along each of the three groundwater transects through the denitrification wall.

Table 5-5. Volumetric nitrate removal rates in May and July for the three transects (T1 – T3)

	May 2010 NO_3 Removal Rate (g N $m^{-3}d^{-1}$)	July 2010 NO_3 Removal Rate (g N $m^{-3}d^{-1}$)
T1	3.25	2.00
T2	1.33	1.95
T3	5.46	4.91
Ave	3.35	2.95

The total Kjeldahl N (TKN) concentration increased from 0.3 ± 0.12 g m^{-3} upgradient of the wall to 0.9 ± 0.25 g m^{-3} in the center of the wall to 1.0 ± 0.31 g m^{-3} downgradient of the wall within all three transects (Figure 5-24). Elevations in ammonium levels generally do not occur in field conditions within denitrification walls (Elgood et al., 2010; Robertson and Cherry, 1995; Schipper and Vojvodic-Vukovic, 1998), although ammonium production and leaching have been observed in mesocosms and in laboratory experiments (Cameron and Schipper, 2010; Greenan et al., 2006).

This rise in TKN is possibly in the form of organic-N associated with DOC leaching, net microbial mineralization (ammonification) or ammonium (NH_4^+) production as a result of dissimilatory nitrate reduction to ammonium (DNRA). The TKN concentration and export rates were largely constant, whereas the DOC export declined in an exponential fashion (Figure 5-23) and the relationship between the two was weak ($r^2 = 0.06$). Net ammonium mineralization (ammonification) generally occurs when organic matter C:N ratios decline below 100 (Reddy and Delaune, 2008). The C:N ratio of the wall media on day 0 was approximately 231±27, which declined in the duration of the study to 140±28. The high C:N ratio indicates ammonium is likely to be retained in microbial biomass to maintain a microbial C:N ratio of 10:1 and net ammonium *immobilization* would occur (Reddy and Delaune, 2008). DNRA occurs in highly reducing environments (Eh<0 mv) with high electron pressure, which would arise in conditions with high electron donor (sawdust) to electron acceptor (nitrate-N) ratios as is likely in the denitrification wall (Reddy and Delaune, 2008). Therefore it is plausible that some of the total nitrate-N load reduced is not lost to the atmosphere but is instead converted to ammonium via the DNRA process. Nitrogen present as TKN is bioavailable and thus can still impact receiving water bodies. Adding TKN-nitrogen to nitrate-N, the total N concentration significantly decreased from 6.6 ± 0.6 g m^{-3} to 2.6 ± 0.5 g m^{-3} (n=29) between the upgradient and downgradient wells for a 62% reduction.

Two methods were used to provide estimates of volumetric treatment rates to provide rigor to the conclusions. Based on measured concentrations and volumetric treatment rate estimates using the groundwater flowmeter (84 m^3 d^{-1}) and head gradients (100 ± 28 m^3 d^{-1}), the wall reduces nitrate-N load by 190±20 kg yr^{-1} (n=2) and 249±161 kg yr^{-1} (n=28) and increases TKN load by 21±9 kg yr^{-1} and 28±17 kg yr^{-1} utilizing the two methods respectively. Because approximately 11% of nitrate-N is converted to TKN presumably due to the DNRA process, the total N load reduction in groundwater estimated from the groundwater flowmeter and head gradients is 170±23 and 228±155 respectively. The total N content of the wall media increased from 0.032±0.01% to 0.051±0.007%, which represents a small total microbial N assimilation of 36±13 kg in the 540 days of the study. It is difficult to include this relatively small N-mass in the load reduction rates, as this microbial N is likely not accumulative.

5.4 RESULTS OF BMP OPERATION AND MAINTENANCE REVIEWS

There were no specific BMP operation and maintenance reviews conducted during the implementation of this project other than those associated with specific BMPs under assessment (cyclical irrigation practices, denitrification wall, intercept berm, swale and tailwater pond). All other BMPs associated with the Notice of Intent were not specifically reviewed and instead these BMPs were implemented and monitored by the nursery essentially replicating how most BMPs are being integrated into production systems

5.5 QUALITY ASSURANCE REPORTING

A copy of the project Quality Assurance Project Plan can be found in section 9.2 Appendix B. As indicated there, all samples used to support findings in this project were analyzed in NELAC certified laboratories (Wetland Biogeochemistry Laboratory cert # E72949, or the University of Florida Analytical Research Laboratory cert #72850). Ms. Yu Wang was the QAQC officer of the Wetland Biogeochemistry Laboratory (WBL) during the period of the study and conducted all audits on water samples analyzed at the WBL. Nancy Wilkinson was the QAQC officer for the University of Florida Analytical Research Laboratory (UF-ARL) and she conducted all audits of water samples analyzed at that facility during the period of this study.

Field sample collection techniques followed FDEP standard operating procedures with the exception of nitrate preservation associated with autosamplers. Due to the remote conditions at the site and budget constraints, refrigeration of samplers in real time was not possible. To verify that acid preservation only would be sufficient to minimize nitrate degradation while stored in the autosamplers a series of tests comparing samples collected and analyzed on day one with samples collected on day one, but not analyzed for 7 days while acid preserved only under field conditions were evaluated. Results indicated no significant change in nitrate concentration under acid preserved conditions therefore it was agreed that it would be acceptable to continue with this protocol.

Groundwater sampling associated with denitrification wall transects or perimeter wells used FDEP standard operating procedures. Sampling associated with the irrigation study integrated FDEP standard operating procedures as much as possible for surface water sampling of leachate collected in the closed outer container, although this was not technically a surface water sample.

Flow related data was downloaded on a weekly basis and transducer stage data was verified against a permanent staff gauge placed in the stream at the time of each data download by Casey Schmidt or Patrick Moran. Sediment loads that accumulated behind weirs were managed on a regular basis, often after any significant storm event, to maintain a sediment free zone in the area immediately upstream of the weir plate as well as to maintain a sufficient stilling zone to minimize turbulent water flowing over the weir. Several calibration checks between actual flow rates and estimated flow rates were conducted by Casey Schmidt at each of the three flow gauging stations and adjustments to flow estimates were made if necessary.

All conclusions derived from the monitoring data were based on either a pre/post implementation of BMP's, which was the case for the irrigation study and overall effects of BMP, or from differences measured using a Before After Control Impact (BACI) comparison. The BACI approach was used to compare the effect of the denitrification wall where a comparison was made between two watersheds, one influenced by the denitrification wall and another watershed that was not affected by the wall.

Statistical analysis applied to the data collected in this study was mainly a simple Anova analysis with an $\alpha = 0.05$. Any treatment effect indicated as a percent reduction in load or water consumption was based on a comparison of mean values for the given time period being compared not based on median or some other range of values. In the case of the load reduction estimated to have occurred at the main gauging station (SW1) as a cumulative result of BMPs implemented at the nursery, parsing the influence of any change in rainfall vs. effect of BMPs on stream discharge was required. To estimate this relationship, an iterative process was used to calculate the volume above the preceding baseflow discharges (illustrated in figure 5-17). Utilizing this methodology, a storm began when at least 0.5 mm of rain had fallen. Storm event runoff ended when no new rainfall had occurred for 30 minutes and the stream discharge was within 1.5 L s^{-1} of the preceding baseflow discharge. Based on these calculations, a relationship was developed between total event rainfall and total event runoff discharges for the entire watershed. Once this was completed differences between total discharge reductions due to less rainfall in a particular year could be differentiated from lower discharges due to BMP implementation.

Regarding the usability of the data and findings from this report, much of this data was used to support a successful Doctoral dissertation defense and therefore methodology, data and findings were thoroughly scrutinized by the graduate advisory committee consisting of Drs. Mark Clark, James Jawitz, Patrick Inglett, Matthew Cohen and Thomas Yeager. In addition, two manuscripts have been peer reviewed by the broader scientific community and approved for publication utilizing data and findings from this study.

6.0 PUBLIC INVOLVEMENT AND COORDINATION

The general public was not a specific target audience for this project since BMP practices being evaluated and new technology being demonstrated were principally related to container nursery operations. However, several presentations were given at meeting that had non industry audience participation as described in section 6.3.

6.1 STATE AGENCIES

The principal state agency involved in this project was the Florida Department of Environmental Protection (FDEP). They have been the lead agency from the beginning of this project and were instrumental in funding and support throughout. Even after the cost share partner was unable to fulfill their commitments FDEP found a way to continue support and make up for the difference in the cost share partners inability to continue with their commitment.

The Florida Department of Agriculture and Consumer Services (FDACS) had committeed to provide matching funds for the project, but on two occasions had to withdrawal funding support due to budget constraints. However, FDACS remained an interested participant in the outcome of the project and assisted in organization of the demonstration field day.

Another indirect partner in the project is the Suwannee River Water Management District (SRWMD). The project site is within the boundaries of the SRWMD and they have been very interested in the projects findings. Presentations on this project along with several other projects in the region were given to the Governing Board on an annual basis. Presentation of these findings has helped them evaluate various approaches to nitrogen reduction in the Suwannee River watershed of which includes the Santa Fe River Basin.

6.2 FEDERAL AGENCIES

Other than US EPA’s funding support for the project, no other federal agency has been involved. At one point the nursery was evaluating a change from overhead irrigation to drip irrigation which would be cost shared through EQUIP dollars, but the nurseryman decided it would not be economically or operationally feasible to integrate into their production system at this time.

6.3 LOCAL GOVERNMENTS; INDUSTRY, ENVIRONMENTAL, AND OTHER GROUPS; AND PUBLIC-AT-LARGE

Multiple additional stakeholders have been made aware of findings from this project including the Alachua County Environmental Protection Department, the Florida Nursery Growers Association and Florida Farm Bureau. These stakeholders have been engaged either through personal communication, presentations or participation at the demonstration field day.

Project results have also been presented in academic settings identified below which has stimulated further investigation into the opportunities associated with denitrification walls as a technology to reduce groundwater nitrate loads.

> American Ecological Engineering Society Conference, Ashville, NC, 2011
> Soil Science Society of America Annual Conference, San Antonio, NM. 2011
> American Geophysical Union Conference, San Francisco, CA. 2011.
> Water, Wetlands and Watersheds Seminar, University of Florida, 2011.
> Soil and Water Science Department Seminar, University of Florida 2011.

Findings related to the denitrification wall are also in press for published in the peer reviewed literature with the following citations.

> Schmidt, C.S.; Clark, M.W. (2012). Efficacy of a denitrification wall to treat continuously high nitrate loads. Ecological Engineering
>
> Schmidt, C.S.; Clark, M.W. (2012). Evaluation of a denitrification wall to reduce surface water nitrogen loads. Journal of Environmental Quality.

6.4 OTHER SOURCES OF FUNDS

No other sources of funds were specifically made available for this project. It should be noted however that the University of Florida agreed to a 40% non-recoverable indirect cost on the project. Although these funds were not directly added to the project to support implementation and monitoring, they did reduce overall cost of the project. In addition one critical project personnel was supported by an alumni fellowship between 2008 and 2010 allowing available funds to support other personnel to assist in monitoring efforts. considerably. Lastly, the nursery operation on occasion provided time and occasionally labor to assist in monitoring related aspects of the project as well as facilitating unlimited access to the site to allow for successful completion of this project.

7.0 ASPECTS OF THE PROJECT THAT DID NOT WORK WELL

There were two main unexpected situations during the project that should be taken into consideration when implementing two of these practices and will require further investigation to determine how best to address these issues in future applications. One issue related to infrastructure impacts to the irrigation system as a result of changing to a cyclical irrigation protocol. The other relates to a sort term anaerobic condition that developed in the headwater subtributary seep immediately downstream of the denitrification wall.

7.1 Impacts to Irrigation Infrastructure in Response to Cyclical Irrigation.

The project nursery site is set up with an electronically controlled zoned irrigation system allowing almost unlimited manipulation of the system. The water source for irrigation is groundwater and there are three wells that feed a network of subsurface irrigation pipes with distances between some well pumps and the furthest microjet emitter being almost 500 meters. As various cyclical irrigation regimes were evaluated an increased number of broken pipes in the main distribution system was noted with the damage typically being a linear rupture along the length of a pipe suggesting a pressure wave expansion of the pipe as opposed to a break at an elbow or joint often related to a “water hammer” where water is moving rapidly through an air filled pipe and then slamming perpendicular into a joint when the water is required to rapidly change direction. It was hypothesized that the frequent cycling of irrigation zones resulted in pressure waves being set up in the system and over the long distances would on occasion resulted in pipes rupturing.

To alleviate the pressure pulse resulting from a rapid closing of a valve as irrigation zones were switched, the nursery invested in variable speed well pumps that allowed for a ramping down of flows before zones were closed and then a ramping up after a new zone was opened up. The ability to maintain a more even pressure in the pipe system by regulating the pumping volume solved the ruptured pipe issue, however the overall duration of time that a zone was being irrigated had to increase to get the same amount of volume to the emitters since pressure in the line had to build up again at the beginning of the cycle and then also relieved at the end of the cycle. Considerations for infrastructure limitations as well as the costs associated with mitigating infrastructure will need to be addressed when moving to the efficient practice of cyclical irrigation.

7.2 Development of Anaerobic Conditions in Downstream Subtributary

Shortly after installation of the denitrification wall, filamentous white bacteria colonized the upper 10 m of the subtributary located immediately downstream of the wall. The bacteria covered large portions of the stream for approximately 50 days (Figure 7-0a-b). This was likely in response to excess C export from the wall which stimulated bacterial colonization and possibly the activities of chemolithotrophic bacteria such as the

Beggiatoa utilizing reduced H_2S to gain energy. *Beggiatoa* is known to be present in sulfur-rich seeps and springs and the odor of H_2S was detectable during this period..

Figure 7-0 – Begiatoa sp bacteria colonizing stream just downstream from anoxic seep shortly after installation of denitrification wall (A & B). Same location as photos A & B, 50 days after installation of dentirifcation wall (C & D)

As a result of this bacterial colonization, dissolved oxygen (DO) and dissolved organic C (DOC) were measured in the stream at the immediate seep headwaters. Dissolved oxygen and DOC values were compared to concentrations measured in groundwater from wells within the wall and 3 m downgradient from the denitrification wall. During this period, dissolved organic C (DOC) in groundwater measured in wells installed 3 m downgradient of the wall regularly exceeded 70 mg L^{-1}. DOC. Concentrations in the stream 14 m from the wall declined over time from a high of 5.32 mg L^{-1} 22 days after wall installation, to 2.32 mg L^{-1} 50 days after installation (Table 7.0) when filamentous bacteria were no longer visually detectable (Figure 7-0c-d). Although no DOC measurements were taken in the surface water seep before wall installation, unimpacted DOC from groundwater wells installed 3 m upgradient from the denitrification wall averaged (1.78 ± 0.29 mg L^{-1}). Similarly to DOC, DO within the stream headwaters rapidly declined 29 days after installation of the denitrification wall and rebounded to DO levels measured from other seeps in the watershed (2.3 – 2.9 mg L^{-1}) (Table 7-0). Even when DO was below the normal concentrations of seeps in the watershed, spatial sampling indicated that after approximately 20 meters downstream from the headwaters, turbulence in the water column had increased the DO concentration to 3.65 mg L^{-1}. Although DO concentrations in the stream headwaters stabilized above background concentrations (2.3 – 2.9 mg L^{-1}) within 50 days, DO concentrations within groundwater around the denitrification wall still ranged from 0.6 – 0.8 mg L^{-1} 499 days after wall installation. It appeared that as DOC leaching from the wall declined or was effectively assimilated by new bacterial growth, BOD at the seep subsequently declined and DO levels were easily elevated to background levels due to rapid aeration upon atmospheric exposure.

These results indicated that when a denitrification wall is installed in close proximity to a stream sensitive to low DO, there may be short-lived negative water quality impacts and temporary mitigating practices should be considered in the future. Some thoughts to mitigate for these issues would be to actively aerate the stream system until elevated BOD levels decrease, reduce the elevated DOC possibly using charcoal filters or pre-leaching labile DOC from the wall media before installation, inoculate the wall and area immediately downstream of the wall with microbes to minimize the duration of the grow-in period, or minimize flow through discharge from the wall during the initial microbial colonization period. The feasibility and cost of these options would need to be weighed against the short-term impacts on surface water quality.

Table 7-0. Dissolved oxygen concentration (DO) and dissolved organic carbon (DOC) within receiving surface waters. Normal DO of seepage headwaters in the vicinity range from 2.3 to 2.9 mg L^{-1}, while unimpacted groundwater DOC was 1.78 ± 0.29 mg L^{-1} during this period.

Receiving Stream Headwaters		
Days since installation	DOC (mg L^{-1})	DO (mg L^{-1})
14	4.8	2.4
22	5.3	
29	4.9	1.2
36	3.6	1.6
50	2.3	2.6
499		2.9
660	0.94	2.8

8.0 FUTURE ACTIVITY RECOMMENDATIONS

As indicated in section x, surface water quality monitoring showed significant improvement over the 4 years of monitoring, however load reductions had not yet leveled off after implementation of BMPs. As a result the full extent of the benefits resulting from BMP implementation have not been realized. Therefore, a follow up period of monitoring for one year is recommended to determine if a new baseline has been achieved postBMP implementation. If upon a follow up monitoring it appears that levels may still be declining then another postBMP monitoring period may be warranted. One of the issues this study has illustrated is that unlike BMP implimentation that primarily influences surface waters, which are expected to result in a relatively rapid response in load reductions, watersheds that have a significant groundwater imput will likely have a delay in response which will vary depending on the hydrologic connectivity of the site. For sites known to have significant groundwater connections, an extended period of monitoring postBMP implimentation would be warreneted and may best be preformed at a low level of frequency or monitoring every other year to balance information gained with resouces expended.

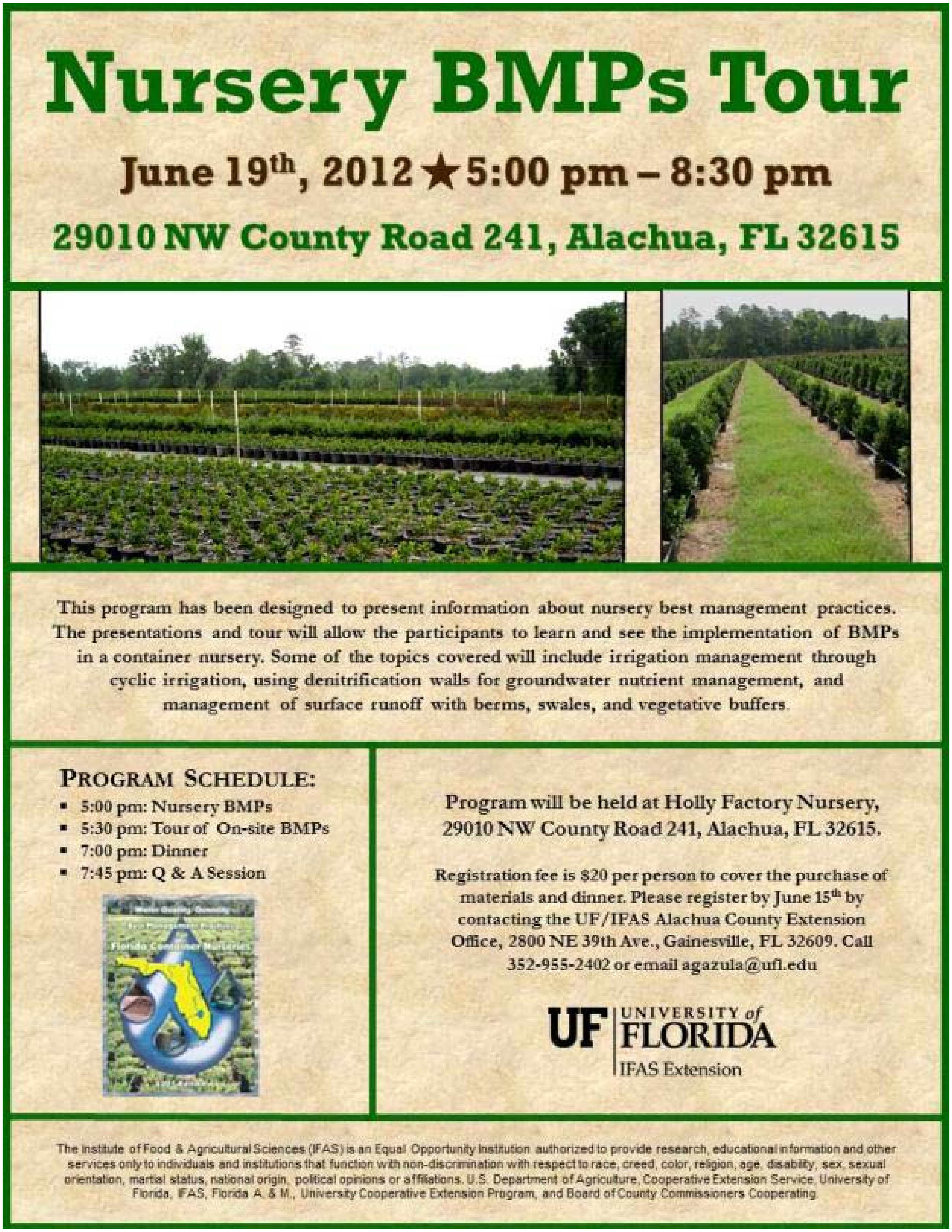
Due to the success of the denitrificaiton wall within the subtributary of this site it is recommended that additional lengths of wall be implemented at strategic points in the groundwater flow path at the property to see how well nitrate loads in the main tributary could be reduced. The present application targeted only 11% of the area in one out of 4 subtributaries origionating from the nursery. It is expected that by installing denitrification walls that could intercept a larger total are of the nursery and more subtributaries nitrate loads could be further reduced.

It is also recommended to expand the investigation of the use of denitrification walls and denitrification beds as a means to reduce nitrate concentrations in groundwater and potentially some surface water situations. One of the challenges using this technology are hydraulic constraints, where high nitrate concentrations under constant low flow conditions, as compared to pulsed stormflow conditions, are much more conducive to application of this technology. Developing specific guidance for where this technology is best applied and investigating how it might be integrated as a co-treatment strategy in high flow systems should be investigated.

9.1 APPENDIX A

MATERIAL USED FOR EDUCATION AND OUTREACH EVENT

SUBSECTIONS



Nursery BMPs Tour

June 19th, 2012 ★ 5:00 pm – 8:30 pm

29010 NW County Road 241, Alachua, FL 32615

This program has been designed to present information about nursery best management practices. The presentations and tour will allow the participants to learn and see the implementation of BMPs in a container nursery. Some of the topics covered will include irrigation management through cyclic irrigation, using denitrification walls for groundwater nutrient management, and management of surface runoff with berms, swales, and vegetative buffers.

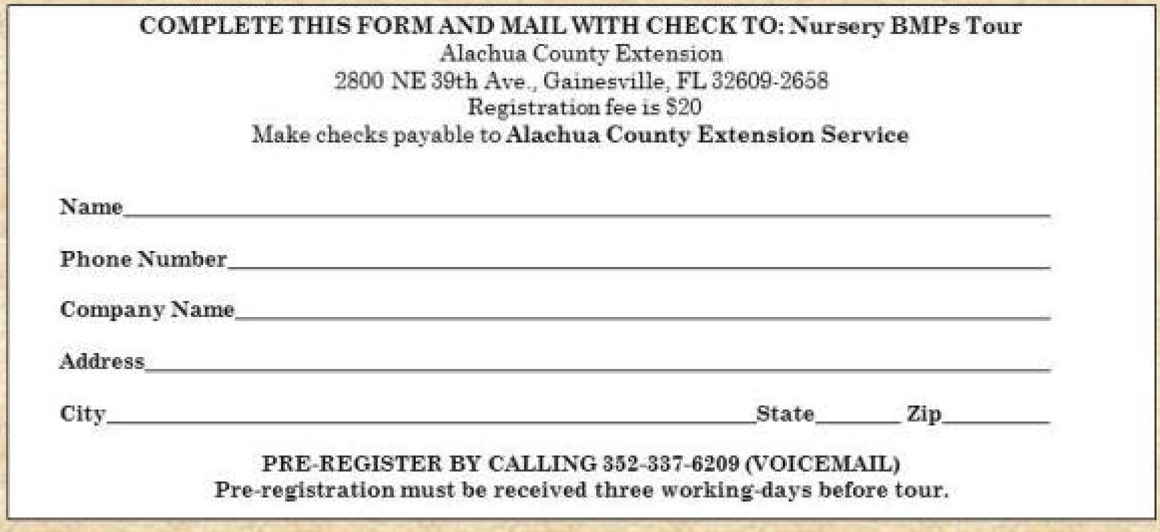
PROGRAM SCHEDULE:

- 5:00 pm: Nursery BMPs
- 5:30 pm: Tour of On-site BMPs
- 7:00 pm: Dinner
- 7:45 pm: Q & A Session

**Program will be held at Holly Factory Nursery,
29010 NW County Road 241, Alachua, FL 32615.**

Registration fee is $20 per person to cover the purchase of materials and dinner. Please register by June 15th by contacting the UF/IFAS Alachua County Extension Office, 2800 NE 39th Ave., Gainesville, FL 32609. Call 352-955-2402 or email agazula@ufl.edu

UF | UNIVERSITY of FLORIDA
IFAS Extension



COMPLETE THIS FORM AND MAIL WITH CHECK TO: Nursery BMPs Tour
Alachua County Extension
2800 NE 39th Ave., Gainesville, FL 32609-2658
Registration fee is $20
Make checks payable to **Alachua County Extension Service**

Name______________________________

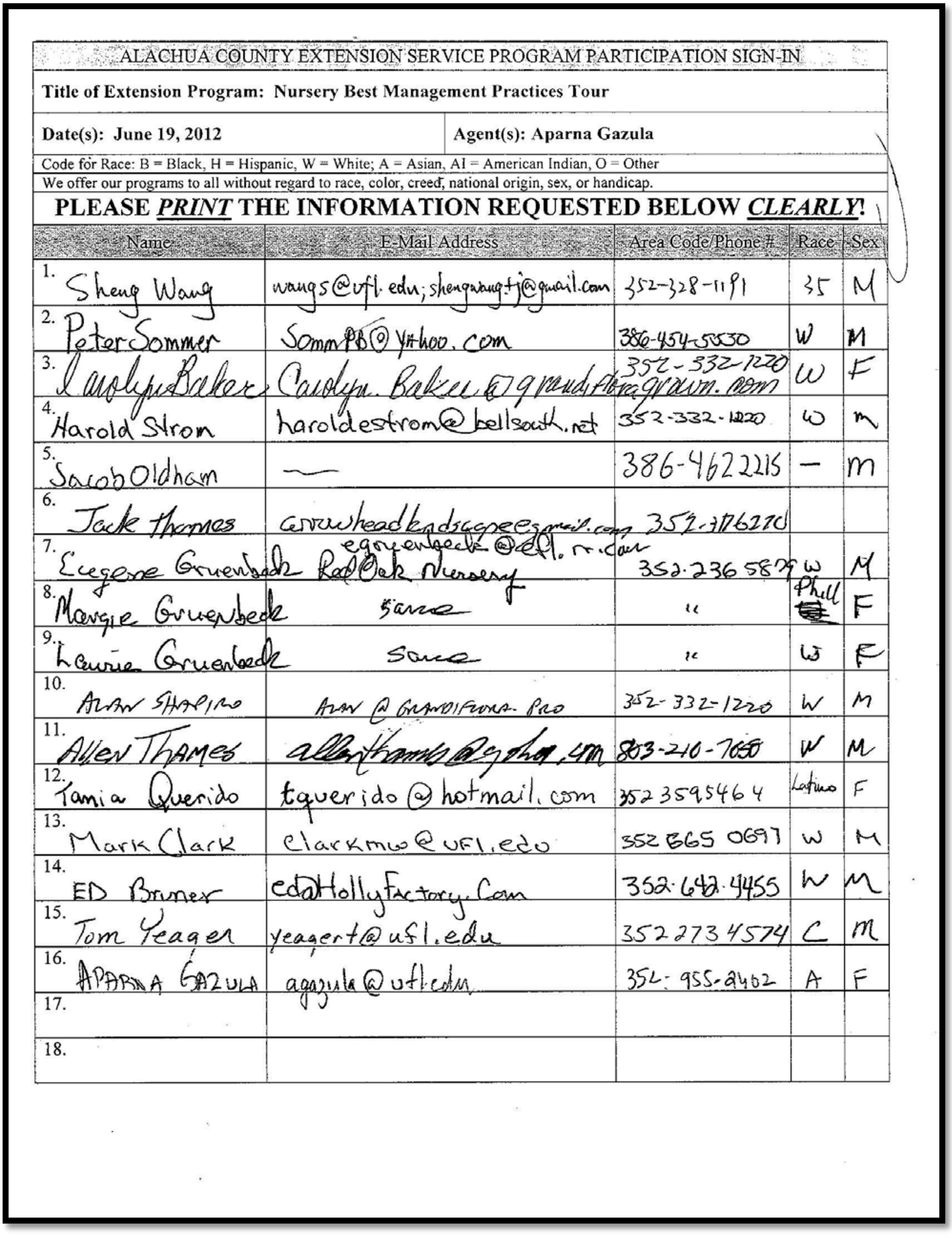
Phone Number______________________________

Company Name______________________________

Address______________________________

City____________________ **State**______ **Zip**______

PRE-REGISTER BY CALLING 352-337-6209 (VOICEMAIL)
Pre-registration must be received three working-days before tour.



ALACHUA COUNTY EXTENSION SERVICE PROGRAM PARTICIPATION SIGN-IN

Title of Extension Program: Nursery Best Management Practices Tour

Date(s): June 19, 2012 **Agent(s):** Aparna Gazula

Code for Race: B = Black, H = Hispanic, W = White; A = Asian, AI = American Indian, O = Other

We offer our programs to all without regard to race, color, creed, national origin, sex, or handicap.

PLEASE *PRINT* THE INFORMATION REQUESTED BELOW *CLEARLY*!

Name	E-Mail Address	Area Code/Phone #	Race	Sex
1. Sheng Wang	wangs@ufl.edu; shengwang.tj@gmail.com	352-328-1191	35	M
2. Peter Sommer	SommPB@yahoo.com	386-454-5530	W	M
3. Carolyn Baker	Carolyn.Baker@grandifloragrown.com	352-332-1220	W	F
4. Harold Strom	haroldestrom@bellsouth.net	352-332-1220	W	m
5. Jacob Oldham	~	386-4622215	—	m
6. Jack thomas	arrowheadlandscapes@gmail.com	352-3176270		
7. Eugene Gruenbeck	egruenbeck@cfl.rr.com Red Oak Nursery	352-236 5879	W	M
8. Margie Gruenbeck	same	"	Phill	F
9. Laurie Gruenbeck	same	"	W	F
10. ALAN SHAPIRO	ALAN@GRANDIFLORA.PRO	352-332-1220	W	M
11. Allen Thames	allenthames@yahoo.com	803-210-7650	W	M
12. Tania Querido	tquerido@hotmail.com	352 359 5464	Latino	F
13. Mark Clark	clarkmw@ufl.edu	352 665 0697	W	M
14. ED Bruner	ed@HollyFactory.Com	352.642.4455	W	M
15. Tom Yeager	yeagert@ufl.edu	352 273 4574	C	m
16. APARNA GAZULA	agazula@ufl.edu	352-955-2402	A	F
17.				
18.				

Container Nursery BMPs Demonstration Event

Holly Factory Nursery
June 19, 2012

Mark Clark[1], Thomas Yeager[2], Aparna Gazula[3] and Todd Stephens[4]

[1]Wetland Biogeochemistry Laboratory
Soil and Water Science Department
[2]Environmental Horticulture Department
[3]Alachua County Extension
University of Florida / Institute of Food and Agricultural Sciences

[4] Owner, Holly Factory Nursery

What's in a BMP?

(Copied from preface of 2007 Florida Container Nursery BMP Manual)

Since 1994, the Florida Department of Agriculture and Consumer Services (FDACS) has been statutorily authorized to assist the agricultural industry with the development and implementation of Best Management Practices (BMPs). As a result, BMPs have become the preferred mechanism for state agencies to address water quality issues related to agricultural discharges, from ground water leaching to surface water runoff. The Florida Department of Environmental Protection (FDEP), the water management districts, the agricultural industry, the academic community, and environmental organizations have endorsed this mechanism. Because of the program's established creditability and the statutory presumption of compliance with state water quality standards for those who implement the BMPs, this is an important program for growers.

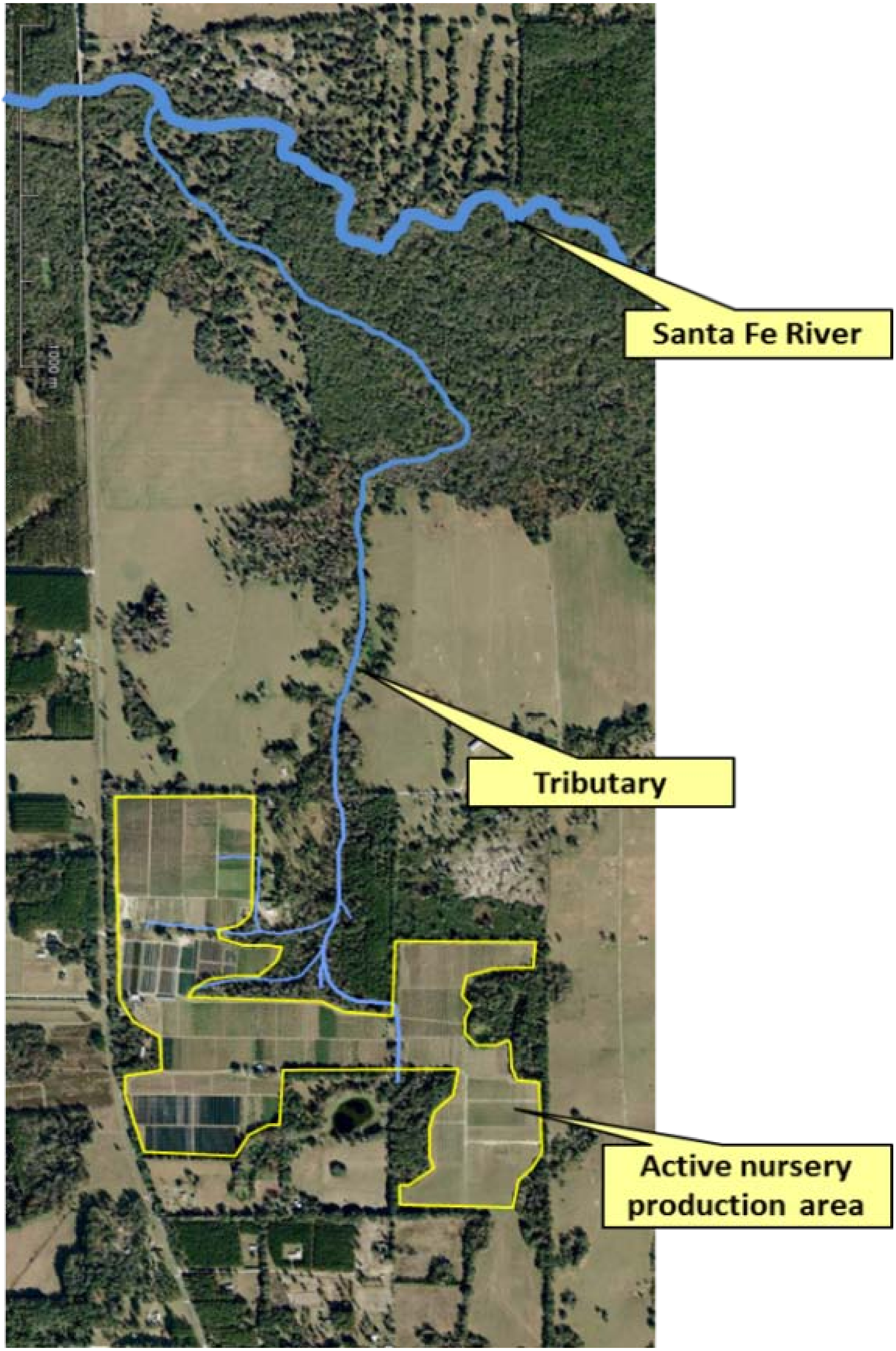
The nursery industry made the decision to participate in the BMP program to offer growers an alternative to existing or future water quality regulation and to address specific water quality issues that may arise locally. The industry has demonstrated a willingness to cooperate with university researchers and extension programs by supporting research projects, and by transferring improved technology related to water resource protection to their nursery operations through the development and implementation of BMPs.

Consistent with the intent of the authorizing legislation, growers and interested parties have had full opportunity to participate in the development of the individual practices contained in the BMP guide, and will have the same opportunity should modifications to the BMP guide be necessary based on new information. Many nursery growers have provided invaluable input throughout the development of this guide. This has enabled the industry to achieve a balance between water resource protection and technically and economically feasible BMPs.

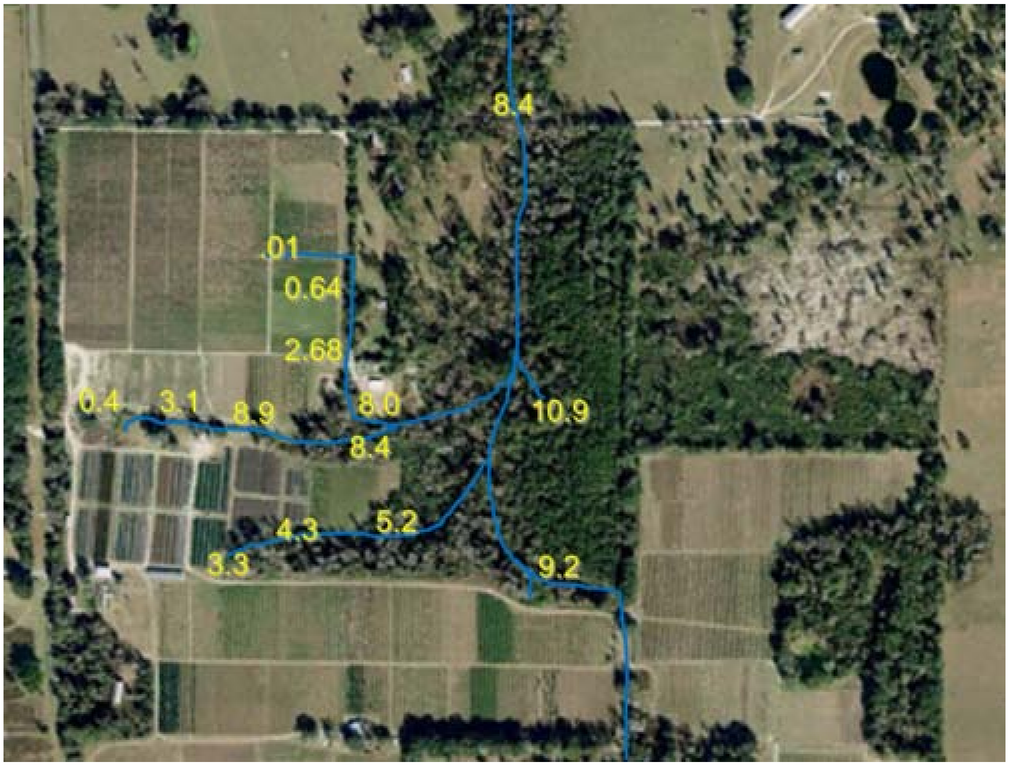
Benefits of Enrolling in the Nursery BMP Program

- Recognition that you are a responsible citizen doing your part as an environmental steward.

- Participants establish eligibility for federal and state cost-share dollars for the implementation of specific practices.
- The implementation of improved management practices for nutrient and irrigation inputs can reduce production costs.
- Grower participation signifies a strong preference for voluntary, consensus-based programs (implementing BMPs) as opposed to the traditional regulatory and/or permitting approach.
- Under the Florida Watershed Restoration Act (s. 403.067, F.S.), implementation of BMPs that FDEP has verified as effective in reducing target pollutants and that FDACS has adopted by rule provides a presumption of compliance with state water quality standards. FDEP is then precluded from recovering costs or damages for contamination related to the target pollutants. Maintaining BMPs is part of implementation.


1000 m
Santa Fe River
Tributary
Active nursery production area

Proximity of Nursery to Santa Fe River

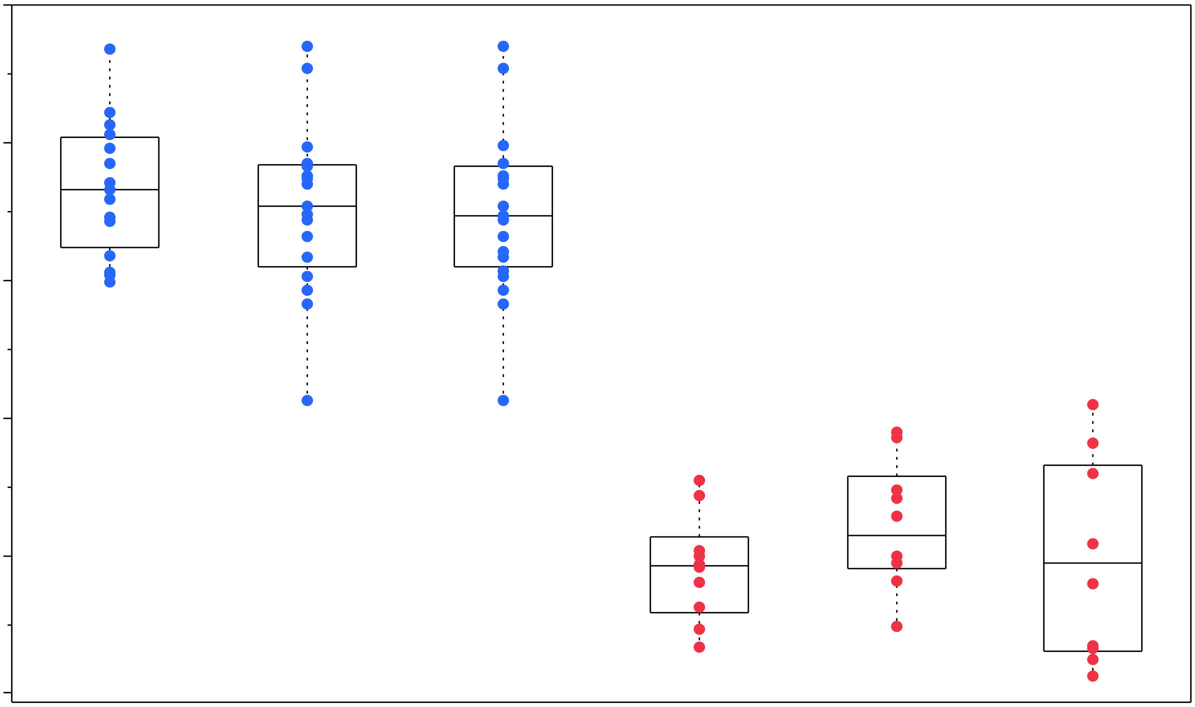


Surface water Nitrate-Nitrogen concentrations (mg L^{-1}) collected in January 2006 from subtributaries and seeps near nursery.

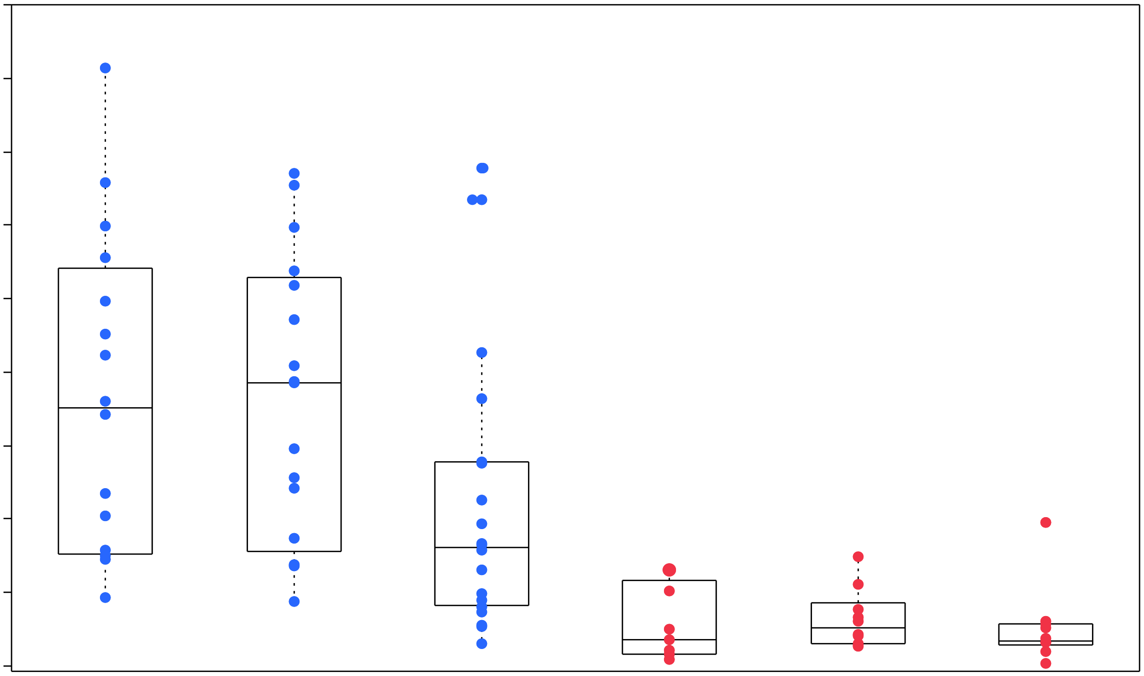
Layout of nursery showing irrigated areas using overhead irrigation (red) and those areas using microirrigation (yellow)

Cyclical Irrigation

During production, most nurseries irrigate on a daily basis (except when rain supplies adequate moisture) in which the daily water allotment is applied in a single application (continuously). An alternative approach to help increase the water holding capacity is cyclic irrigation in which the daily water allotment is applied in more than one application with timed intervals between applications. For example, if the plant need were 0.3 inch of water per day, then for continuous irrigation, 0.3 inch would be applied in a single, one hour application. For cyclic irrigation, 0.1 inch would be applied in 20 minutes; one hour later 0.1 inch would be applied again; one hour later the last 0.1 inch would be applied. Thus, with cyclic irrigation, the 0.3 inch irrigation is applied over a three hour period compared to the one hour period for continuous irrigation. Other cycle durations and intervals might be used, but compared to continuous irrigation, cyclic irrigation has been shown to reduce the volume of irrigation runoff by 30% and the amount of nitrate leached from containers by as much as 41% (Fare et al., 1994). Cyclic irrigation can be used with overhead and microirrigation but automation with controllers and solenoid valves is necessary. Otherwise, cyclic irrigation is too cumbersome.



Flow-through irrigation volume collected during three sampling periods before cyclical irrigation BMPs were implemented (blue) and after cyclical application and lower volumes were implemented (red).



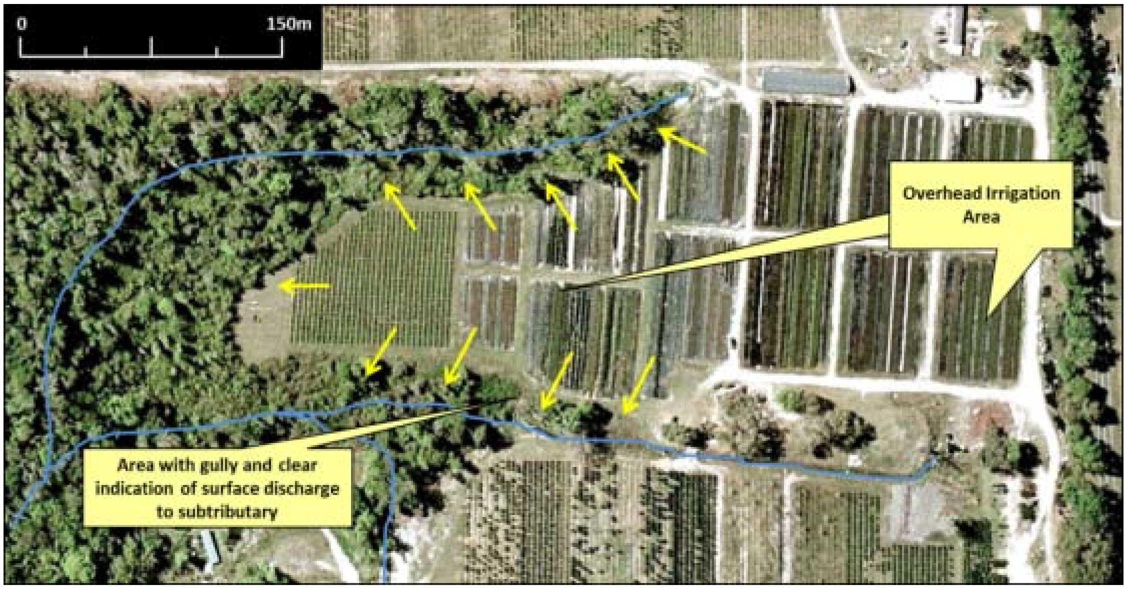
Nitrate-Nitrogen loads in irrigation flow through water from 15 gal containers under preBMP (blue) and postBMP (red) irrigation regimes and fertilizer application rate.

Summary table of PreBMP and Post BMP flow-through volume, nutrient concentration and loads.

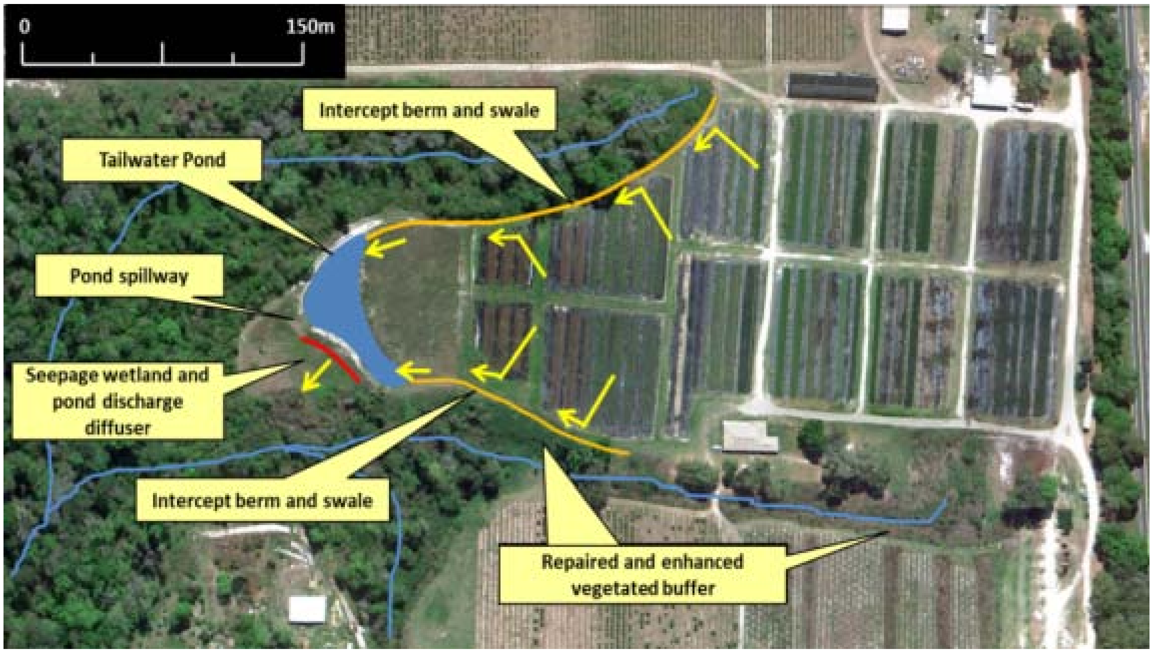
	30 min x 1 application	6 min x 3 applications	% reduction
Irrigation applied	22.9 ± 2.42	8.40 ± 3.74	63.3
Flow-through, L	17.8 ± 2.81	5.13 ± 2.67	71.2
Flow-through, % of irrigatic	87.2 ± 12.8	59.4 ± 17.8	31.9
Flow-through concentration			
TP, mg L^{-1}	4.63 ± 3.77	4.14 ± 4.09	10.6
NOx-N, mg L^{-1}	17.5 ± 11.9	15.1 ± 17.4	13.7
TKN, mg L^{-1}	8.46 ± 5.04	7.06 ± 7.84	16.5
TN, mg L^{-1}	26.0 ± 14.5	22.2 ± 21.1	14.6
Flow-through mass			
TP, mg day^{-1}	80.2 ± 65.3	29.0 ± 40.0	63.8
NOx-N, mg day^{-1}	306 ± 207	57.6 ± 46.7	81.2
TKN, mg day^{-1}	148 ± 82.1	38.6 ± 41.1	73.9
TN, mg day^{-1}	454 ± 251	96.2 ± 78.0	78.8

Intercept Berms, Swales and Tailwater Ponds

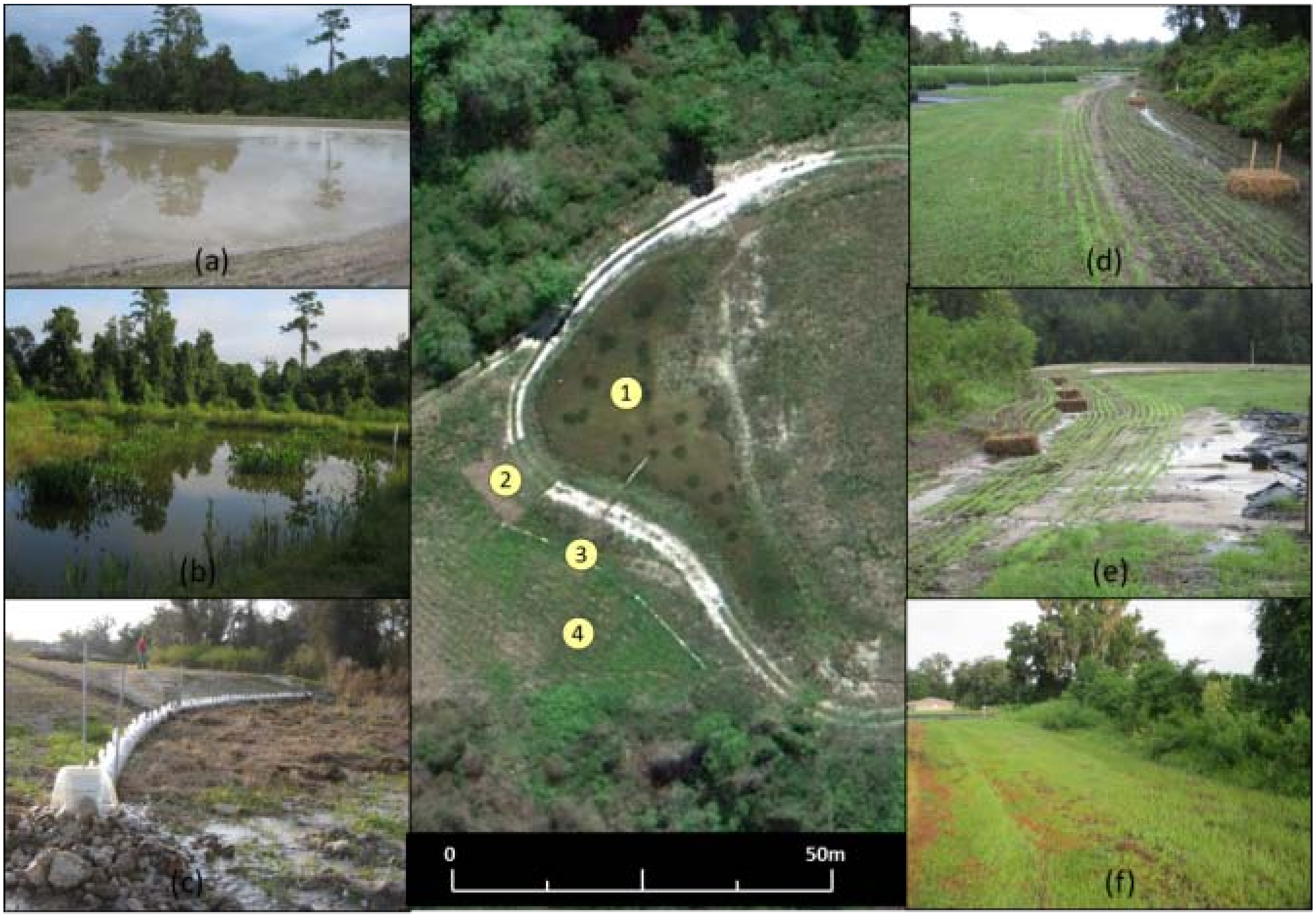
Berms and swales can be used to effectively intercept surface runoff from excess irrigation and storm events and convey the water to a storage area (tailwater pond) for reuse, treatment or discharge to areas with lower impacts.



2006 aerial image of the nursery showing the area of overhead irrigation, overland flow vectors and two subtributaries that receive surface runoff



BMP modifications added to address surface runoff from overhead irrigation area. Post implementation overland flow is intercepted by berms and directed via swales to a tailwater pond. Water detained in the pond is released at a controlled rate to a seepage wetland and eventually flows back to the tributary.



Images of BMPs and other practices integrated into the overhead irrigation area to intercept and treat overland flows previously being discharged directly to the tributary or via vegetated buffers. Center image shows 1) tailwater pond, 2) spillway, 3) pond discharge diffuser pipe and 4) seepage slope/wetland area. Images starting in upper left show a) tailwater pond shortly after first rainfall event, b) tailwater pond nine months after construction, c) tailwater pond discharge diffuser, d and e) intercept berm and swale on south and north side of overhead irrigation area shortly after construction and f) north side berm and swale nine months after construction.

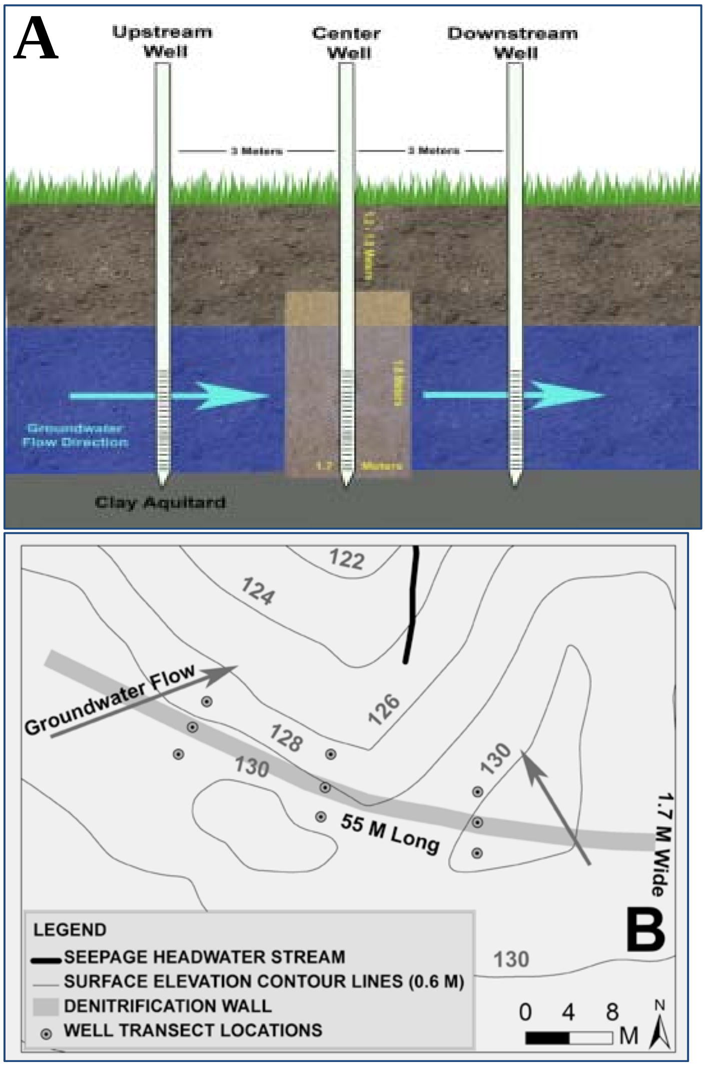
To estimate the benefit of the pond and berm/swale infrastructure to reduce downstream loads, nutrient concentrations in the pond immediately following several storm events were multiplied by the volume of water intercepted by the pond. Using this approach, annualized NOx-N loads intercepted by the pond were 15.7 ± 5.83 kg N yr^{-1} and 28.5 ± 9.49 kg N yr^{-1}. If water intercepted by the pond were detained at least one to two weeks, NOx-N levels were almost completely assimilated into plant material or denitrified in the sediments and released to the atmosphere. It is estimated that upwards of 70% of the TN load intercepted by the tailwater pond (19.4 kg annualized) is removed. Additional removal may also be occurring in the seepage slope/wetland area; however, reductions in nitrogen load from this practice have not yet been quantified.

Denitrification Wall

A denitrification wall bioreactor is a permeable reactive barrier that is used to remove Nitrate from groundwater by enhancing a natural process called denitrification. A large denitrification wall was installed at the Holly Factory Nursery to determine if this was an effective means to reduce surface groundwater nitrate pollution from entering a tributary that flowed into the Santa Fe River.

What is Denitrification?: Nitrate is removed in these barriers through a natural process called denitrification. Denitrification is an anaerobic (no oxygen) respiration reaction where bacteria gain energy from consuming organic carbon (leaf litter, sawdust, wood chips etc.), and predominantly convert nitrate to harmless Nitrogen gas (N_2). For denitrification to occur you need an bioavailalble organic carbon source and waterlogged soils to reduce oxygen levels. These conditions can be created by mixing wood chips, sawdust, or another amendment in to soils that are permanently in contact with high nitrate groundwater.

Denitrification Wall Hydrology and Site Selection: Groundwater travels horizontally from high water table elevation to low elevation and to ditches, streams and wetlands. To intercept and treat groundwater, the wall should be installed at the edge of the field, perpendicularly to the predominant flow direction.



(A) A side-view and (B) an overhead view of the wall indicating the hydrology. In this case the wall is installed down to a clay layer and approximately perpendicularly to the groundwater flow direction.

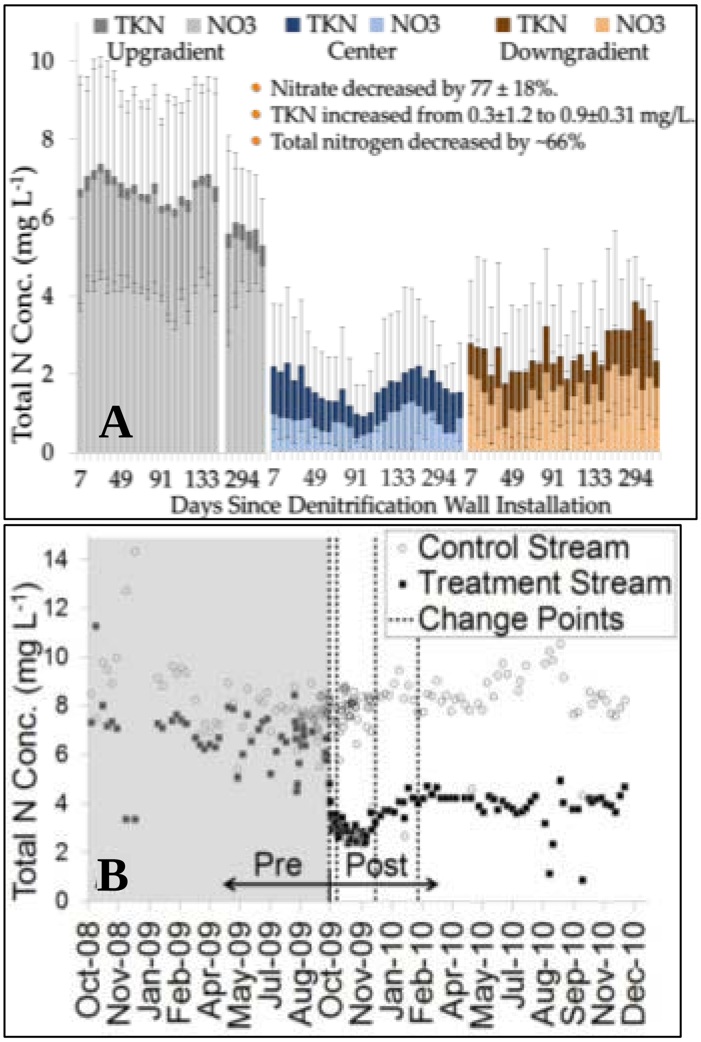
The location and the size of the wall is dependent on the groundwater hydrology and the amount of Nitrate in the water. Below are several factors to consider when evaluating use of a Denitrification Wall:

- The groundwater table should be near the surface to keep the wall media underwater most of the year and reduce construction costs.
- Hydraulic conductivity through the wall must be greater than through the surrounding soil or water must be forced through the wall.
- The detention time of water within the wall must be long enough to create anaerobic conditions and reduce excess Nitrate, this will determine the required width of the wall.
- Locating the wall at strategic locations where groundwater flows are concentrated will result in more effect overall treatment of downstream waters.

Denitrification Wall Installation: The Holly Factory denitrification wall was installed on September 30th, 2009 and it is one of the largest walls in the world. The wall was installed by: mixing pine sawdust with sand in a 50:50 ratio above ground, excavating a trench to the desired depth, adding the sand-sawdust mixture and repeating the process until the full length was completed. The native soils were then backfilled to the surface.

Figure 2 – (A) An image of the sand and sawdust used in the wall. (B) A trench was excavated to the desired depth and was immediately backfilled with the sand and sawdust mixture. (C) the final trench before backfill of surface soils.

Denitrification Wall Results: The wall was evaluated using wells where nitrate was measured upgradient, within (center) and downgradient from the wall. Additionally, to determine if the nitrate was reduced in a stream receiving groundwater from the wall, nitrate concentrations were measured in the receiving ‘treatment’ stream and an adjacent ‘control’ stream. The nitrate concentration declined in the groundwater and stream. We estimate that this denitrification wall will last approximately 23 years and it is cost-effective treatment option compared to other methods (treatment wetlands, riparian buffers, industrial treatment).



(A) Nitrate concentration in the groundwater upgradient, within (center) and downgradient from the wall. (B) Nitrate concentration in the receiving (treatment) and control stream pre and post wall installation. Nitrate reductions were significant in both the groundwater and the stream.

Overall Assessment of Nutrient Load Reduction Resulting from Implementation of Container Nursery BMPs

BMP's implemented in conjunction with this project

- 1.B.1 Retain rainwater – intercept berm, swale and tailwater pond
- 1.B.5 Buffers used – enhanced 25' undisturbed buffer or natural forested buffer around tributaries.
- 1.D.2 Runoff captured – intercept berm, swale and tailwater pond
- 2.C.5 Minimize off-site nutrient loss – intercept berm, swale and tailwater pond
- 3.C.1 Fertilizer Rate – approximate 20% reduction in application of fertilizer to 15 and 30 gal nursery stock on microirigation
- 6.A.5 Cyclic irrigation – applied to all nursery irrigation as described in section 2
- 8.B.1 Water retained – intercept berm, swale and tailwater pond

Location (above) and photo (below) of main monitoring station used to assess overall efficacy of BMP implementation.

Summary of discharge, nitrogen concentration and load data for the main watershed.

Year	TN Conc (mg/L)	Discharge Ave. (L/s)	Annual TN Load Estimate (kg)	Total Rain (mm)	Rain Rate (mm/d)	Ave Rain intensity (mm/min)	Net Storm Runoff (m3)	Net Storm Runoff Load (kg)	Baseflow (10th Percentile) (L/s)
2008*	7.6 ± 0.9	16.8	4206		1.3	0.05	1674		13.2 ± 1.2
2009	6.6 ± 1.2	19.8	4294	1386	3.8	0.17	27005	173.3	11.3 ± 4.3
2010	6.4 ± 0.9	10.0	2097	827	2.3	0.21	26197	162.8	5.57 ± 1.9
2011*	5.5 ± 0.7	8.44	1525		3.2	0.11	1170		5.41 ± 0.05

**2008 and 2011 were only sampled for approximately 3 and 7 months respectively. As such, total rainfall is not indicated, although the rainfall rate is indicated. Additionally, the annual TN load is estimated by extrapolating existing data collection to the entire year.*

9.2 APPENDIX B

QUALITY ASSURANCE PROJECT PLAN FOR PROJECT

QUALITY ASSURANCE PROJECT PLAN

for

REDUCING NONPOINT SOURCE LOSS OF NITRATE WITHIN THE SANTA FE BASIN

FDEP Project Number: GO217

Prepared by:

Mark.W. Clark

September 30th, 2009

MarkW. Clark, Project Principal Investigator | Date

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A3 Distribution List

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A4 Project/Task Organization

Table A4-1. Key personnel and their corresponding responsibilities:

Name	**Responsibility**
Mark Clark	PI; project co-coordinator.
Jim Jawitz	Co-PI: advisory on groundwater monitoring.
Tom Yeager	Co-PI: Container nursery extension specialist and advisor for irrigation and fertilizer BMP components.
Casey Schmidt	Graduate Student working on project who will also be conducting field sampling.
Patrick Moran	Part time field technician hired to assist in data collection.
Yu Wang	Wetland Biogeochemistry Laboratory QA/QC officer
Michael Thomas	FDEP program manager
Todd Stevens	Grower, who’s property the project is on; co-operator

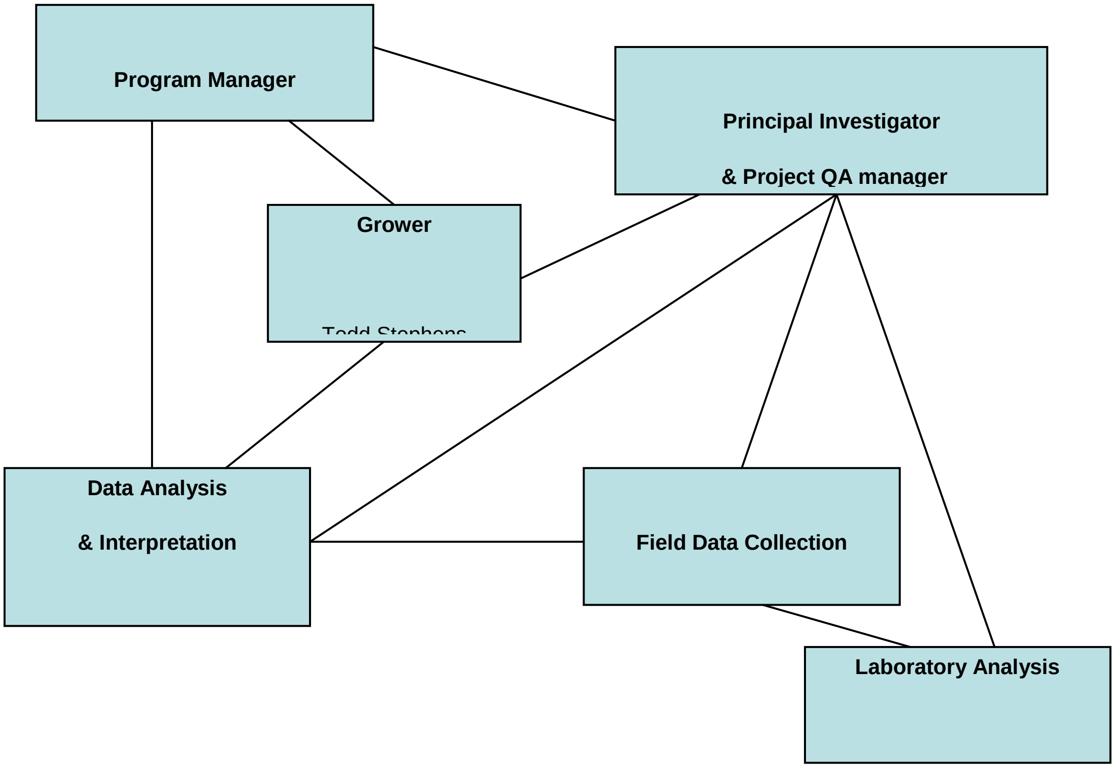


Figure A4-1. Project organization chart showing relationship and lines of communication among all project participants.

A5 Problem Definition/Background

Surface water and groundwater of the Santa Fe Basin has increased nitrate levels. The Santa Fe Basin is part of the 303(d) list for group one basins and is also a 319 priority basin with a SWIM plan approved in 1995. Land use activities combined with the geomorphological characteristics of the basin, result in increased hydrologic connectivity between excess nutrient sources and downstream waters.

The Soil and Water Science Department in collaboration with the Department of Animal Science at the University of Florida/IFAS undertook preliminary water quality surveys of the tributaries downstream of the horticulture unit, to establish baseline water quality data during 2005 and 2006. These findings identified stream reach units (riparian wetlands and seepage slopes) that had high denitrification potential, but also that there were elevated nitrate concentrations in headwaters of tributaries, with headwaters of tributaries originating in the nearby commercial horticulture unit. Results of this survey were presented to the Suwannee River Water Management District and the Suwannee River Partnership. After this, agencies decided to initiate a collaborative proposal to reduce nitrate load from non point sources within the tributary sub-basin.

In addition to the above nitrate related loads from the nursery, baseflow data collected during the dry season indicates that the nursery may be significantly over irrigating. Although the nursery uses micro-jet irrigation, a preliminary investigation at individual plant containers indicated that often more than 75% of the irrigation volume applied was flowing through the bottom of the pot. Most of the excess irrigation volume goes undetected due to the in-ground production practices at the nursery and well drained surface soils. Intervention at this point in the production system by a) providing a feedback mechanism to alert the grower that excess irrigation is occurring and then b) modifying irrigation and fertilizer practices to minimize leaching potential will likely have the greatest benefit in load reduction to the groundwater and down gradient tributary.

This project aims to achieve a reduction in nitrate loads from nonpoint sources by implementing management practices on a horticulture unit within a tributary sub-basin of the Santa Fe River. This project will evaluate multiple management practices to reduce nitrate loads in surface and subsurface waters as well as optimization of irrigation practices to minimize nutrient leaching from plant containers. The first management practice is to use controlled drainage and in-ditch denitrification to reduce nitrate loads in surface waters. The second practice will be to use denitrification walls to reduce nitrate loads in shallow subsurface waters. The third is to implement an alternative irrigation program that will reduce excess irrigation and nutrient leaching to be followed by a modified fertilizer regime once more of the fertilizer applied is available to plants. We will also initiate baseline monitoring of surface and groundwater discharges from the commercial horticulture unit to determine overall efficacy of the pollution reduction strategy at the sub-tributary basin-scale. Implementing the different practices will also provide an opportunity to demonstrate the efficacy of these to watershed stakeholders. We and our partners will achieve this by holding field days to generate awareness among stakeholders. We will also hold a workshop to transfer information and generate awareness among stakeholders of the need to incorporate additional practices to help improve water quality in basins that have impaired water quality.

The intended use of the data is to assess and evaluate the effectiveness of management practices to reduce nonpoint source loss of nitrate from a commercial horticulture unit. This information will be used to demonstrate the efficacy of various management practices to reduce nitrate loss to the Santa Fe River.

A6 Project/Task Description

This project aims to reduce nitrate loads from nonpoint sources by implementing management practices on a horticulture unit within a tributary sub-basin of the Santa Fe River (Figure A6-1). We will use controlled drainage and in-stream denitrification to reduce nitrate loads in surface waters and we will use denitrification walls to reduce nitrate loads in shallow groundwaters. We will use optimized irrigation practices and irrigation controller (human or electronic) feedback mechanisms to reduce excess irrigation and thereby lower nutrient losses at the container-soil interface. In addition, we will initiate baseline monitoring of surface and groundwater discharges from the nursery to determine overall efficacy of multiple nursery wide BMPs.

To determine the efficacy of these low cost, innovative practices, we will implement infrastructure to measure mass load reductions, specifically nitrate, and determine the cumulative effect practices have on water quality at the tributary sub-basin scale. Implementing practices will also provide an opportunity to demonstrate the efficacy of these. We and our partners will achieve this by holding field days to generate awareness among stakeholders. We will also hold workshops to educate and train those stakeholders that are interested in implementing similar management practices. Deliverables arising from public outreach will include technical and non-technical publications.

This project includes ten tasks organized around four major objectives. The project scope involves implementing: (1) a baseline monitoring component to be used to evaluate nursery wide BMP implementation, (2) monitoring of the efficacy of a combination of controlled drainage with in-ditch denitrification to reduce nitrate loads in surface waters (baseflow and storm flows), (3), monitoring of denitrification wall efficacy to reduce nitrate in shallow groundwaters and (4) developing a means to reduce over irrigation and nutrient leaching by establishing a controller feedback mechanisms. The middle two systems are low cost, innovative practices that can target nitrate levels released to ditch networks and shallow groundwater seepage conditions, the third should conserve water, reduce fertilizer application rates (more of fertilizer applied will be available to plant uptake and not leached) and therefore save the grower money.

Conventional surface and subsurface drainage can lead to increased loss of nitrate. Therefore, controlled drainage that is, controlling water levels in drainage ditches by flashboard risers or intercepting runoff using diversion berms and swales to a detention area can help reduce nitrate loss. Reports in literature suggest somewhere in the range of 50% reduction in nitrate loss. Site specific conditions suitable for using controlled drainage include the presence of shallow groundwaters, which are present at our site. In addition, to controlled drainage, we will manage ditches to optimize denitrification processes in ditches. Thus, in-ditch dentrification will mimic, but optimize, natural riparian wetland processes. The processes that are important for denitrification in ditches include anaerobic conditions, a ready supply of nitrate and a suitable organic carbon source. Controlled drainage will intercept unregulated flows and ensure that flooded anaerobic conditions are present in ditches during certain times of the year. Nitrate concentrations in ditch water should be elevated, as ditch waters are drainage waters from nursery application areas. Vegetation in ditches and subsequent accumulation of organic matter on soil surfaces should provide organic matter (carbon source) for denitrification processes to occur. We will optimize all conditions to increase denitrification potential within ditches. Literature values reporting effectiveness of in-stream denitrification processes can range between 80 and 90%.

Denitrification walls are a management practice that enhance microbial conversion of nitrate to dinitrogen gas (see references) and are used as BMPs in other countries. The “wall” typically consists of a trench perpendicular to the groundwater flow paths and the trench is backfilled with a high carbon substrate mixed with native soil. Many sources of carbon have been tested, but typically local, inexpensive sources such as sawdust or woodchips/mulch are used. The depth of the wall depends upon depth to shallow groundwater, the objective being, to intercept groundwater flows, which have high nitrate levels. Pollutant loadings to and estimated load reductions by denitrification walls, will be determined by measuring loads going into and out of denitrification walls. After monitoring groundwater and establishing groundwater flows, a denitrification wall will be sited strategically within the horticulture unit to optimize nitrate load reduction. The use of denitrification walls to reduce nitrate loads in shallow groundwaters is a novel, low cost approach that may be particularly suited to the landscape of north central Florida such as the Santa Fe Basin.

Information transfer

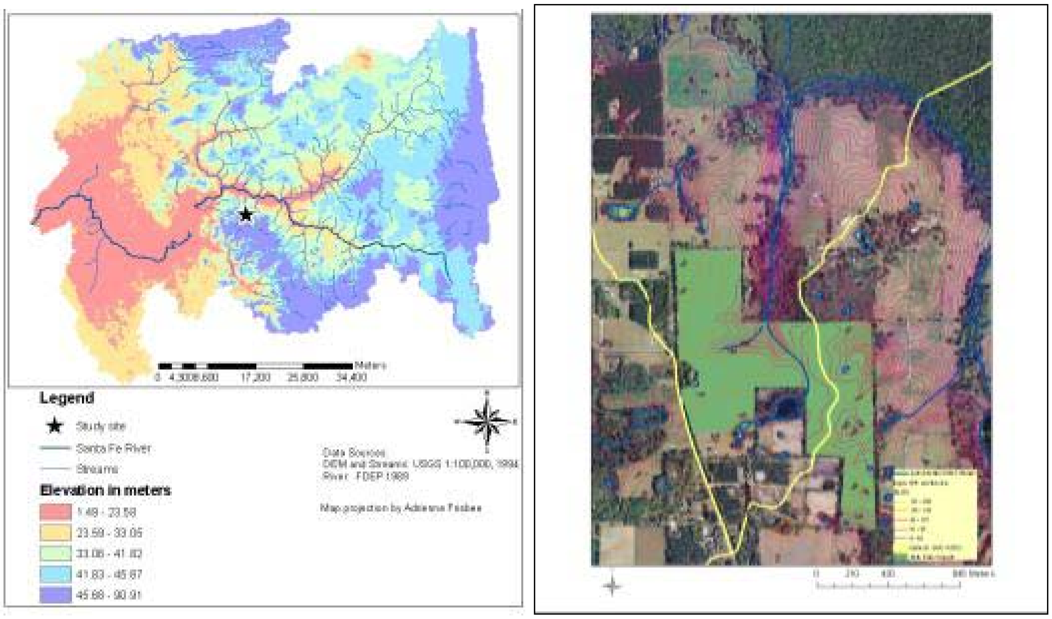
To initiate information transfer from the experiences we and our partners gain by implementing these practices, we will hold at least two field days on the Holly Factory Nursery to generate awareness and build relationships with stakeholders. In addition, we and our partners will also conduct workshops to provide training and technical assistance to those parties that are interested in implementing similar practices within the Santa Fe River Basin. Education materials will include technical and non-technical publications. Participants on field days and workshops will undertake pre and post surveys to measure the effectiveness of the educational program.

The overall project will result in the reduction of pollutants being discharged to the Santa Fe Basin, which is part of the 303(d) list for group one basins and will undergo a TMDL process for nutrients (TP and TN) and oxygen content of waters. In addition, it will generate awareness of different management practices and water quality at the sub-basin scale among growers and the general public.

Table A6-1. Description of task, summary of work, products and anticipated start and end date.

Task	**Summary of work**	**Products**	**Anticipated start and end date**
1	Implement groundwater monitoring wells in localized areas of site and monitor flows for one year.	Map of groundwater flows and loads.	July 2008-October 2010
2	Design controlled drainage, in-ditch denitrification, and denitrification wall. specifications and construction plans will be conducted for each system. Permits will be obtained if necessary.	Report on system design.	July 2009-June. 2009
3	Construction of controlled drainage and in-ditch denitrification systems	Controlled drainage area and in-ditch denitrification system and report on construction.	July 2009-August 2009

4	Construction of denitrification wall	Denitrification wall and report on construction.	July 2009
5	Evaluate effectiveness of controlled drainage and in-ditch denitrification systems by monitoring surface water inputs and outputs, to determine nitrate load reduction.	Report on system effectiveness.	August 2009-December 2010
6	Evaluate effectiveness of denitrification wall systems by monitoring surface water inputs and outputs, to determine nitrate load reduction.	Report on system effectiveness.	August 2009-December 2010
7	Evaluate cumulative effect of BMP practices on tributary water quality.	Report on sub-basin water quality.	July 2008-December 2010
8	Evaluate alternative irrigation practices implemented at the nursery to reduce excess irrigation and modified fertilizer practices based on reduced leaching caused by excess irrigation	Report on modified irrigation strategies and reduced fertilizer demand.	July 2008 - December 2010
9	Demonstration/education and training of controlled drainage, in-ditch denitrification, denitrification wall, and optimized irrigation practices and feedback mechanisms to landowners during field days, workshops and appropriate publications in trade journals and fact sheets.	Field-days, workshops and publications	April 2010 – April 2011
10	Draft and final report	Delivery of final report	January 2011 – April 2011



(a) (b)

Figure A6-1. a) Location of project site within the Santa Fe River watershed, b) topography of project site with nursery site shaded in green.

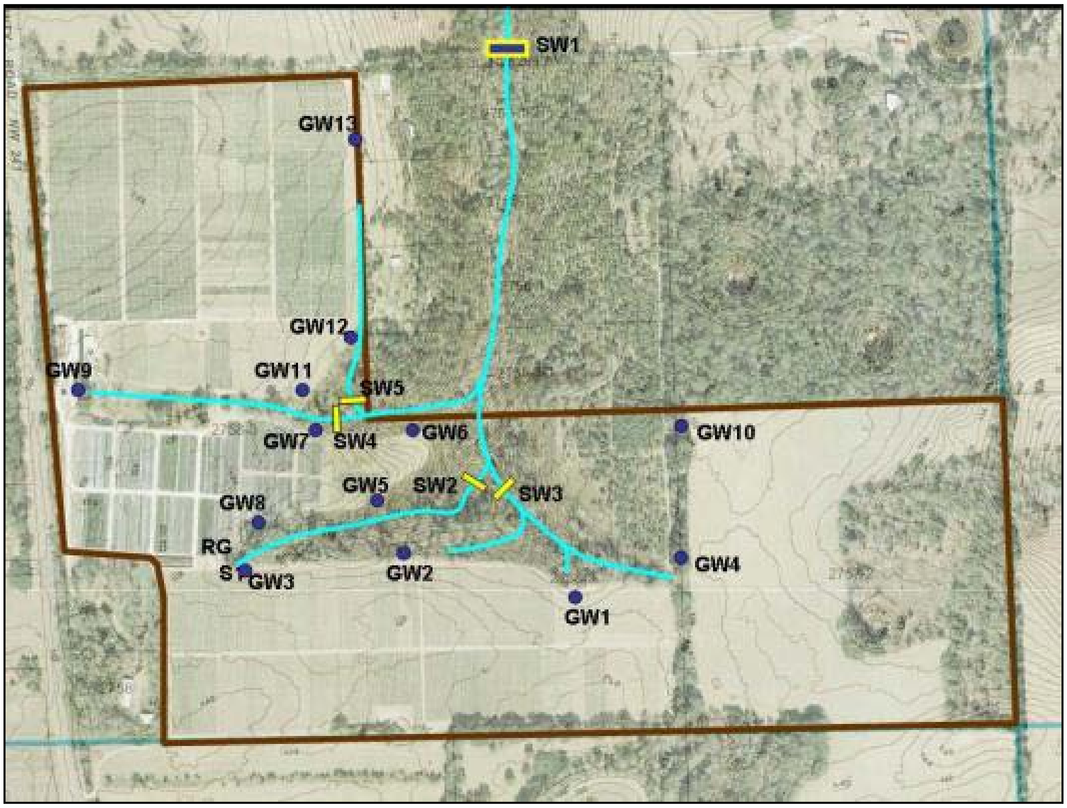


Figure A6-2 Location of surface and groundwater monitoring stations

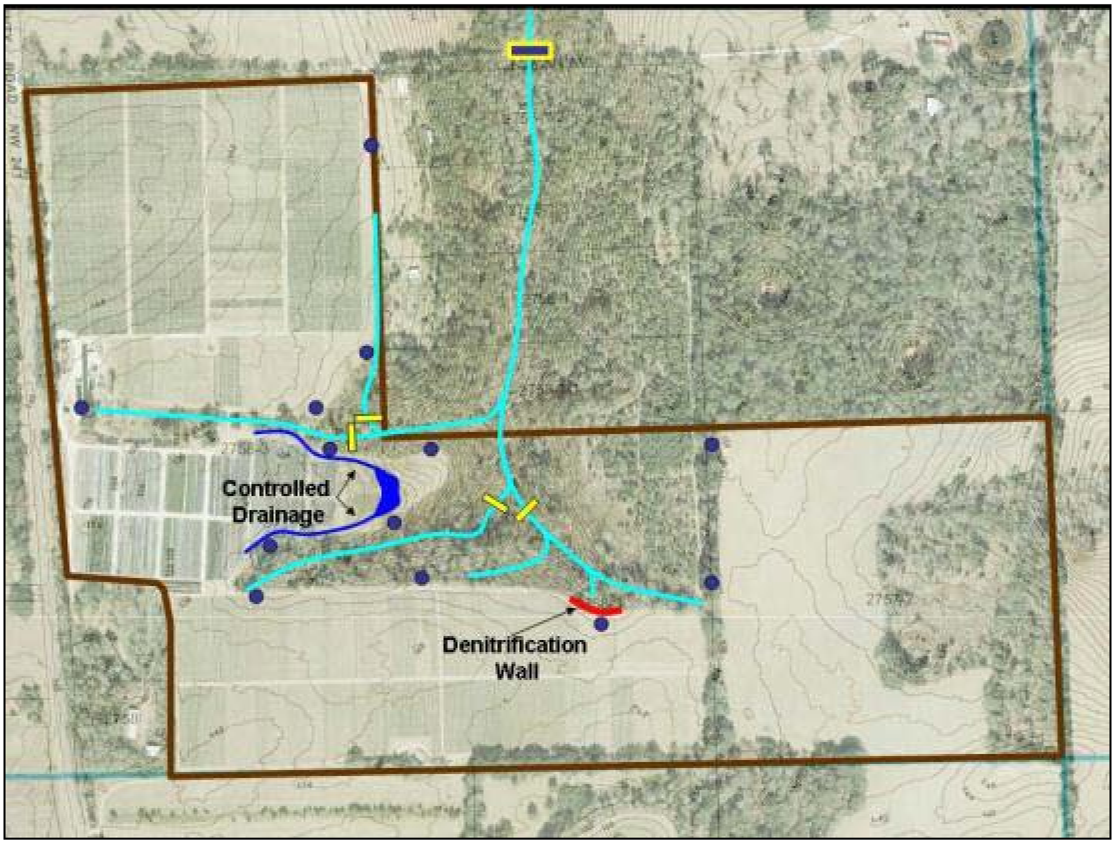


Figure A6-3. Planned location of denitrification wall and controlled drainage practice

A7 Quality Objectives and Criteria

The quality objectives for this project include approved FDEP field water sampling procedures (Table A7-1). Quality objectives for laboratory procedures, analyses and quality assurance/quality control will adhere to NELAC standards, as all analytical samples will be analyzed at the UF-IFAS Wetland Biogeochemistry Laboratory. This laboratory is NELAC certified for non-potable water-general chemistry, pursuant to the Florida Administrative Code 64E-1. Frequency of field-QC blanks and analysis of lab QC samples and calibration standards of all types will conform to FDEP GO217 contract QA requirements.

For further information on analytical methods, see section B4.

Table A7-1. FDEP standard operating procedures that will be used during this project.

FDEP Standard Operating Procedures	SOP Title
FD 1000	Documentation
FQ 1000	Quality Control
FS 1000	General Sampling
FS 2000	General Water Sampling
FS 2100	Surface Water Sampling
FS 2200	Groundwater Sampling

A8 Special Training/Certification

Personnel for field sampling are trained in water sampling methods. No other certification is necessary. The Wetland Biogeochemistry Laboratory to which we submit samples is NELAC certified and therefore personnel running samples have met proficiency requirements on various laboratory instruments. Please see section B4 (Analytical Methods) for more information.

A9 Documents and Records

Reporting will include quarterly progress reports, a draft comprehensive final report (one hard copy and electronic), and a comprehensive final project report. Electronic report will be submitted in Adobe.pdf or MS Word format.

The quarterly progress report will include information as follows:

- Progress Report Form
- Payment Request Summary Form

The Comprehensive final report will include information as follows:

- Accounting of all project expenses
- Report of all matching funds contributed
- Acknowledgement of funding agency
- All final deliverables
- Results
- Discussion
- Conclusions

All field and laboratory records will be retained for 5 years at UF/IFAS Soil and Water Science Department (SWS).

The Wetland Biogeochemistry Laboratory within the Soil and Water Science Department will retain all laboratory documentation, raw data, calibration data, logbooks, etc. that are applicable. After QA validation, the WBL will provide a short narrative report describing analytical anomalies, which could affect data interpretation, along with a summary report of all analytical data and QC samples to the Project Manager for use in the final report. When required, a cover letter will reference specific data if an explanation of reported values is necessary. All laboratory reports will be transmitted to the Project Manager or his designee. The Project Manager will retain custody of all project field records and the WBL will retain custody of all internal laboratory records including run logs, maintenance records, standard and reagent logs, etc.

Field sampling procedures and proper handling will be conducted as specified by DEP-QA-002/02 and are described in Section B. All field records will be retained by SWS for a minimum of five years following the completed project. All field data will be written down in a field notebook and organized in a similar standard format. A photocopy of any new entries in the field notebook will be made after each field sampling event and prior to the next field sampling event. Photocopies of field notebooks will be organized in binders and stored for reference.

GROUP B: DATA GENERATION AND ACQUISTION

B1 Sampling Process Design

B1.1 In-ditch denitrification

Water flow and water quality will be measured at a minimum every month during flow periods to evaluate in-ditch dentrification processes. Flow and water quality (see parameters below) will be measured upstream and downstream of in-ditch denitrification practice. Upstream and downstream control structures will consist of a weir with known cross section area based on water depth that can be used to determine flow (see Figure B-1 for an example of two types of weirs being used for flow determination). Comparing nutrient load upstream of denitrification practice to loads downstream of practices will determine short-term load reduction effectiveness of in-ditch denitrification practice.

(a) (b)

Figure B1-1. Example of two weirs being used to measure surface flows, a) rectangular weir, and b) compound "V-notch" weir.

B1.2 Denitrification wall

Groundwater wells will be located up gradient, within and down gradient of the denitrification wall. Sampling wells will be installed by augering a 20 cm dia. hole to a depth equivalent to the bottom of the denitrification wall. A 5 cm diameter ASTM PVC well screen pipe (0.3 cm spacing) with ASTM PVC well tip will be centered in the bore hole. The bore hole, with tip and screen in it, will be back filled with 20/30 washed sand to a depth of 30 cm below the soil surface. A 5 cm ASTM PVC non porous well casing will be screwed on to the screened portion of pipe and then bentonite clay will be filled to soil surface. The top of the well casing will be capped by screwing on an ASTM PVC plug or 2" PVC slip cap. The well casing will extend at least 60cm above soil surface. Groundwater samples that are taken up gradient of the wall will be regarded as groundwater flow into the wall and those taken down gradient of the wall will be regarded as outflow from the wall. After construction of the denitrification wall, wells will be sampled at least once per month during the monitoring period.

B1.3 Tributary load monitoring

Tributary sampling stations (water quality and water flow) will be located within and downstream of the Holly Factory property, and within the Santa Fe Beef Research Unit property (Figure A6-2). An example of weirs used at monitoring stations can be seen in Figure B-1. At the main tributary (SW-1) a compound rectangular weir is used to monitor the larger flows which occur at this station. The reservoir between the weir and transducer at SW1 is lined with concrete underneath a bridge. At the subwatersheds (SW-2 and SW-3) the compound weir design allows for more refined measurements under baseflow conditions (v-notch weir), as well as measurements under higher flow events (rectangular upper weir). The reservoirs of SW-2 and SW-3 have natural streambeds. Sediment accumulation behind the weir is controlled by periodic removal so that weir calculation assumptions will not be compromised.

B1.4 Field perimeter groundwater monitoring

Thirteen perimeter groundwater monitoring wells are located between the nursery production area and the headwater seepage slope surrounding the various subtributaries (Figure A6-2). These monitoring wells penetrate through the sandy surface soils and stop at what we believe to be the surface of the Hawthorn Formation. Sampling wells will be installed by first auguring a 20 cm dia. Hole. A 5 cm diameter ASTM PVC well screen pipe (0.3 cm spacing) with ASTM PVC well tip will be centered in the bore hole. The bore hole, with tip and screen in it, will be back filled with 20/30 washed sand to a depth of 30 cm below the soil surface. A 5 cm ASTM PVC non porous well casing will be screwed on to the screened portion of pipe and then bentonite clay will be filled to soil surface. The top of the well casing will be capped by screwing on an ASTM PVC plug or 2” PVC slip cap. The well casing will extend at least 60cm above soil surface. The purpose of these wells it to measure the direction, flow rate and nutrient concentration of water moving across the production field boundary toward the seepage slope.

B1.5 Container flow-through monitoring

The majority of the nursery stock is in 15 and 30 gallon containers which are partially recessed in the soil. These containers are presently irrigated by a 0.2 gal/min micro-jet emitters. Any excess irrigation that flows through the bottom of the container infiltrates immediately below the container due to the well drained surface soils. Twelve flow-through monitoring stations will be placed in groups of three under 15 gallon and 30 gallon containers to monitoring rates of excess irrigation flow through. The four sets will be distributed among three prominent 15 gallon stock material (holly, crape myrtle and Leland cypress) and one set under the most common 30 gallon stock material (presently crape myrtle). Each monitoring station will consist of a soil moisture wick, a tipping bucket rain gauge, a sampling reservoir and solenoid valve shutoff as depicted in Figure B1-2

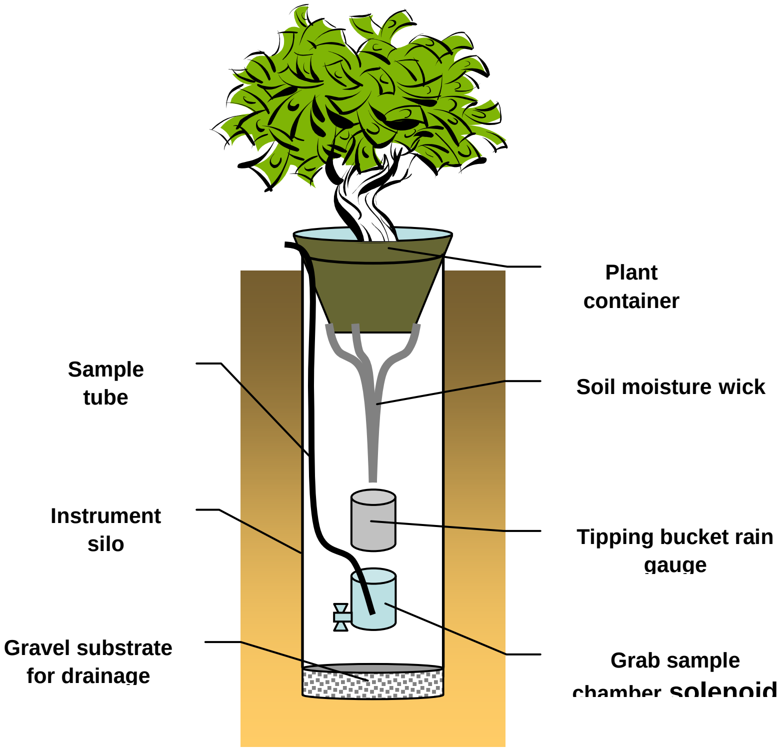


Figure B1-2. Schematic of container flow-through sampling design.

B2 Sampling Methods

B2.1 In-ditch denitrification

Flow rates will be measured upstream and downstream of the in-ditch denitrification practice during water quality sampling periods. Weirs identified for this practice in section B1.1 will be used as control structures. Methods for calculating flows at control structures are outlined below under section B2.4. Grab water samples will be collected

following FDEP-SOP-2100. Water samples to be analyzed for nitrate + nitrate, ammonium and dissolved organic carbon will first be filtered using a 0.45 um disposable syringe filter then acidified with one drop of concentrated H_2SO_4 (94 – 98%) per 20ml of water and placed in a cooler with wet ice within 15 minutes for transfer to the laboratory. Samples being analyzed for TKN or TP will not be filtered, but will be acidified and placed on wet ice as described above. Water samples will be analyzed in the Wetland Biogeochemistry laboratory, which is NELAC certified. Analyses will include: total kjeldahl nitrogen, ammonium, nitrate, total phosphorus, and dissolved organic carbon. (See section B4 for details on laboratory analyses).

B2.2 Denitrification wall wells and perimeter groundwater monitoring wells

A variable speed peristaltic pump will be used for purging and sampling of well water. First the water surface in the well will be determined relative to top of casing and the depth of the water in the well will be calculated. Pump tubing will be lowered to the mid depth of water within the well for purging and sample collection. One well water volume will be purged prior to sampling. Sample water pumped from the will be discharged directly into sample containers. Samples will be acidified with one drop of concentrated H_2SO_4 (94 – 98%) per 20ml of sample water and placed in a cooler with wet ice within 15 minutes for transfer to the laboratory. Water samples will be analyzed in the Wetland Biogeochemistry laboratory, which is NELAC certified. Analyses will include: total kjeldahl nitrogen, ammonium, nitrate, total phosphorus, and dissolved organic carbon.

Perimeter groundwater wells will also have periodic continuous monitoring of water levels. In these wells, pressure transducers with data loggers will be lowered to the bottom and depth of transducer referenced to the top of the well casing. Data will be downloaded from water level data loggers at least monthly and likely on a weekly basis. Prior to downloading well data loggers water depth in the well will be determined and used as a calibration check against readings collected from the data logger.

Perimeter groundwater wells and denitrification wall wells will be periodically monitored for groundwater flow rates and direction. These parameters will be measured using a Model 40 Geoflow groundwater flux meter from Kerfoot Technologies, Inc. The instrument will be calibrated in the laboratory using #20/30 sand following manufacturer protocol.

B2.3 Tributary load monitoring

Each sampling station will be equipped with an automatic water sampler (Sigma Streamline 800SL Portable sampler or ISCO 3700 portable sampler) that will take samples on a flow proportional basis during steady state conditions. Twenty four 500ml water sample containers will be used in the autosampler carousel. When a sampling event is triggered, 100ml of sample will be collected and discharged into a 500ml sample bottle. Five 100ml samples will be composted in one 500ml sample bottle before the carousel is rotated to the next bottle Sample bottles are pre-acidified with 0.5 ml of concentrated H_2SO_4 (94 – 98%) . Samples will be collected from each sampler at least every seven days. pH of composite samples will be checked and documented at the time of collection. Subsamples from composite sample containers will be collected in 20ml scintillation bottles. Water samples to be analyzed for nitrate + nitrate, and ammonium will first be filtered using a 0.45 um disposable syringe filter then placed in a cooler with wet ice for transfer to the laboratory. Samples being analyzed for TKN or TP will not be filtered just placed in a cooler on wet ice for transport to the laboratory. Water samples will be analyzed at the Wetland Biogeochemistry laboratory for total kjeldahl nitrogen, ammonium, nitrate and total phosphorus.

Surface water flow rates will be determined using weirs instrumented with pressure transducers (see Figure B-1 as an example of two weirs being used in the project). Water level pressure transducers will be set upstream of weir four to six times the distance of the maximum flow depth expected over the weir. Depth of water flowing over the weir will be used to estimate flow volumes. At SW1 flow through both the lower and upper rectangular weir is calculated with the Kindsvater-Carter equation (Kindsvater and Carter 1959).

$$Q = C_e L_e h_{1e}^{3/2}$$

Where:

Q = discharge, cubic feet per second (ft^3/s)

e = a subscript denoting “effective”

C_e = effective coefficient of discharge, $ft^{1/2}/s$ (value based on the ratio L/B)

$L_e = L + k_b$

$h_{1e} = h_1 + k_h$

k_b = a correction factor to obtain effective weir length (based on ratio of L/B)

L = measured length of weir crest

B = average width of approach channel, ft

h_1 = head measured above the weir crest, ft

k_h = a correction factor with a value of 0.003 ft

When the lower weir at SW1 is completely submerged and flow is occurring through the upper rectangular weir, an orifice flow equation is used for the lower weir as described in USBR 2001. The orifice flow calculation is as follows.

$$Q = C_d A\sqrt{(2g\Delta h)}$$

Where:

Q = discharge

g = gravitational acceleration

Δh = ½ the height of the orifice

A = the area of the orifice

C_d = coefficient of discharge

The lower v-notch weirs at SW2 and SW3 are calculated using the following equation for a fully contracted weir as described in USBR 2001.

$$Q = C_e\ (8/15)\ \surd(2g \tan(\square/2)\ h_e^{2.5}$$

Where:

Q = discharge

C_e = discharge coefficient (a function of the notch angle, 0.578 for 90^o)

$\square$ = notch angle

$H_e = h_1 + K_h$

K_h = a constant calculated as a function of notch angle (0.833 for 90^o).

The head measurements are manually confirmed by measuring and recording the depth of the water at the pressure transducer weekly using a staff gauge. Sediment is removed from the reservoir upstream of the weir and the transducer from all sites as needed to maintain calculation assumptions for a full contracted weir. Every eight months, discharge calculations are confirmed by collecting a full profile water flow rate over the weir at SW2 and SW3 and a partial profile of the flow at SW1. This manual measurement is compared to the values calculated in the CR10-X and any necessary corrections are made and documented.

An example of the program being used to determine flow and to signal the autosampler at the main gauging station (SW-1) can be found in Appendix A. The programs at SW2 and SW3 are similar except a v-notch weir equation is used and the volume used to signal the autosampler is different. Flow data will be logged on a continuous basis and data will be recorded using a Campbell CR10X data logger. Data will be downloaded at least monthly and most likely on a weekly basis. All documentation from field sampling of tributary sampling stations will be similar to formats outlined by DEP-SOP-001/01; method FD 1000.

<u>B2.4Container flow-through monitoring</u>

Flow-through volume and at least monthly water quality samples will be collected from the twelve monitoring set ups (Figure B2). Flow-through volume will be monitored using a standard tipping bucket rain gauge. The data logger for the rain gauge will be downloaded weekly. Water samples will be collected by closing a valve on the grab sample chamber below the rain gauge and allowing the chamber to fill with any water flowing through during the irrigation period. Flow-through water from the chamber will be sampled using a collection tube that extends from the chamber to the surface similar to sampling groundwater well. After sampling, the drainage valve in the grab sample chamber will be opened up and any container flow through will be allowed to drain freely to the subsoil below the instrument silo.

Water samples to be analyzed for nitrate + nitrate, ammonium and dissolved organic carbon will first be filtered using a 0.45 um disposable syringe filter then acidified with one drop of concentrated H_2SO_4 (94 – 98%) per 20ml of water and placed in a cooler with wet ice within 15 minutes for transfer to the laboratory. Samples being analyzed for TKN or TP will not be filtered, but will be acidified and placed on wet ice as described above. Water samples will be analyzed in the Wetland Biogeochemistry laboratory, which is NELAC certified. Analyses will include: total kjeldahl nitrogen, ammonium, nitrate, total phosphorus, and dissolved organic carbon. (See section B4 for details on laboratory analyses).

B3 Sampling Handling and Custody

A verifiable trail of documentation for each sample will be maintained from the time of sample collection through the analytical laboratory to final reporting and archiving of data.

All samples submitted to the Wetland Biogeochemistry laboratory will be accompanied by a chain of custody form that contains information like date and time sampled, field identification, laboratory identification, sample type, preservation, and analyses required.

Data recorded in the field will be transferred to a binder upon return to the laboratory. Field notes and data will be transferred from hard copy to electronic format for reporting, review and storage.

Samples collected by Wetlands Biogeochemistry Laboratory (WBL) personnel as part of this project will be labeled prior to or in the field at the time of sampling using the following labeling scheme: project name, field identification, date, time sampled, preservation and analysis. Sample containers will be labeled with either a permanent ink marker, directly transcribed onto the sample container, or with a pre-printed label (See sample below).

Samples will be brought back to laboratory on wet ice in a cooler. Samples will then be placed into a designated refrigerator. A chain of custody form will follow sample custody at all times.

HF	SW-1	3-25-2003	13:05	TN, TP	H_2SO_4
Project_ID	Station_ID	Date sampled	Time sampled	Analysis	Preservation

The following criteria shall be used to flag samples in the laboratory at whatever stage the violation is discovered:

- Cracked or broken sample containers when no alternate container is available.
- Incorrect preservation, including cases when samples were not on wet ice or the sample pH is >2.
- A sample that is out of holding time.
- Presence of obvious sample contamination from foreign matter in the sample (animal parts, insects, etc.)
- A sample is obviously mislabeled, e.g. a sample labeled as a blank and vice versa.
- Presence of potential hazard that is beyond the normal handling in the laboratory.

Whenever such criteria are discovered, the problem will be documented, flagged and possibly recommended for rejection by laboratory supervisor and the QA/QC Officer.

Upon receipt of samples in the laboratory, an initial check will be made of sample integrity, proper labeling, and sample count. Confirmation of appropriate sample preservation will also be made at this time. Samples without proper documentation or where the integrity of the sample has been compromised, the sample will be rejected by WBL. Receipt of samples will be documented by signature on chain of custody forms of an authorized WBL employee.

Incoming samples are assigned a lab identification (tracking) number and this number along with field ID label information will be recorded on the chain of custody form.

B4 Analytical Methods

Table B4-1. Approximate number of water samples, analytical methods, quality assurance and quality control.

Sample type	Sple. #	Analytical method	Parameter	Matrix	QA Targets			
					Accuracy Range	Precision % RSD	MDL	PQL
					-----%-----	----------------mg L^{-1}---------------		
Water	200	EPA Method 415.1	Dissolved organic carbon	Water	85-115	<20	0.6	2.5
Water	800	EPA Method 353.2	Nitrate-Nitrite	Water	85-115	<20	0.008	0.03
Water	800	EPA Method 350.1	Ammonium	Water	85-115	<20	0.016	0.05
Water	800	EPA Method 351.2	Total Kjeldahl Nitrogen (TKN)	Water	80-120	<20	0.1-0.2	0.5
Water	200	EPA Method 365.1	Total phosphorus	Water	80-120	<20	0.01	0.05

B5 Quality Control

The types of analytical quality control (QC) checks and the frequency at which they are performed are listed in the tables below. Quality assurance targets for each QC check are defined in terms of accuracy. Analyte concentrations associated with QC check are middle of the range of the calibration curve. The trip blanks prepared by laboratory personnel and field blanks are part of the laboratory quality control checks. Any contamination problems discovered in these blanks initiates an immediate investigation, which may include re-analyzing the blanks and notifying the submitter.

Data quality assessment in the laboratory is based on precision and accuracy checks. The general procedures and minimum frequency requirement for analysis of QC checks is presented in Table B5-2. Additional QC checks may be performed to further assess the operation of individual procedures. Definitions and purpose of each quality control check used in the laboratory are as follows:

Method or field blank:

This is analyzed to ensure that no significant amount of the analyte is present on the background that could potentially affect quality of analysis. A method reagent blank must not have detectable levels of an analyte. Troubleshooting must be initiated if recovery for this blank is greater than MDL.

Matrix spike sample:

Matrix spikes are indicators of analysis accuracy and are an assessment of potential matrix interference. Spiking level must be adjusted depending on the approximate concentration level of the analyte in samples. As a guide, spiked sample result must be within 50-85% of the highest calibration standard and the volume of spike solution <10% of the sample volume. Spike Recovery (%) is calculated and the recovery must be in the range 85-115%. If the value is outside the range, the spike must re- prepared and re-analyzed; meantime Spike Blank must also be prepared and analyzed. If the recovery of spike sample is outside the range again, but recovery of spike Blank is in the range, a sample matrix problem is suspected. The sample exhibits matrix interference.

Quality control check standards:

If the result is outside the current acceptable limits, the run is stopped and the instrument is re-calibrated. If necessary, new calibration standards are prepared and the instrument is checked for leaks, cracks in tubing, correct reaction temperature, correct wavelength or filter, and correct calculation procedure in the computer.

Replicate or Duplicate:

This is used to assure that analytical precision is maintained throughout the analytical run. At least one replicate is run per analytical batch and every 20 samples thereafter. Field duplicates and splits are treated as individual samples and are not considered analytical duplicates.

Digestion replicate:

This is used to assure that analytical precision is maintained throughout the digestion process. At least one digestion replicate is run per digestion batch and every 20 samples thereafter.

Digestion matrix spike sample:

Digestion Matrix spikes samples are indication of accuracy of digestion process and is an assessment of potential matrix interference. The spike solutions must be organic form of phosphorus and nitrogen (SPEX Nutrient 2). Digestion Spike Recovery (%) is calculated and the recovery must be in the range 80-120%.

Blind quality control check samples:

If the results for these blind samples are incorrect, the entire procedure is checked for errors. The analytical results are reported in the quality control report.

Table B5-1. Procedures used to assess precision and accuracy.

Method	**Purpose**	**Concentration Level**	**Method References**
Matrix Spike	Recovery	Low Level Mid Level High Level	All parameters
Duplicates	Precision	Low Level Mid Level High Level	All parameters
Replicate for analytical run	Precision	Mid Level High Level	All parameters
QC Check Samples (PE)	Accuracy	Low Level Mid Level High Level	All parameters
QC Check Standards (QC)	Accuracy and Calibration	Low Level Mid Level High Level	All parameters
Method Reagent Blank	Accuracy	Low Level	Total Nutrients
Mid-Range Check Standard	Precision and Accuracy	Mid Level	All parameters
Digestion Replicate (Dig	Precision	Mid Level	Total P and TKN

R)for digestion		High Level	
Digestion Matrix Spike Sample	Recovery	Low Level Mid Level	Total P and TKN

Table B5-2. Type of laboratory quality control checks, frequency and acceptance criteria.

Type	**Frequency**	**Acceptance Criteria**
Instrument Calibration	5-7 Standards, Daily or failure of CCCS.	$R^2 > 0.995$ All standards must be within 5% of their true value
Quality Control Check Standards (QC)	Analyzed at the beginning of each analytical run to verify standard curve. One QC is also analyzed at ever 20 samples.	85-115
Continuing Calibration Standard (CCCS)	1 per 20 samples in an analytical set	90-110
Method Reagent Blank	1 per sample set (batch)	< MDL
Matrix Spikes (spike added prior to sample analysis) (Sp)	At least 1 per run and 1 per 20 samples analyzed; if more than one matrix, 1 from each matrix.	85-115
Repeat (R)	At least 1 per run and 1 per 20 samples analyzed; if more than one matrix, 1 from each matrix.	20
Digestion Replicate (Dig R)	1 per 20 samples digested.	20

Digestion Matrix Spike (spike added prior to sample preparation) (Dig Sp)	Spike with organic P or N form QC standard at 1 per 20 samples and digest	85-115
PQL (low level Continuing Calibration Standard)	at least one or two in each batch is at a concentration of 5 times the MDL).	70-130

Definitions and Methods of Calculations for QC Terms

Precision

The relative percent of standard deviation (RSD) to compare duplicate samples A and B is based on the formula:

$$\%\ RSD = \frac{\left| A - B \right| \times 200}{\left(A + B \right) \times \sqrt{2}}$$

Accuracy

Percent recoveries are calculated for continuing calibration check standards, QC standard as:

$$\%\ Accuracy = \frac{Observed}{Expected} \times 100$$

Percent spike recoveries are calculated as:

$$\%\,\mathrm{Re}\,\mathrm{cov}\,ery = \frac{SC}{EV} \times 100$$

Where:

SC = Concentration in the spiked sample

EV = Expected value

$$EV\ (mg/L) = \frac{Cs \times Vs + Cstd \times Vstd}{Vs + Vstd}$$

Cs = Concentration in the sample

Vs = Volume of sample used for spike

Cstd = Concentration of standard used for spike

Vstd = Volume of standard used for spike

Standard Deviation and Control Limits

the formulae used for the calculation of standard deviation, mean, upper and lower control and warning limits are shown below. (Reference chapter 6 of "*Handbook for Analytical Quality Control in Water and Wastewater Laboratories" - EPA 600/4-79-019, March 1979*).

Standard deviations are calculated based on the formula:

$$\text{SD} = \sqrt{[\sum_{i=1}^{n} P_i^2 - (\sum_{i=1}^{n} P_i)^2 / n] / n - 1}$$

Where SD = standard deviation of the population n = total number of points in the population

Pi = the value for each point

The mean is calculated as the average of all points:

$$\overline{P} = \frac{\sum_{i=1}^{n} Pi}{n}$$

For recovery, the upper and lower control limits are based on a 99% confidence level.

$UCL = P + t_{(0.99)}SD$

$LCL = P - t_{(0.99)}SD$

The upper and lower warning limits for recovery are based on a 95% confidence level.

$UWL = P + t_{(0.95)}SD$

$LWL = P - t_{(0.95)}SD$

Where $t_{(0.99)}$ and $t_{(0.95)}$ are Student’s t factors for 99% and 95% confidence, respectively.

Because levels of statistical confidence vary with sample size, a fixed level of statistical confidence is employed that approximates 2 and 3 standard deviations. Those control limits are based on requirements specified in various EPA methods and in EPA’s ‘Handbook for Analytical Quality Control in Water and Wastewater Laboratories’. The statistical program utilizes a Student’s t table, setting warning limits at 95% confidence and control limits at 99% confidence. Those Student’s t factors correspond approximately to 2 and 3 standard deviations for 7 collected datum points (~1.9 Sp and ~3.1 Sp, respectively). The advantage of using Student's t factors is that control limits are based on known confidence limits regardless of the number of datum points in the population.

For precision on duplicate samples, the upper warning and control limits are based on a 95% and 99%confidence levels, respectively.

$$UWL = D_3P; \; UCL = D_4P$$

Where D_3 and D_4 are Shewhart factors representing 95% and 99% confidence limits for pairs of duplicates[1,2] and P is the mean for the population of precision values (as %RSD measurements).

Method Detection Limits (MDL) and Practical Quantitation Limits (PQL)

The Method Detection Limit (MDL) and Practical Quantitation Limit (PQL) are defined and used for the same objectives in all analyses. However, because of differences in the nature of various analyses, the calculation procedures vary. Described below are the most representative procedures used in this laboratory.

The MDL is defined as the minimum concentration of an analyte that can be measured by the method with 99% confidence of its presence in the sample matrix.

For most parameters, MDLs are determined using from 7 prepared samples in analyte free water or matrix. The MDL is set at three times the resulting standard deviation of the measured concentrations of the prepared blanks or estimated detection limit. For analytes that have low level contamination problems the MDL is the sum of (student's T value multiple by standard deviation) plus the absolute value of the mean blank result. A processed blank sample is analyzed with each sample set. The MDL is recalculated/verified on annual basis by evaluating at least seven of the most recently analyzed PQL or reagent blanks.

Procedure:

Make an estimate of the detection limit using one of the following:

The concentration value that corresponds to an instrument signal/noise ratio in the range of 2.5 to 5.

The concentration equivalent of three times (n=7.t=3.14) the standard deviation of replicate instrumental measurements of the analyte in reagent water.

That region of the standard curve where there is a significant change in sensitivity, i.e., a break in the slope of the standard curve.

Instrumental limitations.

It is recognized that the experience of the analyst is important to this process. However, the analyst must include the above considerations in the initial estimate of the detection limit.

Prepare reagent (blank) water that is as free of analyte as possible. Reagent or interference free water is defined as a water sample in which analyte and interferant concentrations are not detected at the method detection limit of each analyte of interest. Interferences are defined as systematic errors in the measured analytical signal of an established procedure caused by the presence of interfering species (interferant). The interferant concentration is presupposed to be normally distributed in representative samples of a given matrix,

If the MDL is to be determined in reagent (blank) water, prepare a laboratory standard (analyte in reagent water) at a concentration which is at least equal to or in the same concentration range as the estimated method detection limit. (Recommend between 3 and 5 times the estimated instrument detection limit.) Proceed to Step 4.

If the MDL is to be determined in another sample matrix, prepare a laboratory standard (analyte in the matrix) at a concentration which is at least equal to or in the same concentration range as the estimated method detection limit. (Recommend between 3 and 5 times the estimated instrument detection limit.) Proceed to Step 4.

Take a minimum of seven aliquots of the standard (3-5 times estimated detected limit) to be used to calculate the method detection limit and process each through the entire analytical method. Make all computations according to the defined method with final results in the method reporting units. If a blank measurement is required to calculate the measured level of analyte, obtain a separate blank measurement for each sample aliquot analyzed. The average blank measurement is subtracted from the respective sample measurements.

The standard may be used as is for determining the method detection limit if the analyte level does not exceed 10 times that of the MDL. To insure that the estimate of the method detection limit is a good estimate, it is necessary to determine that a lower concentration of analyte will not result in a significantly lower method detection limit.

Compute the MDL (n=7) as follows:

$$\text{MDL} = 3.14\ (\text{SD})$$

where:

MDL = the method detection limit

SD = standard deviation of the replicate analyses

(b) The 95% confidence interval estimates for the MDL derived in 5a are computed according to the following equations derived from percentiles of the chi square over degrees of freedom distribution.

LCL = 0.64 MDL

UCL = 2.20 MDL

where: LCL and UCL are the lower and upper 95% confidence limits respectively based on seven aliquots.

Reporting of MDL and PQL

The analytical method used must be specifically identified by number or title and the MDL for each analyte expressed in the appropriate method reporting units. If the analytical method permits options that affect the method detection limit, these conditions must be specified with the MDL value. The sample matrix used to determine the MDL must also be identified with MDL value. Report the mean analyte level with the MDL and indicate if the MDL procedure was iterated. If a laboratory standard or a sample that contained a known amount of analyte was used for this determination, also report the mean recovery.

If the level of analyte in the sample was below the determined MDL or exceeds 10 times the MDL of the analyte in reagent water or matrix, do not report a value for the MDL.

Method detection limits will be verified/updated routinely on annual basis by evaluating at least seven of the most recently analyzed PQL or reagent blanks.

The PQL is the lowest level of concentration in the calibration curve that can be reliably achieved within specified limit of precision and accuracy during routine laboratory operating conditions. This laboratory sets the PQLs at 3 to 5 times the MDL depending on the method of analysis and the analyte, unless otherwise specified.

B6 Instrument/Equipment Testing, Inspection, and Maintenance

All field equipment will be visually inspected during data download and sample collection. Inspection will occur at a minimum once every month, but most likely will be conducted weekly. Weirs and other control structures will be inspected for damage, erosion and fouling by debris and corrective actions taken and documented as needed. Inspection of groundwater wells will evaluate bentonite seal and integrity of well casing. Batteries for autosamplers and CR10X data loggers will be exchanged weekly and voltage will be monitored to make sure low battery voltage is not an issue in sample collection. Maintenance of other field equipment will be in accordance with frequencies outlined in table B6-2.

Laboratory maintenance will be conducted based on NELAC certification requirements and is generally outlined in table B6-3

Table B6-1. Laboratory instrumentation and support equipment that will be used during this project.

Instrument	**Manufacturer**	**Model number**	**Analytical components**
Autoanalyzer	Technicon	AA II (206)	Ammonia
		AA3	Nitrate
Autoanalyzer	Technicon	AAII (208)	TKN, TP
CNS analyzer	Carlo-Erba	NA 1500	Total C/N
pH/mVmeter	Fisher	Accumet AR50	pH, Eh
Analytical balance	Denver	XE Series 100A	

Micro-Balance	Mettler Toledo	B303-S
	Mettler Toledo	B203-S
	Mettler Toledo	PG503-S
Top Loading Balance	Mettler Toledo	PG-2200
Autoclave	Napco	8000-DSE
	Harvey	Steril Max
Oven	Fisher	Isotemp
Refrigerators	Kenmore	T49
	American Panel	
Freezer	Whirlpool	EV200NXK
Incubators	Lab-Line	
Block Digestion System	Bran+Lubbe	BD-50

Table B6-2. Routine maintenance activities for field instruments.

Instrument	**Activity**	**Frequency**
DO probe	Change probe membrane	As needed or every 30 days
	Fouled membrane or air trapped under membrane	As needed or every 30 days
	Unacceptable precision or accuracy	As needed or every 30 days
	Clean gold cathode	As needed (unacceptable precision or accuracy)
pH probe	Inspect electrode junction for air bubbles	Every use
	Check for blocked junction	As needed (unacceptable precision or accuracy)
	Clean or recondition pH bulb	As needed (unacceptable precision or accuracy)

Conductivity probe	Inspect electrode	Every use
	Clean surfaces	As needed (unacceptable precision or accuracy)
Redox probe	Inspect electrode	Every use
	Clean surfaces	As needed (unacceptable precision or accuracy)

Table B6-3. Routine maintenance activites for laboratory instruments.

Instrument	Activity	Frequency
Autoanalyzer (AAII,AA-3 & RFA)	Flush system w/ DI water	Daily
	Inspect pump platen surfaces (Clean as needed)	Daily
	Check heater operation	Daily
	Flush w/ Kemwash or cleaning solution	Weekly or as needed
	Clean pump rollers	200 hrs or as needed
	Change pump tubing	200 hrs or as needed
	Clean colorimeter optical system	as needed
	Oil wicks on pump	200 hrs or as needed
	Replace drain tubing	as needed
	Replace transmission tubing	as needed
Carbon analyzer (Shimadzu TOC 5050)	Check/replace O-rings	as needed
	Change acid	as needed (for IC only)
	Halogen Scrubber	as needed
	Membrane filter	as needed (check backpressure)
	Inspect/replace combustion tube and catalyst	as needed
CNS analyzer (EA-1112)	Clean auto sampler	Daily/as need
	Water trap	Daily
	Remove ash from oxidation column	120 samples or as needed
	Repack oxidation column	about 2000 samples when depleted
	Repack reduction column	about 1500 samples when depleted
	Check gas flow rates	as needed
	Check for leaks	As needed (after opening system)
pH meter	Inspect electrode junction for air bubbles	as needed (unacceptable precision or accuracy)
	Check for blocked junction	as needed (unacceptable precision or accuracy)
	Clean or recondition pH bulb	as needed (unacceptable precision or accuracy)
UV/visible spectrophotometer	Flush with DI water before and after use	daily
	Change tubing	as needed
Analytical balances/ Top loading balances	Clean pans and compartment	after every use
	Check with class S weight	before use and monthly
	Manufacturer's service	annually (on contract)
Refrigerators/ Freezer / Incubators	Record temperature (± 2^{o}C)	daily
	Check with NBS calibrated thermometer	annually
Ovens	Check temperature (± 2^{o}C)	daily
	Check with NBS calibrated thermometer	annually

Documentation

Routine maintenance procedures will be documented with checklists, and tables for recording maintenance activities will be kept for each instrument. Records of non-routine repairs will be maintained in permanent files

B7 Instrument/Equipment Calibration and Frequency

Field equipment

Calibration of water level transducers will be based on cross reference between transducer value and staff gauge at each control structure. If there is a discrepancy of more than 1% in the expected range of values than a recalibration of transducer based on manufacturer guidelines will be conducted. Autosampler volume precision will be tested every 6 months to determine if composite sample bottle volumes are within 5% of each other. An initial flow rate calibration for the groundwater flow meter will be conducted based on #20/30 sand used to fill annular space in wells. Calibration of groundwater well transducers will be based on cross reference between tranducer value and water level in well at time of download.

Laboratory instruments

Analytical instrument calibrations will conform to NELAC standards, approved analytical method requirements and the quality assurance requirements for calibrations. See tables below for instrument and equipment calibration and frequency.

Initial calibration for analytical instruments

The number of points for initial instrument calibration is specified in individual analytical SOPs, as determined by the reference method requirements and sample concentration range bracketing. The minimum number of points is five (5), excluding method blank. In cases when a standard point has to be dropped, if considered an outlier, the analyst must determine if sample concentration is still within the valid bracketed calibration range. If more than one standard point is considered an outlier, the analyst must discontinue the run, re-calibrate or prepare another set of calibration standards. If this is a persistent problem with any of the analytical procedures, the laboratory shall investigate the root cause and initiate corrective action. All initial calibration must include a method blank. The recovery for method blanks must be <MDL. QC check standards from a different source than the calibration standards are used to check the initial instrument calibration.

Continuing Calibration Check Standard (CCCS)

At least one standard solution is analyzed every 20 samples to confirm that the calibration remains stable throughout the analytical run. The recovery, calculated as % of initial instrument response, must remain within +/-15 %, otherwise, the run or the affected portion of the run is re-analyzed.

Table B7-1. Laboratory instrument and support equipment calibration and frequency.

Instrument	# Standards Initial Calib.	Accept/Reject Criteria - Initial Calibration	Frequency	# Standards Cont. Calib.	Accept/Reject Criteria - Cont. Calibration	Freq.
Autoanalyzer	5 – 7	Linear Corr. Coefficient >0.995	Daily prior to use or failure of cont. calibration	mid-range	Concentration within 15% of known value	Every 20 samples
				PQL	Concentration within 30% of known value	1 or 2 per run
pH Meter	pH 7 pH 4 or 10	Eff = 1.00+/-0.05	Daily prior to use or failure of cont. calibration	1-2	pH within 0.1	Every 20 samples
Conductivity Meter	3	Concentration within 5% of known value	Daily prior to use or failure of cont. calibration	1-3	Concentration within 10% of known value	Every 20 samples
CNS Analyzer	4	Linear Regression Corr. Coefficient >0.995	Daily prior to use or failure of cont. calibration	1	Concentration within 15% of known value	Every 20 samples

Note: These are minimum calibration requirements. Alternative calibration requirements maybe followed if more stringent than specified on this plan

Table B7-2. Laboratory support equipment calibration.

Equipment	Calibration	Acceptance Criteria	Frequency
Analytical Balance	Entire set (1-50g)of Class S weights	All weights within 2 % of known value	Monthly
	Annual external maintenance	All weights within 2 % of	

	and calibration	known value	Annually
Ovens	Temperature recorded from a calibrated thermometer. Adjustments made as needed	± 2 ^{o}C	Daily
Refrigerators	Temperature recorded from a calibrated thermometer. Adjustments made as needed	± 2 ^{o}C	Daily
Mercury Thermometer	Checked with a NIST(NBS) certified thermometer	± 0.5 ^{0}C	Semi-Annually
Digital Thermometer	Checked with a NIST(NBS) certified thermometer	± 0.1 ^{0}C	Quarterly

B8 Inspection/Acceptance of Supplies and Consumables

All needed supplies will be purchased from the appropriate purveyor. Supplies will be monitored and assessed for necessary quality to allow for project data quality objectives to be met.

B9 Non-direct Measurements

The only Non-direct measurements expected for this project would relate to information provided to participants during field day activities. Information for these activities will be based on peer reviewed data sources and therefore QAQC of that data will be vetted in a manner similar to all scientific data

B10 Data Management

Data management will conform to DEP QA-002/02. Data collected in the field is either taken manually or electronically.

Data entry will be performed by the analyst, project technician or project manager. The project manager will be responsible for checking data entry. The principal investigators will assure that data on the final report are correct, by performing an informal audit of analytical, data entry and data reduction procedures.

B10.1 Documents and Data Storage

WBL maintains the required and necessary documentation of all data generated and other relevant information pertinent to the operation of the organization. Records are kept such that historical reconstruction of all relevant field and laboratory activities is possible. Vital records, including field notes, Chain of Custody Forms, and laboratory analytical reports are preserved.

Field notes

Field records are maintained and stored by the project manager or laboratory manager, depending on the project. Field notes include field information about samples and the data from in-situ measurements.

Sample chain of custody

The Sample chain of custody forms are submitted along with the samples to the laboratory technician. The chain of custody forms are retained by the QA officer.

Log-in

Samples received by WBL are logged into the Laboratory Master Logbook (Excel file) by project. Field sampling information for the project (area, site, date,), field ID, lab ID, types, etc. is logged into the project-specific section of the Laboratory Master Logbook.

Sample Preparation Logs

The sample preparation (extraction, digestion, filtration, weighing) information is recorded in designated lab record books. The information included:

1) preparation: extraction, digestion, filtration, weighing
2) person preparing and the date of preparation
3) Method or WBL SOP
4) Extraction: sample ID, soil weight, extract and volume, shaking time
5) Digestion: sample ID, digestion sample volume, final volume, standards preparation, QC samples, digestion spike, digestion repeat, and digestion date

Original copies of analytical record books are kept in the file cabinets and are maintained by the QA officer. Anyone removing an analytical file from this location must have permission from the QA officer and return the documents promptly to the same location.

Analytical files and QC reports

All data from automated instruments are collected through and stored in the instrument PC and archived periodically. Typically, raw data from the instrument PC is uploaded on to a floppy (or other storage device) and that file is downloaded into an Excel template. Data from certain instruments is manually entered into an Excel template. Once the raw data is inserted into the template, the analyst can enter dilution factors where appropriate, summarize the associated bench QC, and add any necessary comments or narrative using a text box at the top of the report. The analytical data file is saved using a unique identifier. Analysts submit the Excel file to the QA Officer to approve. Data reports are identified with the date, the computer file name if applicable, parameter, method #, and the initials of the analyst. Analysts must keep all sample analyses logs, tray maps, strip charts, and QA/QC log records to be retrievable. The analyst's copy of the data report is stored on an IFAS server that is backed up daily. The QA officer also has the same analytical data copy saved in a different computer as a secondary back up.

The QA officer reviews the data from the analysts. The Lab manager generates the final WBL Analytical Reports. One hard copy is sent to the client, the other hard copy is stored in the lab. The final WBL Report includes: WBL Report number, project, name of Client, sample receipt date, date of report, and results of the analysis. The Analytical reports are stored by year. The electronic files of the WBL report are stored in the laboratory manager's computer and are backed up by the IFAS network.

Reagent Preparation, equipment/instrument calibration, maintenance and troubleshooting logs

Analysts must log all reagent preparation, equipment maintenance and repair, and calibration information in designated notebooks. Completed notebooks are archived by the laboratory supervisor.

Standard Operating Procedures (SOP)

WBL has written SOPs for the laboratory. Original copies of SOPs are maintained by the laboratory manager. At least one copy of every revision of an SOP must be maintained for future reference. Any justification, description, and validation data for changing an SOP must be submitted to the QA officer and laboratory manager.

Quality Assurance Project Plans, Research Quality Assurance Plans, and Quality Manual

Copies of the current Quality Manual are distributed to appropriate personnel. At least one copy of the WBL Quality Manual (since 2004) is stored either in the facility or with relevant records in the off-site storage facility. This manual is effective for a period of years from the date of approval and is subject to updates when necessary. A copy of the revision is retained in-house for future reference.

Quality Assurance Project Plans (QAPPs) and Research Quality Assurance Plans (RQAPs) are prepared, if required, for individual projects. A copy of these plans is retained by the project managers for the duration of the project and 5 years thereafter.

Audit reports and corrective actions

Original completed audit checklists, audit reports, and response are maintained by the QA officer.

Administrative Records

General administrative records, including qualifications and performance appraisals for each personnel are kept in their personnel file. Skill level, training records, and records of demonstration of capability for each analyst must be kept and maintained by the lab manager.

A log of names, initials and signatures for all individuals who are responsible for signing or initialing any laboratory records must be kept and maintained by the lab manager.

B10.2 Record Retention and Storage

Electronic files of data are retained on the instrument’s PC drive until capacity is reached. Files are then transferred to storage media and retained in the laboratory. Hardcopy information is retained in the facility. All plots, chromatograms, data files, manual data entry records, instrumentation logs, and reagent and standard preparation logs must be retained.

The laboratory supervisor is in charge of maintaining document and electronic files. To comply with NELAC requirement, analytical files and supporting documentation must be kept for a minimum of five (5 years) from generation of last entry in the records. For projects that are reported directly or indirectly to FDEP, project records are retained for the life of the project and five years thereafter

GROUP C: ASSESSMENT AND OVERSIGHT

C1 Assessments and Response Actions

Field data collection

Biweekly meetings are held between field personnel and Project QA manager. These meetings discuss data collection, calibrations and maintenance conducted during the previous two weeks with regard to equipment condition, data losses due to equipment failure, and any discrepancies found in field cross references such as transducer readings and staff gauge readings. Prior to this meeting the Project QA officer reviews all new available data and evaluates it for any potential discrepancies. If corrective actions have not already been taken a plan for corrective action will be determined. If corrective actions have already been taken, a discussion of the issue is evaluated project wide and preventative measures are implemented where appropriate. If these corrective actions require changes in protocol they are documented and approved if necessary. Quarterly update meetings are held between the Principal and Co-principal investigators to discuss progress and address any unusual findings. If any are found an investigation and verification of data quality is implemented to confirm findings.

Laboratory Analysis

Laboratory Assessments and Response actions are conducted by the Wetland Biogeochemistry Laboratory QA/QC officer. Issues and corrective actions pertinent to this project will be reported immediately to the Project QA manager so that any issues can be addressed with regard to the project. Performance and system audits as well as corrective actions are outlined below in sections C1.1 and C1.2 respectively

C1.1 *Performance and System Audits*

The laboratory conducts internal system audits on select laboratory systems annually. These internal audit procedures follow the general guidelines listed in section C1.1. External system audits are conducted by outside agencies as described in C1.1.3. Internal and external performance audits are conducted as in section C1.1.2. The laboratory will submit to any external audits conducted by FDOH for accreditation purposes, FDEP, and WBL project sponsors (customers).

C1.1.1. Internal System Audits

1) Systems will be audited annually.

2) The lab director, lab manager will conduct the audits.

3) The audit will consist of the submittal of blind samples and/or the random selection of a previously reported sample project, tracking of these samples through the system, evaluation of sample results, and a follow-up laboratory audit.

4) System components to be audited will include, but are not limited to (WBLSOP-OM-002 QS Management Review):

    (i) All documentation associated with sample and data handling, to include linkage mechanism employed between all records for tracking documentation for any sample datum.

    (ii) Use of established, approved procedures as outlined in this Quality Manual.

    (iii) Proper execution of established procedures.

    (iv) Sample and data handling activities including:

        [a] All sample log-in, that samples are signed at by preparation or analyst person and log-out

        [b] Sample preparations

        [c] Method calibrations

        [d] Sample analyses

        [e] Data reduction, validation and reporting

        [f] Preventive maintenance and repair procedures

        [g] Standard and reagent preparations and storage

        [h] Sample and waste disposal

        [i] Container and lab ware decontamination

        [j] QC management practices and assessment of analytical precision, accuracy and sensitivity

(5) Deficiency lists and associated corrective action orders will be formally promulgated to responsible staff.

(6) An example of a typical audit checklist form is given in Figure 14.1.

Table C1-1 Laboratory Audit Check List

Sample Log-In/Receipt Section	
1	Are up-to-date SOPs available?
2	Are refrigerator temperature logs for refrigerators up-to-date?
3	Are thermometers calibrated ?
4	Are refrigerator temperatures set correctly ?
5	Is sample preservation checked and documented for received samples ?
6	Is the area clean and well-maintained?
7	Is proper chain-of -custody maintained and documented?
8	Comments:
Inorganics-Nutrient/Wet Chemistry Section	
1	Are SOPs available ?
2	Are standards and sample extracts stored separately?
3	Are standard and QC prep logs adequate and up-to-date?
4	Are standards being prepared and checked at the proper frequency ?
5	Are the reagents preparation logs adequate?
6	Do chemists and technicians seem to understand the analytical concepts being utilized in the performance of their duties?
7	Are they trained in the methodological and QA/QC requirements and issues concerning the performance of their daily duties ? Training documentation complete and on file?
8	Do the analysts meet all QA/QC requirements on daily performance and data is review by QA Officer?
9	Are data calculations, data review being carried out correctly and sufficiently?
10	Are balances and pipettes (if used) calibrated on a regular basis?
11	Additional Comments:

C1.1.2 Internal Performance Audits

1) Conducted by QA Officer
2) Initiated only upon observed or suspected problem with specific system (blind QC samples obtained from DEP or PT, PE Studies),
3) Split sample analyses by specific, per-project agreement with regulatory and commercial laboratories.
4) Reports of results, deficiencies and corrective actions are promulgated as with internal system audits, with the addition of reports to affected external organizations.

Table C1-2 Performance Audits Check list

Check List	Yes	No	Problems/ Corrections
Project name			
Methods			
Parameter			
Date and Instrument			
Analyst			
Standard Curve			
Samples ID and QC point			
Dilute factor			
QC Summary			
Commons or Correct action (for analysis)			
Standard prep log			
Reagent prep logs			
Analysis run log			
Digestion or extraction log			
Documentation (Chart) attached			
Instrument maintenance (if have)			

C1.1.3 External Performance Audits

WBL voluntarily participates in available and relevant external performance audits, including:

1) Everglades Technical Advisory Committee Round Robin Exercise for Total Phosphorus in Water (DEP) and Total Phosphorus in Soil (DEP)

2) South Florida Water Management District's Performance Evaluation Studies (PE)

Bi-annual Proficiency Testing Studies (ERA) of WatR^{TM} Pollution and Soil Waste.

C1.2 *Corrective Actions*

Corrective action is required in those cases when the acceptance criteria for QC measures are not met. The specific corrective actions for each type of quality control measure are given in Table C1-3.

The analyst is responsible for assessing each QC measure and initiating corrective action according to Table C1-3, respectively. The QA officer is responsible for approving the corrective action taken or for initiating further steps to solve the problem.

Corrective action may be initiated by external sources or events, which may include performance evaluation results, performance audits, system audits, split sample results, and laboratory/field comparison studies.

Problems requiring corrective action and corrective actions taken are documented in detail in one of the following: QC result log, analysis logbooks, digestion logbooks, or instrument maintenance logs depending on the nature of the problem and how it was solved. The analysts will report the problem to the QA Officer who has the responsibility for determining if the solution is acceptable and, if not, what further steps should be taken.

When the correction actions involve that equipment or instrument repair, replacement, or technical service, the manager may need to communicate with the laboratory director. The lab director is responsible for ensuring that these actions are implemented.

Corrective Actions are presented in Table C1-3. QC checks and acceptance criteria are given in Table C1-3. Corrective actions are initiated based on either the internal quality control checks listed on Table C1-3 or data validation by reviewing authority or performance audits. Outside sources such as proficiency testing (PT), performance evaluation studies (PE), split samples as well as recommendations by the WBL QA Officer may initiate corrective actions.

C1.2.1 Procedures for Reporting Exceptions

Significant deviations from laboratory protocols are reported to the customer and documented with the analytical reports. Any samples that are prepared or analyzed beyond holding times have a notation or qualifier with the data alerting that tests were conducted after the sample had expired. Similarly, the failures of any quality control checks should take correction action, reanalyzing or re digestion, if impossible, notice the client with the details.

Table C1-3 Corrective actions for “out-of control” laboratory quality controls

QC Activity	**Acceptance Criteria**	**Recommended Corrective Action**
Initial Calibration Standards	Correlation coefficient R > 0.995	Re-analyze standards. If same response is obtained, re-optimize instrument & re-start analysis. If same response is obtained, prepare new standards & re-start analysis.
Quality Control or Check Standards (QC)	Accuracy within established limits (85-115%)	Re-analyze or re-prepare QC check standard. If same response is obtained, prepare new primary & calibration standards. If that fails, check against an alternate QC source and stock solution. Obtain approval from QA officer or staff. Discard unacceptable QC once confirmed & document findings on QC result log.
Initial Instrument Blank Method Reagent Blank	<MDL response & value	Prepare new blank & restart analysis. If same response is obtained, determine cause of contamination (reagents, calibration standards, environment, equipment failure, etc) & eliminate the source of contamination.
Continuing Calibration Standard (CCCS)	Within 10% of true value	Recalibrate & re-analyze the affected portion of the run.
PQL	Within 30% of true value	Reevaluate system, recalibrate & re-analyze the affected portion of the run.

Repeat (R)	Precision within established limits (<20%)	Determine & eliminate cause of problem (baseline drift, carryover, etc). Re-analyze all affected samples.
Spikes (Sp)	Recovery within established limits (85-115%)	Re-make spike & re-analyze. If acceptable, re-analyze affected portion of run. If not acceptable, spike a DDI water or Blank Matrix. If the recovery of DDI water or blank matrix is acceptable, then it is likely sample matrix interference. Make proper notation on the analytical report.
Digestion Repeat (Dig R) or Lab duplicates	Precision < 20%	Re-digest sample with duplicate
Digestion Spike (Dig Sp) or Matrix Spike (MSP)	Recovery within established limits (85-115%)	Re-digest sample and spike

C2 Reports to Management

Reports will be made quarterly to FDEP as per contract. Progress reports will be submitted by PIs. Reports will at a minimum include activities, problems and solutions from the reporting quarter, planned activities for the next quarter, and budget expenses. As each task is completed, a final report for that portion of the project will be compiled within six months of final data measurement.

GROUOP D: DATA VALIDATION AND USABILITY

D1 Data Review, Verification, and Validation

Data collected will be analyzed by QA/QC officer and PIs in a timely fashion to ensure that accuracy and quality objectives are being met. Any unusual data will be examined and appropriate methods taken.

Laboratory supervisors or PIs are responsible for ensuring that QC checks are met, investigating any discrepancies, determining the cause, and ensuring that corrective measures are taken to solve the problem. The supervisors are also responsible for the review of all data to identify obvious anomalies.

The laboratory QA Officer or designated staff is responsible for regular tracking laboratory performance through QC plots, and providing feedback to laboratory staff and PIs.

Each analyst and/or technician is responsible for determining that the results of each analytical determination have all associated QC measurements and that the acceptance criteria are met and documented according to protocol. The analyst and/or technicians are responsible for checking calculations, completing sample preparation, calibration, analysis, instrument logs, correction action, and completing all internal custody documentation.

The QA officer or project managers are responsible for ensuring that quality control objectives are met in Table 7-1, investigating any discrepancies, determining the cause, and ensuring that corrective measures are taken to solve the problem. The QA officer and project manager are also responsible for the review of all data to identify obvious anomalies.

The data verification procedures consist of all the QC validations and calculations checks discussed above. In addition, soundness of all data is evaluated by the nature of the sample, the inter-relationship among the parameters and the historical values, etc. Discrepancies or inconsistencies will initiate a recheck of data or reanalysis of the sample (s).

The project manager is responsible for reviewing overall project data before submission to the funding agency. Key areas of review include field and laboratory QC data, supporting documentation, and review of data for any obvious anomalous values

D2 Verification and Validation of Methods

The data verification procedures consist of all the QC validations and calculations checks discussed above. In addition, soundness of all data is evaluated by the nature of the sample, the inter-relationship among the parameters and historical values. Any discrepancy or inconsistency will initiate a recheck of data or reanalysis of the sample (s). Physical and chemical data collected will be compared to associated data sets such as rainfall and flow rates, or irrigation records and container leaching data to validate that the data set being collected is representative of the target variable being measured.

D3 Reconciliation with User Requirements

Treatment efficacy of various BMP practices will be evaluated as difference between nitrogen loads before and after the treatment in either space or time. These differences will be assessed on both an annual as well as seasonal affect basis. Reporting of data will be based on a % mass reduction per length of ditch, area of drainage control or volume of denitrification wall. Results will also report concentration levels pre and post treatment as concentration is a critical variable in many treatment processes being evaluated. Any recommendations resulting from this study that assesses and evaluates the effectiveness of management practices to reduce nonpoint source loss of nitrate may be used by state agencies or municipalities to provide a template for BMPs.

Appendix A

Weir flow monitoring program and sample collection criteria

The datalogger is programmed to trigger the autosampler to take a water sample once a cumulative volume of flow over the weir has been reached. The autosampler collects a 100-ml sample in a 500 ml bottle each time it is triggered, so each bottle is a composite of 5 samples. The cumulative volume that triggers the autosampler has been determined from an analysis of past flows. In particular two large storm events including Tropical Storm Fay and a notably wet week in October 2008 were used to designate an upper bound for flows over the weir. Based on the measured flows during these periods the autosampler was programmed so that all the autosampler bottles would be filled in one week during these extreme events. Additionally, we are constantly monitoring cumulative rainfall for a given week and if a large storm should come, we can collect the samples earlier. This max cumulative volume was calculated to be 380,000 L. During periods with lower predicted rainfall, we have been adjusting this max cumulative volume downward to ensure that approximately 5-9 bottles (25 to 45 samples) are filled per week.

Campbell Data Logger program instructions

```
;---------Pressure Transducer Instructions------------------

;2:  Ex-Del-Diff (P8)
; 1: 2        Reps
; 2: 3        25 mV Slow Range
; 3: 1        DIFF Channel
; 4: 1        Excite all reps w/Exchan 1
; 5: 1        Delay (0.01 sec units)
; 6: 800      mV Excitation
; 7: 9        Loc [ Vr_9      ]
; 8: 1        Multiplier
; 9: 0        Offset
;
;3:  Z=X/Y (P38)
; 1: 10       X Loc [ Vo_10     ]
; 2: 9        Y Loc [ Vr_9      ]
; 3: 7        Z Loc [ Ratio_7   ]
;
;4:  Z=X*F (P37)
; 1: 7        X Loc [ Ratio_7   ]
; 2: 100      F
; 3: 7        Z Loc [ Ratio_7   ]
;
;5:  Z=F x 10^n (P30)
; 1: 0.15217  F
; 2: 0        n, Exponent of 10
; 3: 8        Z Loc [ Mult_8    ]
;
```

```
;6:  Z=X*Y (P36)
; 1: 7        X Loc [ Ratio_7   ]
; 2: 8        Y Loc [ Mult_8    ]
; 3: 7        Z Loc [ Ratio_7   ]
;
;7:  Z=F x 10^n (P30)
; 1: 0.26     F
; 2: 0        n, Exponent of 10
; 3: 6        Z Loc [ Offset_6  ]
;
;8:  Z=X+Y (P33)
; 1: 7        X Loc [ Ratio_7   ]
; 2: 6        Y Loc [ Offset_6  ]
; 3: 5        Z Loc [ WL_Feet_5 ]
;
;9:  Z=X*F (P37)
; 1: 5        X Loc [ WL_Feet_5 ]
; 2: 1.0      F
; 3: 3        Z Loc [ Head_ft   ]
;
;
;10:  Z=X*F (P37)
; 1: 3        X Loc [ Head_ft   ]
; 2: 30.48    F
; 3: 12       Z Loc [ Head_cm   ]
;
;11:  Z=F x 10^n (P30)
; 1: 100      F
; 2: 00       n, Exponent of 10
; 3: 54       Z Loc [ cm_to_m   ]
;
;12:  Z=X/Y (P38)
; 1: 12       X Loc [ Head_cm   ]
; 2: 54       Y Loc [ cm_to_m   ]
; 3: 55       Z Loc [ Head_m    ]
;
;13:  Temp (107) (P11)
; 1: 1        Reps
; 2: 5        SE Channel
; 3: 2        Excite all reps w/E2
; 4: 4        Loc [ WatTemp_C ]
; 5: 1.0      Multiplier
; 6: 0.0      Offset


;------- End pressure transducer instruction----------------


;-------Calculate Flow-----------------------
;------------------------------------------

;--------Weir parameters---------------------
;14:  Z=F x 10^n (P30) ;ft
; 1: 0.5863   F
```

```
; 2: 00       n, Exponent of 10
; 3: 37       Z Loc [ P         ]
;
;15:  Z=F x 10^n (P30) ;feet
; 1: 0.9196   F
; 2: 00       n, Exponent of 10
; 3: 38       Z Loc [ H_Max     ]
;
;
;16:  Z=F x 10^n (P30)
; 1: 1.5      F
; 2: 00       n, Exponent of 10
; 3: 46       Z Loc [ threehalf ]
;
;
;17:  Z=F x 10^n (P30) ;ft/secsqur
; 1: 32       F
; 2: 00       n, Exponent of 10
; 3: 51       Z Loc [ gravity   ]
;
;18:  Z=F x 10^n (P30) ;ft
; 1: 4        F
; 2: 00       n, Exponent of 10
; 3: 47       Z Loc [ b_width   ]
;
;
;19:  Z=X-Y (P35)
; 1: 3        X Loc [ Head_ft   ]
; 2: 37       Y Loc [ P         ]
; 3: 93       Z Loc [ H_sml_wr  ]
;
;20:  Z=X (P31)
; 1: 93       X Loc [ H_sml_wr  ]
; 2: 101      Z Loc [ Hsill     ]
;
;
;-------Small Weir---------------------------
;
;21:  If (X<=>Y) (P88)
; 1: 3        X Loc [ Head_ft   ]
; 2: 3        >=
; 3: 37       Y Loc [ P         ]
; 4: 30       Then Do
;
;
;     22:  If (X<=>Y) (P88)
;      1: 3        X Loc [ Head_ft   ]
;      2: 4        <
;      3: 38       Y Loc [ H_Max     ]
;      4: 30       Then Do
;
;          23:  Z=F x 10^n (P30)
;           1: 0.0612   F
;           2: 00       n, Exponent of 10
```

```
;         3: 77       Z Loc [ C1_smll   ]
;
;        24:  Z=F x 10^n (P30)
;         1: 3.173    F
;         2: 00       n, Exponent of 10
;         3: 78       Z Loc [ C2_smll   ]
;
;        25:  Z=X-Y (P35)
;         1: 38       X Loc [ H_Max     ]
;         2: 37       Y Loc [ P         ]
;         3: 92       Z Loc [ H_crest   ]
;
;        26:  Z=X/Y (P38)
;         1: 93       X Loc [ H_sml_wr  ]
;         2: 92       Y Loc [ H_crest   ]
;         3: 79       Z Loc [ h_ovr_Hmx ]
;
;
;        27:  Z=X*Y (P36)
;         1: 77       X Loc [ C1_smll   ]
;         2: 92       Y Loc [ H_crest   ]
;         3: 80       Z Loc [ h1_small  ]
;
;
;        28:  Z=X+Y (P33)
;         1: 80       X Loc [ h1_small  ]
;         2: 78       Y Loc [ C2_smll   ]
;         3: 44       Z Loc [ Ce        ]
;
;        29:  Z=F x 10^n (P30)
;         1: .00984   F
;         2: 00       n, Exponent of 10
;         3: 48       Z Loc [ K1        ]
;
;        30:  Z=F x 10^n (P30)
;         1: 0.00328  F
;         2: 00       n, Exponent of 10
;         3: 49       Z Loc [ K2        ]
;
;        31:  Z=X+Y (P33)
;         1: 47       X Loc [ b_width   ]
;         2: 48       Y Loc [ K1        ]
;         3: 52       Z Loc [ Qsm_int2  ]
;
;        32:  Z=X*Y (P36)
;         1: 44       X Loc [ Ce        ]
;         2: 52       Y Loc [ Qsm_int2  ]
;         3: 50       Z Loc [ Qsm_int1  ]
;
;        33:  Z=X+Y (P33)
;         1: 93       X Loc [ H_sml_wr  ]
;         2: 49       Y Loc [ K2        ]
;         3: 53       Z Loc [ Qsm_int3  ]
;
```

```
;          34:  Z=X^Y (P47)
;           1: 53       X Loc [ Qsm_int3  ]
;           2: 46       Y Loc [ threehalf ]
;           3: 56       Z Loc [ Qsm_int4  ]
;
;          35:  Z=X*Y (P36)
;           1: 50       X Loc [ Qsm_int1  ]
;           2: 56       Y Loc [ Qsm_int4  ]
;           3: 36       Z Loc [ Q_sm_weir ]
;
;
;
;          36:  Z=X*F (P37)
;           1: 36       X Loc [ Q_sm_weir ]
;           2: 28.3      F
;           3: 95       Z Loc [ Qsm_LperS ]
;
;
;     37:  End (P95)
;
;38:  End (P95)
;
;
;39:  If (X<=>Y) (P88)
; 1: 3        X Loc [ Head_ft   ]
; 2: 4        <
; 3: 37       Y Loc [ P         ]
; 4: 30       Then Do
;
;     40:  Z=F x 10^n (P30)
;      1: 0        F
;      2: 00       n, Exponent of 10
;      3: 95       Z Loc [ Qsm_LperS ]
;
;41:  End (P95)
;
;
;
;42:  If (X<=>Y) (P88)
; 1: 3        X Loc [ Head_ft   ]
; 2: 3        >=
; 3: 38       Y Loc [ H_Max     ]
; 4: 30       Then Do
;
;
;     43:  Z=F x 10^n (P30)
;      1: 0        F
;      2: 00       n, Exponent of 10
;      3: 95       Z Loc [ Qsm_LperS ]
;
;44:  End (P95)

;--------End Small Weir----------------------
```

```
;--------Orifice flow-------------------------

;45:  If (X<=>Y) (P88)
; 1: 3        X Loc [ Head_ft   ]
; 2: 3        >=
; 3: 38       Y Loc [ H_Max     ]
; 4: 30       Then Do
;
;
;     46:  Z=F x 10^n (P30)
;      1: 0.5      F
;      2: 00       n, Exponent of 10
;      3: 88       Z Loc [ one_half  ]
;
;     47:  Z=X*Y (P36)
;      1: 92       X Loc [ H_crest   ]
;      2: 88       Y Loc [ one_half  ]
;      3: 90       Z Loc [ onehalfHm ]
;
;     48:  Z=X-Y (P35)
;      1: 38       X Loc [ H_Max     ]
;      2: 90       Y Loc [ onehalfHm ]
;      3: 70       Z Loc [ height_or ]
;
;     49:  Z=X*Y (P36)
;      1: 92       X Loc [ H_crest   ]
;      2: 47       Y Loc [ b_width   ]
;      3: 71       Z Loc [ Area_orif ]
;
;     50:  Z=F x 10^n (P30)
;      1: 3.5      F
;      2: 00       n, Exponent of 10
;      3: 72       Z Loc [ K_orifice ]
;
;     51:  Z=SQRT(X) (P39)
;      1: 3        X Loc [ Head_ft   ]
;      2: 76       Z Loc [ sqr_H_m   ]
;
;     52:  Z=X*Y (P36)
;      1: 51       X Loc [ gravity   ]
;      2: 91       Y Loc [ sqr_H_ft  ]
;      3: 73       Z Loc [ Qorf_int1 ]
;
;     53:  Z=X*Y (P36)
;      1: 73       X Loc [ Qorf_int1 ]
;      2: 71       Y Loc [ Area_orif ]
;      3: 74       Z Loc [ Qorf_int2 ]
;
;     54:  Z=X*Y (P36)
;      1: 74       X Loc [ Qorf_int2 ]
;      2: 72       Y Loc [ K_orifice ]
;      3: 39       Z Loc [ Q_orf     ]
;
```

```
;
;     55:  Z=X*F (P37)
;      1: 39       X Loc [ Q_orf     ]
;      2: 28.3     F
;      3: 96       Z Loc [ Qor_LperS ]
;
;56:  End (P95)
;
;57:  If (X<=>Y) (P88)
; 1: 3        X Loc [ Head_ft   ]
; 2: 4        <
; 3: 38       Y Loc [ H_Max     ]
; 4: 30       Then Do
;
;     58:  Z=F x 10^n (P30)
;      1: 0        F
;      2: 00       n, Exponent of 10
;      3: 96       Z Loc [ Qor_LperS ]
;
;59:  End (P95)

;--------End Orifice flow---------------------
;--------Big Weir flow-----------------------



;60:  If (X<=>Y) (P88)
; 1: 3        X Loc [ Head_ft   ]
; 2: 3        >=
; 3: 38       Y Loc [ H_Max     ]
; 4: 30       Then Do
;
;     61:  Z=X-Y (P35)
;      1: 3        X Loc [ Head_ft   ]
;      2: 38       Y Loc [ H_Max     ]
;      3: 87       Z Loc [ Offset_H  ]
;
;     62:  Z=F x 10^n (P30)
;      1: 0.322    F
;      2: 00       n, Exponent of 10
;      3: 81       Z Loc [ C1_big    ]
;
;
;     63:  Z=F x 10^n (P30)
;      1: 2.80     F
;      2: 00       n, Exponent of 10
;      3: 82       Z Loc [ C2_big    ]
;
;
;     64:  Z=X/Y (P38)
;      1: 87       X Loc [ Offset_H  ]
;      2: 38       Y Loc [ H_Max     ]
;      3: 83       Z Loc [ H_ov_Hmax ]
;
```

```
;    65:  Z=X*Y (P36)
;     1: 81       X Loc [ C1_big    ]
;     2: 83       Y Loc [ H_ov_Hmax ]
;     3: 84       Z Loc [ h1_big    ]
;
;    66:  Z=X+Y (P33)
;     1: 84       X Loc [ h1_big    ]
;     2: 82       Y Loc [ C2_big    ]
;     3: 61       Z Loc [ Ce_big    ]
;
;    67:  Z=F x 10^n (P30)
;     1: -1       F
;     2: 00       n, Exponent of 10
;     3: 85       Z Loc [ K1_big    ]
;
;    68:  Z=F x 10^n (P30)
;     1: 0.003    F
;     2: 00       n, Exponent of 10
;     3: 86       Z Loc [ K2_big    ]
;
;    69:  Z=X+Y (P33)
;     1: 47       X Loc [ b_width   ]
;     2: 85       Y Loc [ K1_big    ]
;     3: 63       Z Loc [ Qbig_int2 ]
;
;    70:  Z=X*Y (P36)
;     1: 61       X Loc [ Ce_big    ]
;     2: 63       Y Loc [ Qbig_int2 ]
;     3: 62       Z Loc [ Qbig_int1 ]
;
;    71:  Z=X+Y (P33)
;     1: 87       X Loc [ Offset_H  ]
;     2: 86       Y Loc [ K2_big    ]
;     3: 64       Z Loc [ Qbig_int3 ]
;
;    72:  Z=X^Y (P47)
;     1: 64       X Loc [ Qbig_int3 ]
;     2: 46       Y Loc [ threehalf ]
;     3: 66       Z Loc [ Qbig_int4 ]
;
;    73:  Z=X*Y (P36)
;     1: 62       X Loc [ Qbig_int1 ]
;     2: 66       Y Loc [ Qbig_int4 ]
;     3: 40       Z Loc [ Q_big     ]
;
;    74:  Z=X*F (P37)
;     1: 40       X Loc [ Q_big     ]
;     2: 28.3     F
;     3: 97       Z Loc [ QbigLperS ]
;
;
;75:  End (P95)
;
;76:  If (X<=>Y) (P88)
```

```
; 1: 3        X Loc [ Head_ft   ]
; 2: 4        <
; 3: 38       Y Loc [ H_Max     ]
; 4: 30       Then Do
;
;     77:  Z=F x 10^n (P30)
;      1: 0        F
;      2: 00       n, Exponent of 10
;      3: 97       Z Loc [ QbigLperS ]
;
;                              78:  Z=F x 10^n (P30)
;                               1: 0.0      F
;                               2: 1        n, Exponent of 10
;                               3: 109      Z Loc [ Zero      ]
;
;                              79:  Z=F x 10^n (P30)
;                               1: 25333.4  F
;                               2: 1        n, Exponent of 10
;                               3: 112      Z Loc [ Max_Vol   ]
;
;
;
;80:  End (P95)

;--------End Big Weir flow--------------------
;--------Calculate total flow-----------------


81:  Z=X+Y (P33)
 1: 95       X Loc [ Qsm_LperS ]
 2: 96       Y Loc [ Qor_LperS ]
 3: 41       Z Loc [ Q_interm  ]


82:  Z=X+Y (P33) ;L/sec
 1: 41       X Loc [ Q_interm  ]
 2: 97       Y Loc [ QbigLperS ]
 3: 94       Z Loc [ Q_LperSec ]




;--------End Total flow Calculation-----------

;--------Cumulative Volume Calculation--------

;
;83:  Z=F x 10^n (P30)
; 1: 300      F
; 2: 00       n, Exponent of 10
; 3: 113      Z Loc [ ISCOdelay ]
;
;
;84:  Z=F x 10^n (P30)
```

```
; 1: 6        F
; 2: 1        n, Exponent of 10
; 3: 102      Z Loc [ Samp_int  ]
;
;
;85:  Z=X (P31)
; 1: 103      X Loc [ Cum_Vol   ]
; 2: 107      Z Loc [ Vol_int1  ]
;
;
;86:  Z=X*Y (P36)
; 1: 94       X Loc [ Q_LperSec ]
; 2: 102      Y Loc [ Samp_int  ]
; 3: 106      Z Loc [ Vol_int2  ]
;
;
;87:  Z=X+Y (P33)
; 1: 107      X Loc [ Vol_int1  ]
; 2: 106      Y Loc [ Vol_int2  ]
; 3: 103      Z Loc [ Cum_Vol   ]
;
;                       88:  If (X<=>F) (P89)
;                        1: 21       X Loc [ Counter   ]
;                        2: 4        <
;                        3: 121      F
;                        4: 30       Then Do
;
;
;
;                            89:  If (X<=>Y) (P88)
;                             1: 103      X Loc [ Cum_Vol   ]
;                             2: 3        >=
;                             3: 112      Y Loc [ Max_Vol   ]
;                             4: 30       Then Do
;
;
;                            90:  Pulse Port w/Duration (P21)
;                             1: 2        Port
;                             2: 113      Pulse Length Loc [ ISCOdelay ]
;
;                       91:  End (P95)
;
;                            92:  If (X<=>Y) (P88)
;                             1: 103      X Loc [ Cum_Vol   ]
;                             2: 3        >=
;                             3: 112      Y Loc [ Max_Vol   ]
;                             4: 30       Then Do
;
;                            93:  Z=Z+1 (P32)
;                             1: 21       Z Loc [ Counter   ]
;
;
;                            94:  Z=X (P31)
;                             1: 109      X Loc [ Zero      ]
```

```
;                         2: 103      Z Loc [ Cum_Vol   ]
;
;                        95:  Z=X (P31)
;                         1: 109      X Loc [ Zero      ]
;                         2: 107      Z Loc [ Vol_int1  ]
;
;                        96:  Z=X (P31)
;                         1: 109      X Loc [ Zero      ]
;                         2: 106      Z Loc [ Vol_int2  ]
;
;                    97:  End (P95)
;



;-----------------------------------------
;-----------------------------------------
;---------End flow calculation-------------
;-----------------------------------------





;-----------------------------------------------
;-------  OUTPUT TABLES -------------------------
;-----------------------------------------------


;98:  If time is (P92)
; 1: 0        Minutes (Seconds --) into a
; 2: 5        Interval (same units as above)
; 3: 10       Set Output Flag High (Flag 0)
;
;99:  Set Active Storage Area (P80)
; 1: 1        Final Storage Area 1
; 2: 101      Array ID
;
;100:  Real Time (P77)
; 1: 1220     Year,Day,Hour/Minute (midnight = 2400)
;
;101:  Average (P71)
; 1: 1        Reps
; 2: 12       Loc [ Head_cm   ]
;
;102:  Average (P71)
; 1: 1        Reps
; 2: 101      Loc [ Hsill     ]
;
;103:  Average (P71)
; 1: 1        Reps
; 2: 98       Loc [ OffsetHcm ]
;
;104:  Average (P71)
```

```
; 1: 1        Reps
; 2: 94       Loc [ Q_LperSec ]
;
;
;105:  Average (P71)
; 1: 1        Reps
; 2: 95       Loc [ Qsm_LperS ]
;
;106:  Average (P71)
; 1: 1        Reps
; 2: 96       Loc [ Qor_LperS ]
;
;107:  Average (P71)
; 1: 1        Reps
; 2: 97       Loc [ QbigLperS ]
;
;
;108:  Average (P71)
; 1: 1        Reps
; 2: 4        Loc [ WatTemp_C ]
;
;109:  Sample (P70)
; 1: 1        Reps
; 2: 21       Loc [ Counter   ]
;
;
;110:  Minimum (P74)
; 1: 1        Reps
; 2: 0        Value Only
; 3: 1        Loc [ Batt_Volt ]
;
;
;111:  End (P95)
```

9.3 APPENDIX C

DIRECTORY OF ADDITIONAL INFORMATION PROVIDED ON CD

DISK 1

- ELECTRONIC COPY OF FINAL REPORT
- DATA SPREADSHEETS IN EXCELL FORMAT FOR MAJOR COMPONENTS OF PROJECT
  - GROUNDWATER
  - IRRIGATION STUDY
  - RAIN GUAGE DATA
  - SW1 MONITORING STATION
  - TAILWATER POND STUDY
- NURSERY BMP NOTICE OF INTENT
- PRESENTATIONS
- PROJECT VIDEOS
- PUBLICATIONS
- QUALITY ASSURANCE
  - CHAIN OF CUSTODY FILES
  - WATER QUALTIY LABORATORY REPORTS
- QUARTERLY REPORTS
- MONITORING STATION STRUCTURE PERMIT FROM SRWMD

DISK 2

- PROJECT PHOTOS
  - DENITRIFICATION WALL
  - EXTREME EVENT
  - INTERCEPT BERM AND SWALES
  - MISCALANEOUS
  - MONITORING STATION SW1
  - MONITORING STATION SW2
  - MONITORING STATION SW3
  - TAILWATER POND AND SEEPAGE WETLAND