Impact of Irrigation Drainage Tile on Nutrient Loading in the Tri-County Agricultural Area, Northeast Florida

INTRODUCTION

The Lower St. Johns River (LSJR) was been listed as impaired by nitrogen in its marine section and nitrogen and phosphorous in its freshwater section in 2008 of the state of Florida's EPA required Pollution Water Quality Assessment Report under Sections 305(b) and 303(d) of the Clean Water Act since 2008. (Dr. Wayne Magley and Daryll Joyner, 2008)

Figure 1 – Tri-County Agricultural Area (TCAA)

Agriculture in the Tri-County Agriculture Area (TCAA), **Figure 1**, was identified as a significant contributor to nutrient loads in the freshwater section of the LSJR and even with full implementation of BMPs by growers, agricultural load reduction requirements would not be completely met and will require regional treatment systems and other enhanced nutrient reduction techniques to achieve full load reduction requirements. The Tri-County Agricultural Area – Water Management Partnership (TCAA-WMP) is a cost share program that funds projects intended to reduce nutrient loads in the St. Johns River.

The project presented in this paper was designed to determine the potential nutrient (nitrogen and phosphorous) load reductions from different irrigation / drainage practices for use in Basin Management Action Plan (BMAP) calculations. Water use reduction potential from alternate irrigation practices was also investigated during this study. The focus of this study was to determine if the use of alternative irrigation / drainage, specifically Irrigation Drainage Tile (IDT) effectively reduce the nutrient loads within runoff from farms into the local watershed as compared to conventional irrigation and drainage techniques such as seepage and overhead pivot irrigation.

Irrigation Drainage Tile (IDT) is a form of field irrigation and drainage which features drainage pipe buried in a tile pattern beneath the soil at a depth of 36 inches. Water from precipitation and irrigation soaks down through the soil and collects within the buried pipe and is transported off the field to drainage edge of field drainage ditches. In IDT, there are water control structures located at specific main, and at edge of field locations so the water can be held within the field. These water control structures allow drainage during heavy rainfall events, but their movable stoplog features can also be used to stage water within the field at various heights and reduce irrigation / nutrient runoff as well as increase soil moisture residence time and, with the drain spacing installed at half the recommended value for drainage, allow for subirrigation. **Figure 2.**

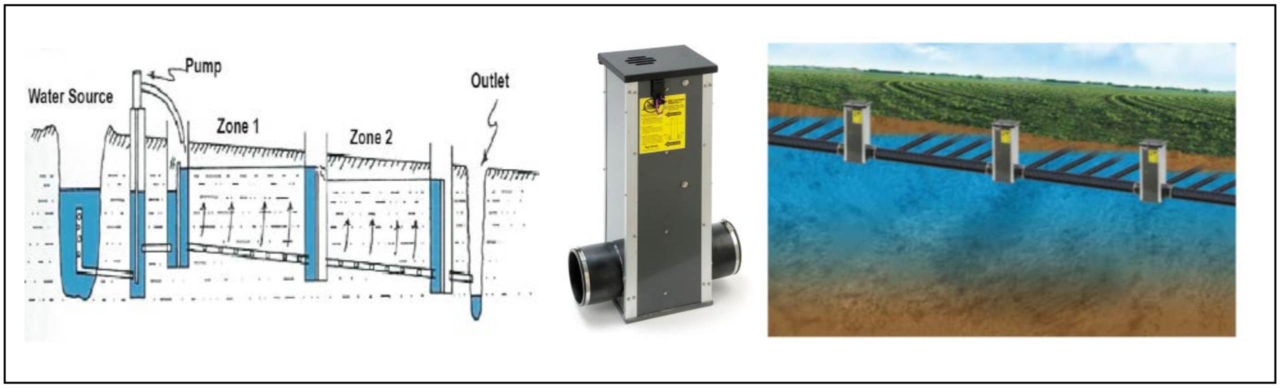
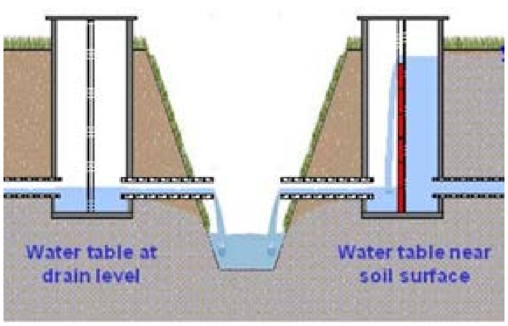


Figure 2 – Irrigation Drainage Tile Layout, IDT Control Box, Field Installation

When the ground is fully saturated and untiled, during a significant rain event the rainwater will have nowhere to go but to run off the field. When it runs off it will carry soil, chemical, and fertilizer with it. In tiled land where the water table has been lowered to 3 or 4 feet down in the soil, there is holding capacity for rain water. Erosion and flooding are both significantly reduced when tile is added to a field. When water seeps through several feet of soil, the water is filtered and by the time water reaches tile lines, it is advertised to be below the drinking water standard target in the U.S. for nitrate-nitrogen below 10 parts per million.

Benefits of IDT are that the water table can be easily raised to the root level. Conventional seepage also attempts to raise and lower the water table to achieve optimal soil moisture for crop, but control is more difficult in seepage because a) there is only one water furrow for every 60' bed, vs every 20-30' of drainage tile so water level can be manipulated up and down more quickly and b) presumably they can manage runoff during the irrigation phase more effectively. By regulating the board height in structures and they have no capacity to do that in the water furrows. Rain water also soaks down through the soil to the tile pipe which more effectively drains the field. Also, by flowing through the soil, some nutrients like phosphorus can adsorb to the soil particles and be kept from potentially harming downstream water resources.



Using control structures to manipulate water table levels

Drainage tile installed throughout the Midwest has often been identified as a significant contributor to nitrate-nitrogen loads to the Mississippi River watershed resulting in impacts to the Gulf of Mexico hypoxic zone. Drainage tile in the Midwest, however, is not used for irrigation only for drainage and is often referred to as an "open drainage" system since it does not have any control structures. Adding control structures to "open drainage" drain tile systems has been promoted as a means to reduce nitrate nitrogen loses by facilitating in the field denitrification to reduce in Nitrate-Nitrogen outflow. (Cooke, 2006)

The study was designed to determine if installation of IDT systems in the TCAA-WMP was a) effective at reducing nutrient loads when compared to traditional irrigation / drainage systems such as seepage and overhead irrigation and b) to quantify those load reductions so that they could be used in load reduction models associated with Basin Management Action Plans.

METHODS

Four farms were selected to participate in the study, Picolata Farms, Sykes & Cooper Farms, Smith Farms, and Tater Farms. These farms were selected due to the types of crops and the availability of at least 2 separate but similar “paired” fields at each location. Both fields were intended to keep the same crops and fertilization techniques throughout the study. One field would continue to be irrigated and drained by traditional seepage irrigation and referred to as the reference field while the second, treatment field, would be managed using an alternate irrigation method, either enhanced seepage, overhead irrigation, or irrigation drainage tile (IDT). In this paper I will only discuss IDT systems. Fields were selected with similar soils and management practices in fertilization and other grower activities. Reference and treatment fields at each farm were only selected if runoff could be distinctly isolated between each field as well as other external sources.

Monitoring stations were established at each farm, one at the reference field and one at the treatment field. Flow meters were also installed at the irrigation pumps of each field to identify any water use reduction via the alternative practices.

Monitoring stations consisted of a Teledyne ISCO 3700 or 6712 Autosampler, a Blue-Siren Flow Meter / Data Logger and 12VDC deep cycle battery within a lockable shelter. One site per field also was also configured with an Onset RG3 Rain Gauge (HOBO datalogger removed) connected to the datalogger. **Figures 3 & 4**. The Blue-Siren flow meter was connected to the ISCO auto samplers and set send a signal to the ISCO to trigger sample collection when a specified amount of water was calculated to have passed the av sensor located in the field outflow pipes. Samples sites were configured as appropriate according to field being studied. For IDT fields one site was located with a flow sensor within the IDT exit pipe from the field to calculate the volume of water leaving the field. The ISCO sample collection tube was located just upstream of the water control structure stop logs to ensure the water being sampled was coming exclusively from the IDT field and was not mixed with any water from the drainage ditch that could be top of soil runoff or rain water. A second sample structure was placed near the edge of field to collect water from the drainage ditch for comparison. For the paired seepage fields at each farm a single sample station was located at the seepage/drainage ditch to collect water leaving the site. An AV sensor and sample swing arm was located within the culverted pipe to calculate flow and collect samples at a determined volume for comparison to the IDT field. **Figures 5-8** display monitoring station configurations and variations in setup.

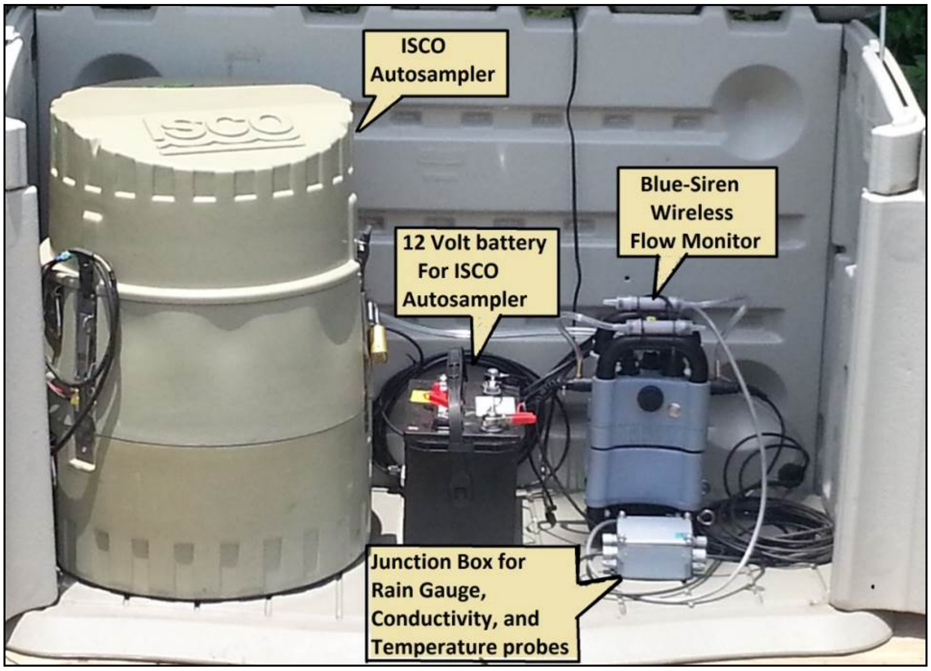


Figure 3 - Contents of monitoring station shelter. ISCO automatic water sampler, 12 VDC, Blue-Siren data logger / flow meter, and junction box for connection of rain gauge, conductivity, and temperature probes.

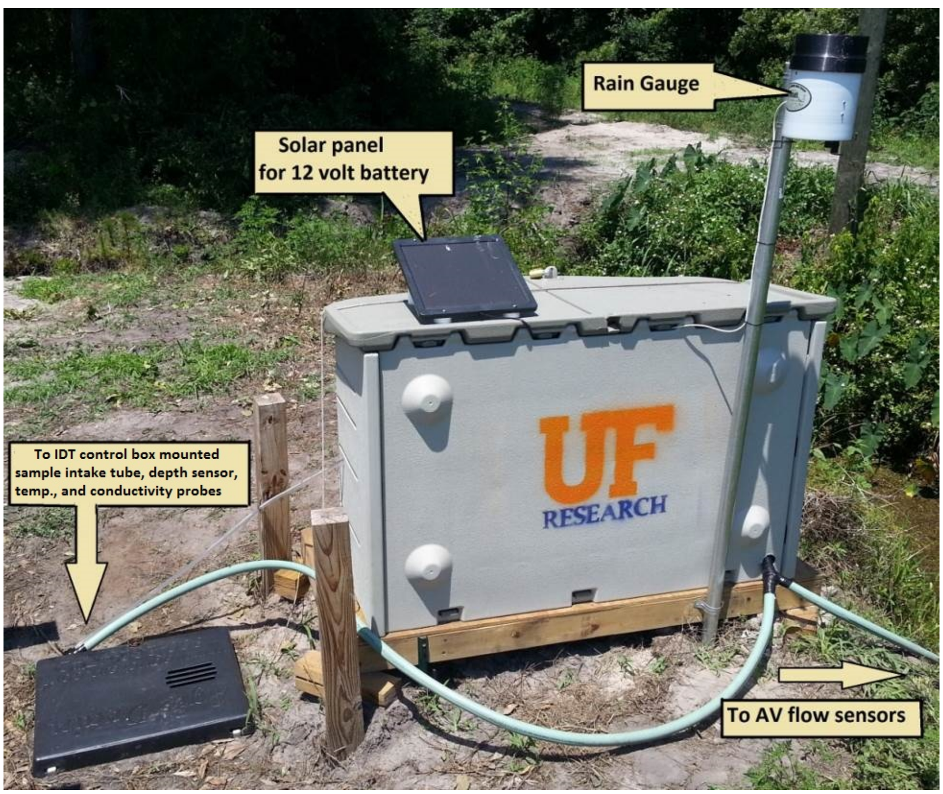


Figure 4 - Typical monitoring station. Flow meter AV sensors within IDT discharge pipe to right. Autosampler Intake tube, temperature, and conductivity probe wihthin IDT control box to on left. Rain gauge attached to Blue Siren data logger / flow meter and solar panel connected to 12VDC power supply within shelter.

Figure 5 - Monitoring station at IDT field (left) and AV flow sensor within IDT discharge pipe (right)

Figure 6 - AV sensors within surface water monitoring culver pipe (left), AV sensors installed within IDT discharge pipe (right)

Figure 7 -Autosampler intake tube, conductivity, and temperature probe (left) prior to installation within IDT control box (right)

Figure 8 -Typical surface water collction within seepage ditch (left) and culvert (right). Autosampler intake tube, temperature and conductivity probes are loctated within PCV pipe attached via hinge to top of culvert to allow high flow events.

Along with measuring flow and triggering ISCO samples, each Blue-Siren flow meter/data logger was connected to water quality probes to collect temperature and conductivity at the sample collection point. These values, as well as the flow and depth volumes were collected by the datalogger at 5-minute intervals. The Blue-Siren datalogger was also connected to the internet via modem and uploaded data to a Blue-Live website on a 30-min basis so live data from samples sites could be monitored and stored. The real-time levels within the IDT control box as well as the drainage ditch culverts were shown on the Blue-Live website and changes, such as ISCO trigger volumes, could be made according to observed levels and weather forecasts. Stations were monitored via Blue-Live website for water levels, flow, depth, velocity, rain gauge tips and ISCO sample trigger times. This information was useful to view rain events and field irrigation response as well as illustrate sample collection volumes as well as potential problems prior to weekly visits. Real-time data acquisition and monitoring using the Blue-Siren flow sensors and Blue-Live virtual data server also facilitated assessment of monitoring sites and determination of any calibration, maintenance and repair that may need to be conducted.

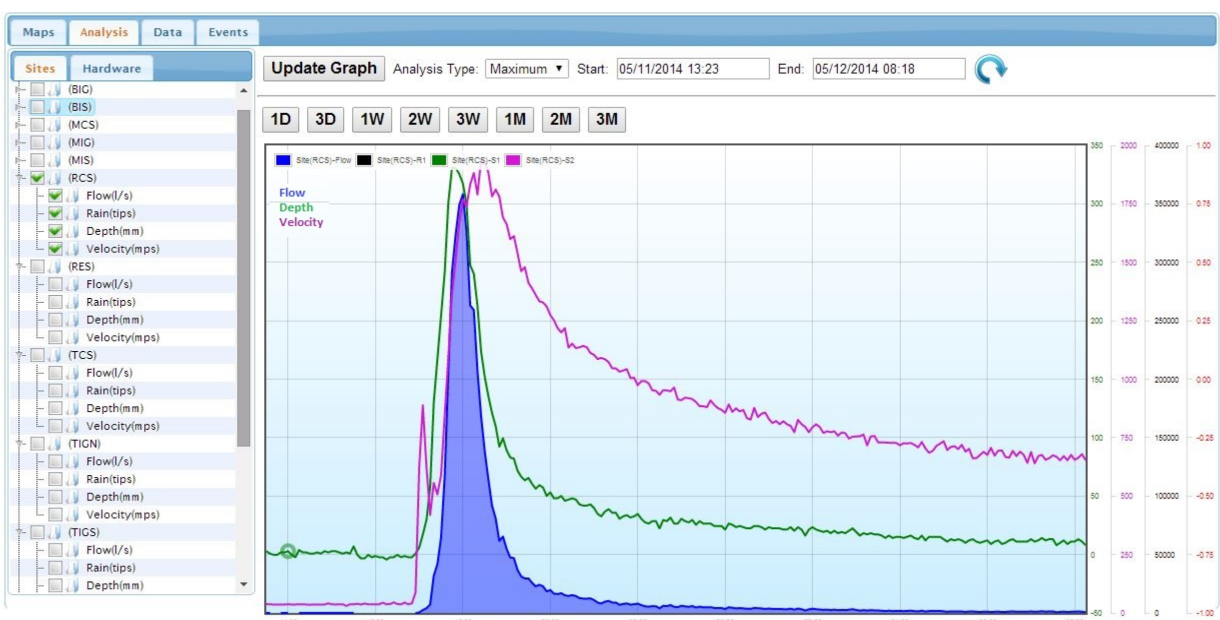


Figure 9 – Blue-Live website showing increased depth, volume, and flow at a monitoring station

A total of 13 monitoring stations were installed on 9 fields within the 4 farms. At each IDT field one groundwater monitoring station and one surface water station was installed. This system allowed a comparison between groundwater drainage resulting from the IDT system within the field and the surface water leaving the field in the perimeter tailwater ditches. The monitoring station distribution is as follows: Picolata farms, one IDT field groundwater station (MIG) and surface water station (MIS), one seepage field surface water station (MIG) (Figure 10); Sykes & Cooper Farms, one seepage field surface water station (BCS), one IDT field groundwater station (BIG) and one surface water station (BIS) (Figure 11); Tater Farms, two IDT field groundwater monitoring stations (TIGS, and TIGN) and surface water station (TIS), one overhead irrigation field surface water station (TOS), and one seepage field surface water station (TCS) (Figure 12). Smith Farms one surface water station was installed on the farms seepage field (SCS), one surface water station (SIS), and one additional groundwater station (SIG2) was installed at the southern end of the IDT field. The northern IDT drainage was also monitored, but samples were not collected from this site (SIG1) – Figure 13.

Figure 10 – Picolata Farms

Figure 11 – Sykes & Cooper Farms

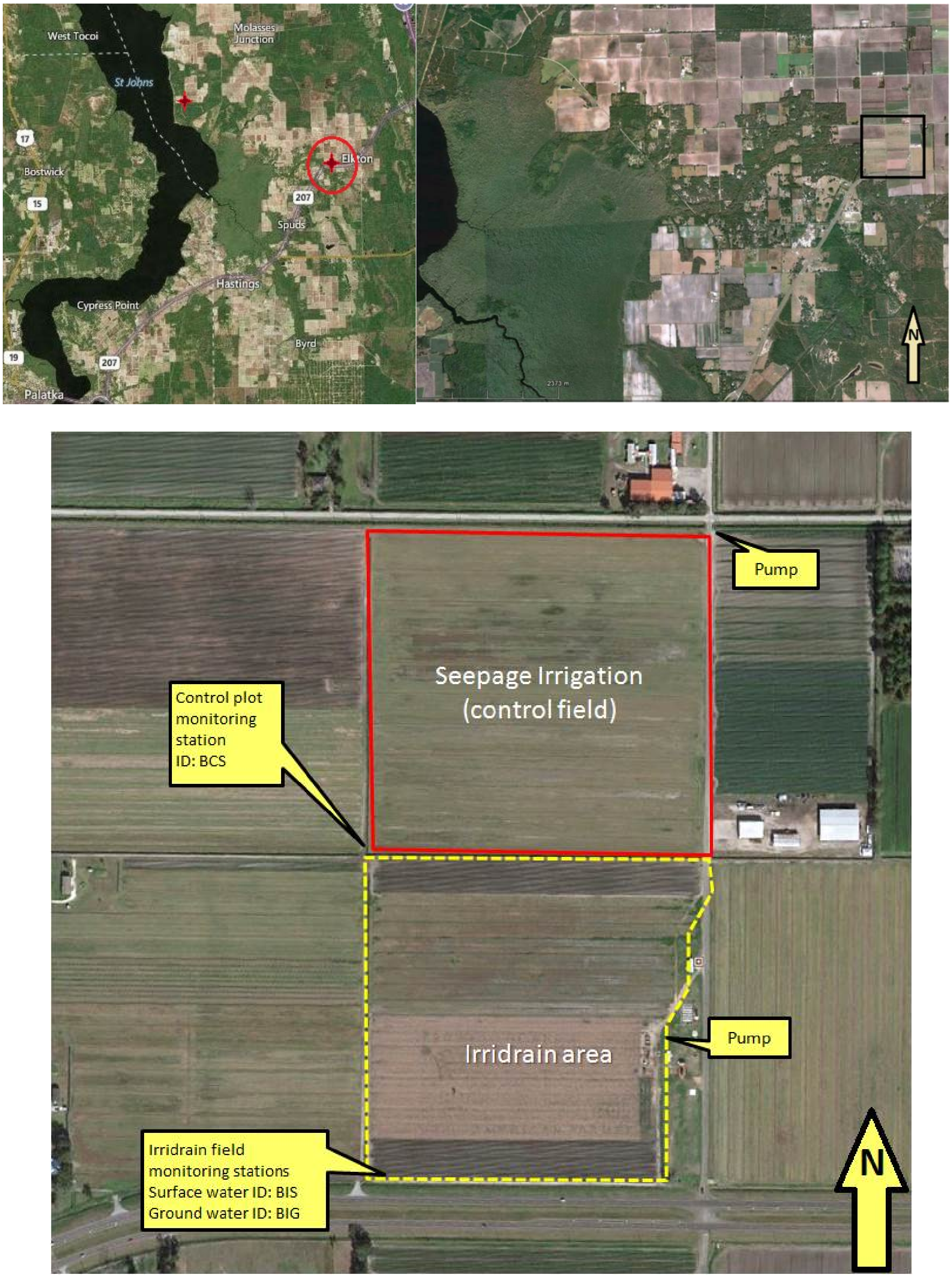
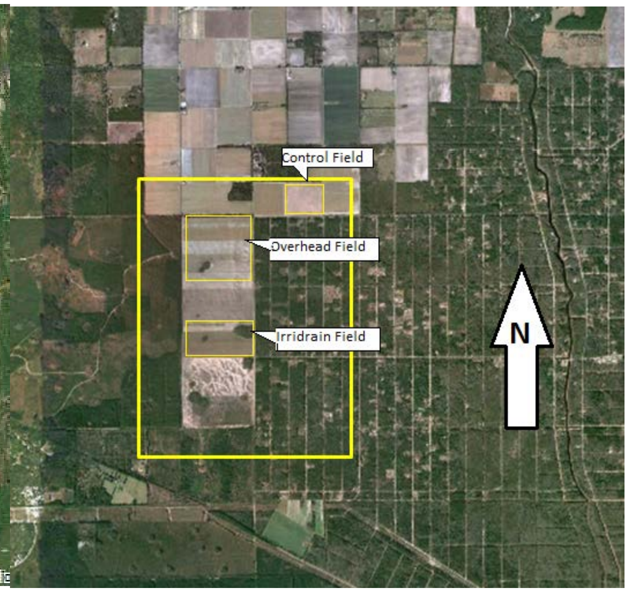
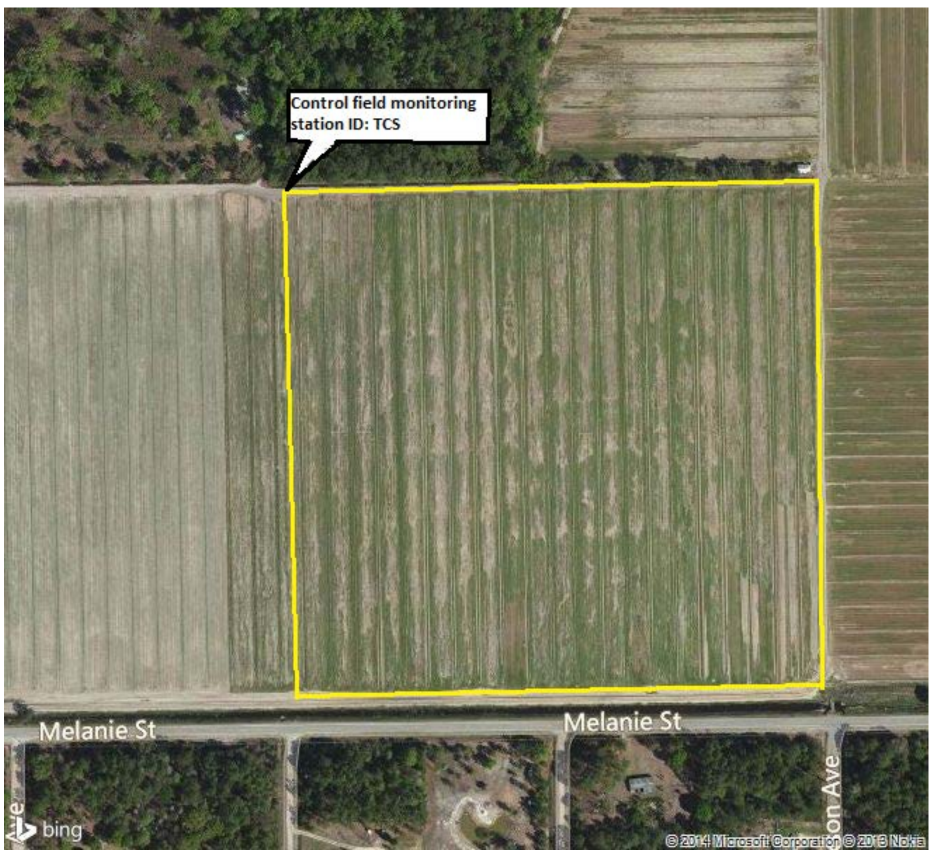
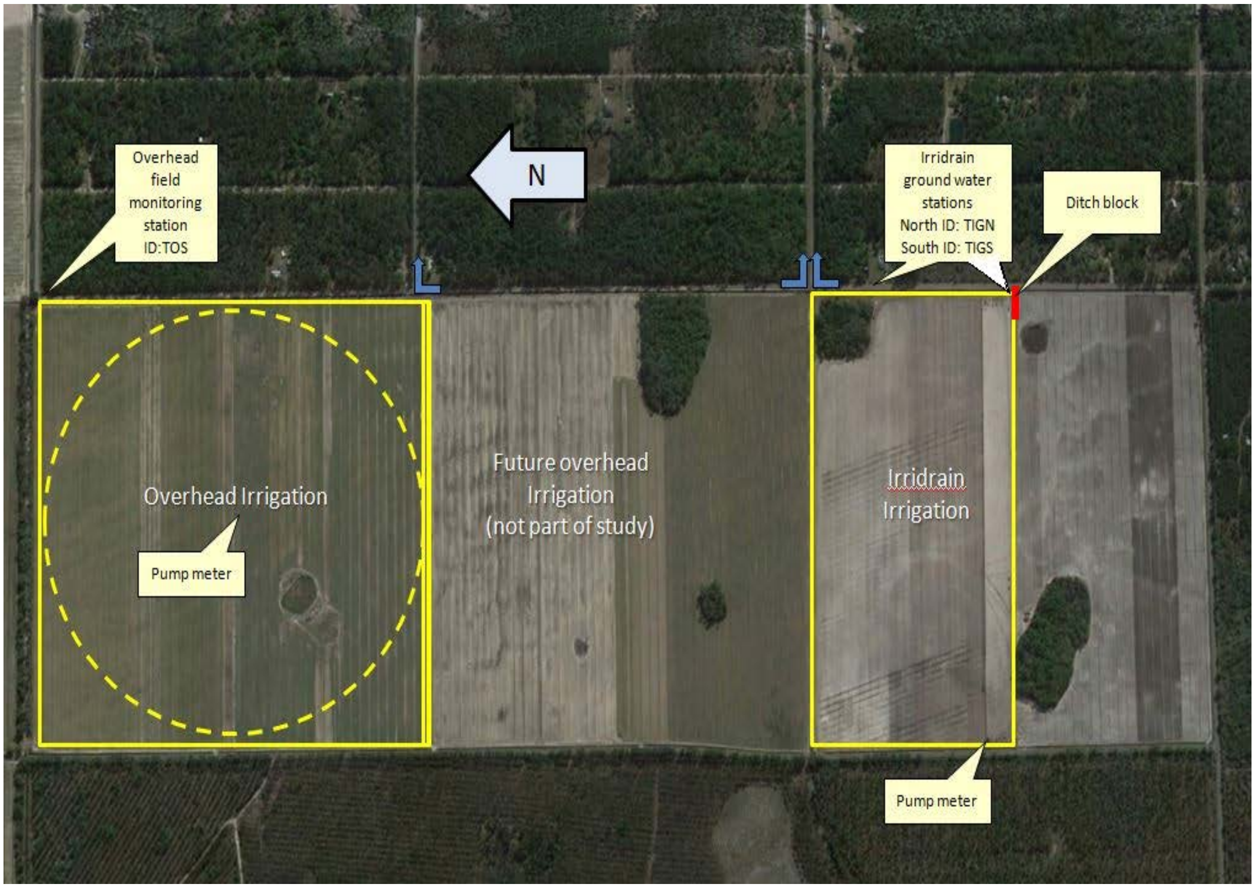


Figure 12 – Tater Farms

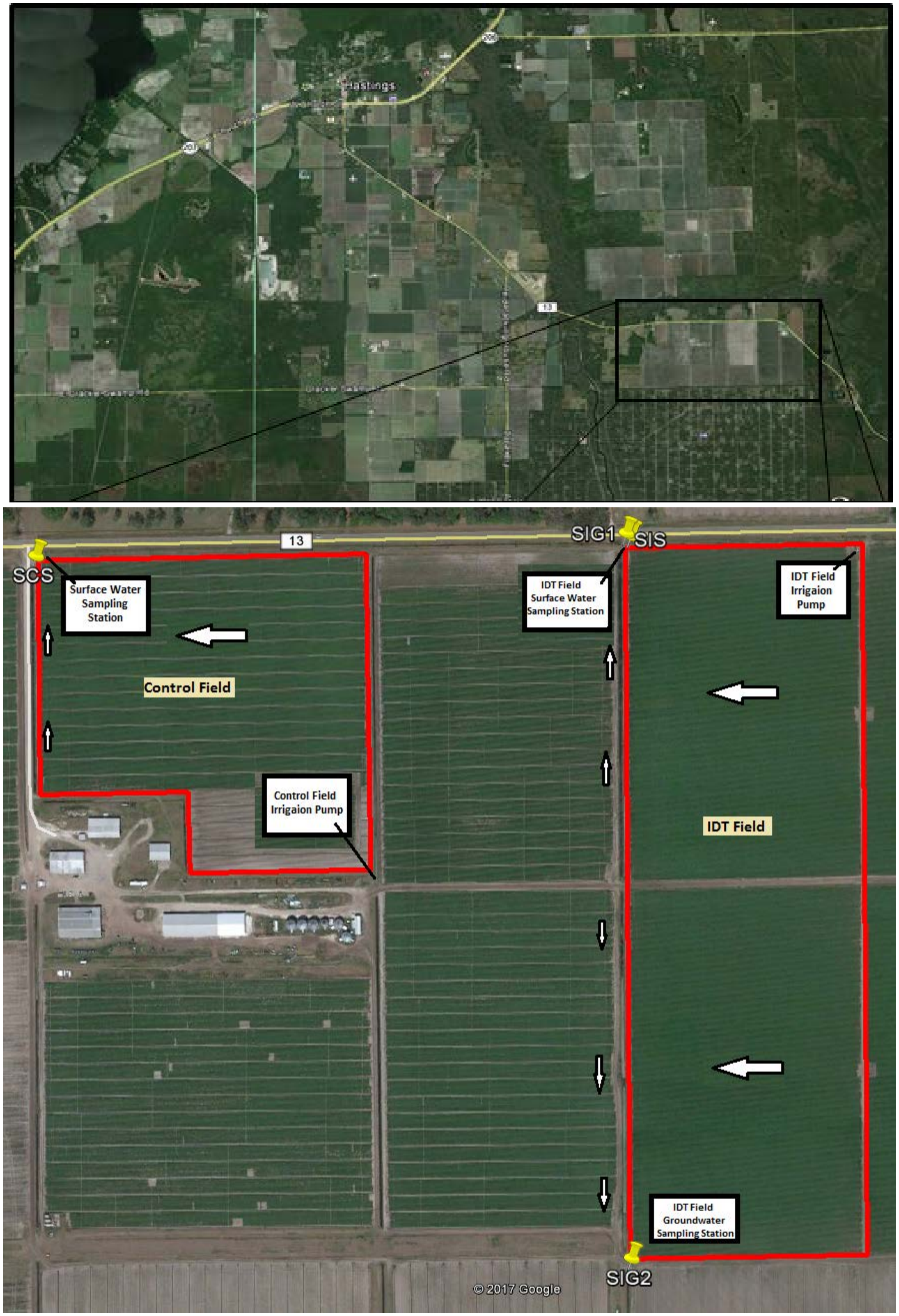






N
Overhead field monitoring station ID:TOS
Irridrain ground water stations North ID: TIGN South ID: TIGS
Ditch block
Overhead Irrigation
Pump meter
Future overhead Irrigation (not part of study)
Irridrain Irrigation
Pump meter

Figure 13 – Smith Farms



Sample collection and analysis

At each sampling station the Blue-Siren flow meters were programmed to send a signal to an attached ISCO automatic sampler that triggered sample collection once a certain volume of water has flowed past the flowmeter sensor at that site. The specific flow volumes for triggers were determined at each site at an initial estimated volume and then adjusted following weekly monitoring during site visits to ensure the most accurate representation of the weekly water flow through the field could be collected and contained within the automatic sampler. Surface water sample triggers from the seepage canals were set to 75,108 liter (20,000 gallon), while IDT sites were set to flow volumes between 10,000 and 30,000 liters (2,641 and 7,925 gallons).

Water samples were collected weekly from the automatic samplers at each station, brought to Environmental Water Quality Laboratory (NELAC certification #E72850) on UF main campus and submitted for analysis for total phosphorous (TP), Total Kjeldahl Nitrogen (TKN), and Nitrate - Nitrite (NOx). Discrete grab samples were also collected from each site during weekly visits if flow was occurring at the time of visit. Grab samples were analyzed for TP, TKN, NOx, ammonium (NH4), and orthophosphate (Ortho-P). The irrigation wells for each field were visited each week and the total flow was recorded to determine weekly irrigation water input to the fields. The irrigation wells were also sampled periodically (initially monthly, then quarterly) for TP, TKN, NOx, NH4, and Ortho-P for comparison to the field outflow samples.

RESULTS and DISCUSSION

Analysis results

First Quarter of Monitoring – July 1 to September 30, 2014.

This quarter occurred in a time of year that most fields have been planted in a cover crop and little or no irrigation occurs due to typically high rainfall. Of the farms being monitored in this study, Picolata farms was in cover crop only beginning to get prepared for the winter crop during the end of the quarter. Sykes and Cooper Farms and Tater Farms were in active production either with the production of Asian vegetables or sod, respectively. All farms were monitored during the period, but interpretation of results should consider the active vs. fallow phase of each farm.

Water quality among the four farms and alternative irrigation practices varied significantly during this sampling period. In general, total phosphorous from irrigation drainage tile (IDT) fields and specifically from IDT pipes was lower and in many instances significantly lower than that of conventional irrigated fields (Figure 1 and Table 1). Both Tater Farms and Sykes and Cooper Farm had clearly lower Total Phosphorus concentrations discharging from IDT fields when compared to conventional seepage fields. At Picolata Farms this difference becomes a bit more confusing where the Total Phosphorus concentration from the IDT pipe is very low, but the Total Phosphorus concentration collected in the tailwater ditch that the IDT pipe and surface runoff from the IDT field discharge into are higher than the conventional irrigated field. During the second quarter sampling we plan to investigate the source of phosphorus increase between the IDT pipe monitoring station and the surface water monitoring stations downstream of the pipe.

Nutrient Concentrations

In the case of Total Nitrogen two farms had lower nitrogen discharge concentrations from IDT systems than conventional systems (Picolata and Tater) while Sykes and Cooper Farm had significantly higher discharge concentrations (Figure 1 and Table 2). These differences are also more apparent during baseflow conditions than under stormflow conditions.

Sample collection analysis and comparison findings seem to indicate that phosphorous concentrations from IDT fields are significantly lower than those from conventional fields.

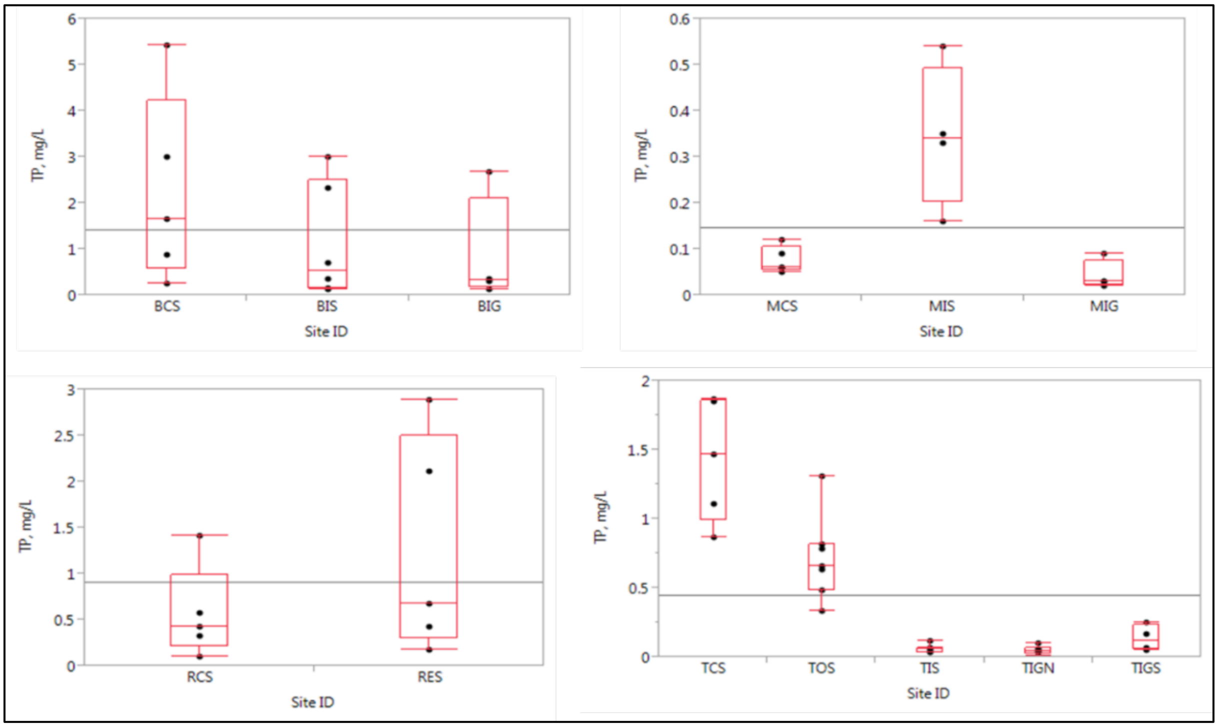


Figure 1: **Total Phosphorus concentrations measured at each of the 13 stations among the four assessment farms. Site identification code is as follows, first letter signifies farm (B = Sykes and Cooper, M = Picolata, R=Riverdale, T = Tater), second letter signifies irrigation type (C = conventional seepage, I = irrigation drainage tile, E = enhanced seepage, O = Overhead), third letter indicates water sample location (S = surface, G = ground or groundwater pipe from irrigation drainage tile).**

As shown in Figure 2 and Table 1 for nitrogen concentration, two of the four farms (Picolata Farms and Tater Farms) showed lower concentrations from the IDT field than conventional seepage fields. However, at Sykes & Cooper Farms the nitrogen level was significantly higher than that farms seepage field, and showed to be more elevated during baseflow than during stormflow events.

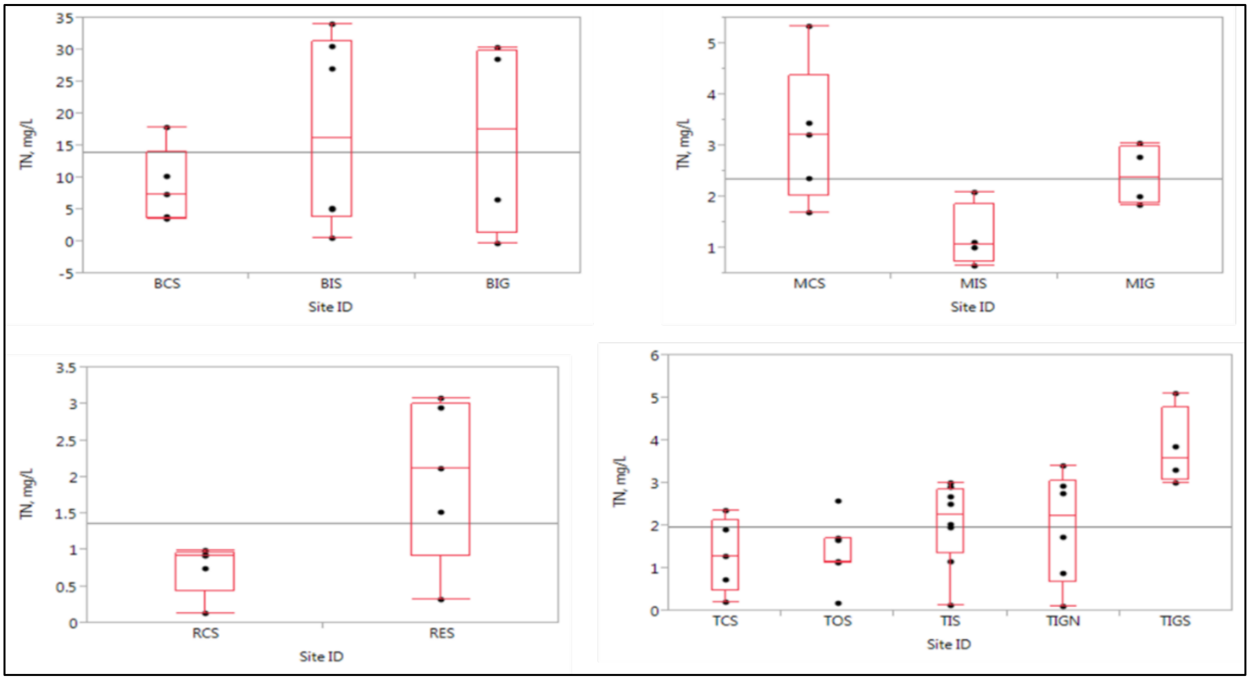


Figure 2: Total Nitrogen concentrations measured at each of the 13 stations among the four assessment farms. Site identification code is as follows, first letter signifies farm (B = Sykes and Cooper, M = Picolata, R=Riverdale, T = Tater), second letter signifies irrigation type (C = conventional seepage, I = Irrigation drainage tile, E = enhanced seepage, O = Overhead), third letter indicates water sample location (S = surface, G = ground or groundwater pipe from irrigation drainage tile).

	Grab Samples (generally base-flow)		Autosampler samples (generally storm-flow)	
Farm and Treatment	**Total Phosphorus mg/L**	**Total Nitrogen mg/L**	**Total Phosphorus mg/L**	**Total Nitrogen mg/L**
Picolata				
Conventional Seepage	0.056 ± 0.035	3.23 ± 2.23	0.378 ± 0.459	4.58 ± 2.27
Irridrain (surface and irridrain)	0.345 + 0.156	1.08 ± 0.375	1.00 ± 0.583	2.45 ± 0.987
Irridrain only	0.042+ 0.029	2.41 ± 0.592	0.092 ± 0.0.048	3.56 ± 1.14
effect of irridrain*	84%	-67%	165%	-47%
Sykes and Cooper				
Conventional Seepage	2.25 ± 2.05	8.50 ± 5.85	4.74 ± 3.13	11.33 ± 9.49
Irridrain (surface and irridrain)	0.955 + 1.20	19.63 ± 15.33	0.811 ±.798	13.5 + 12.2
effect of irridrain*	-58%	131%	-83%	19%
Riverdale				
Conventional Seepage	0.448 ± 0.454	1.01 ± 0.381	1.81 ± 0.905	2.72 ± 0.1.58
Enhanced Seepage	1.26 ± 1.18	2.26 ± 0.722	1.12 ± 1.10	2.18 ± 0.518
effect of enhanced seepage*	158%	124%	-38%	-20%
Tater				
Conventional Seepage	1.51 ± 0.444	3.04 ± 3.23	1.36 ± 0.576	4.43 ± 5.95
Overhead Irrigation	0.599 ± 0.336	2.86 ± 3.88	0.931 ± 0.699	4.08 ± 3.25
Irridrain (surface and irridrain)	0.060 ± 0.027	2.55 ± 0.746	0.172 ± 0.130	3.21 + 1.32
effect of overhead irrigation*	-60%	-6%	-32%	-8%
effect of irridrain*	-96%	-16%	-87%	-28%

* positive value means treatment concentration was greater than conventional seepage concentration, negative value means treatment concentration was less than conventional seepage concentration.

Table 1. Average Total Phosphorus and Total Nitrogen concentrations measured at the four assessment farms during baseflow (grab samples) and generally stormflow (autosamplers).

Nutrient Loads

The combined effect of differences in nutrient concentrations and differences in runoff volumes during this sampling period generally indicate lower phosphorus loads from IDT fields, and nitrogen loads that are lower on some IDT fields and higher on others when compared to conventional seepage fields (Table 2). The anomaly farm for phosphorus is Picolata, which as previously identified had low phosphorus discharge concentrations at the IDT pipe, but higher concentrations at the tailwater monitoring site. This would suggest that the source of the elevated phosphorus may not be the irrigation drainage tile system specifically, but instead a source of phosphorus within the ditch itself. This will be investigated in more detail during the second quarter monitoring period. With regard to nitrogen loads, the Sykes and Cooper Farm was the anomaly where nitrogen discharge was higher in the IDT field than for the conventional seepage fields. This difference may have to do with the active farming activities that were occurring at the Sykes and Cooper Farm during this sampling period as compared to Picolata Farm and due to the more intensive fertilizer regime at Sykes and Cooper Farm when compared to Tater Farm.

Farm	Treatment	Total Phosphorous kg/ha^{-1}	Total Nitrogen kg/ha^{-1}
Picolata	Conventional	0.66	8.55
	Irrigation Drainage Tile	2.02	5.01
Sykes and Cooper	Conventional	11.6	28.4
	IDT	2.74	46.8
Tater	Conventional	1.93	3.55
	IDT	0.17	3.29

Table 2. Measured loads of Total Phosphorus and Total Nitrogen in the four assessment farms during the period of July 1 to September 30, 2014.

Although the paired field sampling design has allowed us to make direct comparisons between the fields during this first quarter, these results are still very preliminary and only represent the effect of alternative irrigation/drainage practices during one phase of farming activities within the TCAA.

Second quarter of monitoring - October 1, 2014 to February 28, 2015

This monitoring period represents a time of the year when most agricultural fields are being prepared for winter planting or entering a more dormant phase of continuous cropping such as for sod. Picolata Farm planted beans in the conventional seepage plot early in the quarter with no planting in the IDT treatment plot. This resulted in difference in management between the control and treatment fields and therefore problems comparing these two fields during the last part of 2014; however, both fields were planted in potatoes by the end of January and therefore were again considered comparable for monitoring purposes. The other two farms (Sykes and Cooper and Tater Farms) were in active production throughout the sampling period either with the production of Asian vegetables or sod, respectively. This is also a time of limited irrigation demand due to lower evapotranspiration rates. The exceptions to this were at Picolata Farm on the conventional seepage irrigation field planted in beans and at Sykes and Cooper Farm which irrigated to a limited extent during this period. All farms were monitored during the period, but interpretation of results should consider the transitional phase of farm production during this time.

Water Quality Characteristics (Table 3)

Phosphorous - Total Phosphorus (TP) concentrations ranged from 0.067 $\pm$ 0.127 mg L^{-1} (Tater Farms, IDT (surface) Station) to 1.49 $\pm$ 1.44 mg L^{-1} (Sykes and Cooper Farm, Conventional Seepage). At the three farms where IDT is being evaluated, TP concentration from IDT fields where the IDT pipe discharges into the tailwater ditch all had lower concentrations than the comparable conventional seepage irrigation field. In the case of Sykes and Cooper farm and Tater Farms this difference was statistically significant and was an order of magnitude lower than the conventional seepage field. When looking at the combined IDT and surface runoff (as measured at the IDT "surface" station), TP concentration was still significantly lower at Tater Farms, but was similar at Sykes and Cooper Farm and significantly higher at Picolata Farms.

An area of further investigation will be determining the reason we are seeing significantly lower phosphorus concentrations in the IDT system. One reason is likely the reduced particulate loads coming from surface runoff and erosion of soil within the field. However, in addition to this likely component of reduction, we also hypothesize that phosphate may be binding to iron and aluminum found in the soil profile that is now being exposed as a result of the change in flow path of water discharged from the field via the IDT system (Figure 2). Soil samples have been collected to a depth of 1-1.2 m within IDT fields as part of another project looking at soil salinity and will be analyzed for Soil Phosphorus Sorption Capacity (SPSC). This soil test looks at the ratio of phosphorus to iron and aluminum and estimates the phosphorus binding or release capacity of the soils. This will allow us to test the P sorption hypothesis we have and it will also allow a prediction of the amount of phosphorous that could be sorbed over time since this sink is finite and limited to the amount of iron and aluminum present in the soil and the rate of phosphate loading.

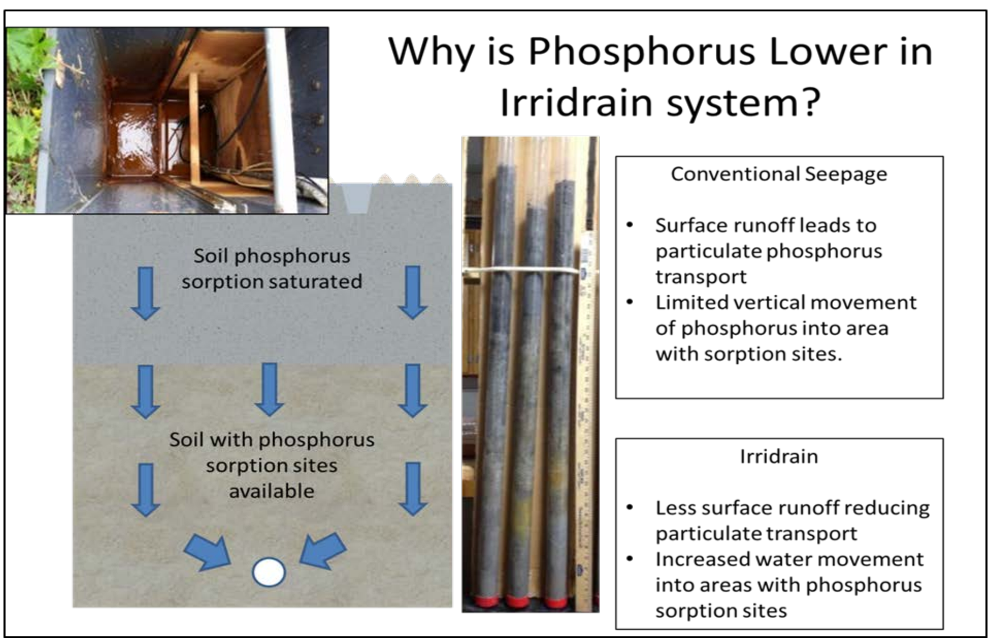


Figure 2. Possible mechanism for lower Phosphorus concentrations found in IDT discharge vs. conventional seepage fields. Inset in upper left shows iron precipitate in IDT control structure. Core tubes in center image represent samples collected in IDT field that also depict iron concentrations at a depth of 2-3 feet in the soil profile. Slide presented to TCAA growers during a field day updating them on findings of the project.

Nitrogen - Total Nitrogen (TN) concentrations generally showed the opposite trend to that of TP when comparing IDT fields to conventional seepage irrigated fields or showed that there is no significant difference between fields. Concentrations at Picolata and Tater Farms had slightly higher TN concentrations at the IDT (ground) monitoring station than at the IDT (surface) monitoring station indicating some assimilation or dilution of nitrogen in the tailwater ditch, but IDT fields at these farms were not found to be significantly different from conventional seepage irrigated fields. Sykes and Cooper Farm however, had significantly higher TN concentrations from the IDT field than from the conventional seepage field with most of this nitrogen being in the form of nitrate which differed from the dominant nitrogen form found at Tater and Picolata farms which was TKN and likely ammonium. These differences in nitrogen species and significant differences in total nitrogen concentrations found between farms may indicate how important water level management in IDT fields is to reducing nitrogen loss. Further evidence of the relationship between field groundwater level and nitrate concentration discharge through IDTs is illustrated in Figure 3. The graphic shows nitrate concentration at Picolata Farm IDT field between August 1, 2014 and February 28, 2015. Between August 1, 2014 and mid-January, 2015 water levels in the field were kept high and nitrate concentrations in runoff were relatively low (below 1 mg L^{-1}). In mid-January 2015 water levels were lowered in to allow equipment into the field for planting, which also appeared to cause a significant increase in nitrate nitrogen concentrations (approximately 4 mg L^{-1}). This was also a time when fertilizer was applied so specifically which factor (fertilizer or water level) resulted in the significant increase in nitrate concentrations is uncertain and it is likely that both contributed to the increase in concentration to some extent. But lowering the water table in the field and allowing "free drainage" of the IDT system would have removed any potential for an anaerobic zone in the soil that nitrate leached through the profile would have to encounter before entering the IDT system. Holding at least some water in the soil profile above the IDT system would likely be beneficial to reduce nitrate losses.

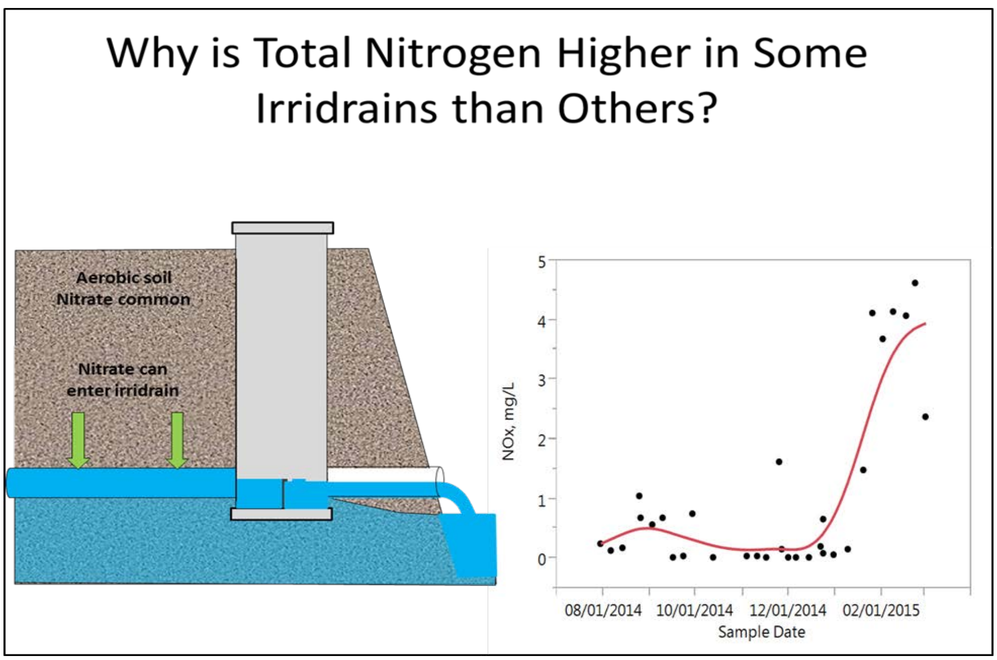


Figure 3. Water level management as likely mechanism explaining differences in nitrogen concentration between IDT and conventional seepage irrigation fields. Graph inset shows nitrate concentration at Picolata Farm IDT field with high water table from August 1, 2014 through mid-January 2015 and then lowering of water level for the rest of the monitoring period. Slide presented to TCAA growers during a field day updating them on findings of the project.

Total Phosphorus	Conventional Seepage	Irridrain (ground)	Irridrain (surface)	Enhanced Seepage	Overhead Seepage
Farm		------------------- mg L^{-1} ------------------------			
Picolata Farm	0.201 ± 0.288 a	0.123 ± 0.195 a	0.615 ± 0.621 b		
Sykes and Cooper Farm	1.49 ± 1.44 a	0.157 ± 0.094 b	1.13 ± 1.34 ab		
Riverdale Farm	0.765 ± 0.822 a			0.481 ± 0.096 a	
Tater Farms	0.637 ± 0.275 a	0.067 ± 0.127 c	0.058 ± 0.045 c		0.285 ± 0.162 b

Total Kjedahal Nitrogen	Conventional Seepage	Irridrain (ground)	Irridrain (surface)	Enhanced Seepage	Overhead Seepage
Farm		------------------- mg L^{-1} ------------------------			
Picolata Farm	1.43 ± 0.759 a	3.98 ± 1.31 b	3.44 ± 1.92 b		
Sykes and Cooper Farm	3.79 ± 3.75 a	1.09 ± 0.81 b	2.01 ± 1.06 ab		
Riverdale Farm	2.54 ± 2.13 a			1.57 ± 0.836 a	
Tater Farms	1.32 ± 0.521 ab	2.53 ± 2.08 a	1.10 ± 0.51 b		1.35 ± 0.678 ab

Nitrate + Nitrite - Nitrogen	Conventional Seepage	Irridrain (ground)	Irridrain (surface)	Enhanced Seepage	Overhead Seepage
Farm		------------------- mg L^{-1} ------------------------			
Picolata Farm	5.09 ± 2.19 a	1.07 ± 1.62 b	1.46 ± 1.54 b		
Sykes and Cooper Farm	3.37 ± 4.68 a	16.6 ± 9.56 b	12.93 ± 9.19 b		
Riverdale Farm	0.578 ± 0.787 a			0.684 ± 0.304 a	
Tater Farms	0.276 ± 0.444 a	0.124 ± 0.151 a	0.165 ± 0.163 a		0.056 ± 0.053 a

Total Nitrogen	Conventional Seepage	Irridrain (ground)	Irridrain (surface)	Enhanced Seepage	Overhead Seepage
Farm		------------------- mg L^{-1} ------------------------			
Picolata Farm	6.52 ± 2.99 a	5.05 ± 0.949 a	4.91 ± 2.99 a		
Sykes and Cooper Farm	7.52 ± 8.36 a	17.7 ± 9.47 b	14.8 ± 8.55 ab		
Riverdale Farm	3.11 ± 2.27 a			2.26 ± 0.991 a	
Tater Farms	1.59 ± 0.860 ab	2.65 ± 2.11 a	1.27 ± 0.554 b		1.40 ± 0.688 ab

Table 3. Average nitrogen and phosphorous concentration in runoff water sampled between October 1, 2014 and February 28, 2015. Values represent mean concentration ± 1 std. dev. Lower case letters to the right of vales are results of statistical comparisons between irrigation practices within the same farm where different letters represent values that are statistically different (α = 0.05).

Nutrient Loads (Table 4)
Phosphorus loads from monitored fields ranged from 0.053 ± 0.002 kg ha^{-1} (Tater Farms Irridrain) to 3.82 ± 3.69 kg ha^{-1} (Sykes and Cooper Farm, conventional seepage) during the monitoring period. Nitrogen loads ranged from 1.16 ± 0.56 kg ha^{-1} (Tater Farms, irridrain) to 32.7 ± 14.9 kg ha^{-1} (Picolata Farm, conventional seepage). The combined effect of differences in nutrient concentrations and differences in runoff volumes during this sampling period generally indicate significantly lower phosphorus loads from irridrain fields, and significantly lower, or no difference in nitrogen loads between irridrain fields and conventional seepage fields. In addition, no significant differences were found between conventional seepage irrigation fields and other alternative irrigation practices being monitored.

One limitation of the comparison at Picolata Farm during this monitoring period was the difference in management that occurred in the irridrain field (no irrigation since the field had no fall planting of beans) and the conventional seepage field (irrigated and planted in beans) during the early part of this monitoring period. This difference in management will mean that comparisons between fields at Picolata Farms during the last quarter of 2014 will be limited. However, this issue has been discussed with the landowner at Picolata and beginning in January 2015 management practices in the two fields will be similar and a more direct comparison between the two fields will be possible beginning at the end of the spring growing season.

Total Phosphorus	**Conventional Seepage**	**Irridrain (surface)**	**Enhanced Seepage**	**Overhead Seepage**
Farm		-------------------- kg ha^{-1} ------------------------		
Picolata Farm	1.01 $\pm$ 1.45	0.405 $\pm$ 0.409		
Sykes and Cooper Farm	3.82 $\pm$ 3.69	0.946 $\pm$ 1.12		
Riverdale Farm	0.597 $\pm$ 0.641		0.678 $\pm$ 0.135	
Tater Farms	0.676 $\pm$ 0.292	0.053 $\pm$ 0.002		0.529 $\pm$ 0.301

Total Kjedahal Nitrogen	**Conventional Seepage**	**Irridrain (surface)**	**Enhanced Seepage**	**Overhead Seepage**
Farm		-------------------- kg ha^{-1} ------------------------		
Picolata Farm	7.17 + 3.81	2.27 + 1.27		
Sykes and Cooper Farm	9.71 +9.61	1.68 + 0.888		
Riverdale Farm	1.98 +1.66		2.21 + 1.18	
Tater Farms	1.40 + 0.553	1.01 + 0.466		2.51 + 1.26

Nitrate + Nitrite - Nitrogen	**Conventional Seepage**	**Irridrain (surface)**	**Enhanced Seepage**	**Overhead Seepage**
Farm		-------------------- kg ha^{-1} ------------------------		
Picolata Farm	25.5 $\pm$ 10.9	0.962 $\pm$ 1.01		
Sykes and Cooper Farm	8.63 $\pm$ 11.9	10.8 $\pm$ 7.69		
Riverdale Farm	0.452 $\pm$ 0.614		0.964 $\pm$ 0.429	
Tater Farms	0.293 $\pm$ 0.471	0.151 $\pm$ 0.149		0.104 $\pm$ 0.099

Total Nitrogen	**Conventional Seepage**	**Irridrain (surface)**	**Enhanced Seepage**	**Overhead Seepage**
Farm		-------------------- kg ha^{-1} ------------------------		
Picolata Farm	32.7 $\pm$ 14.9	3.24 $\pm$ 1.97		
Sykes and Cooper Farm	19.2 $\pm$ 21.4	12.4 $\pm$ 7.16		
Riverdale Farm	2.43 $\pm$ 1.77		3.10 $\pm$ 1.39	
Tater Farms	1.69 $\pm$ 0.912	1.16 $\pm$ 0.56		2.60 $\pm$ 1.28

Table 4. Average nitrogen and phosphorous loads in runoff water sampled between October 1, 2014 and February 28, 2015. Values represent mean load $\pm$ 1 std. dev.

Continued evidence of reduction in phosphorous loads from IDT systems as compared to conventional seepage. During second quarter sampling period it appears that the nitrogen loading is also not increased in the IDT field as compared to seepage. There also may be the benefit of denitrification if the IDT fields are maintained in a way that allows water retention which can create an anaerobic zone within the soil profile.

Findings during this sampling period have strengthened the evidence that IDT systems likely provide a significant reduction in Total Phosphorous concentrations and load when used for row crop and sod production. Findings also indicate that IDT systems may not have a significant increase in nitrogen loads as long as groundwater levels within the field are managed in a manner that maintains an anaerobic zone within the soil profile, which could be providing denitrification.

Third quarter of monitoring - March 31, 2015 to July 31, 2015

Water Quality

Phosphorous: At Picolata Farms and Sykes & Cooper Farms the IDT (surface) sampling stations have significantly higher total phosphorus concentrations from the autosampler than from the grab samples; however, at Tater Farms there was no significant difference between autosampler and grab samples. These findings suggest that some of the significant phosphorus concentration reductions we are seeing due to the IDT system are being negated due to phosphorus rich sediments being transported to the ditch via surface runoff and then transported downstream during high flows.

Nitrogen: Nitrogen concentrations generally showed an opposite trend to that of total phosphorous when comparing IDT to conventional seepage irrigated fields where nitrogen species, generally had higher concentrations associated with IDT fields when compared to conventional seepage irrigation fields.

Nutrient Loads (Table 5)

This sampling period generally showed lower phosphorus loads from IDT fields, and lower nitrogen loads between IDT fields and conventional seepage fields with much of these reductions being the result of lower runoff volume.

Total Phosphorus	**Conventional Seepage**	**Irridrain (ground)**	**Irridrain (surface)**	**Enhanced Seepage**	**Overhead Seepage**
Farm	--		**kg ha^{-1}**	--	
Picolata Farm	1.34 ± 2.00	0.172 ± 0.440	1.20 ± 0.1.24		
Sykes and Cooper Farm	4.32 ± 3.23	0.086 ± 2.54	2.54 ± 2.03		
Riverdale Farm	0.872 ± 0.861			1.11 ± 1.02	
Tater Farms	3.88 ± 3.78	0.036 ± 0.000	0.419 ± 0.447		0.865 ± 0.177

Total Kjedahal Nitrogen	**Conventional Seepage**		**Irridrain (surface)**	**Enhanced Seepage**	**Overhead Seepage**
Farm	--		**kg ha^{-1}**	--	
Picolata Farm	4.86 + 4.28	0.840 ± 0.1.57	3.19 + 3.32		
Sykes and Cooper Farm	8.30 + 6.89	0.265 ± 0.253	3.50 + 2.93		
Riverdale Farm	1.02 + 1.31			3.29 + 3.82	
Tater Farms	1.47 + 2.05	1.42 ± 1.38	2.28 + 1.66		1.41 + 1.18

Nitrate + Nitrite - Nitrogen	**Conventional Seepage**		**Irridrain (surface)**	**Enhanced Seepage**	**Overhead Seepage**
Farm	--		**kg ha^{-1}**	--	
Picolata Farm	4.59 ± 6.13	0.887 ± 1.95	1.94 ± 3.69		
Sykes and Cooper Farm	4.52 ± 6.56	6.77 ± 9.54	4.57 ± 9.30		
Riverdale Farm	1.02 ± 1.31			1.07 ± 0.619	
Tater Farms	0.386 ± 0.147	0.057 ± 0.059	0.310 ± 0.239		0.167 ± 0.134

Total Nitrogen	**Conventional Seepage**		**Irridrain (surface)**	**Enhanced Seepage**	**Overhead Seepage**
Farm	--		**kg ha^{-1}**	--	
Picolata Farm	9.45 ± 8.99	1.73 ± 3.23	5.17 ± 4.48		
Sykes and Cooper Farm	12.8 ± 7.04	7.04 ± 9.32	8.07 ± 10.20		
Riverdale Farm	4.57 ± 3.40			4.36 ± 4.11	
Tater Farms	1.87 ± 2.12	1.48 ± 1.39	2.60 ± 1.76		1.58 ± 1.08

Table 5. Average nitrogen and phosphorous loads in runoff water sampled between March 1 and July 31, 2015. Values represent mean load ± 1 std. dev.

Summary:

Findings during this sampling period have strengthened the evidence that IDT systems likely provide reductions in Total Phosphorous load when used for row crop and sod production. Findings also indicate that IDT systems may have the potential to reduce nitrogen loads.

Total phosphorous remains to show lower concentrations from IDT fields than from conventional seepage fields. Total nitrogen was seen to be elevated in the IDT fields that in seepage, however, species of nitrogen existed at different levels within different IDT fields at different farms. Fields managed with higher water levels may, again, be facilitating denitrification due to the creation of an anaerobic zone where bacteria use the nitrogen for respiration when oxygen is no longer available.

Management of IDT fields by via control box boards to retain a high water level within the soil may be a way to enhance the denitrification potential within IDT fields. Minimum height of 24 inches may be the minimum target height of control box stoplogs to see beneficial denitrification while still maintaining an aerobic zone above the saturated zone to reduce nitrate loss in the upper soil profile.

Fourth quarter of monitoring – April 1, 2016 to June 30, 2016 (Year 2, Q1)

Water Quality: (Table 6)

Phosphorous - TP concentration from IDT fields had lower concentrations than the comparable conventional seepage irrigation field.

Nitrogen - Total Nitrogen (TN) concentrations showed considerable variability in concentration from conventional seepage fields when compared to IDT, with TN concentration higher from Conventional fields at Sykes and Cooper and Tater Farms, but higher from IDT fields at Picolata. Most of the nitrogen sources were in the form of nitrate nitrogen with concentrations as high as 7.97+6.23 at the irrigation discharge pipe at Picolata.

Nutrient Loads (Table 7)
Phosphorus loads from monitored fields ranged from 0.03 ± 0.01 kg ha^{-1} (Tater Farms Irridrain) to 2.24 ± 1.07 kg ha^{-1} (Sykes and Cooper Farm, conventional seepage) during the monitoring period. Nitrogen loads ranged from 0.41 ± 0.30 kg ha^{-1} (Tater Farms, IDT) to 10.55 ± 7.64 kg ha^{-1} (Sykes and Cooper Farm, conventional seepage). The combined effect of differences in nutrient concentrations and differences in runoff volumes during this sampling period generally indicate significantly lower phosphorus loads from IDT fields, and significantly lower, or no difference in nitrogen loads between IDT fields and conventional seepage fields.

Total Phosphorus	**Conventional Seepage**	**Irridrain (ground)**	**Irridrain (surface)**	**Overhead Seepage**
Farm	--	**mg L^{-1}**	--	
Picolata Farm	0.65 + 0.59	0.16 + 0.20	0.83 + 0.38	
Sykes and Cooper Farm	1.93 + 0.92	0.13 + 0.14	1.77 + 1.85	
Tater Farms	1.06 + 0.35	0.02 + 0.01	0.09 + 0.04	1.37 + 0.74

Total Kjedahal Nitrogen	**Conventional Seepage**	**Irridrain (ground)**	**Irridrain (surface)**	**Overhead Seepage**
Farm	--	**mg L^{-1}**	--	
Picolata Farm	1.39 + 0.96	0.90 + 0.64	3.30 + 1.92	
Sykes and Cooper Farm	4.13 + 2.14	0.73 + 0.68	3.26 + 2.55	
Tater Farms	2.96 + 1.20	0.93 + 0.45	0.97 + 0.62	2.95 + 1.43

Nitrate + Nitrite - Nitrogen	**Conventional Seepage**	**Irridrain (ground)**	**Irridrain (surface)**	**Overhead Seepage**
Farm	--	**mg L^{-1}**	--	
Picolata Farm	0.18 + 0.15	7.97 + 6.23	3.86 + 3.26	
Sykes and Cooper Farm	4.95 + 5.19	4.44 + 8.25	2.43 + 2.72	
Tater Farms	0.46 + 0.57	0.02 + 0.04	0.19 + 0.22	0.15 + 0.17

Total Nitrogen	**Conventional Seepage**	**Irridrain (ground)**	**Irridrain (surface)**	**Overhead Seepage**
Farm	--	**mg L^{-1}**	--	
Picolata Farm	1.58 + 1.05	8.87 + 6.68	7.16 + 4.14	
Sykes and Cooper Farm	9.08 + 6.57	5.17 + 8.84	5.69 + 4.9	
Tater Farms	3.42 + 1.56	0.95 + 0.42	1.16 + 0.84	3.10 + 1.38

Table 6. Average nitrogen and phosphorous concentration in runoff water sampled between April 1, 2016 and June 30, 2016. Values represent mean concentration + 1 std. dev.

Total Phosphorus	Conventional Seepage	Irridrain (ground)	Irridrain (surface)	Overhead Seepage
Farm	----------	kg ha^{-1}	----------	
Picolata Farm	0.43 ± 0.39	0.04 ± 0.05	0.26 ± 0.12	
Sykes and Cooper Farm	2.24 ± 1.07	0.06 ± 0.07	1.22 ± 1.2	
Tater Farms	2.18 ± 0.73	0.01 ± 0.00	0.03 ± 0.01	0.41 ± 0.22

Total Kjedahal Nitrogen	Conventional Seepage	Irridrain (ground)	Irridrain (surface)	Overhead Seepage
Farm	----------	kg ha^{-1}	----------	
Picolata Farm	0.91 + 0.63	0.22 ± 0.16	1.03 + 0.60	
Sykes and Cooper Farm	4.80 + 2.49	0.35 ± 0.32	2.34 + 1.75	
Tater Farms	6.09 + 2.47	0.20 ± 0.10	0.34 + 0.22	0.88 + 0.43

Nitrate + Nitrite - Nitrogen	Conventional Seepage	Irridrain (ground)	Irridrain (surface)	Overhead Seepage
Farm	----------	kg ha^{-1}	----------	
Picolata Farm	0.12 ± 0.10	1.93 ± 1.51	1.21 ± 0.1.02	
Sykes and Cooper Farm	5.75 ± 6.03	2.10 ± 3.91	1.67 ± 1.87	
Tater Farms	0.95 ± 1.17	0.01 ± 0.01	0.07 ± 0.08	0.05 ± 0.05

Total Nitrogen	Conventional Seepage	Irridrain (ground)	Irridrain (surface)	Overhead Seepage
Farm	----------	kg ha^{-1}	----------	
Picolata Farm	1.04 ± 0.69	2.12 ± 1.62	2.24 ± 1.29	
Sykes and Cooper Farm	10.55 ± 7.64	2.45 ± 4.19	3.91 ± 3.36	
Tater Farms	7.03 ± 3.21	0.21 ± 0.09	0.41 ± 0.30	0.92 ± 0.41

Table 7. Average nitrogen and phosphorous loads in runoff water sampled between April 1, 2016 and June 30, 2016. Values represent mean load ± 1 std. dev.

Summary and Status moving forward.

Findings for nutrient concentration and load during this first quarter of year two were similar to that of the first year sampling. Two exceptions being that Picolata Farm has a higher nitrogen concentration and lower phosphorus concentration than year one and Sykes and Cooper farm had lower nitrogen concentrations than year one.

Fifth quarter of monitoring – July 1 to July 30, 2016 (YR 2, Q2)

Water Quality: (Table 8)

Phosphorous - Total Phosphorus (TP) concentrations suggest that the high P values at the IDT surface monitoring station are the result of surface runoff at the site and not subsurface flows through the IDT system.

Nitrogen - In general, IDT surface monitoring stations had higher total nitrogen than conventional seepage fields. Nitrate nitrogen concentrations were also generally higher in conventional seepage fields than IDT fields. Overhead irrigation had concentrations of TN and TP slightly lower than that of Conventional Seepage and similar to the IDT surface station at Tater Farms.

Nutrient Loads: (Table 9)

Phosphorus loads from monitored fields ranged from 0.14 ± 0.5 kg ha^{-1} (Smith Farms IDT surface) to 3.94 ± 1.48 kg ha^{-1} (Tater Farms, conventional seepage) during the monitoring period. Nitrogen loads ranged from 0.41 ± 0.09 kg ha^{-1} (Smith Farms, IDT surface) to 9.29 ± 5.62 kg ha^{-1} (Tater Farm, conventional seepage).

Total Phosphorus	**Conventional Seepage**	**Irridrain (ground)**	**Irridrain (surface)**	**Overhead Seepage**
Farm	-------------------	**mg L^{-1}**	-------------------	
Picolata Farm	2.11 ± 2.07	0.13 ± 0.25	1.55 ± 1.08	
Sykes and Cooper Farm	3.72 ± 1.69	0.08 ± 0.06	5.51 ± 9.54	
Smith Farm	0.78 ± 0.51		0.78 ± 0.30	
Tater Farms	1.80 ± 0.68	0.02 ± 0.01	1.56 ± 2.44	1.38 ± 1.03

Total Kjedahal Nitrogen	**Conventional Seepage**	**Irridrain (ground)**	**Irridrain (surface)**	**Overhead Seepage**
Farm	-------------------	**mg L^{-1}**	-------------------	
Picolata Farm	6.34 ± 6.99	1.72 ± 2.19	4.64 ± 2.15	
Sykes and Cooper Farm	4.59 ± 1.43	0.58 ± 0.29	5.93 ± 7.06	
Smith Farm	1.70 ± 0.05		2.09 ± 0.52	
Tater Farms	3.48 ± 1.53	0.66 ± 0.31	3.85 ± 3.96	2.98 ± 0.95

Nitrate + Nitrite - Nitrogen	**Conventional Seepage**	**Irridrain (ground)**	**Irridrain (surface)**	**Overhead Seepage**
Farm	-------------------	**mg L^{-1}**	-------------------	
Picolata Farm	1.89 ± 2.27	8.71 ± 3.98	2.21 ± 2.51	
Sykes and Cooper Farm	1.10 ± 1.03	0.49 ± 1.10	0.58 ± 1.17	
Smith Farm	0.19 ± 0.14		0.19 ± 0.14	
Tater Farms	0.77 ± 0.17	0.07 ± 0.04	0.10 ± 0.11	0.39 ± 0.40

Total Nitrogen	**Conventional Seepage**	**Irridrain (ground)**	**Irridrain (surface)**	**Overhead Seepage**
Farm	-------------------	**mg L^{-1}**	-------------------	
Picolata Farm	8.32 ± 6.48	9.81 ± 3.76	6.65 ± 2.12	
Sykes and Cooper Farm	5.69 ± 1.43	1.07 ± 1.35	6.52 ± 6.69	
Smith Farm	2.06 ± 0.19		2.28 ± 0.51	
Tater Farms	4.25 ± 2.57	0.74 ± 0.31	3.95 ± 3.93	3.45 ± 1.19

Table 8. Average nitrogen and phosphorous concentration in runoff water sampled between July 1, 2016 and September 30, 2016. Values represent mean concentration ± 1 std. dev.

Total Phosphorus	Conventional Seepage	Irridrain (ground)	Irridrain (surface)	Overhead Seepage
Farm	----------	kg ha^{-1}	----------	
Picolata Farm	1.82 ± 1.78	0.02 ± 0.04	0.313 ± 0.22	
Sykes and Cooper Farm	0.81 ± 0.37	0.03 ± 0.03	1.38 ± 2.39	
Smith Farm	0.21 ± 0.13		0.14 ± 0.05	
Tater Farms	3.94 ± 1.48	0.01 ± 0.000	0.81 ± 1.26	0.30 ± 0.23

Total Kjedahal Nitrogen	Conventional Seepage		Irridrain (surface)	Overhead Seepage
Farm	----------	kg ha^{-1}	----------	
Picolata Farm	5.46 + 6.02	0.26 ± 0.33	0.94 + 0.43	
Sykes and Cooper Farm	1.00 + 0.31	0.25 ± 0.12	1.49 + 1.77	
Smith Farm	0.45 + 0.01		0.38 ± 0.09	
Tater Farms	7.61 + 3.34	0.32 ± 0.15	1.99 + 1.91	0.65 + 0.21

Nitrate + Nitrite - Nitrogen	Conventional Seepage		Irridrain (surface)	Overhead Seepage
Farm	----------	kg ha^{-1}	----------	
Picolata Farm	1.63 ± 1.95	1.29 + 0.59	0.45 ± 0.51	
Sykes and Cooper Farm	0.24 ± 0.22	0.21 ± 0.47	0.15 ± 0.29	
Smith Farm	0.05 ± 0.04		0.34 ± 0.025	
Tater Farms	1.68 ± 0.37	0.03 ± 0.02	0.05 ± 0.06	0.09 ± 0.09

Total Nitrogen	Conventional Seepage		Irridrain (surface)	Overhead Seepage
Farm	----------	kg ha^{-1}	----------	
Picolata Farm	7.16 ± 5.58	1.46 ± 0.56	1.34 ± 0.43	
Sykes and Cooper Farm	1.24 ± 0.311	0.46 ± 0.58	1.63 ± 1.68	
Smith Farm	0.54 ± 0.05		0.41 ± 0.09	
Tater Farms	9.29 ± 5.62	0.34 + 0.15	2.05 ± 2.04	0.76 ± 0.26

Table 9. Average nitrogen and phosphorous loads in runoff water sampled between July 1, 2016 and September 30, 2015. Values represent mean load ± 1 std. dev.

Summary:

The data collected during this period was overall representative of typical conditions found during this period of production.

CONCLUSIONS

Field sampling and laboratory analysis have generally shown that both phosphorous and nitrogen is reduced in the irrigation and stormwater outflow from fields with irrigation drainage tile installed. The phosphorus levels are reduced due to adsorption to soil particles when the water flows downward toward the IDT drainage pipe. Reduction in nitrogen was also seen in farms with IDT if the systems were managed properly by holding water at a depth of at least 24”in the control structures. This we believe creates a oxygen depleted or anoxic environment within the soil profile leading to microbial denitrification of water passing through the soil profile before being discharged through the IDT system. While this study indicates the advantages of IDT systems for reduction in nutrient discharge, it was also shown that proper management of the systems is a requirement. If water is not held within the field the potential for denitrification is not achieved and this results in similar, and sometimes increased, nitrogen releases to the watershed in comparison to the seepage and overhead irrigation fields that were a part of this study. With the increased phosphorous reduction that has been shown in IDT fields as well as the potential for denitrification and therefore reduced nitrogen off load, the next focus on IDT with the TCAA-WMP may be introduction of IDT system management requirements or incentives to encourage the most efficient use of this system for reduction of both phosphorous and nitrogen offloading to the environment.

References

Magley, W. and D. Joyner (2008). *Florida Department of Environmental Protection Division of Water Resource Management, Bureau of Watershed Management TMDL Report Total Maximum Daily Loads for Nutrients for the Lower St. Johns River.* https://floridadep.gov/sites/default/files/lower-stjohns-nutrients_0.pdf

Cooke, Sands, Brown (2006). *Drainage Water Management: A Practice for Reducing Nitrate Loads From Subsurface Drainage Systems.* https://www.epa.gov/sites/production/files/2015-07/documents/2006_8_24_msbasin_symposia_ia_session2.pdf

Monitoring Station Equipment:

Blue-Siren Flow-Siren – Flow Meter and Data Logger, with Temperature and Conductivity Probes

http://www.blue-siren.com/index_product_bluesiren.html

Blue-Live Online Big Data Cloud Hosting

http://www.blue-siren.com/index_product_bluelive.html

ONSET HOBO RG3 Rain Gauge / Data Logger

http://www.onsetcomp.com/products/data-loggers/rg3

Teledyne ISCO Automatic Samplers

http://www.teledyneisco.com/en-uk/waterandwastewater/Pages/3700-Sampler.aspx

http://www.teledyneisco.com/en-us/waterandwastewater/Pages/6712-Sampler.aspx