SPECIFIC CONDUCTANCE IN THE EVERGLADES AGRICULTURAL AREA

FINAL REPORT

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Executive Summary

The Everglades Forever Act of 1994 mandated a research and monitoring program on the evaluation of water quality standards in the Everglade Agricultural Area (EAA) (Chapter 40E-63). The goal of this research was to evaluate the constituents that have been previously identified as elements of water quality concern that will likely not be significantly improved by the Storm Treatment Areas (STAs) and current Best Management Practices (BMPs) being widely implemented throughout the EAA; and to identify strategies needed to address such parameters (40E-63.301(2)). These parameters were identified by Florida Department of Environmental Protection (FDEP) as specific conductance, particulate phosphorus (P), and the pesticides Atrazine and Ametryn. This report deals with the issue of specific conductance. Particulate P will be addressed in a separate report. The Everglades Agricultural Area-Environmental Protection District (EAA-EPD) and the South Florida Water Management District (SFWMD) are responsible for the monitoring of Atrazine and Ametryn.

The objectives of this work as stated by Chapter 40E-63, Part III: "the farm-scale research shall be expanded to include monitoring for specific conductance at all points where total phosphorus is currently being monitored. The expanded research program shall include the development, testing, and implementation of BMPs to address reduction of specific conductance".

Specific conductance was monitored at ten EAA farms (12 discharge sites: 72 months at UF9200A and UF9206A&B, 61 months at UF9209A, 50 months at UF9202A, UF9203A, UF9204A, UF9207A&B, 44 months at UF9208A, and 24 months at UF9201A and UF9205A). All data were collected using Hydrolab DataSonde (series 3, 4, and 4a) multi-parameter water quality data loggers. In order to identify the specific ions and ion ratios that comprise specific conductance, weekly grab samples were taken in 2001 and 2002 from eight farms (10 pump structures) and analyzed for ionic composition.

Summary statistics showed that mean specific conductance above 1.275 mS/cm occurred at only two out of the ten farms monitored. The farms with conductance above 1.275 mS/cm were UF9206A&B and UF9208A. Higher concentrations of sodium (Na^+) and chloride (Cl^-) were also observed at these two farms. Of the two farms, UF9208A, also showed high levels

of sulfate (SO_4^{2-}). Determination of ion compositions in grab samples at the ten pump structures indicated that the major anions are bicarbonate (HCO_3^-), Cl^- and SO_4^{2-} and the major cations are Na^+ and calcium (Ca^{2+}) in farm canal water of the EAA farms.

Potential sources of specific conductance were evaluated. These included geological influences, drainage pumping, irrigation water and fertilizer application. Comparing average specific conductance data points of the study sites to historical Cl^- concentration maps of shallow groundwater (Parker et al., 1955 and Jones et al., 1948) revealed that the current elevated farm conductance readings of UF9208A coincided with historically high Cl^- concentrations in 20-50 ft ground water wells. UF9206A&B also is located in an area that has wells of high Cl^- concentration. The Na/Cl ratio in the farm canals ranged from 0.57 to 0.78. The Na/Cl ratio in seawater is 0.55. It has been reported that connate seawater underlies the area and exchanges with the surface water where canals are cut into the limestone (Parker et. al., 1955; Gleason, 1974; Waller and Earl, 1975; CH2M Hill, 1978). Shallow ground water hydrology and quality has a major impact on specific conductance in the EAA.

The effect of drainage pumping on specific conductance was variable and site specific. There was a low correlation between drainage pumping and conductance when all the sites were combined. Irrigation had a low negative correlation with specific conductance. Statistical analysis of the daily average specific conductance at three intensively monitored farms indicated that drainage pumping increased specific conductance at UF9200A and UF9209A, but not at UF9206A&B. Irrigation decreased specific conductance at all three farms, UF9200A, UF9206A&B and UF9209A. Drainage event analysis on the two elevated specific conductance farms (UF9206A&B and UF9208A) also demonstrated the variable effect of pumping. For example, out of six selected drainage events on UF9206A, three were observed to have increased conductance with volume pumped. Specific conductance had no relationship with drainage pumping to rainfall ratio. One farm that had the lowest drainage pumping to rainfall ratio, showed the highest specific conductance. This strengthened the conclusion that farm conductance is strongly influenced by underlying ground water composition.

The irrigation water utilized by the farms with the highest specific conductance (UF9206A&B and UF9208A) was also characterized by higher specific conductance. Farm UF9208A received irrigation water via a secondary canal that connects to the Hillsboro canal. Farm UF9206A&B received irrigation water from a secondary canal that connects to the Ocean canal. The Ocean canal may source its water from either the West Palm Beach Canal to the east, or the Hillsboro Canal to the west. Both the Ocean and the Hillsboro Canals have historically had relatively high specific conductance compared to other major district conveyance canals in the EAA.

Previous research in the EAA indicated that potassium chloride (KCl) fertilizer application contributed less than 3% to the total dissolved solids (TDS) concentrations in canal waters. It is also reported that a sugarcane crop at harvest takes up more P and K from the soil than that applied by fertilizers. Our results show KCl fertilizer application in one of the high conductance farms with mixed cropping systems contributed less than 6.5% of the TDS in drainage water. This was calculated assuming that all the KCl fertilizer ended up in the drainage water which is highly unlikely as crops take up Cl^- in large quantities.

To assess the impact of current P load reduction BMPs on specific conductance, non-parametric Mann-Kendall trend analyses and Sen's slope analysis of specific conductance at different pump structures in the EAA were conducted. Both of these analyses indicated that downward trends were statistically significant at structures UF9202A, UF9205A and UF9207B during the study period. One farm UF9208A showed an upward trend using the Mann-Kendall trend analysis, however there was no significant trend using the Sen's slope analysis. So the current P load reduction BMPs have had a positive impact on 30% of the farms monitored.

In conclusion, specific conductance in the EAA canals is strongly influenced by the composition of the shallow ground water, historically reported to be high in Na^+ and Cl^- due to connate seawater entrapment and the mixing of surface and ground water. The effect of drainage pumping was variable and site specific. Canal specific conductance is governed mainly by the quality and the hydrology of the underlying shallow ground water, which is farm specific. Fertilizers contributed a very small percentage to the total dissolved solids in the drainage water therefore had no substantial contribution to specific conductance in the EAA. Current P load reduction BMPs have reduced specific conductance in some locations in the EAA. It is the conclusion of this study that no further BMPs can be identified by additional research that would provide abetment of specific conductance in the discharge in the EAA. The issue of specific conductance in the EAA is a geological one, and shallow ground water is the major factor controlling the level of specific conductance in the EAA farm canals.

INTRODUCTION

In April of 1994 the Florida state legislature passed “The Everglades Forever Act” (EFA) which mandated: 1) the construction of six STAs encompassing 16,188 ha; 2) Everglades water supply and hydroperiod improvement and restoration; 3) an EAA research and monitoring program; 4) evaluation of water quality standards; 5) research and implementation of BMPs in the EAA; and 6) monitoring and control of exotic species (Florida Statute Section 373.4592, 1994). The research and implementation of BMPs component of the EFA required the SFWMD “to conduct research in cooperation with the EAA landowners to identify water quality parameters that are not being significantly improved either by the STAs or the BMPs, and to identify further BMP strategies needed to address these parameters” (Florida Statute Section 373.4592, 1994).

In 1997 the SFWMD revised the Everglades Regulatory Program, Chapter 40E-63 in accordance with the EFA, to include a research/monitoring program to address concerns regarding particulate P, specific conductance, and concentrations of the pesticides Ametryn and Atrazine found in surface waters of the EAA. The UF/IFAS project began to monitor particulate P and specific conductance at three farm sites in early 1997; in early 1998 all ten project sites were equipped to monitor particulate P and specific conductance. This report deals with the issue of specific conductance in the EAA. The issue of particulate P will be addressed in a separate report. The monitoring of the pesticides Ametryn and Atrazine is conducted by the EAA-EPD and the SFWMD.

The conductivity of a body of water is a function of the quantity of ions contained in it, the equivalent conductivity of each ion, and water temperature. Compensation of this measurement to 25 degrees Centigrade yields specific conductance. Specific conductance is an indirect measure of the total concentration of ionized substances (e.g. Ca^{2+}, magnesium (Mg^{2+}), Na^+, potassium (K^+), Cl^-, HCO_3^-, SO_4^{2-} and fluoride (F^-)) in the water. Although all ions contribute to specific conductance, their valences and mobilities differ, so their actual and relative concentrations affect specific conductance. When the concentration of ions is high, specific conductance is high, and the resistance to electrical passage is low.

Under natural conditions, the specific conductance of a water body is generally based on the geology of the watershed through which the water flows. Water coming in contact with soils and erodible source rock material will dissolve salts, especially when soil drainage is poor. Some rocks and soils release ions very easily when water flows over them. Concentrations generally are greatest in streams draining basins with rocks and soils that contain easily dissolved minerals (Risey and Doyle, 1997). The chemistry of the surface water can be modified by precipitation and evapotranspiration, weathering of geological formation, and chemical changes brought about by biological organisms and chemical equilibria (Flora and Rosendahl, 1981). Naturally occurring geothermal activity can also contribute to high specific conductance level. Streams that run through areas with granite bedrock tend to have lower specific conductance because granite is composed of more inert materials that do not ionize (dissolve into ionic components) when washed into the water. On the other hand, streams that run through areas with clay soils tend to have higher specific conductance because of the presence of materials that ionize when washed into the water (USEPA, 1997). Groundwater inflows can have the same effect depending on the bedrock they flow through. For example, if acidic water flows over rocks containing calcite ($CaCO_3$), such as calcareous shales, Ca^{2+} and HCO_3^- will dissolve into the water; therefore, specific conductance will increase (Virginia DEQ, 2003).

One important source of salts in EAA waters is from connate sea water entrapped in shallow ground water formation (Parker et al., 1955, Gleason, 1974; Waller and Earle, 1975; CH2MHill, 1978). Saline waters, left by Pleistocene invasions of the area, are present in formations in the Everglades (Parker et al., 1955). Other potential sources of specific conductance ions in the EAA reported in the literature include dissociated ions from fertilizer application, dissolution of limestone, which is abundant in the soils of the area, and solubilization of ions at newly exposed rock faces after blasting or scarping. It has also been reported that the high mineral concentrations in ground waters are related to the occurrence of muck soils and to the low permeability of both the muck and the underlying marls (Parker et al., 1955; Gleason, 1974). The ionic concentration of precipitation is too low to influence the ionic composition of the surface water in the Everglades, but the rainfall dilutes the ionic concentration of the water thereby lowering specific conductance in the Everglades National Park (Flora and Rosendahl, 1981).

OBJECTIVES

The objectives of this research are as stated by Chapter 40E-63, Part III: “the farm-scale research shall be expanded to include monitoring for specific conductance at all points where total phosphorus is currently being monitored. The expanded research program shall include the development, testing, and implementation of BMPs to address reduction of specific conductance”.

To achieve these objectives required by chapter 40E-63, Part III, the following studies were conducted:

1. Characterization of specific conductance at farms that are representative of the EAA (different cropping systems, geographical locations, farm size and management practices).
2. Identification of potential sources of specific conductance.
3. Determination of the impact of current P load reduction BMPs on specific conductance.
4. Determination if additional BMPs are needed to abate specific conductance in the EAA.

MATERIALS AND METHODS

Specific Conductance Monitoring Program in the EAA

A monitoring program was established in January 1997 to measure specific conductance in accordance with Chapter 40E-63. Hydrolab DataSonde (series 3, 4, 4a) multi-parameter water quality data logger was used to measure and record specific conductance in situ. The DataSonde units were also equipped to measure temperature, pH, dissolved oxygen, oxidation-reduction potential, depth, and turbidity. The DataSonde units were calibrated according to instrument specifications and programmed for a six-day run (programmed to record a measurement every hour). The units were transported to the site canals and deployed at a depth of one meter beneath the canal water surface. After the DataSonde's programmed run ended, it was retrieved from the field. A freshly calibrated and programmed unit was then placed in the canal. A DataSonde unit, which completed its six-day deployment, was brought back into the laboratory where the data were downloaded to a computer and stored in electronic format. A post-run assessment for drift of the instrument's sensors was subsequently conducted. The instruments were then cleaned, maintained, and re-calibrated in the laboratory and returned to the field for deployment during the subsequent monitoring cycle. All field and laboratory activities strictly followed relevant Standard Operating Procedures and the National Environmental Laboratory Accreditation Program (NELAP) approved quality manual (Chen, 2001). Quality control criteria regarding sensor drift and biofouling were as follows: pH <± 0.2 at pH=7.0 check; specific conductance < ± 0.1 mS/cm at 1.413 mS/cm (0.01 M KCl); percent oxygen saturation < ± 7.0% at 100 % air saturation; redox < ± 20 mv of a pH 7.0 and quinhydrone solution; and turbidity < ± 8.0 NTU at 80 NTU check.

Ion concentrations in grab samples were determined to identify the major ions that are associated with specific conductance in the EAA. Grab samples were taken from near hydrolab locations. Analyses for Ca^{2+}, Mg^{2+}, and K^+ concentrations were conducted via an atomic absorption spectrometer, and analysis of Na^+ was conducted with a flame emission spectrophotometer using EPA Method 200.0 (USEPA, 1983). Analyses for Cl^-, SO_4^{2-}, and F^- were conducted using an ion chromatography specified by EPA Method 300.0. A Dionex

DX-500 ion chromatograph, equipped with an injection valve, a sample loop, guard column, and ion separator columns (IONPAC AS-HC 4-mm, AG9, ASRS-ULTRA, C16, CG16, CSRS-ULTRA), was chosen to measure anion concentrations. The cations Ca^{2+}, Mg^{2+}, Na^{+}, and K^{+} were analyzed within 6 months holding time. The anions F^{-}, Cl^{-}, and $SO_4{}^{2-}$ were analyzed within 28 days of holding time (Chen, 2001). Bicarbonate anion was not analyzed for in our monitoring program since it was used as the eluent in the ion chromatography determinations. However, we did calculate HCO_3^{-} ion concentrations as the difference between the sum of the cations and anions measured.

Site Descriptions and Farm Management Practices

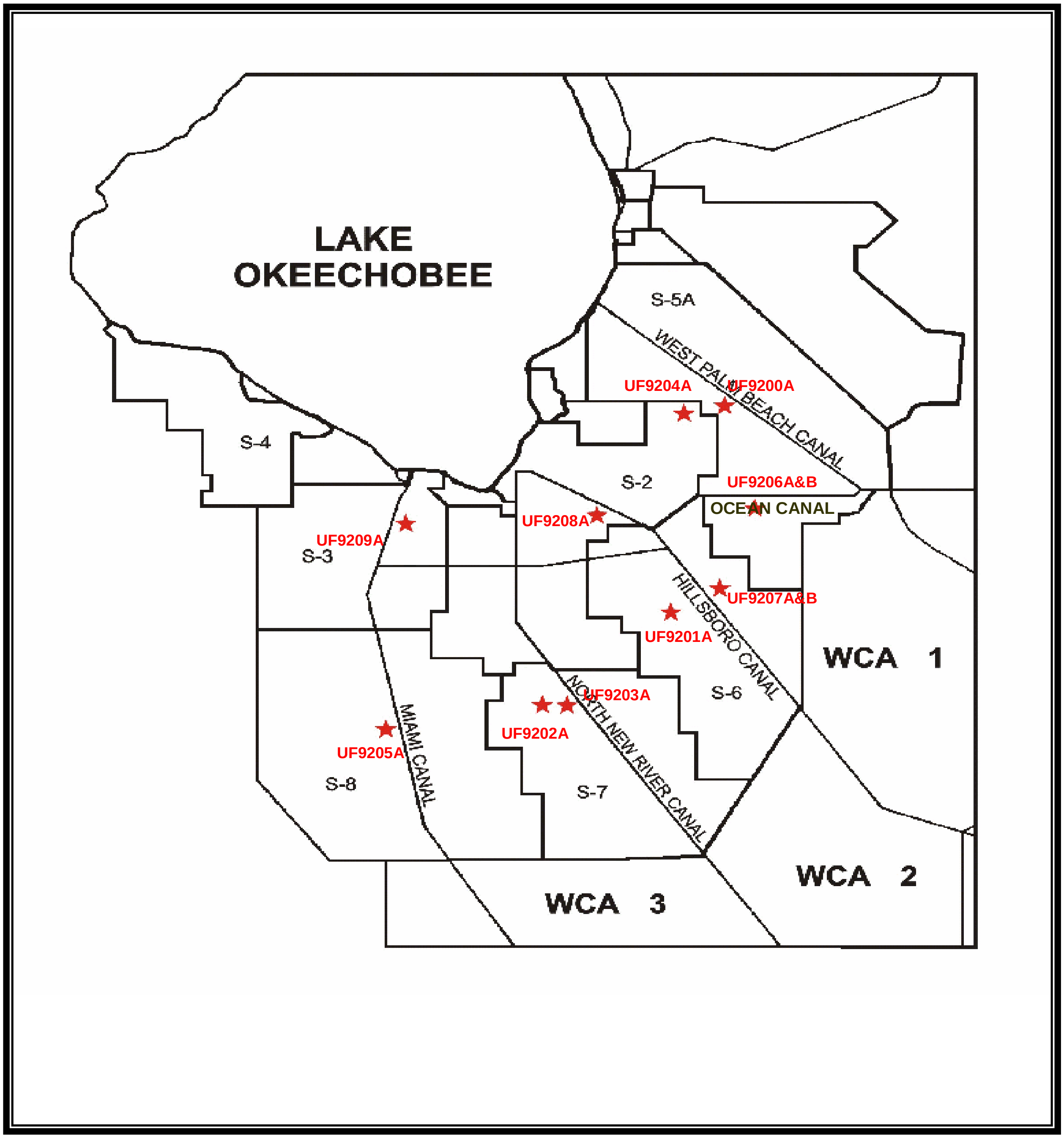
Beginning in early 1997, the UF/IFAS began to monitor specific conductance at two selected farms, UF9200A and UF9206A&B. The monitoring of specific conductance was expanded in January 1998 to include ten farms in the EAA (Figure 1). Maps of each monitored farm are presented in the appendix on the accompanying CD. The farm maps show individual fields, pump stations, drainage canal systems, and water control structures. All data used in this report are found in files on the accompanying CD. Following is a short description of each farm with the farm management practices employed.

UF9200A

Site UF9200A is a 1280-acre sugarcane farm located in the S-5A Sub-basin in the northern EAA. This farm started P load reduction BMP operations in January 1994. Beginning in early 1997, UF/IFAS began to monitor specific conductance at this farm. Up to December 2002, the project had acquired 72 months of specific conductance data on this farm. This site is one of the three currently monitored sites.

The grower focused on reducing the amount of irrigation water being let into the farm. In the past this grower tended to irrigate frequently in his attempt to micro-manage water table levels. This micro-management led to increased drainage pumping and often involved pumps being switched directly from the irrigation to the drainage mode. The grower

Figure 1. Specific Conductance Monitoring Sites.



monitored farm drainage more closely, allowing at least one inch of rain to accumulate prior to pumping initiation. At the end of the drainage event, the grower allowed evapotranspiration (ET) to rid fields of at least one inch of water that would otherwise have been pumped off-farm. This was accomplished by turning the pumps off earlier and letting water tables redistribute.

UF9201A

Site UF9201A is a 1280-acre block of a much larger, predominantly vegetable production farm located in the S-6 Sub-basin in central EAA. This site started P load reduction BMP operations in September 1994. The UF/IFAS began monitoring specific conductance on this farm in January 1998. By shunting adjacent farm water through this site's pump station, the value of the site for our research projects decreased. Specific conductance research was then discontinued after December 1999. Twenty-four months of data on specific conductance was acquired at this farm.

In addition to fertilizer BMPs, the grower practices controlled drainage pumping. The two sections of land were split apart, allowing independent control of water levels in each section. The grower routed water from the first section to the second section for temporary storage while cultivation activities progressed in the first section. Water was then drained back into the first section once cultivation activities were completed. In order to prepare the second section nearest the pump station for planting, off-farm drainage was usually necessary to remove excessive water that had not been redistributed by seepage or lost to ET. When possible, floodwaters were allowed to subside naturally through ET and percolation prior to pumping.

UF9202A

Site UF9202A is a 320-acre sugarcane farm located in the S-7 Sub-basin in south central EAA. This farm started P load reduction BMP operations in April 1994. Monitoring of specific conductance on this farm started in January 1998 and was discontinued on Dec. 31, 2001. The specific conductance data covers 50 months.

The grower could not drain the back four fields of his farm using his single main farm pump. To address this concern, the backup pump that was originally at the main farm pump station was moved back internal to the farm. In situations where the back of the farm required drainage but the front of the farm did not, the grower left the main pump off and simply used the internal pump to drain water from the back to the front of the farm. This also enabled the grower to keep more water on the front fields of the farm when desired. This water management scheme enabled the grower to achieve more uniform drainage and water table levels while inhibiting over-drainage of areas of the farm near the main pump station. This grower also practiced minimum tillage for sugarcane by planting the new crop between old rows of stubble. UF9202A generally tended to be dry since it is located on a knoll. The relatively higher elevation of this farm helped to keep it drier after most typical rainfall events and reduced the need for frequent and/or long duration drainage pumping.

UF9203A

Site UF9203A is a 4608-acre sugarcane farm located in Sub-basin S-7 in south central EAA. This farm started P load reduction BMP operations in January 1995. Monitoring of specific conductance on this farm started in January 1998 and was discontinued on Dec. 31, 2001. The specific conductance data covers 50 months.

The grower implemented water management BMPs to reduce off-farm drainage pumping. Drainage pumping was reduced by improving uniform drainage across the farm through utilization of booster pumps and control structures. Each of the back two sections of the farm has the capability of being managed as separate hydraulic units. Blocking the farm into smaller hydraulic units and conducting water management activities accordingly allows the maintenance of more uniform drainage, the avoidance of over-drainage, and higher water tables. The main farm pump station is no longer solely relied on to drain the back of the farm, which reduces the amount of pumping required.

UF9204A

This site, a 640-acre sugarcane farm, is located in Sub-basin S-6 in the northern EAA. The farm pursued independent BMP implementation strategies, which were initiated beginning January 1, 1995. Monitoring of specific conductance on this farm started in January 1998 and was discontinued on Dec. 31, 2001. The specific conductance data covers 50 months.

This site has modified the decision-making criteria used to determine pumping operations by adopting strict stage and antecedent rainfall condition criteria for pumping initiation and cutoff. This farm also employed calibrated soil tests and improved fertilizer practices, and planted rice in rotation with sugarcane.

UF9205A

This site was a 320-acre farm adjacent to the Miami canal in Sub-basin S-8 in the southwestern EAA. The site began the BMP monitoring program as a sugarcane-pasture system. In early 1994, a portion of the pastureland was converted to sod and the remaining pasture was rotated into corn in March 1994. After the corn harvest, land was fallowed, and then rotated into melon production in May 1995. After the melon harvest, land was fallowed in October 1995 and subsequently rotated back into sugarcane in February 1996. The farm remained under a combination of sugarcane production and fallow fields. Monitoring on this site started January 1998. The site was included in STA development and therefore was discontinued after December 1999. Twenty-four months of data was acquired on this farm.

UF9206A&B

Site UF9206A&B is a 1754-acre mixed-crop farm located in Sub-basin S-5A in the eastern EAA. The farm started P load reduction BMP operations in May 1994. The UF/IFAS began monitoring specific conductance in early 1997 on this farm. This site is the second farm that we are still currently monitoring for specific conductance. Up to December 2002, the project had acquired approximately 72 months of specific conductance data at this farm.

The grower installed a sophisticated hydraulic system with culverts, risers, and pumps placed strategically throughout the farm. The grower has partitioned the farm into multiple hydraulic units. Water can be moved from any production block into one of the other hydraulic units for temporary storage, irrigation, or drainage. Rice is grown on a large percentage of the land during the summer season. This greatly reduces the need for off-farm pumping for much of the wet season. During minor to moderate rainfall events in the wet season, sugarcane field and sod field drainage waters can be diverted to adjacent rice fields instead of being pumped directly off-farm. Virtually every field ditch has an operable riser and board structure allowing for maximum water control, uniform drainage, and the utilization of the longest paths for routing water to the main pump stations.

UF9207A&B

This site is a 2500-acre mixed-crop farm located in the S-6 Sub-basin in the southeastern EAA adjoining the Hillsboro canal. The farm initiated BMP implementation strategies in January 1995. Monitoring for specific conductance on this farm was started in January 1998 and stopped at on Dec. 31, 2001 after acquiring 50 months of data.

The site has been engaged in sugarcane-vegetable rotations, generally involving sweet corn. The BMPs implemented include routing drainage water around the farm boundaries. This farm has two off-farm drainage pump stations. The first pump station, UF9207A, is the primary structure that discharges 86% of the drainage volume off the farm. The second pump station, UF9207B, was utilized usually only after large rainfall events (>3 inches).

UF9208A

This site is a 262-acre sugarcane farm located in the S-6 Sub-basin in the central EAA between the Hillsboro and Bolles Canals. The farm initiated P load reduction BMPs in January 1995. Monitoring of specific conductance was started in January 1998 and stopped August 2001 after acquiring 44 months of data. This is a small, sugarcane monoculture site. It has a history of infrequent pumping events involving minor discharges of water relative to other project sites. New management changed crop rotation to include corn.

UF9209A

Site UF9209A is a 3072-acre sugarcane monoculture farm located in the S-8 Sub-basin in the western EAA. The farm began P load reduction BMP operations in May 1994. Monitoring of specific conductance started in January 1998. This farm site is the third farm currently still being monitored for specific conductance. Up to December 2002, the project had acquired 61 months of specific conductance data on this farm.

The grower adopted enhanced pump operation strategy. The program uses established upper and lower main canal stages (measured at the main pump station and at the geographic farm center) that serve as criteria for pump operations. An internal booster pump was installed approximately two-thirds of the way down the length of the main farm canal to block the farm into two hydraulic units.

Statistical Data Analysis

Histogram analyses and goodness-of-fit tests were conducted to check the distribution patterns of specific conductance and ions measured (Gilbert, 1987). Summary statistics were conducted using UNIVARIATE and ANOVA procedures to assess significant differences between different parameters (SAS, 1999). A box and whisker plot was then used to display visual summaries (site by site and aggregates) of: (1) the center of the data (the median = the centerline of the box), (2) the variation or spread (interquartile range = the box height), (3) the skewness (quartile skew = the relative size of box halves) and (4) presence or absence of unusual values ("outliers" and "extreme" values) (Antonopoulos et al., 2001).

Correlation analysis was used to relate water quality parameters with management practices, such as monthly irrigation and sugarcane percentage in the cropping system. Monthly averages of specific conductance for ten farms were used for time series trend analysis. To determine if there are trends in the data over the monitoring period, two tests were done. The upward and downward trends over time were evaluated using a nonparametric Mann-Kendall test for zero slope of the linear regression of time-ordered data versus time using the ChemStat® 6.0 software (Starpoint Software Inc., Cincinnati, OH). A positive value of Z indicates an upward trend, whereas a negative value of Z indicates a downward trend (Gilbert, 1987). The Sen's slope test was also used to detect yearly trends. Generally, downward trends in specific conductance indicate an improvement in water quality with time; whereas upward trends indicate a general deterioration in water quality with time (Lietz, 1996). The results were examined by plotting the data and by observing the statistically significant trends (SAS Institute, 1999).

HISTORICAL SPECIFIC CONDUCTANCE INFORMATION ON SOUTH FLORIDA

Historical water quality information on the EAA and surrounding areas provides an important role in evaluating current specific conductance status of farm canals in the EAA. Parker et al. (1955) conducted an exhaustive field study from 1941 to 1943 on surface and ground water in South Florida. The Hillsboro Canal near Deerfield Beach and the North New River Canal near Ft. Lauderdale showed wide fluctuations in specific conductance. For example, the Hillsboro Canal specific conductance ranged from 0.22 to 1.44 mS/cm from July through August. North New River Canal specific conductance ranged from 0.28 to 1.04 mS/cm during the same time period. The Corps of Engineers (1971) reported specific conductance of waters in the Water Conservations Areas (WCA) from 1950 to 1970. Hillsboro Canal at S-6 showed specific conductance ranging from 0.49 to 1.11 mS/cm for its 10th and 90th percentiles; with a median value of 0.78 mS/cm. The Diversion Canal at S-143 showed specific conductance ranging from 0.45 to 1.00 mS/cm for its 10th and 90th percentiles; with a median value of 0.74 mS/cm. Gleason (1974) measured specific conductance data in marsh water of WCA-2A and canal waters that were actively flowing into WCA-2A. Specific conductance reported ranged from 0.22 to 2.10 mS/cm for the WCA-2A marsh water during June 26 through August 14, 1973. The Hillsboro Canal specific conductance ranged from 1.10 to 1.50 mS/cm, whereas North New River Canal specific conductance ranged from 0.93 to 1.20 mS/cm on July 31, 1973 (Gleason, 1974).

Several factors were reported to cause the conductance fluctuations: 1) groundwater in the Everglades is highly mineralized; 2) wide variations in canal water composition due to the additions of lake Okeechobee water; 3) the agricultural drainage from the EAA; and 4) active dissolution of the underlying bedrock as water is drained out of bedrock, which is overlain by peat, within the EAA (Gleason, 1974).

A water quality study in the EAA sponsored by the Florida Sugar Cane League and the SFWMD demonstrated that higher specific conductance in the pumped drainage water of three intensively monitored EAA farms were attributed mainly to the exchange of soil water with the highly mineralized shallow (8- to 10- ft) ground water, instead of fertilization application (CH2M Hill, 1978). In particular, shallow ground water and the soil solution at the elevated specific conductance sites had greater Na^+ and Cl^- concentrations as well as specific conductance than those of the other sites (CH2M Hill, 1978). Shallow groundwater specific conductance measurements from 20 shallow wells in Palm Beach County in the vicinity of Lake Okeechobee ranged from 0.92 to 9.08 mS/cm (Parker et al., 1955). Another study indicated that the specific conductance of the shallow aquifer in the EAA varied from 1.10 to 30.0 mS/cm (Scott, 1977). Sodium, K^+ and Cl^- concentrations in this area were the highest in the entire Palm Beach County (Scott, 1977). The saline groundwater was reported to occur in association with overlaying low permeability muck and/or marl deposits (Gleason, 1974). Parker (1955) and Waller and Earle (1975) refer to the ground water immediately south of Lake Okeechobee as being mineralized due to its contact with connate seawater from ancient marine sediments. They reported that during periods of back pumping, this ground water is drawn into the canals, thereby increasing the mineral content of the surface water.

A collaborative study by the University of Florida Agricultural Experimental Station and the USDA Soil Conservation Service described an isolated area of fairly permeable rocks underlying about half of Lake Okeechobee and nearby lands to the south and east, perhaps 25 feet thick and encountered at a depth of 12 to 30 feet (Jones, 1948). The water from this area contained total solids concentration of 4,000 to 5,000 ppm, Cl^- ion concentrations as high as 1,500 ppm and SO_4^{2-} ion concentrations up to 500 ppm (Jones, 1948). In a later study conducted jointly by the U.S. Geological Survey and the U.S. Army Corps of Engineers, specific conductance of surface water in the EAA was measured and higher values was found in the northern half of this area than that from the southern half (Waller and Earle, 1975). This historical information indicated that higher specific conductance water in certain areas in the EAA is a natural phenomenon.

Summary statistics of specific conductance data obtained from the SFWMD indicate variable and significantly high values of specific conductance in wells of the EAA, with a mean value of 2.45 mS/cm (Table 1). During 1990-1992, mean specific conductance in main canals decreased in the order of: Ocean Canal (1.63 mS/cm); West Palm Beach Canal (1.49 mS/cm); Hillsboro Canal (1.35 mS/cm); North New River Canal (1.09 mS/cm); Miami Canal (1.01 mS/cm). Lake Okeechobee had an average specific conductance of 0.62 mS/cm during the time period of 1978-1999 (Table 1). Historically, high and variable concentrations in the Hillsboro Canal caused the city of Belle Glade difficulty in treating its public water supply (Parker et al., 1955).

Geologically, underlying organic soils of the Lake Okeechobee-Everglades depression is the Fort Thompson formation, a series of alternating beds of limestone, shells, sand, and marl of marine, brackish, and fresh water origin (Jones, 1948; Parker et al., 1955). The marine beds represent times when the area was flooded by the sea; the fresh-water beds record times when sea-level was below the present level and fresh-water lakes and marshes occupied the sea; and the brackish-water beds may represent either times of rising or falling sea levels when the water in the area was neither salt nor fresh but was a mixture of the two. The water in most part of the Everglades region comes mostly from precipitation within the basin (~54 in./yr.) and that upon Lake Okeechobee drainage basin (~51 in./yr.). The quantity of flow into the region through sub-surface aquifers is negligible. However, in the EAA, ditches or wells penetrating the underlying rock may release sufficient flow to increase materially the amount of pumping required for drainage. The water yielded by the occasional solution holes and lenses of permeable material in the Fort Thompson formation under the upper Everglades, is usually so highly charged with minerals that it cannot be used for household purposes or irrigation (Jones, 1948). Water from agricultural lands around the Hillsboro Canal is typically high in Na^+ and Cl^- concentrations derived from ground water used for irrigation and from connate seawater (McKenzie, 1995).

Table 1. Summary Statistics for Historical Specific Conductance of Lake Okeechobee, Ground Water, and Canal Water in the EAA.

Water Sources	Time	No of	Specific conductivity, mS/cm								Significant Test	
	period	Observation	Range	Median	Minimum	Maximum	10th pctl	90th Pctl	Std Dev	Mean	Difference	Pr>F
Wells	1984-1997	284	48.01	0.62	0.00	48.01	0.28	7.01	5.75	2.45	a	<0.0001
Ocean Canal	1990-1992	142	3.36	1.52	0.37	3.73	0.85	2.53	0.65	1.63	b	
West Palm Beach Canal	1990-1992	265	4.94	1.26	0.42	5.36	0.87	2.55	0.88	1.49	bc	
Hillsboro Canal	1990-1992	277	10.45	1.34	0.39	10.83	0.71	1.73	0.67	1.35	bcd	
North New River Canal	1990-1992	335	2.50	1.08	0.16	2.66	0.56	1.56	0.39	1.09	cd	
Miami Canal	1990-1992	125	1.72	1.06	0.27	1.99	0.70	1.30	0.25	1.01	de	
Lake Ockeechobee	1978-1999	667	1.28	0.60	0.34	1.62	0.43	0.80	0.18	0.62	e	

Note: Raw data from SFWMD DBHYDRO database.

RESULTS

I. General Characteristics of Specific Conductance in the EAA

Specific Conductance

Averages of specific conductance and other parameters over the entire study period are presented in Table 2. Crop and water management characteristics of the farms monitored as well as rainfall are presented in Table 3. The skewness and kurtosis values for turbidity and pump hours are not close to zero, and the mean values of the monthly average of these parameters are above the median. This indicates that data sets for these two parameters are highly positively skewed and a log-transformation of the data is necessary. Geometric means instead of arithmetic means are therefore better representations of the true mean for turbidity and pump hours, while arithmetic mean is used for all other parameters.

Monthly averages of specific conductance at the ten farms (12 discharge structures) are presented in Figure 2. Means of specific conductance and other parameters at each pump structure for the entire monitoring period are presented in Table 4. Specific conductance data from two farms (UF9206A&B, and UF9208A) show averages above 1.275 mS/cm (Table 4). No differences in rainfall, evaporation or irrigation were observed among sites. The percentage of cane in the cropping system was different between sites, varying from less than 30% in UF9206A&B to 99.8% in UF9202A. Arithmetic means of specific conductance at the 12 pump structures decreased in the following order (in mS/cm): UF9208A (1.682)> UF9206A (1.513), UF9206B (1.540) > UF9201A (1.169) ≥ UF9204A (1.076), UF9207A (1.091), UF9207B (1.086) ≥ UF9202A (0.954) ≥ UF9200A (0.888) ≥ UF9203A (0.862), UF9209A (0.818) ≥ UF9205A (0.738).

Historical data have indicated monthly fluctuation in dissolved salts in the Everglades canals (Parker et al., 1955). A box and whisker plot of the monthly specific conductance data

Table 2. Summary Statistics for Hourly Averages of Specific Conductance and Other Parameters in All Sites during the Study Period.

Parameter	Units	No. of Obs.	Mean	Standard Deviation	Standard Error	Range	Minimum	Maximum	Median	Skewness	Kurtosis	Pr.>F by Site[†]	Pr.>F by Month[‡]
Sp. Cond.	mS/cm	258162	1.13	0.47	0.00	3.98	0.10	4.08	1.05	0.82	0.91	<0.0001	<0.0001
Temperature	^{0}C	260831	24.38	3.99	0.01	25.23	10.79	36.02	24.69	-0.44	-0.26	0.5648	<0.0001
pH	-	251171	7.51	0.38	0.00	4.99	4.41	9.40	7.47	0.58	1.02	<0.0001	<0.0001
TDS	g/L	255618	0.720	0.301	0.001	2.544	0.066	2.610	0.674	0.84	1.05	<0.0001	<0.0001
Diss. Oxy.	% Sat.	251064	34.0	27.7	0.1	192.1	0.0	192.1	30.3	0.50	-0.76	<0.0001	<0.0001
Diss. Oxy.	mg/L	251569	2.90	2.51	0.01	17.29	0.00	17.29	2.51	0.59	-0.59	<0.0001	<0.0001
ORP	mV	253714	275.6	235.3	0.5	1418.0	-608.0	810.0	329.0	-0.75	-0.39	<0.0001	<0.0001
Turbidity	NTU	153816	14.0	22.6	0.1	658.0	0.0	658.0	7.3	7.47	119.28	<0.0001	0.3481

† Variation as a result of different pump structures

‡ Variation as a result of different months.

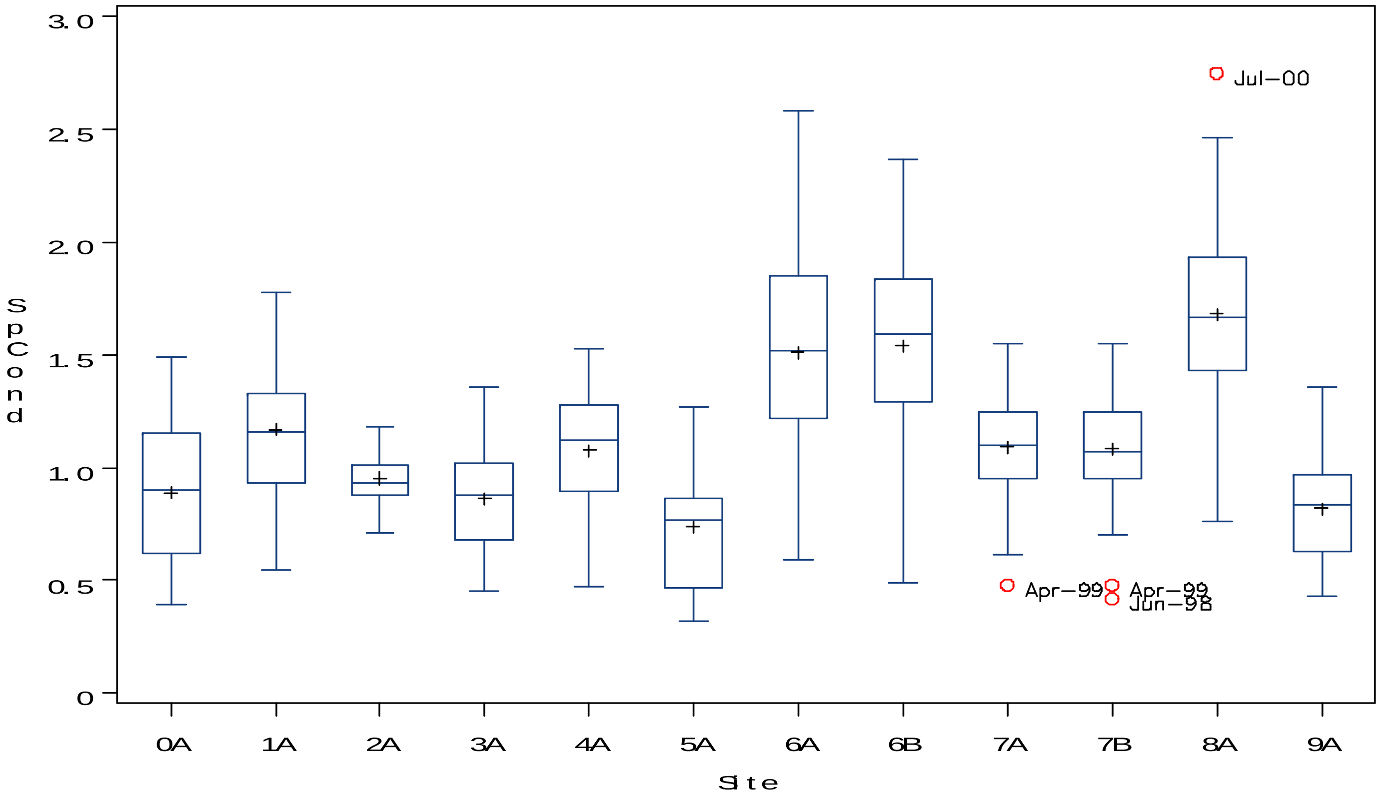
Table 3. Summary of Rainfall, Water and Crop Management at the Ten Farms Combined.

Parameter	Units	No. of Obs.	Mean	Standard Deviation	Standard Error	Range	Minimum	Maximum	Median	Skewness	Kurtosis	Pr.>F by Site[†]	Pr.>F by Month[‡]
Rainfall	in.	617	3.79	3.08	0.12	13.62	0.00	13.62	3.15	0.86	-0.02	0.9982	<0.0001
Evaporation	in.	617	5.90	1.48	0.06	5.59	3.06	8.65	5.96	-0.02	-1.02	0.9996	<0.0001
Irrigation	in.	617	2.75	2.30	0.09	8.20	0.00	8.20	2.80	0.35	-0.83	0.9994	<0.0001
Cane	%	617	67.0	31.6	1.3	100.0	0.0	100.0	84.4	-0.69	-1.01	<0.0001	1.0000
Pump	hrs	617	62.6	87.5	3.5	516.8	0.0	516.8	21.6	1.88	3.99	<0.0001	<0.0001

[†] Variation as a result of different pump structures.

[‡] Variation as a result of different months.

Figure 2. Plot for Monthly Averages of Specific Conductance (SpCond, mS/cm) by Site.



Note: red circles depict observations outside the lower and upper fences.

Table 4. Means of Specific Conductance and other Parameters by Site.

Site	Start Date	Stop Date	Sp. Cond (mS/cm)	Temp.† (^{0}C)	pH†	TDS† (g/L)	DO† (% Sat.)	DO† (mg/L)	ORP† (mV)	Turbidity‡ (NTU)	Rainfall† (in.)	Evap.† (in.)	Irrigation† (in.)
UF9200A	Nov-96	Dec-02	0.888	24.4	7.57	0.568	38.1	3.29	312.1	17.1	3.69	5.95	2.84
UF9201A	Jan-98	Dec-99	1.169	25.5	7.78	0.744	43.3	3.61	376.3	32.2	4.13	5.72	2.46
UF9202A	Jan-98	Dec-01	0.954	24.3	7.52	0.610	27.7	2.35	231.4	18.3	3.60	5.90	2.86
UF9203A	Jan-98	Dec-01	0.862	24.6	7.44	0.550	48.6	4.12	373.3	6.62	3.88	5.90	2.72
UF9204A	Jan-98	Dec-01	1.076	24.3	7.65	0.690	37.3	3.19	288.0	5.48	3.43	5.84	2.92
UF9205A	Jan-98	Dec-99	0.738	23.8	7.12	0.468	17.3	1.49	86.0	6.97	3.86	5.72	2.78
UF9206A	Nov-96	Dec-02	1.513	24.7	7.45	0.984	27.8	2.37	235.1	12.8	3.98	5.95	2.62
UF9206B	Nov-96	Dec-02	1.540	24.5	7.36	0.969	27.0	2.29	201.1	9.44	3.98	5.95	2.63
UF9207A	Jan-98	Dec-01	1.091	24.4	7.39	0.699	26.1	2.23	243.9	9.23	3.77	3.84	2.70
UF9207B	Jan-98	Dec-01	1.086	24.0	7.31	0.695	18.8	1.59	191.3	9.27	3.89	5.85	2.66
UF9208A	Jan-98	Aug-01	1.682	23.5	7.48	1.076	29.0	2.54	196.3	6.07	3.59	5.92	2.92
UF9209A	Jan-98	Dec-02	0.818	25.1	7.65	0.525	53.6	4.50	372.5	8.89	3.76	6.02	2.79

† Arithmetic mean.
‡ Geometric mean.

indicates that specific conductance shows monthly fluctuation (Figure 3). ANOVA of the data ($p=0.05$) shows the overall monthly trend of specific conductance in canal water of EAA farms decreased as follows (arithmetic mean in mS/cm): August (1.280), September (1.263) and October (1.253) > February (1.200), November (1.185), January (1.180), July (1.175), December (1.171), and March (1.136) > April (1.027) > May (0.934) and June (0.892). The three highest months (August, September, and October) also had the highest rainfall (8.12, 6.52, and 5.77 in., respectively). This is consistent with the observation by Parker et al. (1955) who found that Cl^- and Na^+ concentrations in September samples were considerable higher than concentrations in May.

Ion Composition

Determination of ion compositions in grab samples at ten pump structures indicated that HCO_3^-, Cl^- and SO_4^{2-} are the major anions and Na^+ and Ca^{2+} are the major cations in farm canal water of the EAA farms (Table 5). It is believed that in the current pH range of 7.0 to 7.5, the principal ion responsible for alkalinity is HCO_3^- (Hem, 1985; Gleason, 1974). In this study, the mean concentrations of HCO_3^- varied from 190.3 mg/L at UF9209A to 398.8 mg/L at UF9208A (Table 6). The mean concentrations of Cl^- varied from 71.6 mg/L at UF9202A to 174.2 mg/L at UF9208A (Table 6; Figure 4). It was reported that many of the surface waters in southeastern Florida had less than 15 mg/L of Cl^-, but ground waters with 100 mg/L, or more, were not uncommon (Parker et al., 1955). Mean concentrations of SO_4^{2-} ranged from 45.2 mg/L at UF9203A to 118.8 mg/L at UF9208A.

Mean concentrations of Na^+ ranged from 41.7 mg/L at UF9202A to 136.5 mg/L at UF9208A. The quantity of Na^+ in ordinary surface or ground water is reported to be less than 30 mg/L; considerable quantities of Na^+ would be found in waters contaminated with sea water or in waters with salts enclosed in the older marine deposits (Parker et al., 1955). Mean concentrations of Ca^{2+} ranged from less than 51.0 mg/L to 78.8 mg/L (Table 6). Mean concentrations of Mg^{2+} ranged from 18.9 mg/L to 46.1 mg/L, and mean concentrations of K^+ varied from 5.8 mg/L to 11.4 mg/L (Table 6).

Figure 3. Plot of Mean Specific Conductance from all sites combined (SpCond, mS/cm) against Month of the Year.

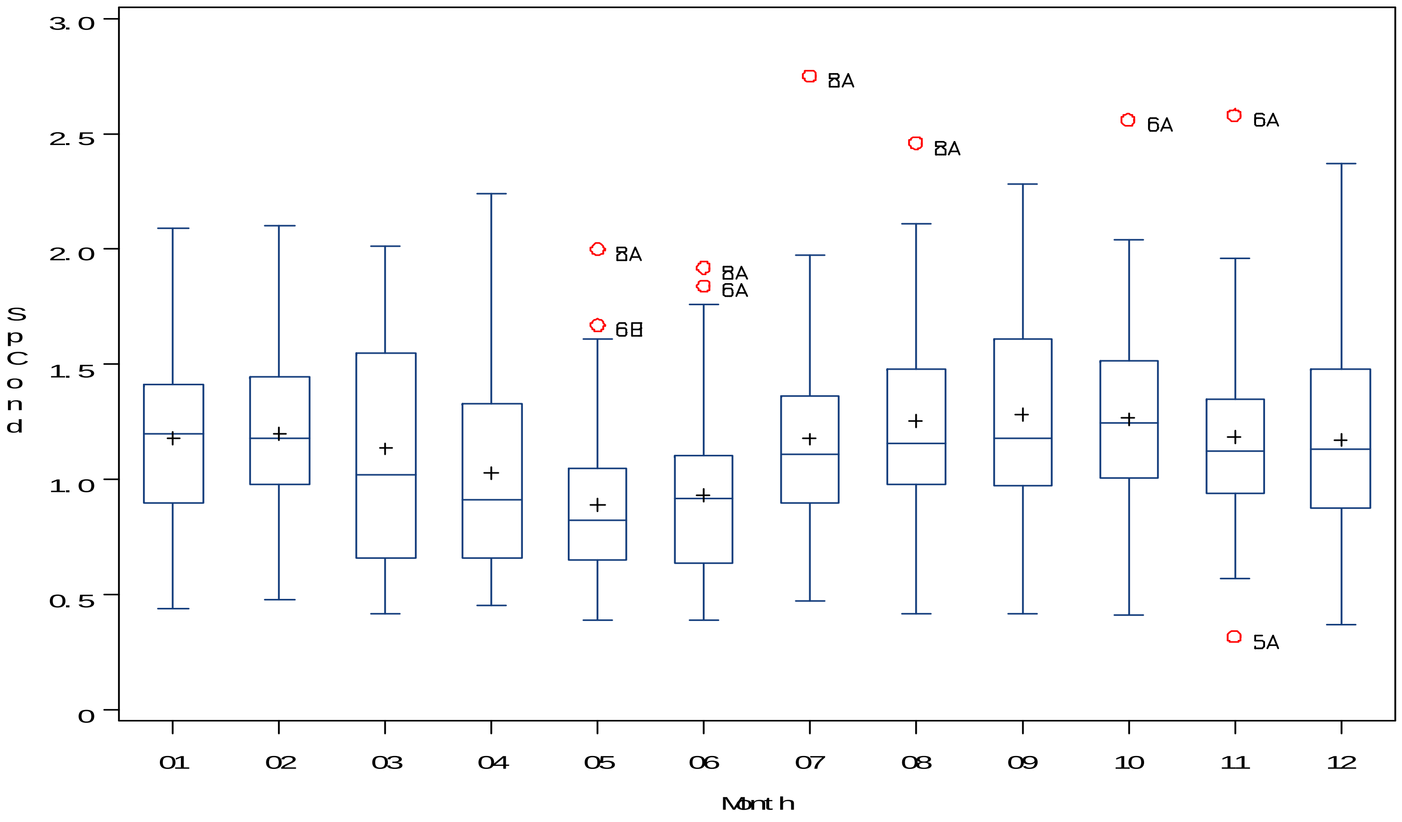


Table 5. Statistical Summary for Ion Composition and other Parameters in Grab Samples Combined for 10 Pump Structures.

Variable	N	Range	Median	Minimum	Maximum	Mean	Std Dev
K (mg/L)	464	14.11	8.14	3.46	17.57	9.00	2.92
Na (mg/L)	464	223.9	64.9	20.2	244.2	80.1	42.7
Ca (mg/L)	464	129.7	56.6	17.4	147.1	57.3	19.6
Mg (mg/L)	464	54.5	26.6	0.2	54.7	26.5	9.7
Cl (mg/L)	464	270.1	98.5	28.2	298.2	115.0	52.7
SO_4 (mg/L)	464	138.6	58.7	14.4	153.1	63.9	21.9
F (mg/L)	464	6.64	0.61	0.19	6.82	0.71	0.44
HCO_3 (mg/L)[†]	464	667.5	129.1	-90.8	576.7	142.2	70.7
Temperature, ^{o}C	428	15.87	27.08	15.80	31.67	26.66	2.40
pH	387	2.69	7.57	6.27	8.96	7.62	0.43
Sp. Cond. (mS/cm)	426	2.050	0.950	0.430	2.480	1.019	0.376
TDS (mg/L)	426	1.310	0.610	0.280	1.590	0.652	0.242
Diss. Oxy. (% Sat.)	412	124.5	34.8	0.0	124.5	36.4	29.2
Diss. Oxy. (mg Sat.)	412	9.87	2.66	0.00	9.87	2.94	2.39
Redox (mV)	402	1041.3	387.5	-294.3	747.0	307.6	228.1
Turbidity (NTU)	314	118.1	8.9	0.3	118.4	13.9	17.6
Pump volume (galon)	464	46252	0.0	0.0	46252	2408	7395
Rainfall (in.)	464	1.65	0.00	0.00	1.65	0.19	0.34

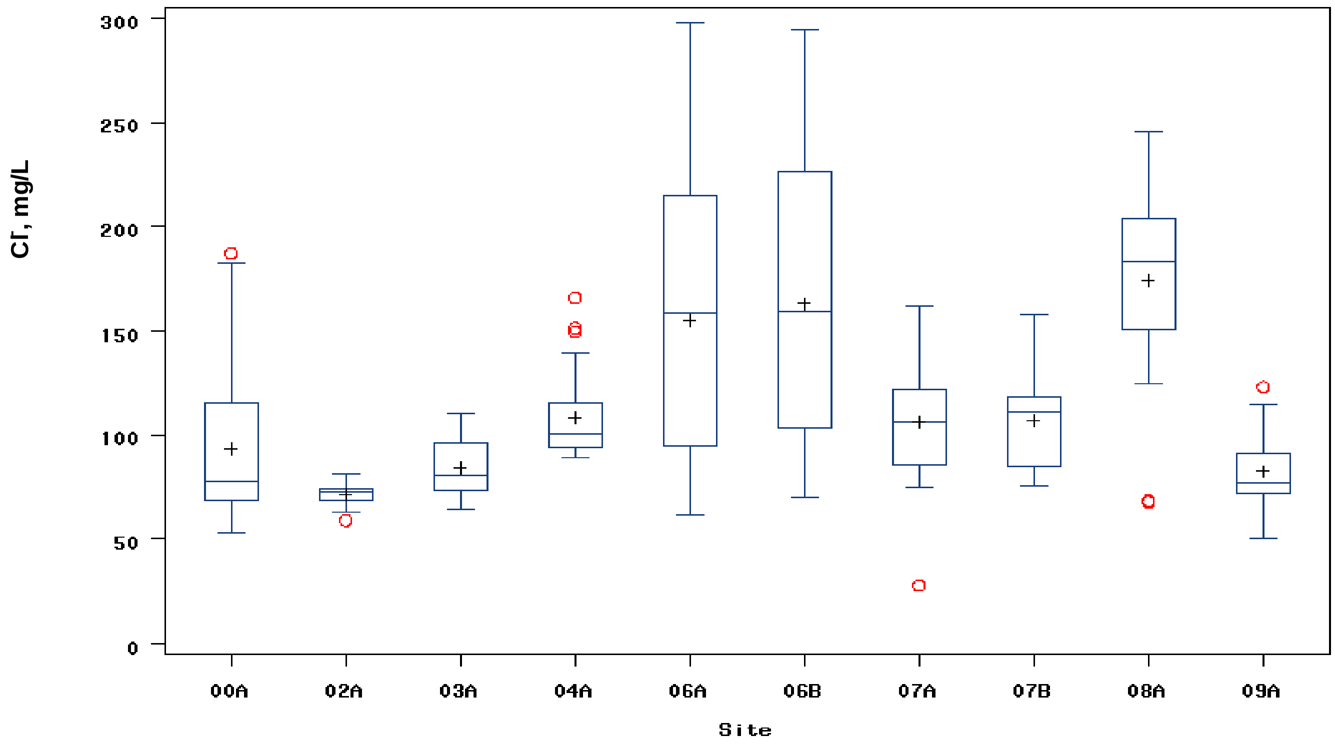
[†] Calculated based on the balance of cations and anions.

Table 6. Mean Ion Concentrations in Grab Samples by Site.

Site	K	Na	Ca	Mg	Cl	SO_4	F	HCO_3[†]	Na/Cl
	----------mg/L----------								
UF9200A	8.7 b	64.0 cd	52.2 c	22.3 d	93.6 cd[1]	61.3 de	0.61 c	215.0 ef	0.65 c
UF9202A	5.8 d	41.7 e	77.7 ab	26.7 c	71.6 e	70.3 bc	0.57 c	277.7 c	0.57 d
UF9203A	7.3 c	56.7 d	49.1 c	22.2 d	84.2 de	45.2 g	0.54 c	220.4 def	0.67 bc
UF9204A	9.1 b	79.1 c	67.8 b	35.9 b	108.5 c	76.5 b	0.65 bc	326.8 b	0.72 ab
UF9206A	10.8 a	110.7 b	51.0 c	25.8 c	155.3 b	65.8 cd	0.91 a	249.7 cde	0.68 bc
UF9206B	11.4 a	114.8 b	54.7 c	28.3 c	163.2 ab	68.6 c	0.82 ab	262.7 cd	0.68 bc
UF9207A	9.7 b	77.5 c	54.9 c	26.6 c	106.5 c	54.3 f	0.72 abc	269.2 c	0.72 bc
UF9207B	9.6 b	77.6 c	56.4 c	27.6 c	107.1 c	55.3 ef	0.73 abc	276.6 c	0.70 bc
UF9208A	10.9 a	136.5 a	78.8 a	46.1 a	174.2 a	118.8 a	0.89 a	399.8 a	0.78 a
UF9209A	6.5 cd	49.8 d	51.8 c	18.9 d	82.6 de	49.1 fg	0.61 c	190.3 f	0.59 d

[†] Calculated based on the balance of cations and anions.

Figure 4. Plot for Cl^- Concentration (mg/L) from Feb. 28, 2001 to Oct. 27, 2002 by Site.



It is noted that concentrations of Na^+ and Cl^- in farm canal water at UF9208A and UF9206A&B are significantly greater than at other pump structures in the EAA (Table 6). Correlation coefficient analysis shows a strong correlation coefficient (r=0.95) between concentrations of Na^+ and Cl^- in canal water near the EAA farms. The concentration of SO_4^{2-} ion is the highest at UF92008A. We also calculated the Na/Cl ratio in these farm canals. The average Na/Cl weight ratio for farm canal water in the EAA ranged between 0.57 and 0.78 (Table 6). The Na/Cl weight ratio for seawater is 0.55 (Stumm and Morgan, 1981). Most of these farm canals are close to this ratio or slightly higher. The Na/Cl weight ratio for Hillsboro Canal water and WCA-2A marsh water varied from 0.76 to 0.85 (Gleason, 1974). The relatively high Na content of canal water in the EAA may partly from the remnants of saline residues that have not been completely flushed out of the ground and partly from cation-exchange processes (Parker et al., 1955). Because the muck and rock of the EAA are much less permeable than the sandstones and limestones, the saline residues have not been entirely flushed out, and the organic colloids are still partly saturated with Na, presumably adsorbed from ancient seawater. When brought in contact with Na^+ bearing clays, the Ca^{+2} in the solution is exchanged for Na^+ in the clays. The water then comes in contact with more lime rock, which dissolves to form more Ca^{+2} and HCO_3^-. Repetition of the process increases HCO_3^- and Na^+ to high values.

II. Potential Sources of Specific Conductance in the EAA

It is clear from Section I (general characteristics of specific conductance in the EAA) that specific conductance was not a problem in the majority of the farms monitored. Eight out of the ten farms monitored showed mean specific conductance values below 1.275 mS/cm. Only two farms (UF9206A&B, and UF9208A) had mean specific conductance values higher than 1.275 mS/cm. In this section, the effect of geological influences, water management practices, and fertilizer on specific conductance in the EAA will be investigated.

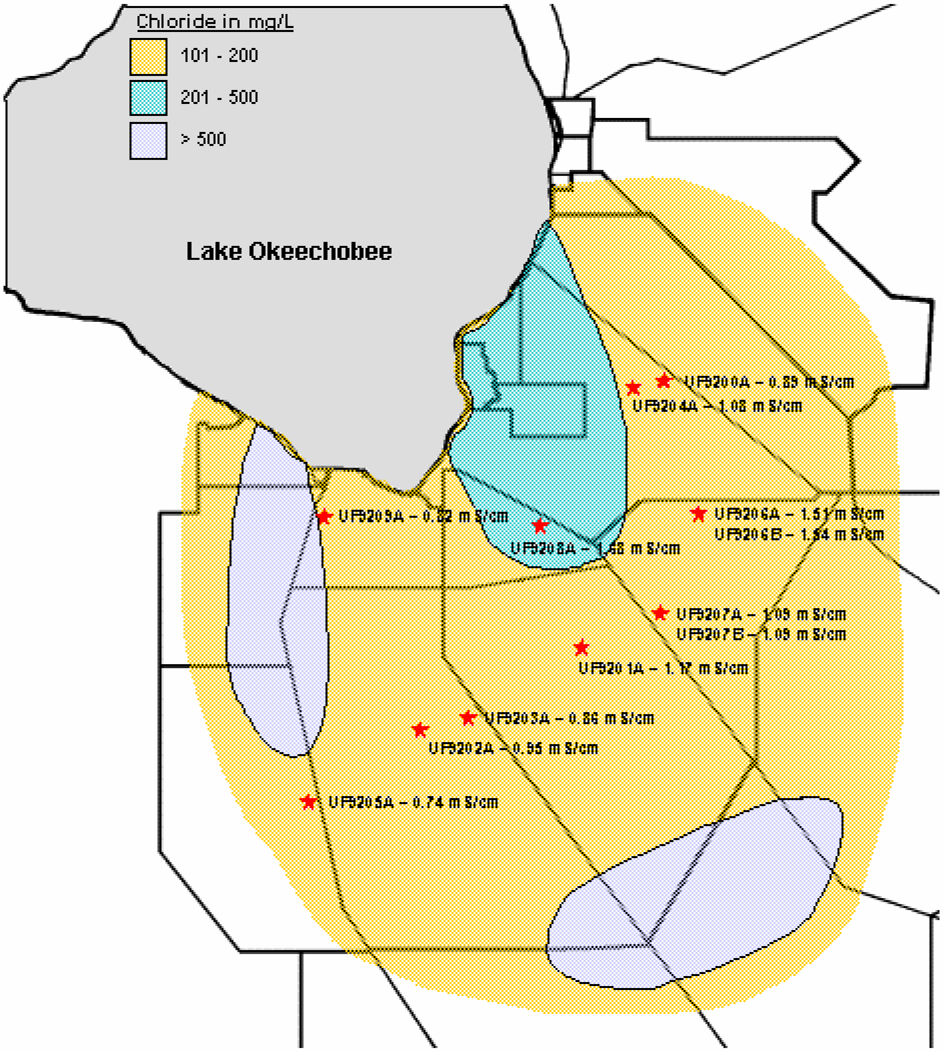
Geological Influences

Historically, groundwater in the Everglades is highly mineralized and dissolved solids increase with depth. Saline waters and residues left by Pleistocene invasions of the area by the sea have never been completely flushed out of the formations in much of the Everglades, particularly in areas near Lake Okeechobee (Jones, 1948; Parker et al., 1955). Some wells in the EAA less than 50 ft deep yield water high in specific conductance, SO_4^{2}- and Cl^- (Parker et al., 1955, Scott, 1997).

We superimposed the average specific conductance of the monitored discharge structures on the variation map of the shallow ground water (20 to 50 ft well depths) Cl^- levels from Parker et al. (1955) (Figure 5). The current specific conductance data points show that the high elevated conductance at UF9208A are in the area of wells that have a Cl^- concentration ranging from 201-500 mg/ L and those of UF9206A&B are in the area of wells that have a Cl^- concentration of 101-200 mg/L (Figure 5). Chloride concentrations greater than 100 mg/L were considered to be evidence of saltwater mixing with freshwater in the surficial aquifer system and indicate the presence of saltwater interface (Hittle, 1999). Up to 400 mg/L of Cl^- and 390 mg/L of Na^+ were reported in shallow ground waters close to UF9206A&B in two separate investigations conducted by Scott (1977) and Miller and Lietz (1976). They also documented specific conductance values of up to 2.35 mS/cm in the ground water samples in the same wells. Specific conductance in three farms in the vicinity of UF9206A&B averaged 1.56, 2.15 and 2.29 mS/cm, respectively, and the shallow groundwater had a mean specific conductance of 1.54 mS/cm (CH2M Hill, 1978).

High specific conductance values and ion concentrations were found in shallower wells (16.5-18.1 ft.) in an area just south of Lake Okeechobee, between West Palm Beach and

Figure 5. Study Sites with Mean Specific Conductance Superimposed Upon a Map of Chloride Concentration of Shallow Wells (20 To 50 Feet Depth) in the EAA (Chloride Map Recreated from Parker, 1955).



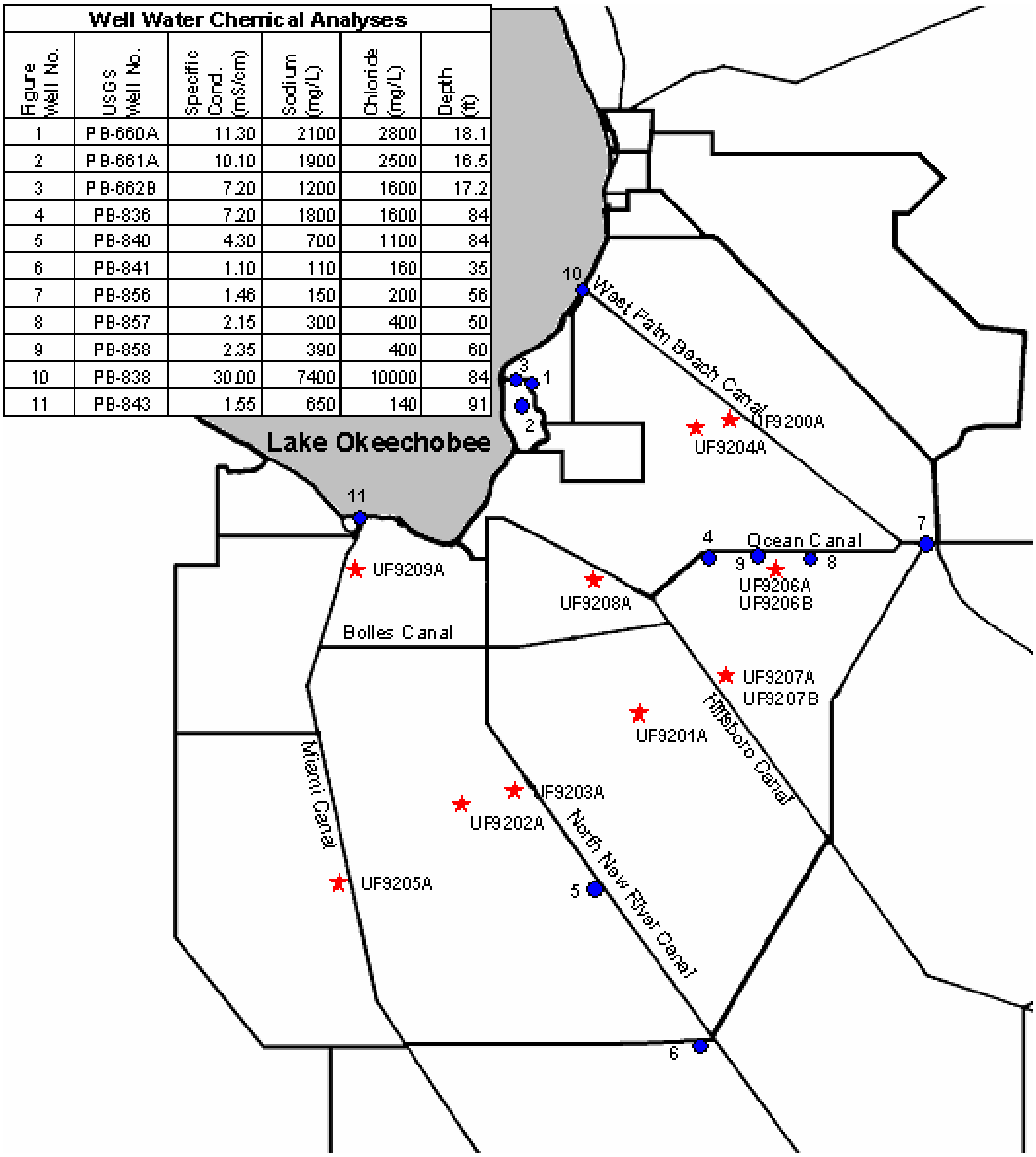
Hillsboro canals (Miller and Lietz, 1976)(Figure 6). It is most likely that these two canals (the depth of the canals is between 15-18 ft.) intersect this highly mineralized area and get the saltwater intrusion by cutting into the saltwater interface. The current specific conductance data correspond well also with documented specific conductance data of the SFWMD (Table 1). This is indicative that the elevated specific conductance in certain canals in the EAA is a result of saline groundwater intrusion from ancient seas. This is especially true for specific conductance in the northern portion of Hillsboro Canal (Figure 1), which agrees with result of McKenzie (1995), who documented that the quality of the water in the southern part of the Boca Raton canal system is affected by the Hillsboro Canal water channeled from conservation and agricultural areas to the west. UF9208A is located near the north end of the Hillsboro Canal.

Drainage Pumping

Data from three intensively monitored farms (UF9206A&B, UF9200A and UF92009A) were analyzed to determine if there were specific management practices that affect specific conductance; specifically, the effects of drainage pumping and irrigation on specific conductance. Table 7 shows the effect of ambient conditions, irrigation and drainage pumping on specific conductance on these three farms. Drainage pumping had no significant effect on specific conductance at UF9206A&B (Table 7). Specific conductance was higher during drainage pumping than during irrigation or ambient conditions for both UF9200A and UF9209A. The specific conductance values of drainage waters at these two farms, however, were below 1.275 mS/cm. The pumping effect on specific conductance is site specific as seen by the significant site by pumping interaction (Table 8).

To illustrate the effects of drainage pumping on specific conductance at the three pumping structures with mean elevated specific conductance (UF9206A, UF9206B, and UF9208A), graphs of hourly specific conductance observations over time and against cumulative drainage volume were plotted. Six drainage events were plotted for each of the three structures (Appendix 1). Example graphs of drainage events from each structure are presented in Figures 7, 8, and 9. The drainage event chosen for structures UF9206A and UF9206B occurred in March 2001 (Figures 7 and 8). Drainage pumping was initiated after a rainfall of approximately one inch had occurred on the 29th of March. At both structures, specific conductance prior to drainage initiation was > 1.75 mS/cm. As drainage volume

Figure 6. Water Quality of Shallow Wells in the EAA and Current Study Farm Locations (Well Data from Miller and Lietz, 1976).



Well Water Chemical Analyses

Figure Well No.	USGS Well No.	Specific Cond. (mS/cm)	Sodium (mg/L)	Chloride (mg/L)	Depth (ft)
1	PB-660A	11.30	2100	2800	18.1
2	PB-661A	10.10	1900	2500	16.5
3	PB-662B	7.20	1200	1600	17.2
4	PB-836	7.20	1800	1600	84
5	PB-840	4.30	700	1100	84
6	PB-841	1.10	110	160	35
7	PB-856	1.46	150	200	56
8	PB-857	2.15	300	400	50
9	PB-858	2.35	390	400	60
10	PB-838	30.00	7400	10000	84
11	PB-843	1.55	650	140	91

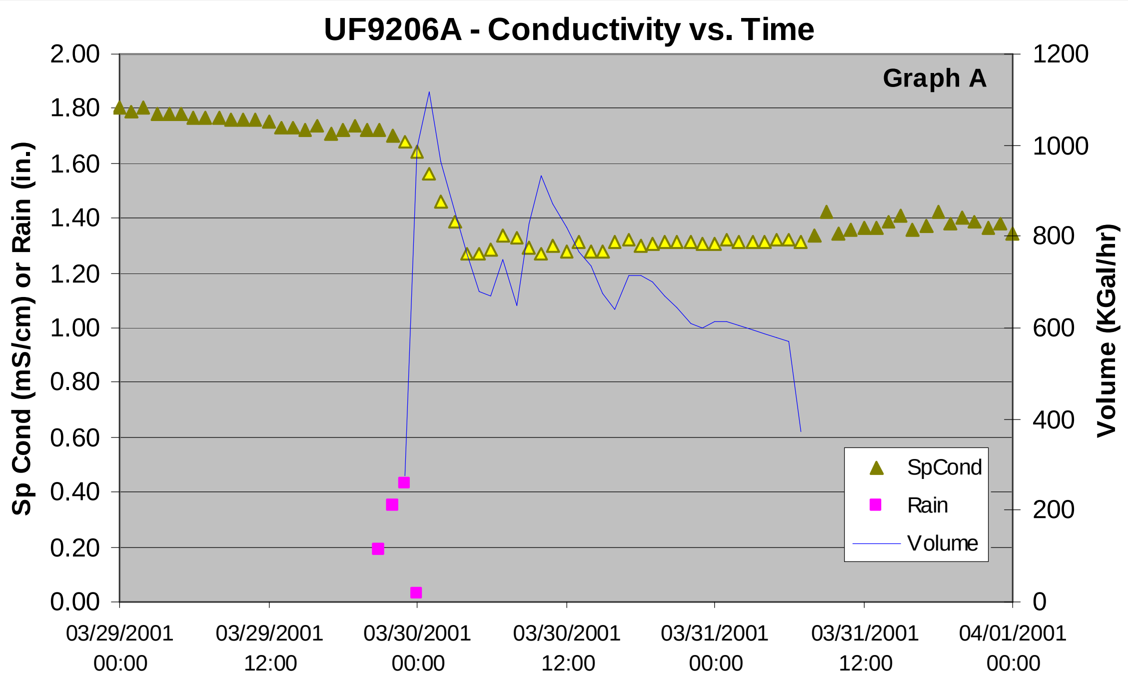
Table 7. Statistical Summary of the Effects of Ambient Conditions, Pumping, and Irrigation on Specific Conductivity at Four Structures.

Water Management	No of	Statistical Summary (Specific conductivity, mS/cm)						Significant Test	
Practices	Observation	Range	Median	Minimum	Maximum	Std Dev	Mean	Difference	Pr>F
				Site=UF9200A					
Ambient	1039	1.77	0.77	0.39	2.16	0.35	0.86	b	<0.0001
Pump	188	0.98	0.97	0.40	1.38	0.23	0.94	a	
Irrigation	227	1.57	0.55	0.37	1.94	0.31	0.64	c	
				Site=UF9206A					
Ambient	1107	3.15	1.55	0.44	3.59	0.57	1.53	a	<0.0001
Pump	238	2.71	1.48	0.40	3.11	0.37	1.46	a	
Irrigation	110	3.54	0.76	0.41	3.95	0.69	1.02	b	
				Site=UF9206B					
Ambient	1079	2.44	1.59	0.33	2.77	0.50	1.55	a	<0.0001
Pump	243	2.02	1.63	0.40	2.42	0.36	1.51	a	
Irrigation	133	1.96	0.76	0.32	2.28	0.45	0.87	b	
				Site=UF9209A					
Ambient	973	0.97	0.78	0.40	1.37	0.22	0.78	b	<0.0001
Pump	312	0.98	0.94	0.45	1.43	0.19	0.96	a	
Irrigation	166	0.86	0.62	0.41	1.27	0.21	0.67	c	
				All 4 sites (UF9200A, UF9206A&B, UF9209A)					
Ambient	4198	3.26	1.08	0.33	3.59	0.57	1.19	a	<0.0001
Pump	981	2.71	1.13	0.40	3.11	0.39	1.20	a	
Irrigation	636	3.63	0.60	0.32	3.95	0.44	0.76	b	

Table 8. Effects of Interactions between Site, Pumping, Rainfall, and Irrigation on Daily Average Specific Conductance at Four Intensively Monitored Pump Structures.

Variables	Degree of freedom	Type I hypotheses	
		F Value	Pr > F
Site	3	1155.94	<.0001
Irrigation	1	398.25	<.0001
Pump	1	7.70	0.01
Rainfall	2	4.14	0.02
Site **X** Irrigation	3	42.44	<.0001
Site **X** Pump	3	14.50	<.0001
Site **X** Rainfall	6	2.31	0.03
Irrigation **X** Pump	1	0.00	0.95
Irrigation **X** Rainfall	2	0.03	0.97
Pump **X** Rainfall	2	0.06	0.94
Site **X** Irrigation **X** Rainfall	3	0.26	0.85
Site **X** Irrigation **X** Pump **X** Rainfall	6	0.96	0.45

Figure 7. Hourly Specific Conductance of Drainage Event UF9206A-010329 Plotted against Time (Graph A) and Cumulative Volume Pumped per Acre (Graph B).



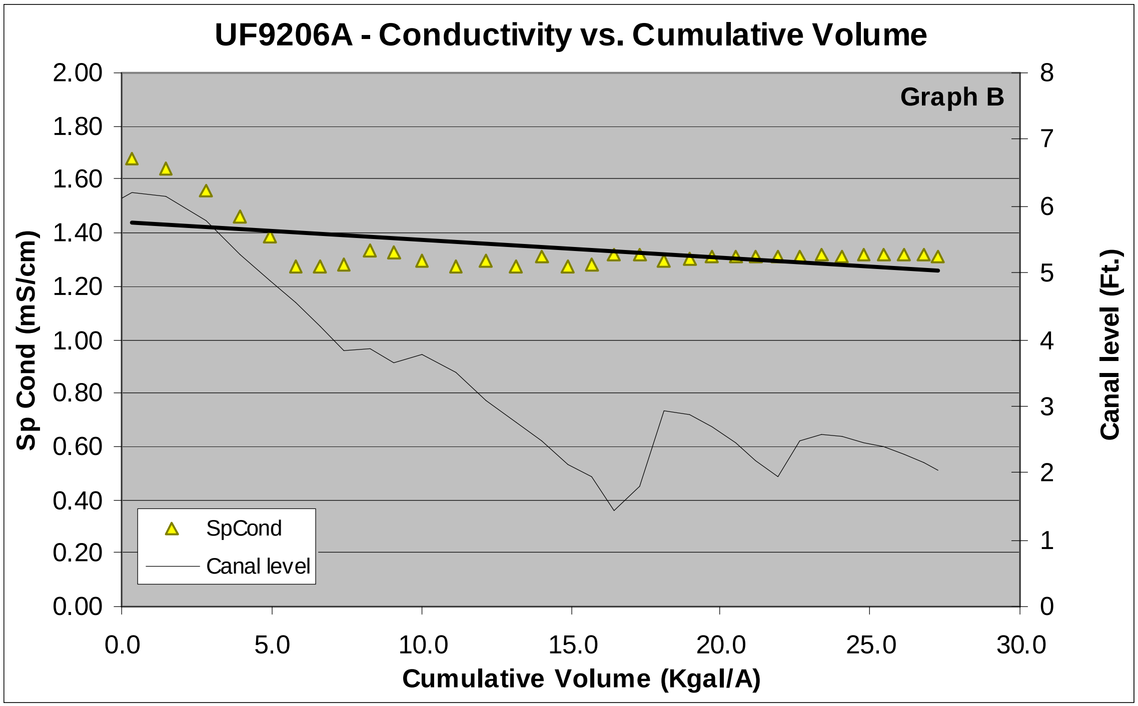
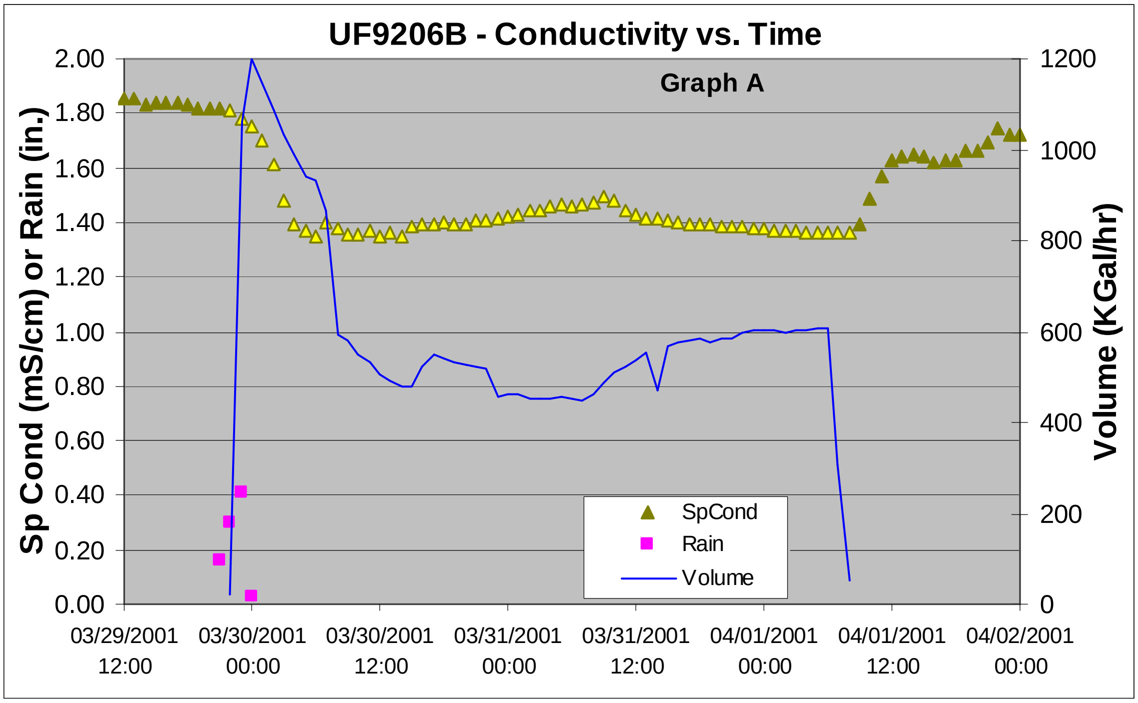
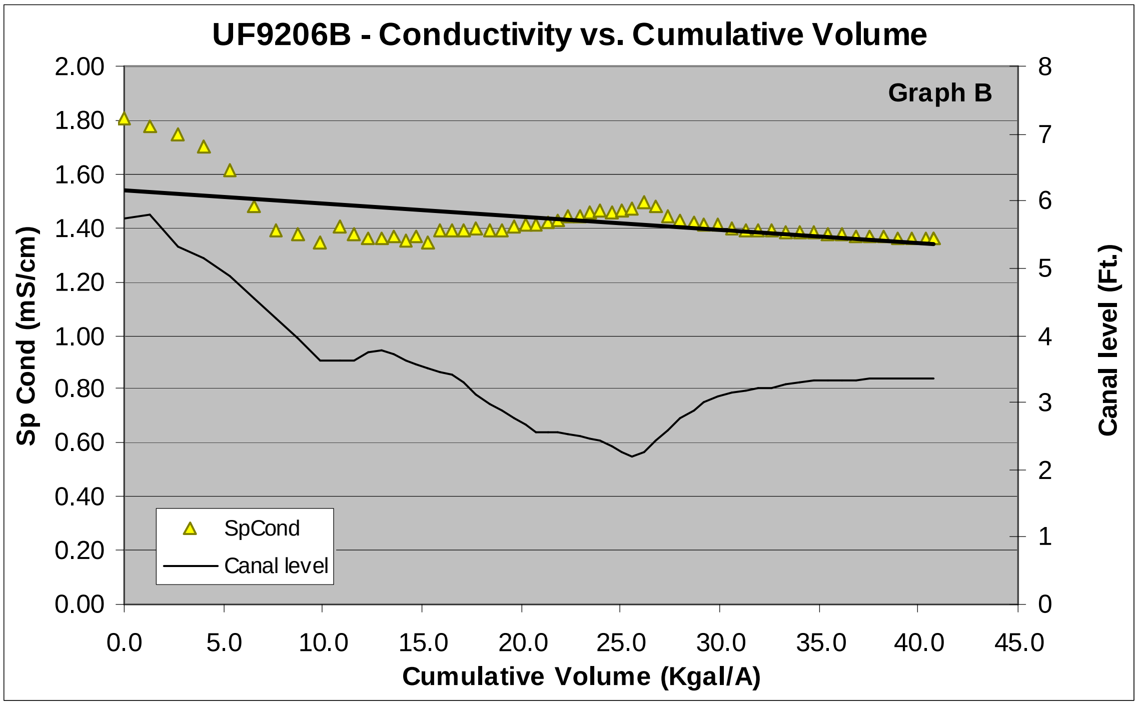


Figure 8. Hourly Specific Conductance of Drainage Event UF9206B-010329 Plotted against Time (Graph A) and Cumulative Volume Pumped per Acre (Graph B).



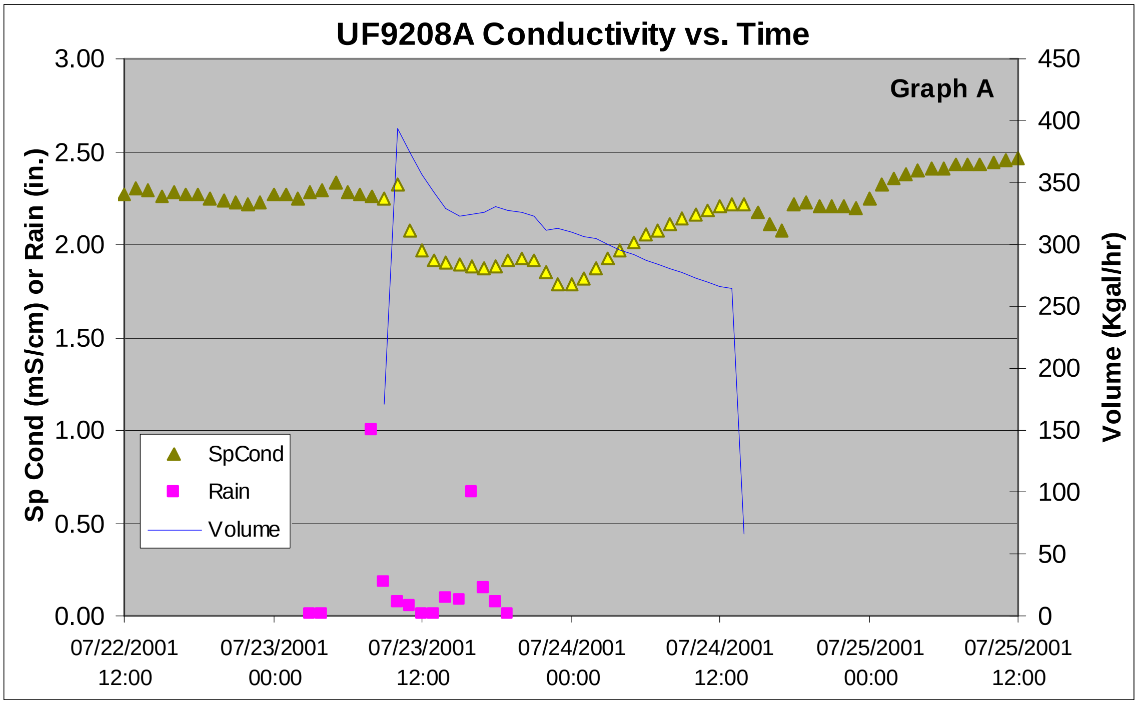


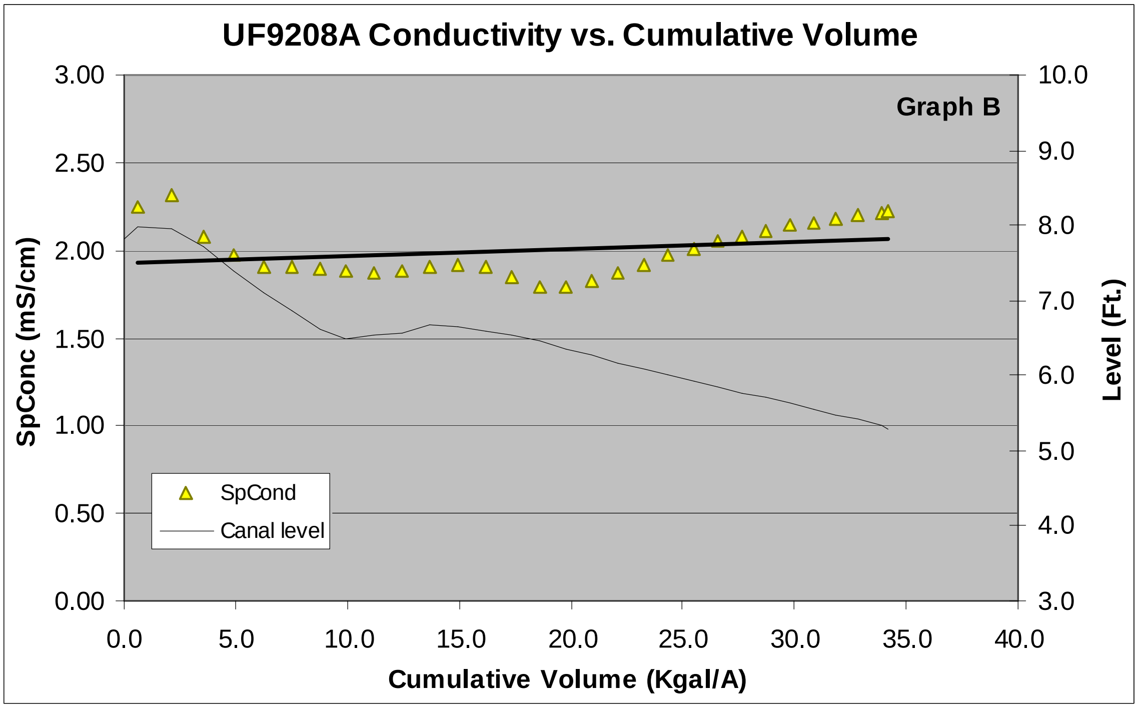
increased (Figure 7 & 8), specific conductance decreased; once pumping ceased specific conductance at UF9206B returned to pre-pumping levels (Figure 8, Graph A), at UF9206A specific conductance did not change (Figure 7, Graph A). Three of six drainage events plotted for UF9206A were observed to have increased conductance with volume pumped; at UF9206B the same trends were observed with three of six events producing trends of increased specific conductance with pumping. This variable effect of pumping on specific conductance explains results reported in Table 7.

The inconsistent effect of drainage pumping on specific conductivity within UF9206A&B is the result of the dynamic hydrologic conditions that exist in the area (and within the EAA). Contrary to previous, widely held perceptions that Everglades peat is impermeable and that hydraulic driving forces are too small to cause recharge and discharge, significant exchanges of surface and ground water in Everglades peat can occur at very low pressure differences (Harvey, 2004). The flow of shallow aquifer water into farm canals is dependent on pressure differences. Conditions that create pressure differences and favor groundwater flow into the farm canals are dependent on relative pressures of surface canals and the shallow aquifer, both off-farm and on-farm. As the farm and its adjacent farms are drained or kept flooded and as SFWMD canals are raised and lowered, pressure gradients are created which may or may not favor the movement of shallow groundwater into farm canals. The complex conditions that favor groundwater flow into the farm canals are not thought to be significantly influenced by any management practices on this farm, but are mainly governed by off-farm hydrologic influences, i.e. district conveyance canal levels and adjacent farm water levels.

The drainage event used to illustrate the influence of drainage pumping on specific conductance at structure UF9208A occurred in July 2001 (Figure 9). A rain of 2.42 inches fell on July 23, 2001; drainage pumping started on July 23, and ended on July 24, 2001. Specific conductance was greater than 2.00 mS/cm prior to the drainage event; during the initial stages of drainage pumping specific conductance decreased slightly then returned to pre-pumping levels. Five of the six events plotted at this structure exhibited a trend towards increased specific conductance with pumping duration and volume.

Figure 9. Hourly Specific Conductance of Drainage Event UF9208A-010723 Plotted against Time (Graph A) and Cumulative Volume Pumped per Acre (Graph B).





This 262-acre sugarcane farm is bordered on the north by the Hillsboro Canal and on the south by a large private canal. As mentioned earlier in this report, water from agricultural lands around the Hillsboro canal has been reported to be high in Na^+ and Cl^- concentrations (McKenzie, 1995). The farm drainage structure discharges into the private canal to the south. During drainage events the Hillsboro canal to the north is normally at a higher stage level relative to the private drainage canal to the south of the farm. The difference in stage level between the two canals directly influences farm canal water level, field water tables, and creates a pressure gradient between the two conveyance canals across the farm. The consistent increase in specific conductance with drainage pumping indicated, that for most drainage events at this farm, conditions exist that favor shallow groundwater intrusion into the farm drainage stream.

Irrigation Water

At the three intensively monitored farms, UF9200A, UF9206A&B, and UF9209A, the addition of irrigation water decreased specific conductance in farm canals (Table 7). The irrigation water flowing through the structures with the highest specific conductance (UF9206A, UF9206B, and UF9208A) was also characterized by higher specific conductance (Table 1). Site UF9208A received irrigation water via a secondary canal that connects to the Hillsboro canal. Sites UF9206A and UF9206B receive irrigation water from a secondary canal that connects to the Ocean canal. The Ocean canal may source its water from either the West Palm Beach canal to the east, or the Hillsboro Canal to the west. Both the Ocean and the Hillsboro Canals have historically had relatively high specific conductance compared to the other major district conveyance canals in the EAA (Table 1).

The effect of irrigation water quality on farm canal mean specific conductance is also presented in Table 9. Sites that received irrigation water directly from low specific conductance district canals (Miami and North New River) had lower mean specific conductance values. Sites that received irrigation water from district canals with relatively higher specific conductance (Ocean and Hillsboro canals) had relatively higher mean specific conductance values. It was also evident that the sites that did not receive irrigation water directly from main conveyance canals, but received irrigation water via secondary or branch canals had relatively higher mean specific conductance values. The quality of

Table 9. Specific Conductance, Irrigation Source, and Pumping to Rainfall Ratio by Site.

Site	Non-Drainage Specific Conductance (mS/cm)	Irrigation Source	Drainage Specific Conductance (mS/cm)	Pumping to Rainfall Ratio
UF9205A	0.678	MC	0.941	1.04
UF9209A	0.788	MC	0.970	0.48
UF9203A	0.825	NNR	0.911	0.25
UF9200A	0.881	WP	0.951	0.34
UF9202A	0.945	interior-NNR	0.874	0.17
UF9204A	1.053	interior-OC	1.140	0.17
UF9207AB	1.066	HC	1.119	0.44
UF9201A	1.105	interior-HC	1.116	0.85
UF9206AB	1.495	interior-OC	1.509	0.66
UF9208A	1.676	interior-HC	1.718	0.24

Note: MC=Miami Canal, NNR=North New River, WP=West Palm Beach, OC=Ocean Canal, HC=Hillsborough Canal.

irrigation water that a farm receives appears to have a direct influence on the specific conductance of the subsequent water that leaves the farm during drainage pumping events. The drainage volume to rainfall ratio appeared to have had little or no effect on farm canal specific conductance (Table 9). The farm that had the highest average specific conductance during drainage pumping (UF9208A) also had a low drainage pumping to rainfall ratio (0.24). Site UF9205A had the highest drainage pumping to rainfall ratio (1.04), but had relatively low drainage pumping specific conductance (0.941 mS/cm). Two sites, UF9202A and UF9204A (both farms are 640-acre sugarcane monoculture farms), had the same drainage pumping to rainfall ratios (0.17), similar management practices, yet had different drainage pumping specific conductance values (0.87 and 1.14 mS/cm, respectively). These observations lend support to the conclusion that farm canal specific conductance is governed mainly by the quality and hydrology of the underlying shallow ground water, which is farm specific. Farm canal specific conductance also appears to be influenced to a lesser degree by the quality and quantity of the irrigation water it receives.

Fertilizers

Based on the current level of fertilizer BMPs in the EAA, K and P applied would be taken up by the crop during the growing season. Coale et al. (1993) evaluated nutrient accumulation and removal by sugarcane grown on Everglades histosols. They concluded that 63 and 64% of total accumulated P and K, respectively, were removed from the field as millable sugarcane. Phosphorus and K removal from the field by crop harvest was higher than the amount applied by fertilizers at that season. For example, an average of 343 kg K/ha was removed by crop harvest, with a fertilizer application of 150 kg K/ha.

The predominant fertilizers applied to sugarcane in the EAA are potassium chloride (KCl: potash), and diammonium phosphate (DAP: $(NH_4)_2HPO_4$) or triple super phosphate (TSP: $Ca(H_2PO_4)_2.H_2O$). From the fertilizer recommendations of the UF/IFAS Soil Testing Laboratory at the Everglades Research and Education Center, an average application of plant nutrients for a ratoon sugarcane crop in the EAA would be 125 lbs K and 20 lbs P per acre. Utilizing the most commonly applied fertilizers for sugarcane in the EAA, this is approximately equivalent to 240 lbs of KCl (115 lbs Cl^-) and 87 lbs of DAP or 75 lb of TSP per acre. The main fertilizers applied to leafy vegetables in the EAA are ammonium polyphosphate (APP:$(NH_4PO_3)_n$) and KCl. Following UF/IFAS' recommendations, an average application rate of P and K plant nutrients for a leafy vegetable crop growing in the EAA would be 166 lbs K and 175 lbs P per acre. Utilizing the most commonly applied fertilizers for vegetables in the EAA, this would be approximately equivalent to 320 lbs of KCl (153 lbs Cl^-) and 1080 lbs of APP per acre.

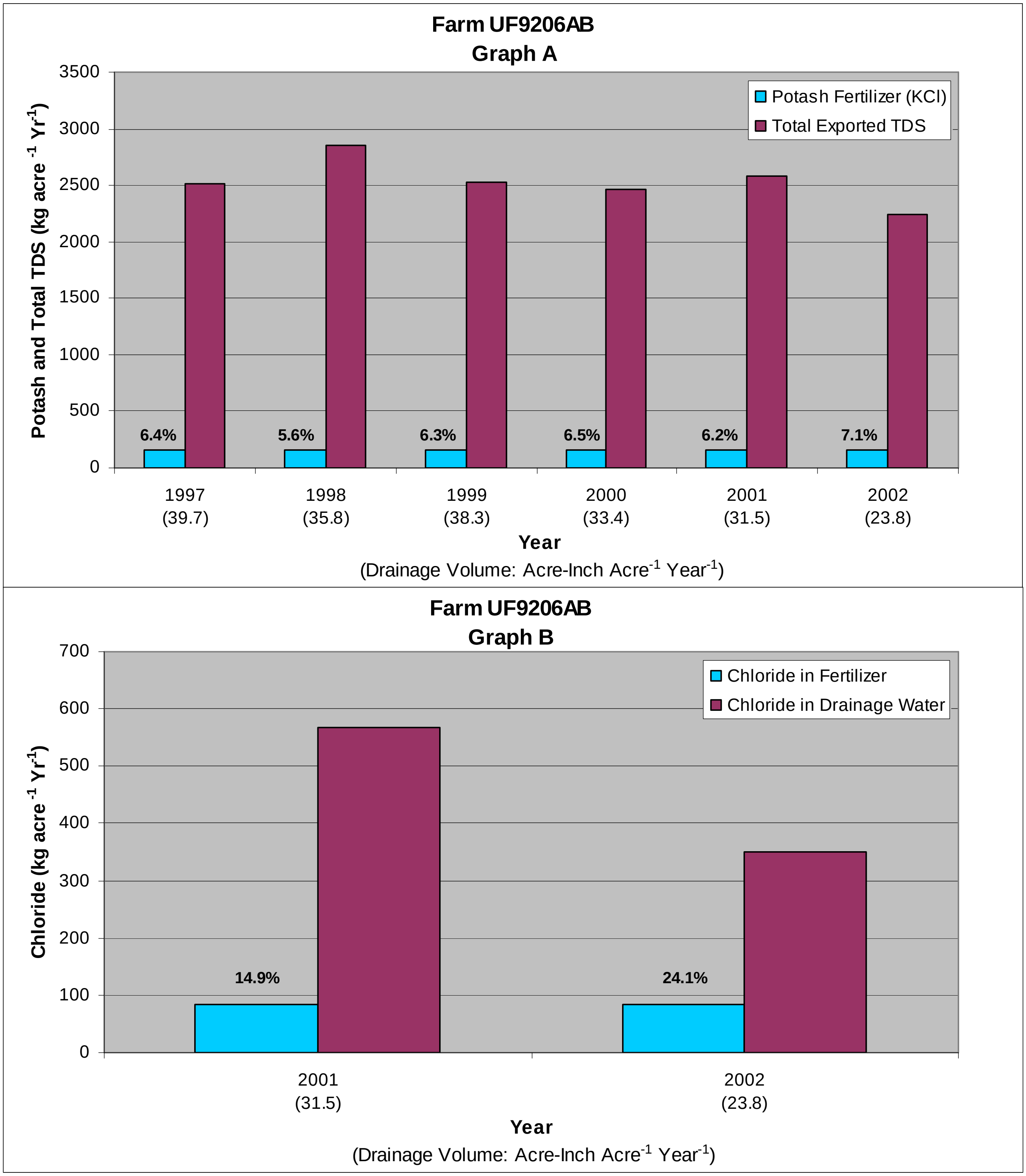
A comparison of potential Cl^- load additions from fertilizer to the TDS loads produced by farm drainage waters has been reported for vegetable, sugarcane, and cattle farms of the EAA (CH2M Hill, 1978). The comparison showed that even if the entire annual Cl^- load from fertilizer application at the highest rate of fertilization site (vegetable farm) was exported in the drainage water, the amount of Cl^- derived from fertilizer would account for less than 3% of the annual drainage water TDS loading from the farm. The Cl^- load applied to the farm through crop fertilization at the vegetable farm was reported to be 233 lbs/a for the 14-month study period (July 1976 through September 1977). The vegetable farm, located close to UF9206A&B in the current research, had a mean specific conductance value of 2.29 mS/cm during the study period (CH2M Hill, 1978).

An analysis of drainage volumes, total dissolved salts, and calculated potash fertilizer applications was conducted for the elevated specific conductance farm UF9206A&B. From 1997 through 2002 the farm planted an average of 45, 30, and 25% of its cultivated acreage to sod, cane, and leaf vegetables, respectively. By applying moderate level potash fertilization rates to each crop and multiplying fertilizer rates by the percentages planted to each crop, a mean fertilizer application rate (353 lb KCl per acre per year) was calculated for potash, the predominant and most commonly applied fertilizer at this farm and throughout the EAA. A graphical comparison between potash fertilizer application and total TDS exported by farm UF9206A&B is presented in Figure 10 (Graph A). Total TDS exported by the farm is normalized to kg per acre per year for ease of comparison with fertilizer rate. Even by assuming the unlikely scenario of total export of all fertilizer KCl via drainage water, the potential average annual contribution of applied KCl fertilizer to total TDS exported in the farm drainage water would only be 6.4%. The potential percent contribution of potash fertilizer to total TDS load varied directly with yearly drainage volume, further emphasizing the minor role of fertilizer application in farm total TDS export (and specific conductance).

Chloride is a highly mobile ion in the soils, subsurface strata, and waters of the EAA (CH2M Hill, 1978). Most plant species, however, take up Cl^- in relatively high rates. Plant tissues usually contain substantial amounts of Cl^- often in the range of 2 to 20 mg Cl/g dry weight but in the chlorophilic species Cl^- may amount to 100 mg Cl/g dry weight (Mengel and Kirkby, 2001). Anderson and Bowen (1990) report that critical level of Cl^- in sugarcane is 0.068% and toxic level is 0.5%. Assuming a Cl^- concentration in leaves of 0.3% (3 g/kg dry weight) and an average dry matter yield of 15 tons (1 ton = 2000 lbs) per acre, the uptake of Cl^- by a sugarcane crop is about 40 Kg (90 lb) per acre.

A comparison of total Cl^- from calculated potash fertilizer applications to total Cl^- exported in drainage waters was conducted for farm UF9206A&B for the calendar years of 2001 and 2002 (Figure 10 Graph B). Yearly Cl^- drainage loads were calculated from annual drainage volumes and average Cl^- concentrations of weekly water samples collected in 2001 and 2002. The comparison shows the potential relative contribution of fertilizer Cl^- to the total Cl^- exported in drainage water. Even with the implausible assumption that no fertilizer-sourced Cl^- is removed by harvested crops, the maximum potential contribution as a percentage of fertilizer-sourced Cl^- to exported Cl^- load was 14.9 and 24.1 % for 2001 and 2002, respectively. The higher percentage for calendar year 2002 was the result of greatly reduced drainage pumping due to drought. Reductions or changes in fertilizer use are not projected to have a significant impact upon mean specific conductance at this farm.

Figure 10. Potential contribution of potash fertilizer to total exported dissolved solids from farm UF9206AB (Graph A); potential contribution of Cl$^-$ from potash fertilizer to total exported Cl$^-$ (Graph B).



III. Impact of Current Load P Reduction BMPs on Specific Conductance

Current Drainage and fertilizer BMPs Impact on Specific Conductance

It was evident from the results presented in section II, that the shallow ground water mineralogy in the EAA plays the major role in determining levels of specific conductance in the EAA. Both drainage pumping and fertilizer application were shown to have either inconsistent or minimal effect on specific conductance. Correlation analysis was conducted to determine relationships between specific conductance and certain management practices. Correlation analysis does not indicate a cause and effect, but merely that a relationship exists. There is a weak correlation between monthly pump hours and specific conductance (r = 0.21), and a weak negative correlation between specific conductance and irrigation (r=-0.25) (Table 10).

The correlation analysis showing the weak relationship between specific conductance and pump hours emphasizes the conclusions we had regarding the inconsistent effect of drainage pumping on specific conductance. Farm canal specific conductance is governed mainly by the quality and the hydrology of the underlying shallow ground water, which is farm specific. Therefore the current P load reduction water management BMP of delaying drainage till ½” or 1” of rain has fallen is expected have variable effects on specific conductance.

The Fertilizer analysis provided in the pervious section illustrated that Cl from KCl fertilization at the recommended rates in the EAA comprises a small percentage of the total TDS in drainage water. It is concluded that the current soil testing/ fertilizer BMPs currently employed are adequate in maintaining low levels of ions in drainage water coming from fertilizers.

Table 10. Correlation Coefficients between Parameters Monitored for all the Sites Combined.

r value	Temp.	pH	SpCond	Diss. Oxy.	ORP[†]	Turbidity	Rainfall	Evap.	Irrigation	Pump
Temp. (°C)	1									
pH	-0.25	1								
SpCond. (mS/cm)	-0.10	-0.18	1							
Diss. Oxy. (% Sat.)	-0.28	0.69	-0.39	1						
ORP (mV)	-0.17	0.59	-0.32	0.71	1					
Turbidity (NTU)	0.06	0.05	-0.05	-0.07	-0.02	1				
Rainfall (in.)	0.54	-0.33	0.13	-0.41	-0.25	0.09	1			
Evaporation (in.)	0.56	0.02	-0.19	0.07	0.01	-0.02	0.04	1		
Irrigation (in.)	-0.20	0.27	-0.25	0.41	0.25	-0.11	-0.78	0.44	1	
Pump (hrs)	0.23	-0.31	0.21	-0.27	-0.13	0.03	0.63	-0.11	-0.53	1

[†] **ORP: Oxidation-reduction potential.**

Trends of Specific Conductance since 1997

Water quality data possess unique characteristics that may exhibit seasonal variation, which may include a seasonal fluctuant, as well as a yearly trend. This variation may be the result of a diversity of conditions, including specific agricultural land use practices, biological activity, or sources of steam flow or sediment (Lietz, 2000). To be able to ascertain the impact of current BMPs on specific conductance, trend analysis was conducted.

A trend in water quality is defined as a monotonic change in a particular constituent with time (Lietz, 2000). Historically, canal waters exhibit widely fluctuating levels of specific conductance, HCO_3^-, Ca^{2+}, nitrate, and orthophosphate rather than strong trends (Gleason, 1974). In the current study, box and Whisker plot of the yearly specific conductance data from 1997 shows a generally decreasing trend (Figure 11). In 1997, however, two farms only were being monitored and therefore the significance of this decreasing trend using ANOVA analysis is not possible.

To determine if this general yearly trend decrease is significant, non-parametric Mann Kendall trend analyses, and Sen's slope analyses were conducted for each site separately (Table 11). The non-parametric Mann-Kendall trend analysis (p values less than 0.05) confirmed statistically significant downward trends in specific conductance at UF9202A, UF9205A and UF9207B (Table 11). Sen's non-parametric estimator of slope analysis indicates reduction rates of specific conductance at UF9202A, UF9205A and UF9207B are at 4.32, 33.5, and 5.00 µS/cm per year, respectively (Table 11). A statistically significant upward trend in specific conductance at UF9208A was also detected using the non-parametric Mann-Kendall trend analysis (p values less than 0.05). However, the upward trend is not significant using the Sen's non-parametric estimator of slope analysis.

To visually show the trends, monthly averages of specific conductance over the entire monitoring period were plotted with time. A time series line generated by SAS ® (SAS, 1999) was also plotted (Figures 12 through Figure 23). The figures show the downward trend at the previously mentioned three farms. With the exception of UF9208A, all other farms show no change in specific conductance. Although UF9201A showed visually a downward trend (Figure 13), this trend was not significant due to the variability of the data. In summary, the trend analysis presented in this section demonstrates that a downward yearly trend of specific conductance is obvious in three out of the ten farms monitored. This is an indication that current P load reduction BMPs have had a positive effect on specific conductance on some farms in the EAA.

Figure 11. Plot of Average Monthly Specific Conductance (SpCond, mS/cm) from all sites combined by Year.

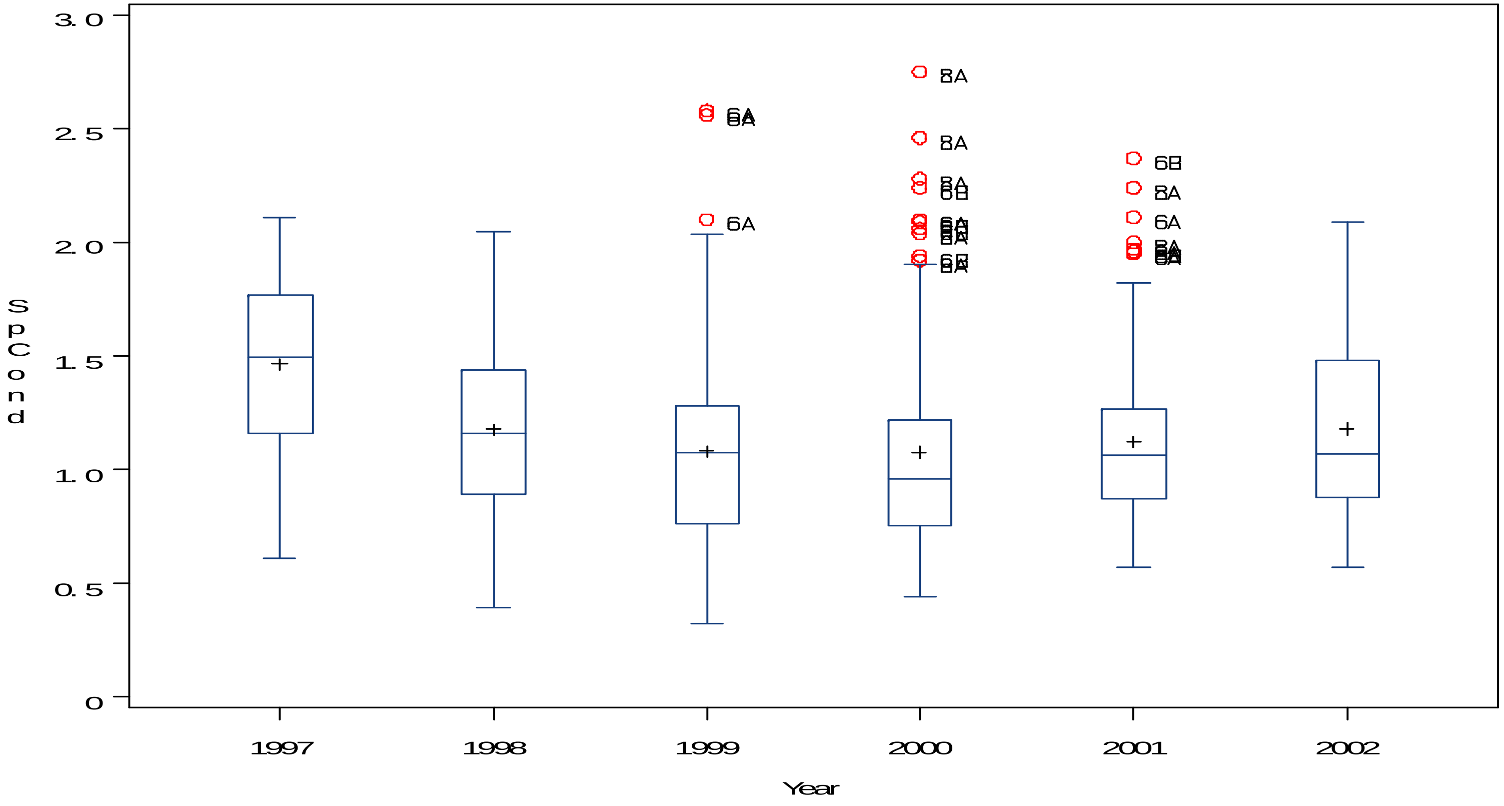


Table 11. Non-Parametric Mann-Kendall Trend Analysis and Sen's Slope Analysis of Specific Conductance by Site.

Site	Mann-Kendall Test		Sen's Slope Analysis	
	Z-score (µS/cm)	95% confidence level	Estimator median Q (µS/cm)	90% confidence level
UF 9200A	-0.78	No trend	-1.21	No trend
UF 9201A	-0.37	No trend	-6.74	No trend
UF 9202A	-4.08	Downward trend	-4.32	Downward trend
UF 9203A	0.05	No trend	0	No trend
UF 9204A	-1.01	No trend	-3.08	No trend
UF 9205A	-4.62	Downward trend	-33.5	Downward trend
UF 9206A	-0.82	No trend	-1.82	No trend
UF 9206B	-0.52	No trend	-1.18	No trend
UF 9207A	-0.51	No trend	-0.77	No trend
UF 9207B	-1.86	Downward trend	-5.00	Downward trend
UF 9208A	1.73	Upward trend	+7.26	No trend
UF 9209A	1.06	No trend	+2.32	No trend

Figure 12. Time Trend of Specific Conductance at UF9200A.

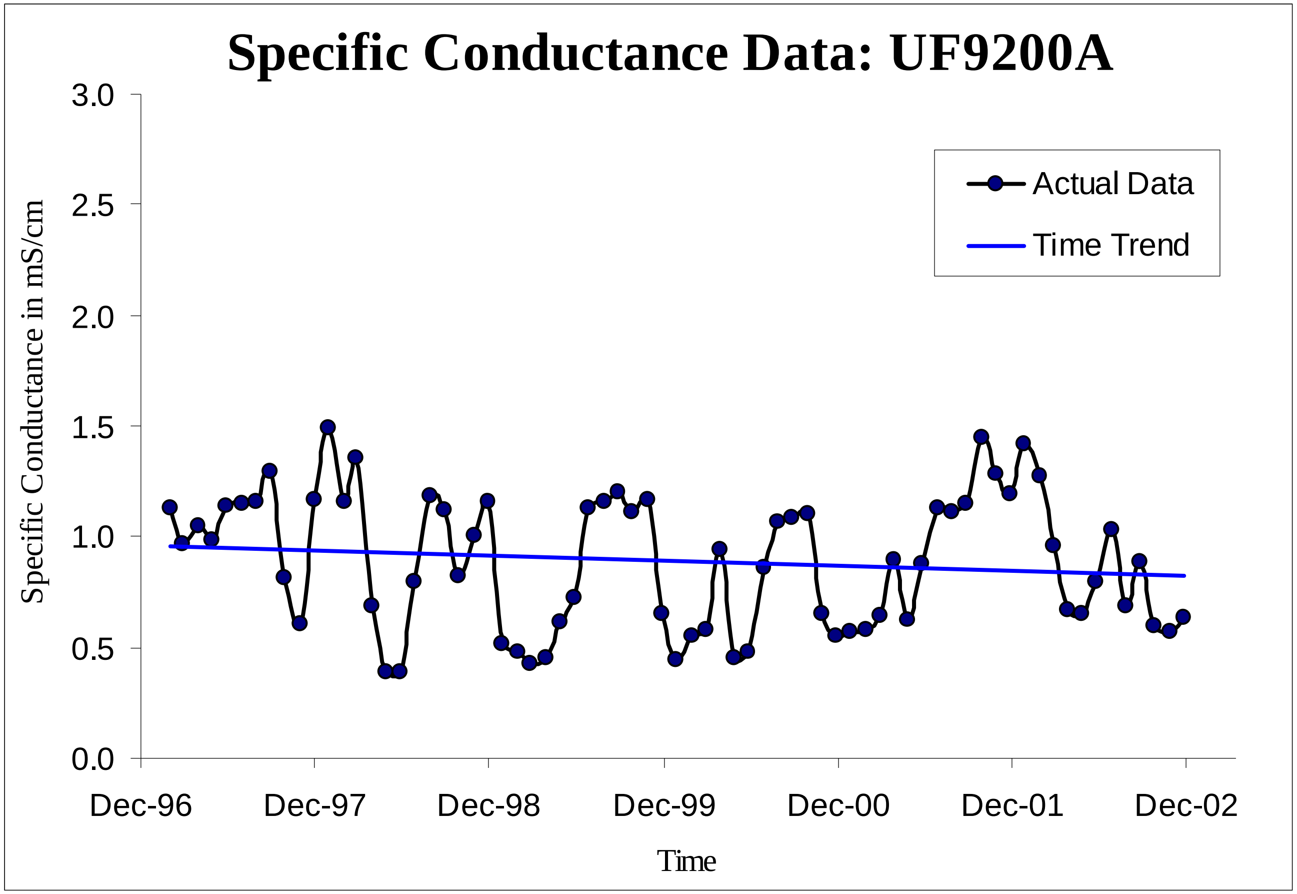


Figure 13. Time Trend of Specific Conductance at UF9201A.

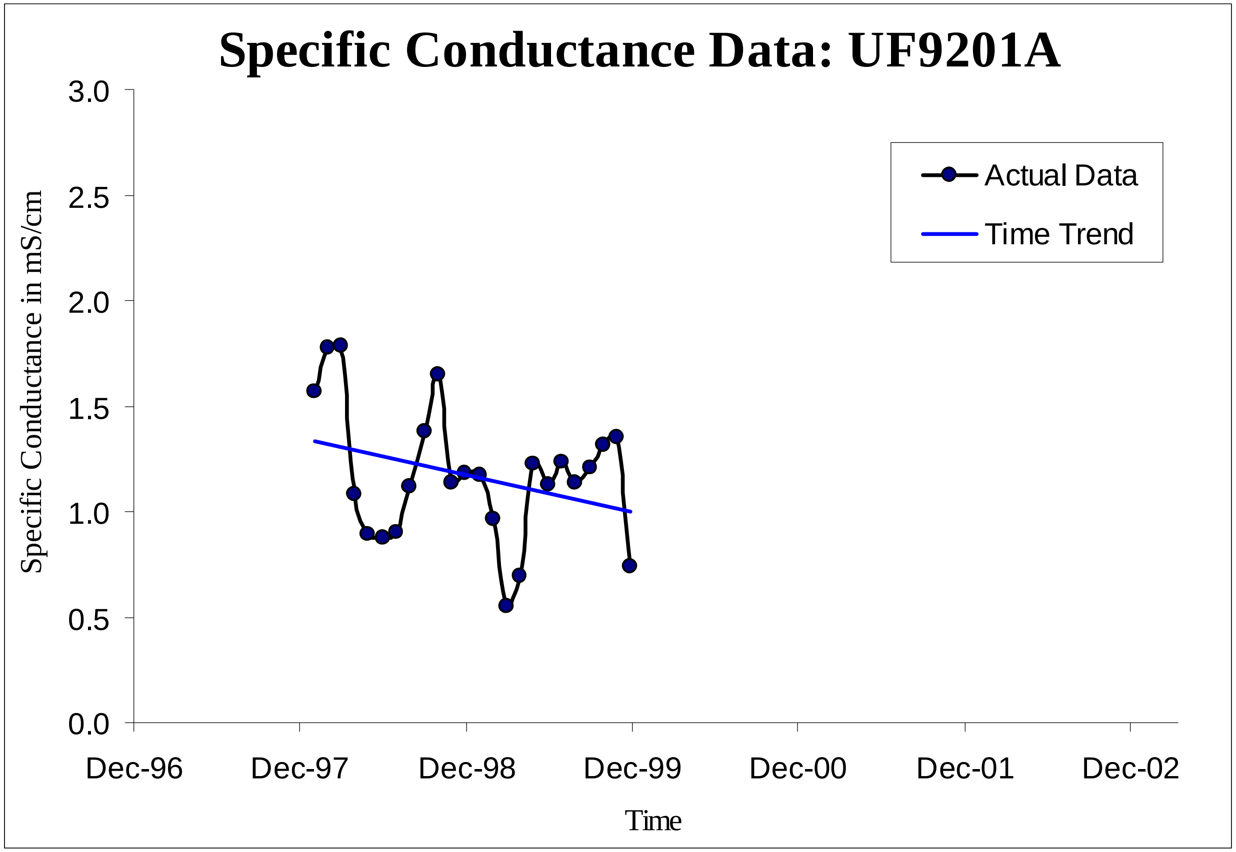


Figure 14. Time Trend of Specific Conductance at UF9202A.

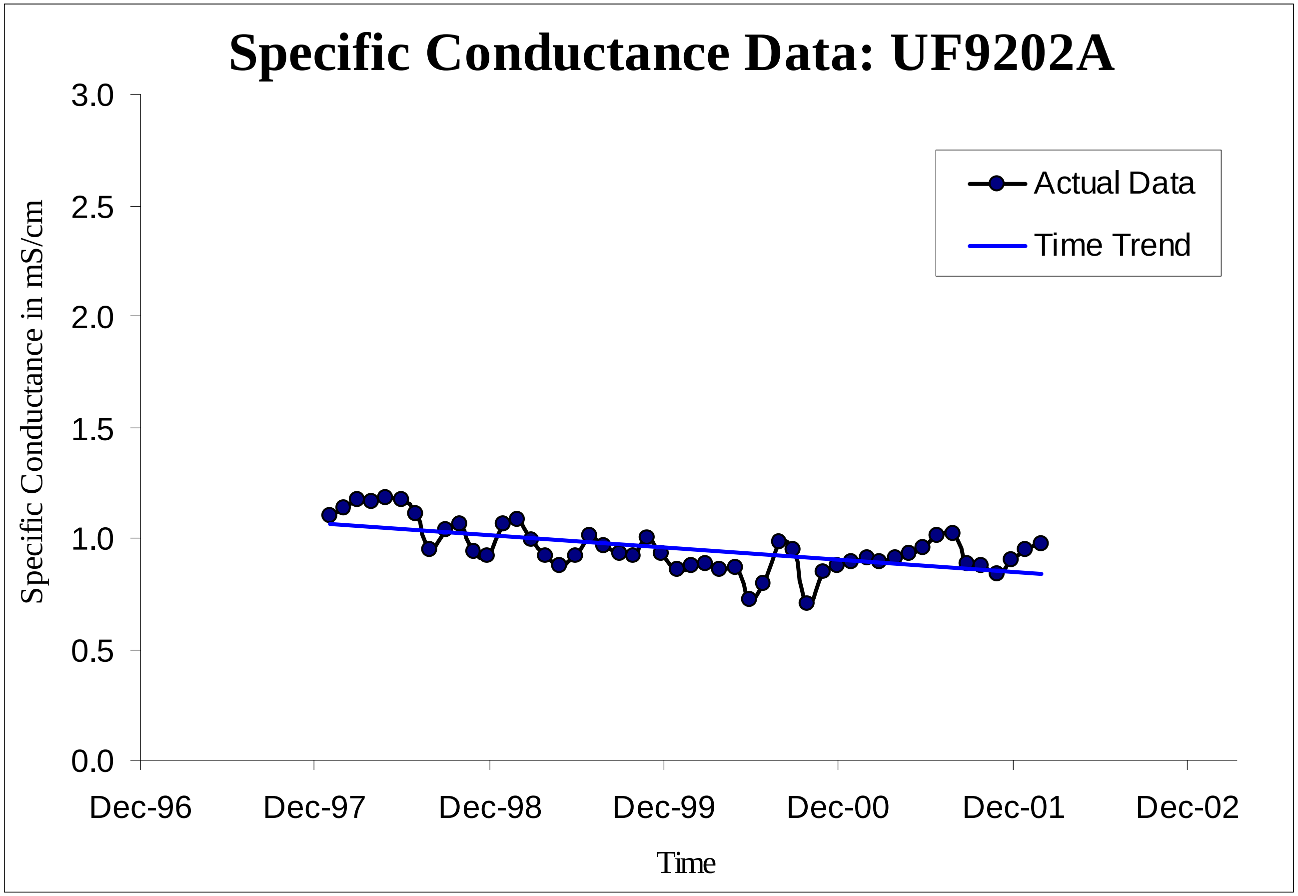


Figure 15. Time Trend of Specific Conductance at UF9203A.

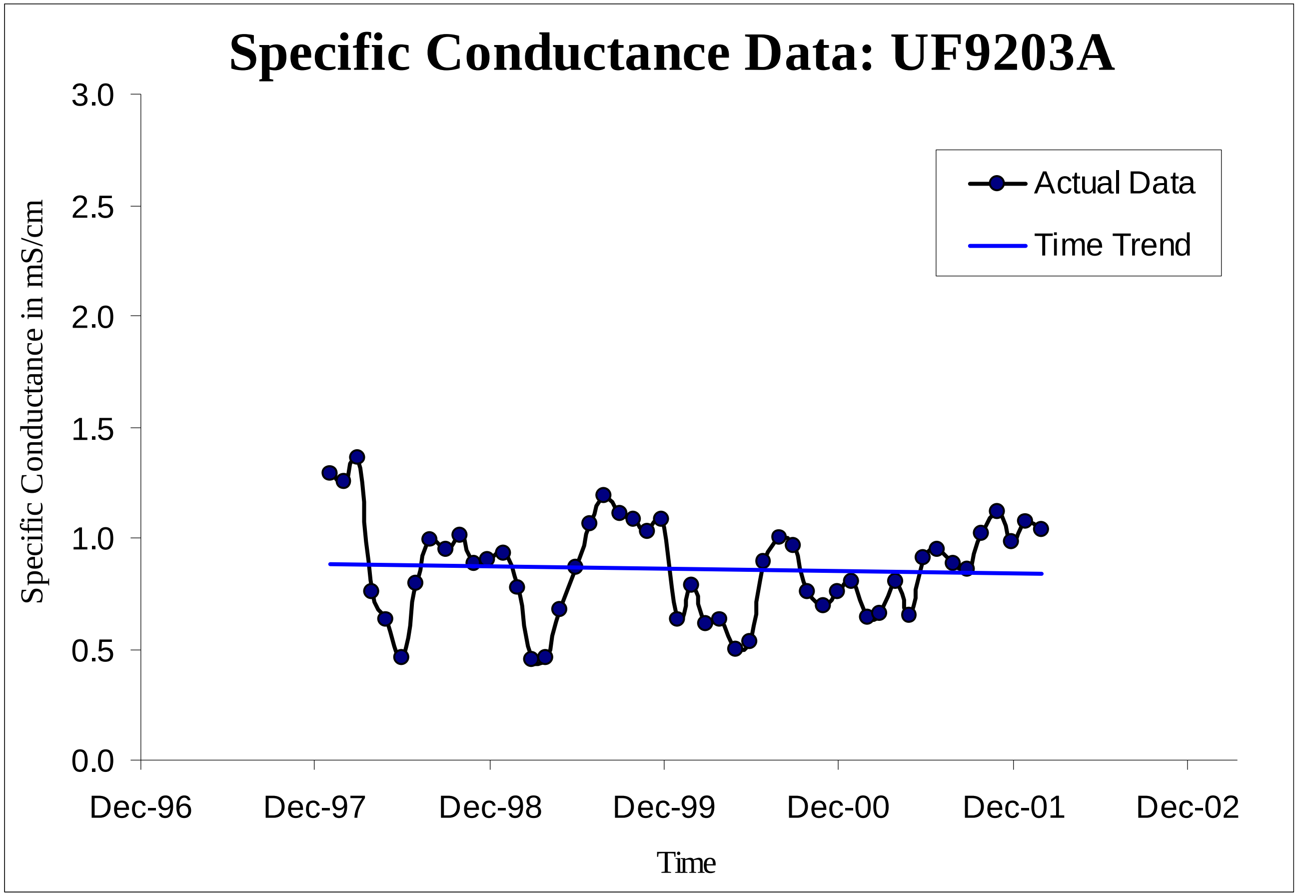


Figure 16. Time Trend of Specific Conductance at UF9204A.

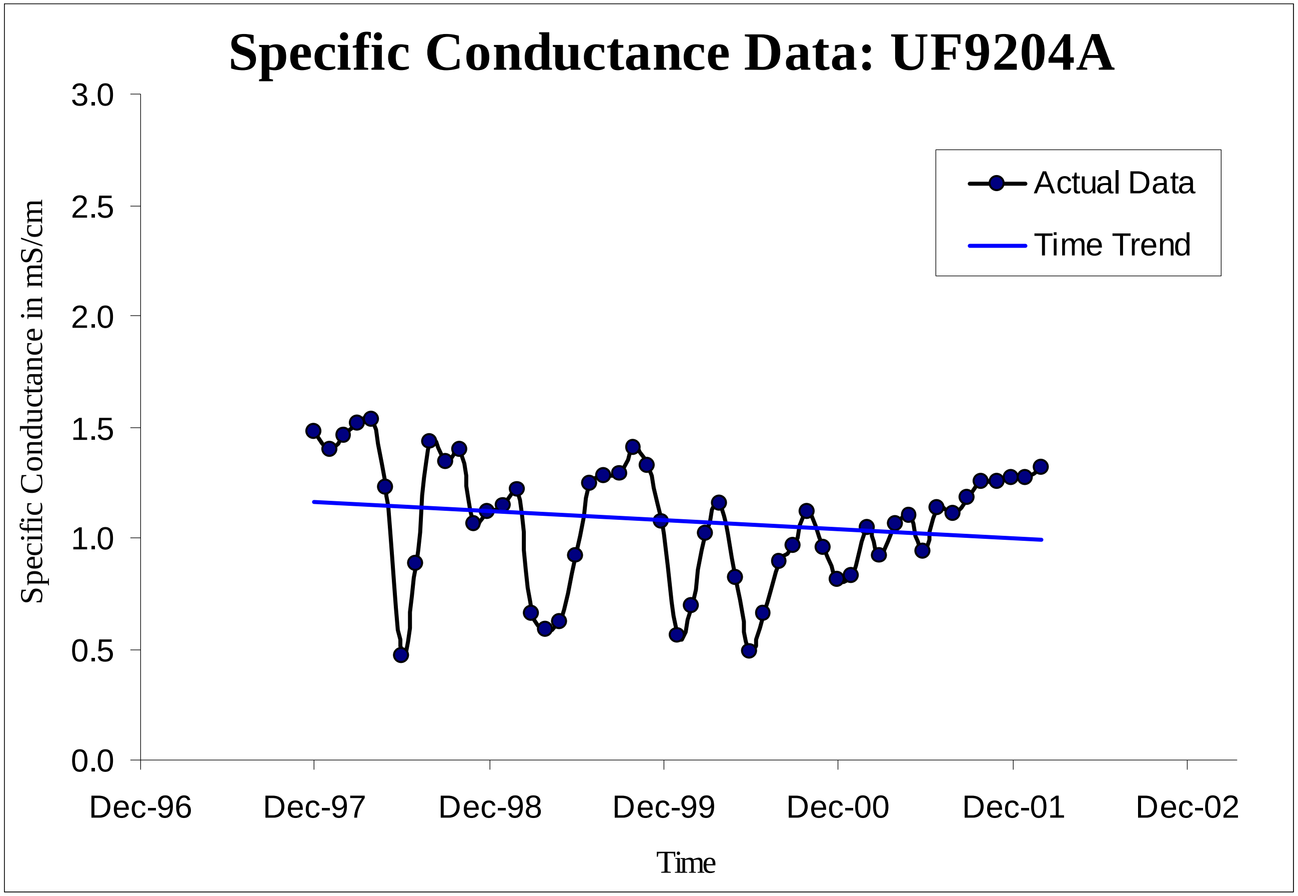


Figure 17. Time Trend of Specific Conductance at UF9205A.

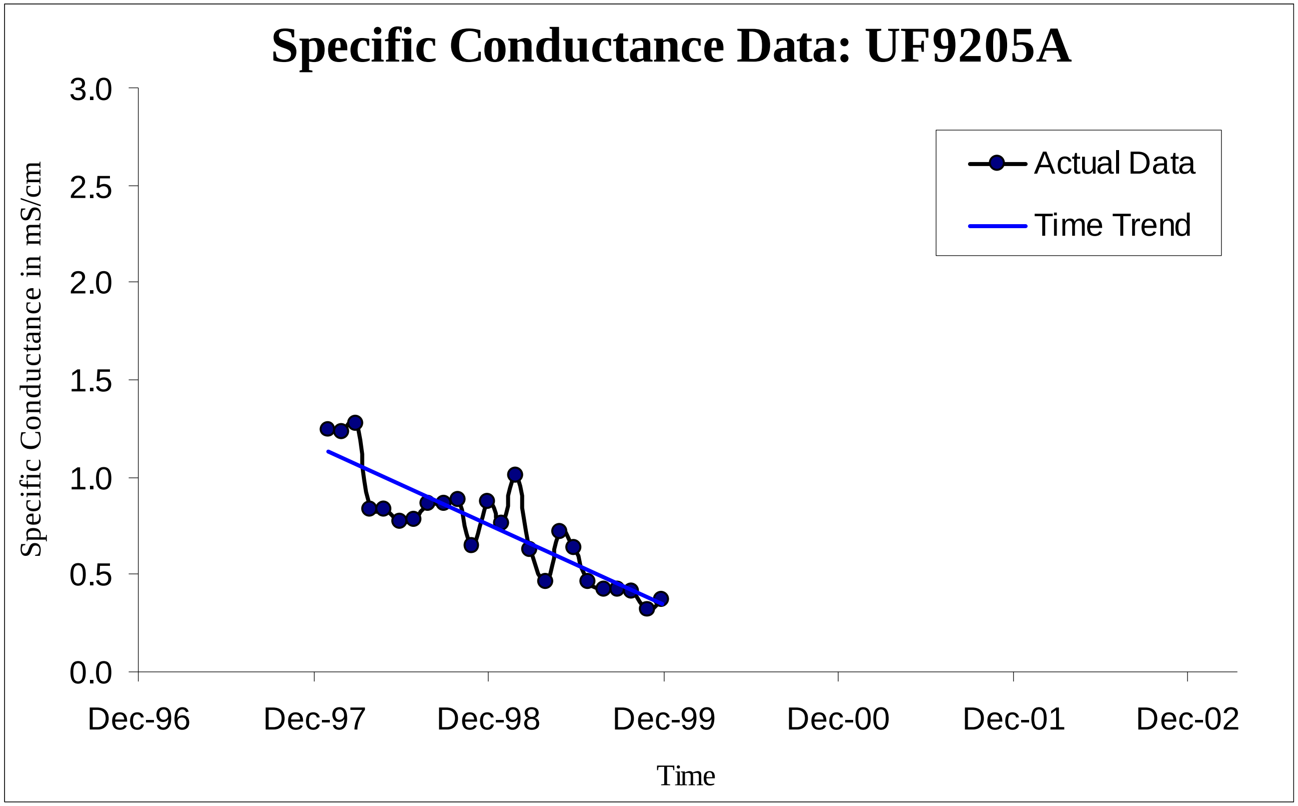


Figure 18. Time Trend of Specific Conductance at UF9206A.

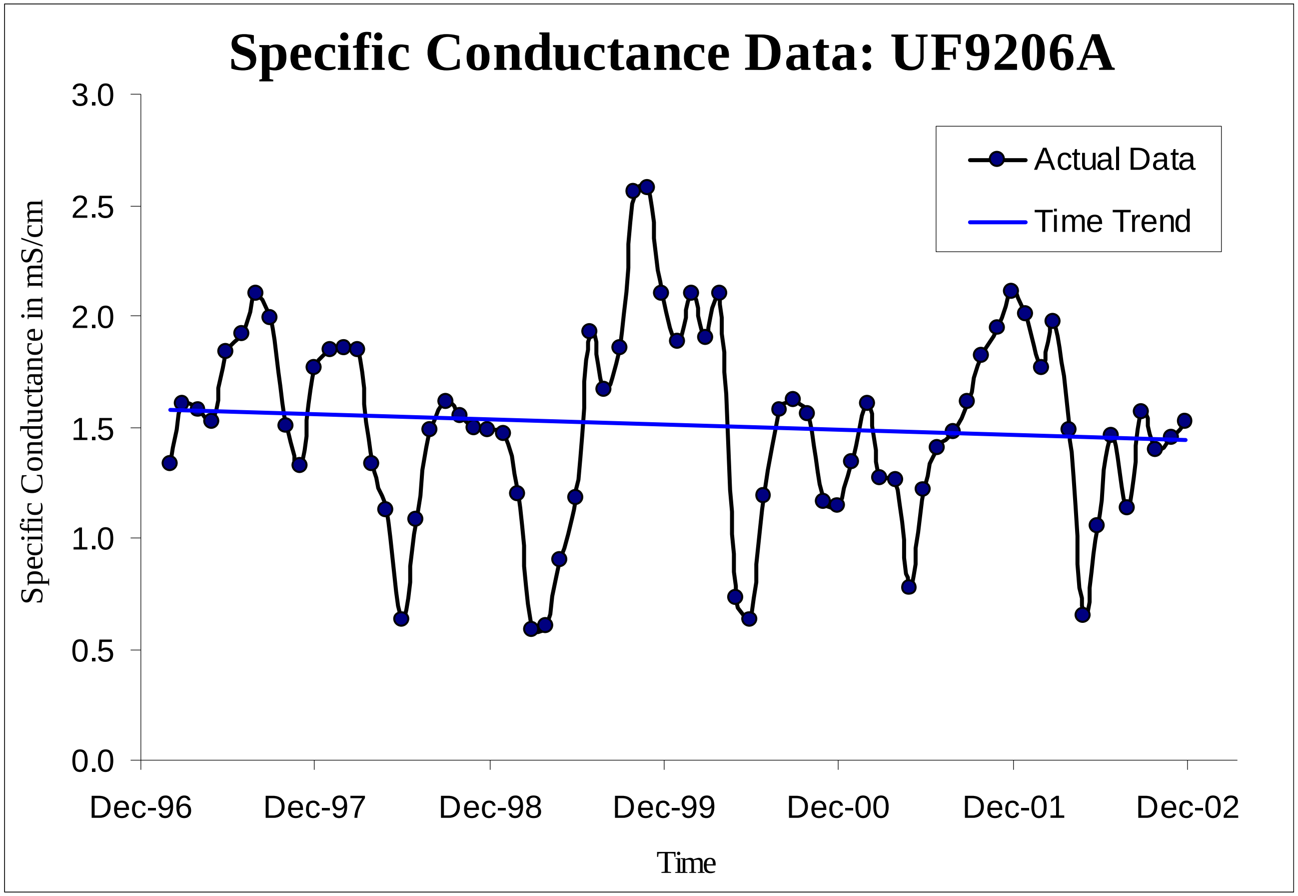


Figure 19. Time Trend of Specific Conductance at UF9206B.

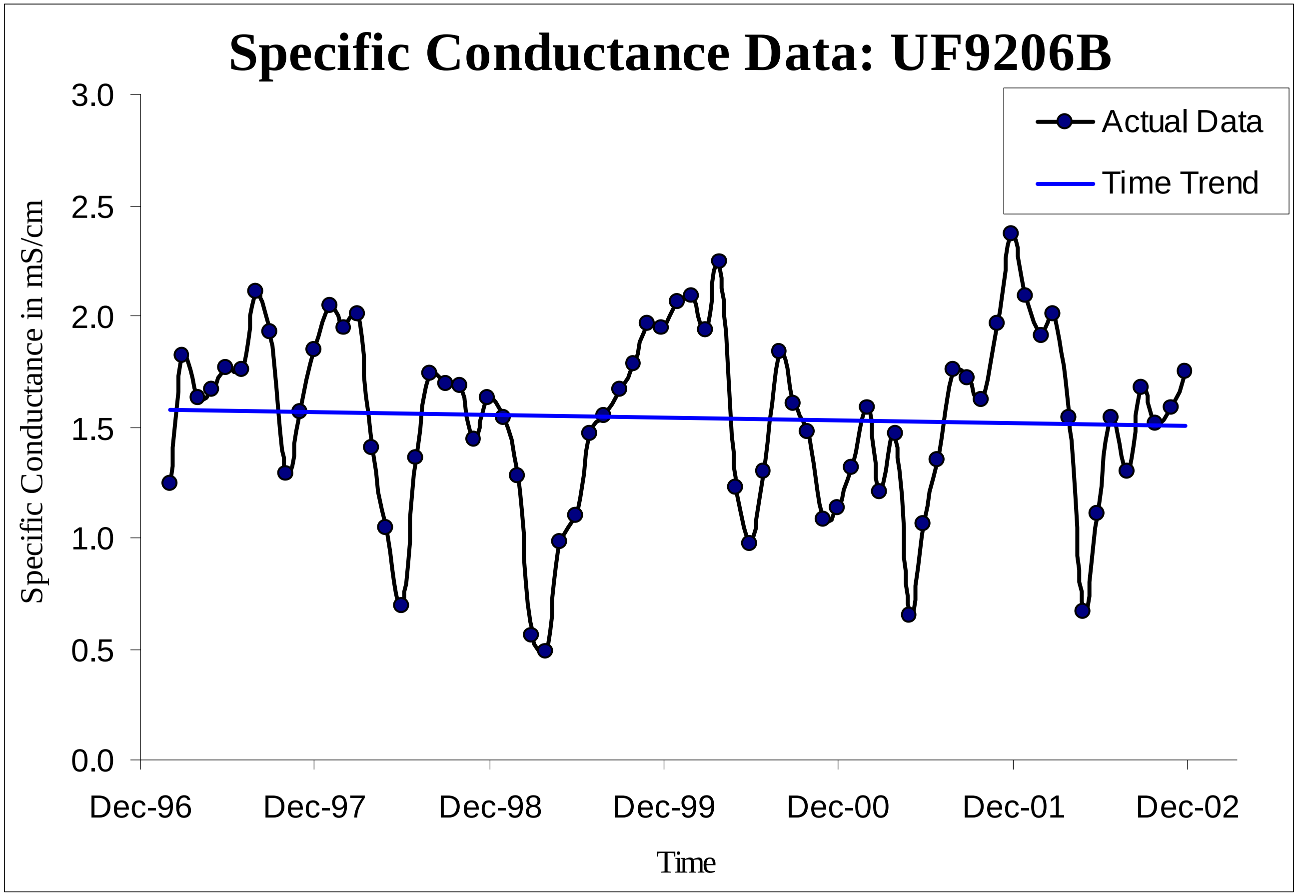


Figure 20. Time Trend of Specific Conductance at UF9207A.

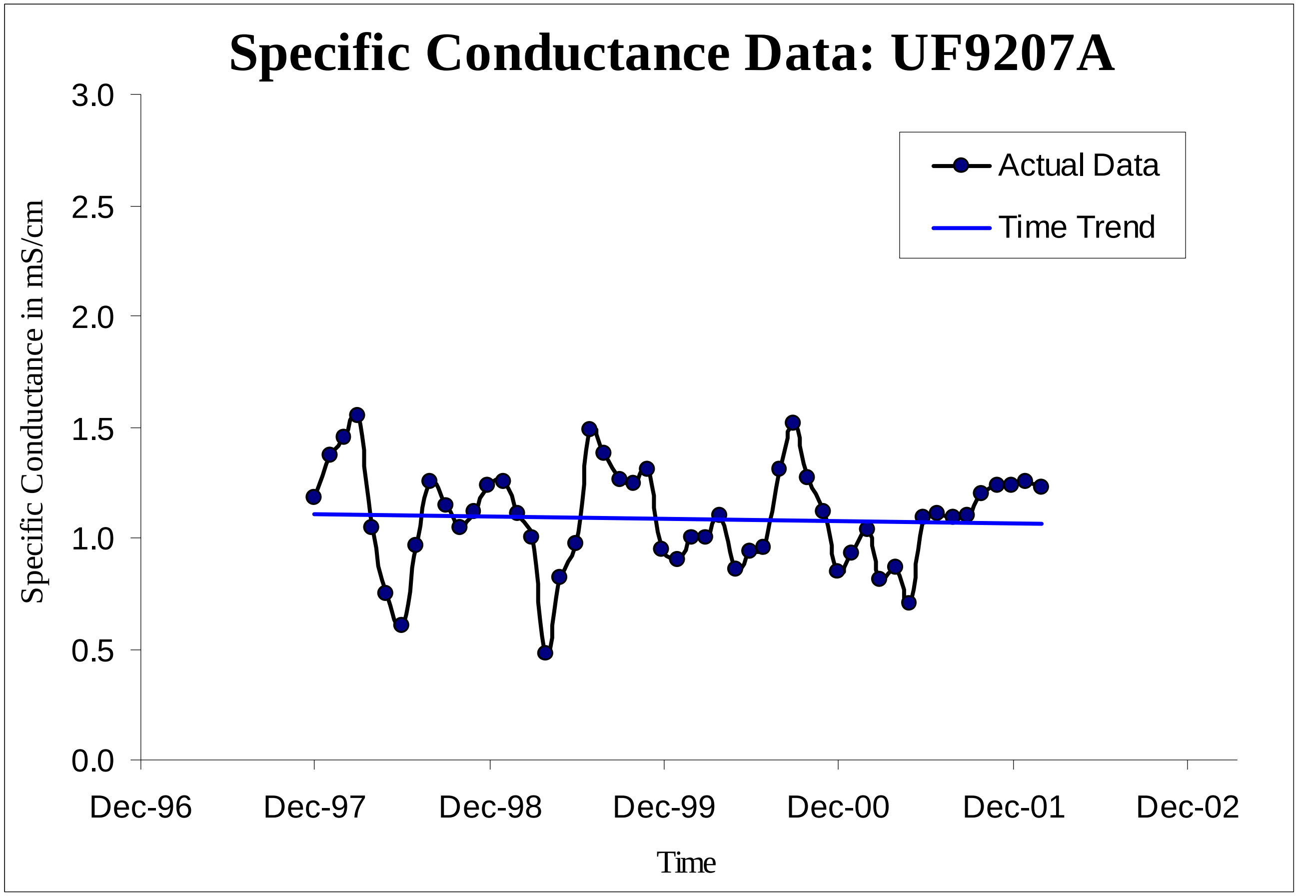


Figure 21. Time Trend of Specific Conductance at UF9207B.

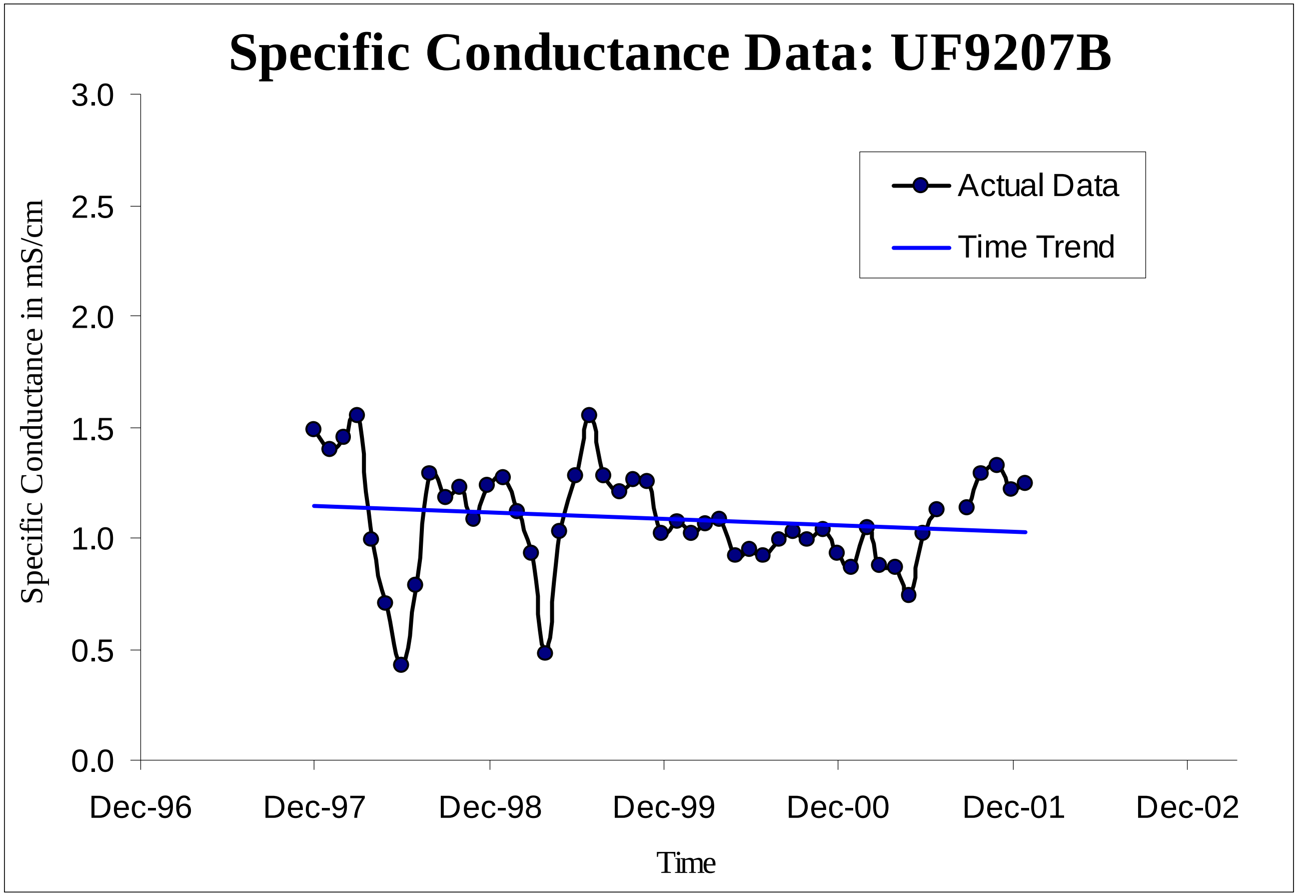


Figure 22. Time Trend Of Specific Conductance at UF9208A.

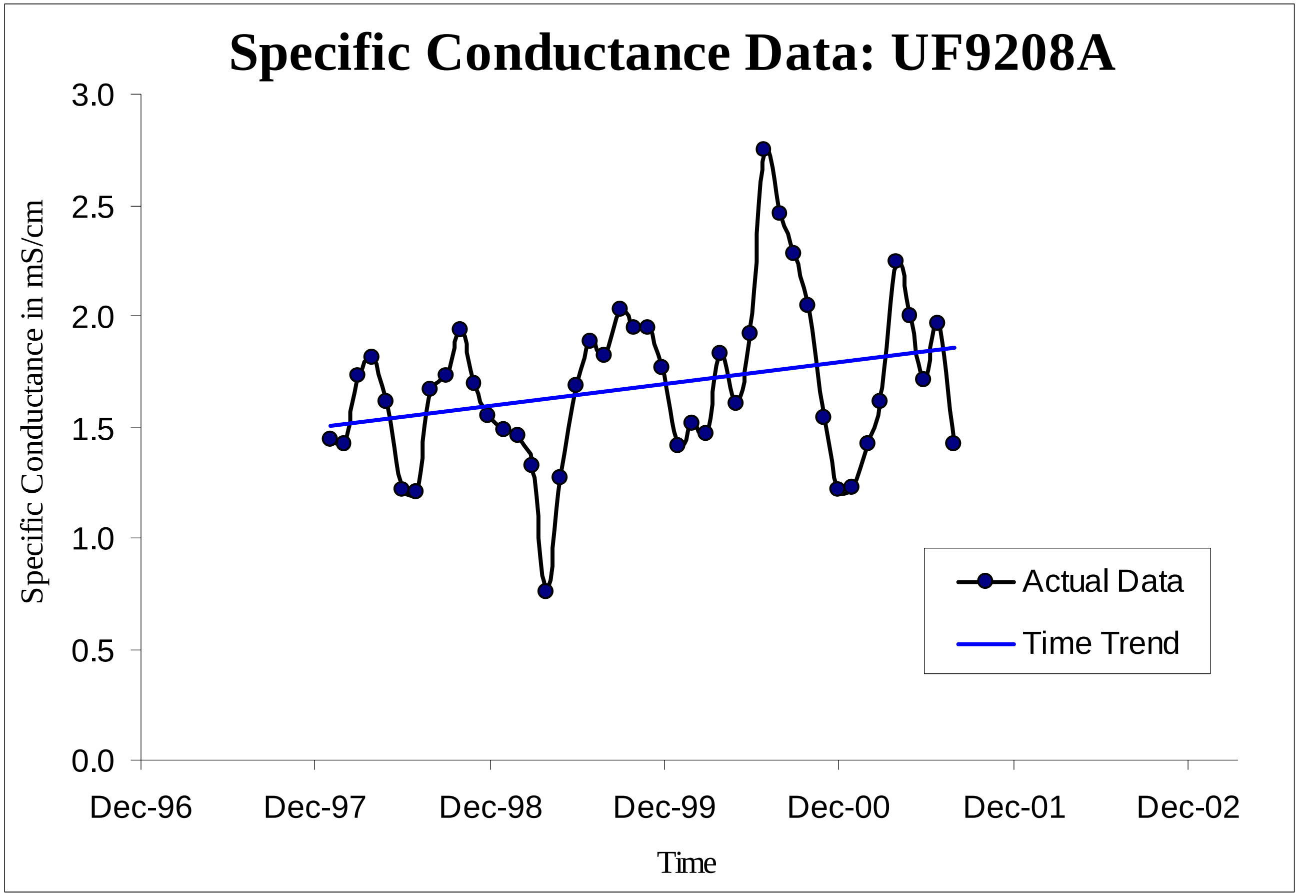
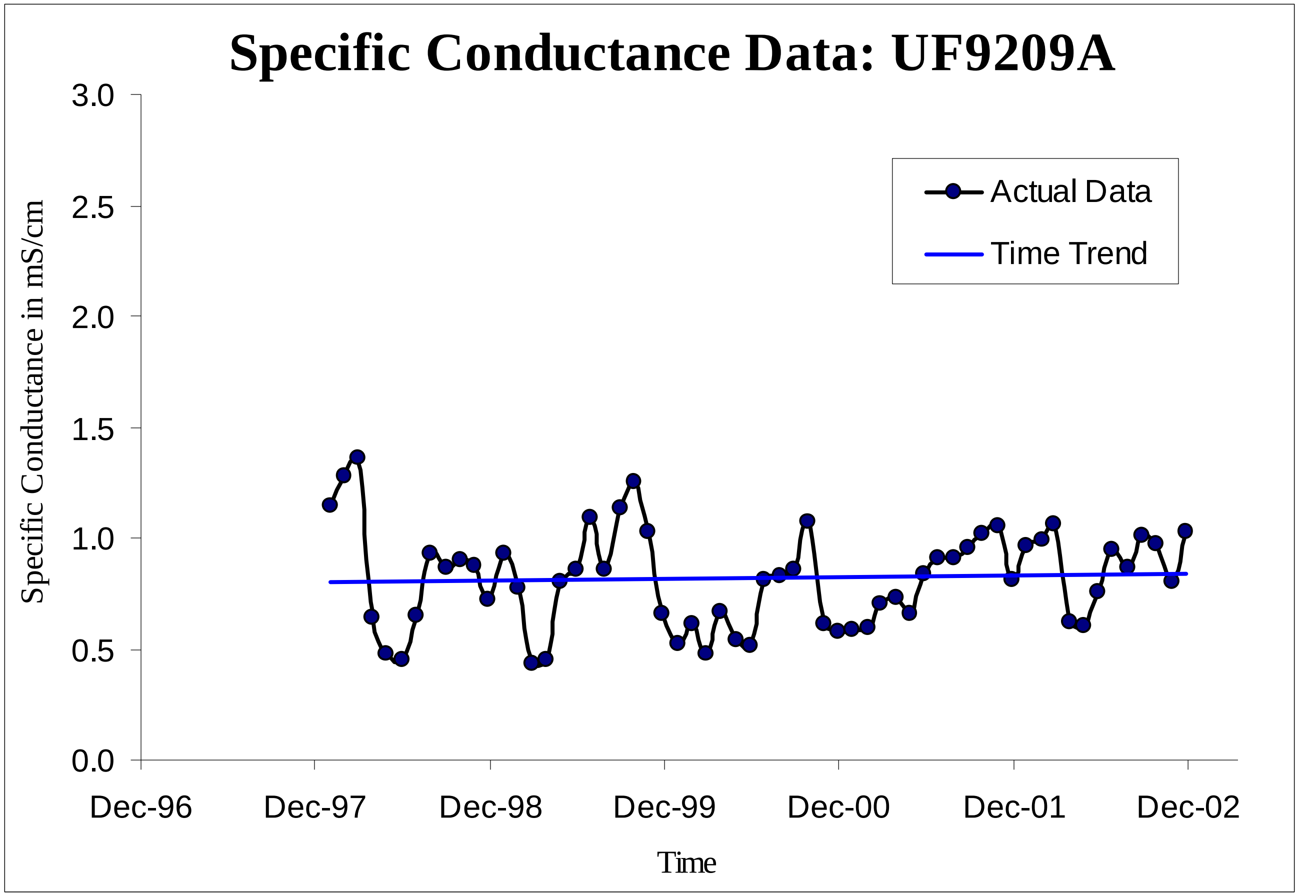


Figure 23. Time Trend of Specific Conductance at UF9209A.



DISCUSSION

Best management practice or “BMP” means a practice or combination of practices determined by the district, in cooperation with the department, based on research, field-testing, and expert review, to be the most effective and practicable, including economic and technological considerations, on-farm means of improving water quality in agricultural discharges to a level that balances water quality improvements and agricultural productivity (373.4592 section 2 of the F.A.C.).

The questions that this study aimed to address are the following: is the high specific conductance in the EAA man-induced, and can it be abated by additional BMPs? The quality and hydrology of the shallow aquifer are the major factors controlling specific conductance in the EAA. High specific conductance in the EAA is a natural phenomenon. High levels of specific conductance and Cl^- concentrations in shallow wells in the EAA have been documented in 1948 and 1955, before the advent of major agricultural operations in the area. High conductance levels in the EAA canals are due to the mixing of surface and ground water, as many of the canals in the EAA are dug into the limestone. Elevated specific conductance is historically attributed to Na^+ and Cl^- ions that are sourced from saline water of the shallow aquifer. The levels of Na^+ and Cl^- concentrations and the Na/Cl ratio found in the EAA canals are a strong indication that the source of these ions is ancient sea water.

Because the ions that are contributing to increased specific conductance in the EAA are sourced from ancient saline water entrapped in the Everglades formation, the current management practices employed by EAA farmers to reduce P loads were found to have minor effects on abating specific conductance. Lower specific conductance trends were observed in three out of the ten farms monitored, and with no adverse impacts on the other farms with the exception of one.

Drainage pumping and fertilizer application were the two major management practices that we investigated that may lead to high specific conductance. It was shown that although specific conductance is the highest during the high rainfall months of the year, the effect of drainage pumping is inconsistent and site-specific. Specific conductance was not related to the drainage pumping to rainfall ratio. For example, one farm that had the lowest drainage pumping to rainfall ratio had the highest specific conductance among the ten farms. Canal specific conductance is governed mainly by the quality and the hydrology of the underlying shallow ground water, which is farm specific. Farm canal water appears also to be influenced to a lesser degree by the quality and the quantity of irrigation water it receives. The irrigation water that flows into the high specific conductance farms in this study was also characterized by high specific conductance.

One of the potential sources of high specific conductance that was mentioned in the literature is fertilizer application. We investigated this claim and found this to be false. Using data from one of our mixed crops farm that had high specific conductance values, the contribution of KCl fertilization to the total TDS export was negligible. This contribution was less than 6.5% of the total TDS exported in the drainage water assuming that all the KCl fertilizer applied ended up in the drainage water. This of course will never be the case as EAA crops take up large amounts of K^+ and Cl^-. Sugarcane, for example, removes about 40 Kg Cl /acre (90 lb Cl/acre) at harvest. Chloride is an essential element for crops.

Keeping the BMP definition in mind, it is the conclusion of this study that no further BMPs can be identified by additional research that would provide abatement of specific conductance for farm discharge waters of the EAA. The currently employed P load reduction BMPs have reduced specific conductance slightly at three out of the ten farms, but we conclude that further BMPs that target specific conductance will not be effective or practical. The issue of specific conductance is a geological problem in the EAA and additional farm management practices will have minimal effect on specific conductance.

CONCLUSIONS

Specific conductance was monitored at ten representative farms in the EAA and ion composition was determined in grab samples from eight of the ten farms. The specific conductance monitoring started in 1997 and continues through 2004 for three farms. The sampling for ion composition was conducted on a weekly basis in 2001 and 2002.

Historical data on specific conductance in South Florida waters, including the EAA, showed wide variability. Data obtained from the SFWMD showed high specific conductance in EAA wells. Main canals in the EAA showed variable and often high specific conductance levels. The factors reported in the literature that affect conductance in the EAA conveyance canals included groundwater composition, agricultural farm drainage, active dissolution of the underlying bedrock, and the effects of Lake Okeechobee water. Saline waters left by ancient sea invasions are present in the underlying formation of the Everglades.

Specific conductance was not an issue in the majority of the EAA farm canals monitored. Out of the ten farms that were monitored, only two had average specific conductance higher than 1.275 mS/cm. Higher levels of Na^+ and Cl^- were observed at the two elevated specific conductance farms. Of the two farms, one also contained higher concentrations of SO_4^{2-} ions. Ion composition data confirmed that the ions determining specific conductance in the EAA waters are Na^+, Ca^{2+}, HCO_3^-, Cl^- and SO_4^{2-}. The Na/Cl ratio in most of the EAA canals approximated the ratio of seawater (0.55). This was a strong indication that the source of the salts is from connate seawater entrapped in ground water and not from agrochemicals.

Relationships between specific conductance, geographical influences, and management practices were explored. Shallow ground water quality plays a major role in the elevated specific conductance in some of the EAA farm canals. Historical data showed elevated concentration of Cl^- and high specific conductance in shallow ground water in the EAA. One farm with an elevated specific conductance level, UF92008A, is located in an area of shallow wells of reported Cl^- concentration range of 201-500 mg /L. This farm is also influenced by the Hillsboro canal, which historically has had high conductance and high levels of Na^+ and Cl^-. The second farm with high specific conductance level, UF9206A&B, is also in an area of shallow wells that have had concentrations of up to 400 mg/L of Cl^- reported. The irrigation water flowing into these two farms (UF9206A&B and UF9208A) is characterized by higher specific conductance.

The effect of drainage pumping on specific conductance was also investigated. There was a weak correlation between specific conductance and pump hours. This drainage pumping effect was variable and site specific. For example, at UF9206A&B drainage pumping did not affect specific conductance. Drainage event analysis on the two elevated specific conductance farms demonstrated the variable effect of drainage pumping and strengthened the conclusion that specific conductance in farm canals is strongly influenced by the underlying ground water hydrology and quality. In addition, farm drainage volume pumped to rainfall ratio had little or no effect on farm canal specific conductance. So, the current P load reduction BMP of delaying pumping until an accumulated ½” to 1” of rain has fallen may help or have no influence on mitigating increased conductance levels in the EAA farm canals.

Irrigation had a weak negative correlation with specific conductance. On the three intensely monitored farms, UF9200A, UF9206A&B, and UF9209A, irrigation had the effect of decreasing specific conductance. Sites that received irrigation water directly from low specific conductance district canals (Miami and North New River canals) had lower mean specific conductance values. Sites that received irrigation water from district canals with relatively higher specific conductance (Ocean and Hillsboro canals) had relatively higher mean specific conductance values. It was also evident that the sites that did not receive irrigation water directly from main conveyance canals, but received irrigation water via secondary or branch canals had relatively higher mean specific conductance values.

The literature suggests that the effect of fertilization is negligible on the specific conductance in the farm canals. It was reported that even if the entire annual Cl^- load from fertilizer application on vegetables was exported in the drainage water, the amount of Cl^- derived from fertilizers in the farm canals would account for less than 3% of the annual drainage TDS loading from the farm. It has also been reported in the literature that the sugarcane crop takes up more P and K than applied by ferilizers. In our analysis, Cl^- from KCl fertilization contributed less than 6.5% of the annual drainage TDS loading from one farm with elevated specific conductance assuming the highly unlikely scenario that all of the KCl fertilization ends up in the drainage water. Crops take up a lot of Cl^- and in the case of sugarcane, an average of 90 lb of Cl^- per acre is taken up.

Yearly trend analysis, conducted on each site over the monitoring period of each site, showed a decreasing trend of specific conductance in three farms and an upward trend in one farm. The full implementation of farm level BMPs in the EAA in 1995 may have contributed to the improvement of water quality by reducing specific conductance in canal water at these three farms (UF9202A, UF9205A and UF9207B).

No further BMPs were tested as it was concluded that specific conductance is not a farm management problem, but a geological one. It is the conclusion of this study that no further BMPs can be identified with additional research. Ground water in the EAA is highly mineralized and has high specific conductance values. As many of the canals are dug into the limestone, mixing of surface and ground water occurs and leads to increases of specific conductance. Specific conductance is attributed to certain ions that are sourced from saline water of the shallow aquifer. Drainage pumping could be a factor leading to the high specific conductance in some of the farm canals in the EAA depending on location and the specific conductance of the ground water wells. The currently employed water management BMPs are mitigating the problem as much as can be accomplished given the geological presence of a highly mineralized shallow aquifer.

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