Restoration Strategies Regional Water Quality Plan – Science Plan for the Everglades Stormwater Treatment Areas:

Evaluation of the Influence of Canal Conveyance Features on STA and FEB Inflow and Outflow TP Concentrations

Supporting Information for Canal Evaluations

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Prepared by:

Hongying Zhao, Ph.D., P.E., Tracey Piccone, P.E., and Orlando Diaz, Ph.D.
South Florida Water Management District

and

Tetra Tech, Inc.
759 South Federal Highway, Suite 314
Stuart, FL 34994

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BACKGROUND

To address water quality concerns associated with existing flows to the Everglades Protection Area (EPA), the South Florida Water Management District (SFWMD or District), Florida Department of Environmental Protection (FDEP), and United States Environmental Protection Agency (USEPA) engaged in technical discussions starting in 2010. The primary objectives were to establish a Water Quality Based Effluent Limit (WQBEL) that would achieve compliance with the State of Florida's numeric total phosphorus (TP) criterion in the EPA and to identify a suite of additional water quality projects to work in conjunction with the existing Everglades Stormwater Treatment Areas (STAs) to meet the WQBEL. The National Pollutant Discharge Elimination System (NPDES) and Everglades Forever Act (EFA) watershed permits and associated Consent Orders also require that the District develops and implements a science plan to enhance the understanding of mechanisms and factors that affect phosphorus treatment performance, particularly those that are key drivers to performance at low TP concentrations [< 20 micrograms per liter, or µg/L, or parts per billion (ppb)]. The Restoration Strategies Regional Water Quality Plan for the Everglades Stormwater Treatment Areas (Science Plan; SFWMD, 2013a) is being implemented to investigate critical factors that influence phosphorus (P) treatment performance. It was developed in coordination with key state and federal agencies and experts and was designed to increase the understanding of factors that affect treatment performance; in particular, factors that affect performance at low TP concentrations (< 20 µg/L). The findings from these studies are intended to be used to inform design and operation of other Science Plan projects, which will ultimately help improve the District's capabilities to manage TP in the STAs for achievement of the WQBEL.

Surface water TP concentrations have been observed to change along canal reaches between STA inflow pump stations and inflow structures at the upstream end of the flow-ways. Several mechanisms could drive these changes. Total suspended solids (TSS) are a component of stormwater and are present in STA inflow and outflow canals. Particulate and soluble P may sorb to suspended solids and settle in these canals. High flow velocities can induce sediment resuspension, resulting in elevated TP in inflow water or elevated TP in the outflow collection canals. During severe droughts, water levels in some canals are significantly lowered to the extent that portions of the canal sediments are exposed. When reflooded, mineralized sediment P may be released to the overlying water column, which could also influence the water TP concentrations observed at the inflow and outflow structure sampling locations. Stagnant canal segments may allow excessive phytoplankton growth and settling of organic material that decomposes and removes dissolved oxygen. Anaerobic conditions at the sediment-flood water interface could trigger release of soluble P. Seepage of water into or out of STA canals to or from adjacent water bodies might also be a contributing factor in changes in surface water TP concentration. All these factors may contribute to TP concentration changes along canals.

In support of the Evaluation of the Influence of Canal Conveyance Features on STA and Flow Equalization Basin (FEB) Inflow and Outflow TP Concentrations Study (Canal Study) under the Science Plan, a literature review, review of canal configuration documents (record drawings and operation plans) and data query efforts were conducted. This report summarizes this information. The information contained in this report will support analyses conducted for the canals listed below:

- STA-1E Discharge Canal
- STA-1 Inflow Basin Canal between S-5A and G-302
- STA-1W Discharge Canal
- STA-2 Inflow and Supply Canal
- STA-2 Discharge Canal, and
- STA-3/4 Inflow and Supply Canal

PART I: LITERATURE REVIEW

This literature review was conducted in support of the Canal Study under the Science Plan. The information reviewed relates to topics such as canal conveyance, suspended sediment transport, nutrient transport, nutrient sediment flux, and sediment control measures, which help us to better understand the role of STA canals in P transport. Information gained from this review will also be useful to gain knowledge on analytical and data collection methods (statistical analysis, modeling approaches, and sediment sampling) for future study tasks.

Over fifty documents were reviewed during the literature review. The results of the literature review were divided into three main headings, Transport, Field Assessment, and Best Management Practices (BMPs), as presented in the following summaries.

TRANSPORT

Sediment Transport

Sediment transport is a critical factor in predicting contaminant transport in a surface water system, in that contaminants in an aquatic system may be hydrophobic, and highly dependent on this transport system. In a study by James et al. (2010), a modeling approach that extends variables in sediment classes, suspended load and bedload, and bedding resistance is identified. The goal of the study was to validate a three-dimensional sediment transport model that can accurately predict sediment behavior, and to improve the functionality of a transient hydrodynamic model that drives flow and transport, the Environmental Fluid Dynamics Code. The study considered a combination of site and laboratory data and a sediment bed dynamics model with a unified treatment of cohesive and non-cohesive sediment erosion and transport that more accurately represents physical processes. To apply this particular model in the field, it is noted by the author that a spatial distribution of the sediment bed must be described including critical shear stress, particle size as a function of depth into the bed, and erosion rate as a function of shear stress and depth.

Uncertainty in sediment transport modeling is an important factor and one seldom explored or explained beyond initial identification. Osidele et al. (2003) presents a computational approach to identifying the significance of uncertainty in assessing the consequences of sediment and nutrient transport, integrating a sediment-nutrient dynamics model with a Monte Carlo-based methodology for model uncertainty evaluation. The study utilizes an example case study with a three-tier model (hydraulic, sediment transport, and water quality components) incorporating influences from both the natural system and anthropogenic management system. The hydraulic component of the model incorporates discharge, flow velocity, depth, wetted area, and elevation. The sediment transport component incorporates sediment transport potential, actual sediment transport rate, and possible morphological changes. The water quality component includes orthophosphate, nitrate, ammonium, and dissolved oxygen. The study demonstrates the utility of dynamic process-based models in total maximum daily load development, especially in support of decision making currently facilitated by empirical models and statistical data analyses.

In south Florida, waterways move considerable amounts of sediment material annually (Stuck et al., 2001; Daroub et al., 2003; Diaz et al., 2006). Sediment transport is an important component in the design and maintenance of water control facilities. In a study of sediment control issues in the Central and Southern Florida (C&SF) Project, Ansar et al. (2014) provided a comprehensive account of canal sections with historical sedimentation problems and potential control considerations. The canals in the C&SF Project were designed with bottom slopes and cross sections that would maintain slow flow velocities [< 2.5 feet per second (ft/s)] to minimize scouring and sediment transport. However, despite the design considerations, the C&SF project has experienced sedimentation problems in several regions. The C-23/C-24 canals have historically experienced substantial bank sloughing especially during large flood-control discharges. The St. Lucie Canal has also historically experienced significant sedimentation problems, transporting sand and organic suspended material to the St. Lucie Estuary. One of the major sedimentation issues of the C&SF Project is the transport of suspended sediments to ecologically sensitive water bodies. Sedimentation rates to the St. Lucie Estuary as high as 0.5 to 1.0 centimeters per year (cm/yr) over the past 100 years were estimated during this study, with erosion in the C-44 Canal and suspended sediments from Lake Okeechobee considered as the primary sources since the creation of the C&SF Project. Some of the potential sediment control measures suggested by this study include bank stabilization techniques, use of weirs as sediment control barriers, agricultural BMPs, sediment traps, and dredging. However, initial cost and maintenance are some of the main challenges when considering some of these potential solutions. Sediment type also plays an important role on the potential sediment control measure. Weirs and sediment traps may effectively trap larger sediment particles, but their ability to control suspended organic sediment material may be limited (Stuck et al., 2002; Diaz et al., 2005). In addition, the maintenance costs of these sediment control measures have been deemed to be cost-prohibitive. Due to the significance of the sediments issue on water quality in the Everglades, the study suggested that more studies dealing with sediment transport and potential control measures should be a priority at key District canals discharging into the STAs. The study concluded that the sediment issue is complex and case specific; thus, a better understanding of sediment types and sources in selective basins is needed to develop effective sediment control measures.

Sediment transport can be classified as either suspended load or bed load. Larger particulate matter is usually transported at higher flow velocities near the bottom of stream and rivers and is classified as bed load. Suspended load is the portion of the sediment that is carried by a fluid flow, which settle slowly enough such that it almost never touches the bed. The seminal work by Bagnold (1966) has been consistently utilized over the years as a foundation for other studies in sediment transport. This study takes a methodological and analytical approach to examining and explaining both sediment bed-load and suspended sediment load dynamics. The work constitutes an attempt to explain the natural process of sediment transport along open channels quantitatively, by reasoning from the principles of physics and from the results of experimentation. To this end, numerous technical, research, and professional papers attempt to reexamine and/or revisit Bagnold’s conceptions and formulas, with the goal of confirming, and revising the author’s original works. For example, in a study by Martin and Church (2000), Bagnold’s original formula for bed-load is reexamined using a much larger data set than was available to Bagnold, as the authors concluded the original set was based on limited data. The ultimate goal of the research were to reach a rational result that delivers superior predictive performance and increase confidence that a formulation of bed-load transport based on stream power correlation adjusted by an empirical scale of depth and grain size is a viable representation of the phenomenon. To this end, Martin and Church (2000) found that based on the available data set, the depth and grain size scales were no more interpretable than the ones identified by Bagnold.

In a study by Van Rijn (1984a and b), another approach by Bagnold (computational analyses) is followed, in that the motion of bed-load particles is presumed to be dominated by gravity, with turbulence being of minor importance. The study attempts to investigate the motion of bed-load particles and to establish simple expressions for particle characteristics and transport rate for both large and small particles. The research finds that saltation of a small particle is dominated by drag forces resulting in long but flat particle trajectories, while the saltation (i.e., movement) of a large particle is dominated by lift forces resulting in short but high trajectories. Also, close to the bed, the lift force is relatively large compared with the submerged particle weight both for small and large particles (Van Rijn, 1984a). In addition, Van Rijn concludes that using a simple expression for saltation height and particle velocity, a simple function for the bed-load concentration can be derived from measured bed-load transport rates. Van Rijn (1984b) presented new relationships to represent the size gradation of the bed material and the damping of the turbulence by the sediment particles. A verification analysis showed that about 76 percent of the predicted values were within 0.5 to 2.0 times of the measured values.

Nutrient Transport

In watersheds draining agricultural areas, P can be transported in soluble and particulate forms. Particulate P (PP) consists of all solid phase forms, including P sorbed by organic material and soil particles transported during runoff (Diaz et al., 2005). Earlier studies in the Everglades Agricultural Area (EAA) have demonstrated that farm canals have a major impact on TP loads discharged from EAA farms (Stuck et al., 2001, 2002). Several studies in the EAA have indicated that the bulk of the exported PP is sourced from biotic material growing within main farm canals (Stuck et al., 2001, Daroub et al., 2003). These findings contradict previous assumptions that overland soil flow erosion and field ditch erosion were the primary sources of PP transport during pumping events. Biological contribution consists of detritus, emergent and submerged aquatic vegetation, planktonic growth, and other floating or suspended organic matter that are easily detached during pumping events. Field studies have showed that even minor pumping events are capable of transporting recently deposited biological sediment material that is high in P content, while more intense pumping events tend to transport heavier material with lower P content (Stuck et al., 2001). Following this trend, canal water conditions greatly affect the distribution potential of these PP contributors. Stuck et al. (2001, 2002), identified high velocity in farm canals as the single most important factor in PP transport. These studies found that the velocities in main canals are generally highest in the furthest downstream extent of the canals, so the greatest tendency toward PP mobilization will be in the lower reaches of the main agricultural canal system (Stuck et al., 2002). According to Daroub et al. (2002a), high velocity and turbulence create conditions that promote disengagement, suspension, and mobilization of particulate matter into the watershed. Stuck et al. (2002) describes PP transport in the EAA canal system as a tri-modal process. The first transport group is described as very light and mobile particles readily resuspended and can be transported under low to moderate flow conditions. The denser second particle group includes the underlying transportable base sediment or the overlying aquatic weeds. The third particle group consists of randomly generated matter that can come from localized concentrations of biomass, abnormal hydraulic conditions, storm events, water stage, or an engineering-specific contribution like erosion from a construction site, etc. To this end, the study identifies the majority of PP load sourced in the first flush by a continued high velocity and turbulence during a pumping event, thus control efforts should be focused on minimizing these two factors (Daroub et al., 2002b).

Nutrient transported by canals may present an environmental problem to natural areas that have developed under low nutrient conditions. Surratt et al. (2008), quantified canal water intrusion into the Arthur R. Marshall Loxahatchee National Wildlife Refuge (Refuge) using conductivity as a tracer for canal water movement. Results showed the greatest canal intrusion into the marsh occurred on the west side of the Refuge. Stage differences between the perimeter canal and the marsh were one of the main factors that influenced the distance of canal intrusion into the marsh. This study demonstrated that continuous monitoring of conductivity can be used as a valuable tool to trace water movement in and out of marshes. It was also concluded that to reduce the risk of canal water impacts into this rainfall-driven marsh, some changes to canal water management may be required. Knowledge of canal inflow, outflow, and stages between the marsh and canal can be applied to improve water management operations to reduce the risk of canal water intrusion into the marsh.

Suspended particulate matter plays a significant role in the cycling and transport of energy and nutrients in aquatic ecosystems, more specifically P and its relationship with suspended sediments in rivers and streams (Noe et al., 2007). Information regarding the nature and degree of the fluxes involved in the system is essential to establishing nutrient budgets within a watershed, assessing potential sources and sinks, and to quantify nutrient load transfer downstream (Walling et al., 1997). The composition of suspended particles also has implications for the identification of particle sources, reactivity, and transport (Noe et al., 2007).

A study conducted by Foster et al. (1996) attempts to identify the partitioning of P between soluble and particle forms and the potential for various soil types under different land management systems to deliver sediment-associated P to rivers. The study employed a time-based rather than flow-based sampling methodology due to the size of the drainage basin and involved the collection of water as well as sediment samples, and analyses, including P. Sediment sampling was limited to the upper 5 centimeter (cm) of the soil profile under the assumption that this portion is representative of the soil that would erode and potentially contribute to suspended sediment load. The research study found that high PP contribution to the TP load appears to be controlled by in-stream adsorption and the difference in the PP concentration between rivers receiving and not receiving effluent appears to diminish as suspended sediment concentrations increase. The study also suggests that this trend may reflect the dominance of diffuse over point sources at high discharges and the shorter residence times of water in the channel to allow P adsorption by the suspended sediment.

Based on research by Walling et al. (1997) to distinguish between the dissolved and particulate components of total suspended load associated with P and nitrogen (N) content, a combination of desktop studies and field sampling activities was utilized. The river study involved access to a collection of suspended sediment transport records based on continuous monitoring (optical turbidity sensors), direct collection of bulk suspended sediment samples, as well as water samples collected by automatic sampling technology. Suspended sediment loads were calculated at 15-minute intervals as the product of instantaneous values of discharge and suspended sediment concentration extracted from the discharge and sediment concentration records, and then summed to provide values of hourly load. It is noted by the author that this study covered four rivers, studied over the period of one year, and therefore the data must be treated with a degree of caution in terms of its wider ranging representativeness. The study concluded that sediment-associated with contribution to TP flux is expected to be greater than or equal to 50 percent in most river systems with average or greater suspended sediment yields. The study also suggested that this contribution is expected to fall below 50 percent where effluent inputs represent an important component of the system nutrient budget. In the case of N transport, the study found the sediment associated component to be a much smaller than the dissolved component. The magnitude of the sediment-associated contribution varied through the year in response to seasonal patterns of suspended sediment transport.

Phosphorus in streams and rivers is transported to a large extent adhered to suspended particles. It is also theorized that P adhered to smallest grain sizes by electrical bounding may be transported in the water column by wash load, a sediment in transport that is derived from sources other than the bed (Biedenham, et al. 2006) . Thodsen et al. (2004) took advantage of a monitoring program in the River Varde Å in Denmark to study the connection between the transport of TP, suspended sediments, and wash load. It was concluded that P is transported adhered to the fine grain size particles in the wash load transport fraction. The study also reported that P transport was not affected by the passage of the river through an impounded area. While the impounded area reduced the amount of suspended sediments transported by 57 percent, the transport of washload was only reduced by 27%. The study concluded that TP concentrations were well correlated with suspended solids and wash load, and poorly correlated with water discharge, thus; if possible, suspended sediments and wash load should be used as TP concentration predictor in this river.

According to two separate river studies conducted by Domagalski et al. (2008) and Skhiri and Dechmi (2011), irrigation water practices play a considerable role in nutrient and chemical transport. Both studies alluded to this conclusion based on water sample data collection from river and stream watersheds. In each of the studies, significant seasonal (environmental and anthropogenic) variability in nutrient load was observed with regard to water management practices. Domagalski et al. (2008) found that irrigation practices (sources of irrigation water) and timing of chemical use greatly affect nutrient and pesticide transport. Based on the five watersheds researched, it was also found that irrigation with imported water tended to increase groundwater and chemical transport, whereas the use of locally pumped irrigation water may eliminate connections between streams and groundwater, resulting in lower annual loads (Domagalski et al., 2008). In addition, the study found that overland flow contributed to the greatest loads, but that a substantial portion of the annual load of nitrate and some daughter-product pesticides can be transported under base-flow conditions. The study by Skhiri and Dechmi (2011) was conducted in watersheds characterized by low levels of precipitation, and samples were comparatively analyzed during irrigation and non-irrigation seasons. The study observed significant inter-seasonal and inter-watershed P concentration variability. The data suggest that during the irrigated season, average annual TP concentrations were over the defined eutrophication limit and more importantly total dissolved P was the dominant form in all drainage waters. In all the river watersheds studied, except one, average TP concentrations obtained during the irrigation season were higher than average TP concentrations obtained during the non-irrigation season (Skhiri and Dechmi, 2011).

In a study excluding a nutrient load component, Low Hui Xiang et al. (2011) paired TSS measurements with turbidity measurements, a correlation being established to offer more efficiency in predicting TSS concentrations in a river. The study sites (sample locations) were specifically selected for sampling due to ongoing construction activities along rivers and streams, providing an elaborate data set. Although the data set encompassed a wide range of TSS and turbidity values, it was found that as TSS increases, the turbidity uncertainty increases. The data show that an increase in TSS concentrations affect an increase in turbidity levels, as suspendered solids have the ability to hinder light transmittance in a water sample turbidity reading (Low Hui Xiang et al., 2011). The study concluded that turbidity could provide a good estimate of the TSS concentration in a water sample, but the relationship can change spatially and temporally due to variations in sediment composition.

FIELD ASSESSMENT

Field Sampling Approach

Nutrient Measurements

River water quality models seek to describe the spatial and temporal changes in constituents, which are of concern, and also present the possibility of pollutant concentration prediction in a water system. In a study by Zelenakova et al. (2013), a model was developed that determines P and N concentrations in a river based on a dimensional analysis and how it can be applied specifically to water quality monitoring. The study considered water discharge (flow), drainage area, water velocity, air and water temperature, and concentration of the contaminant (P and N) as essential parameters for the development of this model. Results of the research indicated that predication error increases when single concentration values are considered, but the model performed well when average values were used. A sensitivity analysis of the model identified that both air and water temperatures have major influences on the P and N concentration, and expressed little sensitivity to a change in velocity and flow of water in a river (Zelenakova et al., 2013). In another study, Chomat et al. (2013) developed a mass balance model to improve the understanding of P fluxes between sediment and the overlying water column in a river that is highly influenced by low-head dams and discharges from wastewater treatment plants. The overall analysis from this study focused on sorption process at the sediment-water interface as a function of the P flux rate into the sediment, reactions within the sediments with partitioning between dissolved and particulate P forms, and inorganic P concentration in the overlying waters. This study required the collection of intact sediment cores, which were incubated under controlled laboratory conditions to measure P-flux rates under both aerobic and anaerobic conditions. Results showed that the P-flux rates and direction of the P exchange from the Assabet River sediments vary over the course of an annual cycle and are seasonally influenced. Results suggested that the river sediments act as a P source during the summer months but as a P sink during winter months. The study also suggested that P exchanges between the sediment and the overlying water are dependent on the P concentration gradient between the two and the amount of P loading that enters the river and much less dependent on initial sediment P concentrations. This study showed the importance of incorporating P-flux measurements in river systems to better understand the role that sediments play in controlling P-fluxes in freshwater systems.

Velocity Assessment

Stream and wetlands are open systems where dissolved and suspended materials are transported through the system interacting with sediments and vegetation along the flow path. At low flow and shallow depths, most of the interaction occurs primarily with the canal bed, whereas at high flow and depths, most of the interaction occurs in the floodplains and adjacent wetlands. In a field study at WCA-3A, Harvey et al. (2011) studied sediment transport in the Everglades by progressively increasing flow velocity in a field flume constructed around undisturbed bed sediments and emergent macrophytes. Results reported that high-flow pulses are capable of resuspending and transporting fine, P-rich floc to downstream ecosystems. The study concluded that sediment entrainment from epiphyton in shallow aquatic ecosystems may be an important contributor in the transport and redistribution of organic carbon and P stored in accreted sediments. A study by House et al. (1995), attempted to quantify the effects of water velocity on the net flux of soluble reactive P (SRP) to bed sediments. The study involved the collection of sediment samples from outdoor channels (surface sediments to a depth of 5 cm) and their application in fixed laboratory flume experiments, modeling, and calculation. The study sought a mathematical description of influx by modeling the experimental results using the Elovich equation, a boundary-layer model, and a parabolic rate equation (House et al., 1995). The study highlights the importance of bed sediments to SRP losses from river water, principally when compared to the faster kinetics involved in the interaction of SRP with suspended material.

One of the most important factors in designing canals, especially irrigation canals, is to establish special conditions to avoid settling of suspended particles on the beds of these agriculturally relevant waterways (Ansar et al., 2014). A study was conducted by Karimi and Moazed (2012), with the objective of studying the influence of the transmitted sediments on the hydraulic capacity of canals, to examine existing relationships and theories for determining settling and non-settling velocities in irrigation canals, as well as recommend the best possible and economical solutions to avoid sedimentation progression. The study included the collection of canal hydraulic and geometry data from stations selected along irrigation networks (both lined and unlined canals) based on their accessibility, availability, uniformity, and continual hydraulic conditions. Geometry characteristics included cross-sectional area and bed slope, while hydraulic characteristics included flow velocity and flow rate. During data collection, bed slope and cross-sectional data were obtained by survey, flow velocity was recorded by micromullinet, and both suspended materials as well as bed materials were collected for analyses. This study concluded that the limiting concentration method for lined irrigation canals showed the best agreement with the measured values in determining the settling and non-settling velocities. In unlined irrigation canals, the Kennedy Method and Girshkan Method showed the best agreement with the measured values. Therefore, these methods could be utilized in the design of irrigation canals to avoid the sedimentation process.

Canal Coring Technique

Sediments play an important role in P cycling in many freshwater ecosystems such as wetlands, streams, and canals. Thus, an understanding of their physical and chemical properties is important to understand their role on internal nutrient cycling, release to the overlying water, their stability and potential for resuspension and transport to downstream ecosystems (Reddy eta al., 1995). Zaimes and Schultz (2002) did a comprehensive literature review on the importance of P in agricultural watersheds. This review highlights the increased concerns in the mid-western states of the potential impacts of the different P fractions on surface water quality and the increased interest of P movement and management in the landscape. Reddy et al. (1995) investigated P behavior in soil/sediment-water-vegetation components of selected wetlands and stream in the Lake Okeechobee watershed. They reported that although assimilation of P by vegetation is usually short-term, undecomposed organic P from plant tissue decomposition accumulates and becomes an essential part of the soil/sediment P pool. However, depending on the water column and stored sediment physico-chemical properties, sediments can function as net sinks for P, or net sources of P, becoming very important to quantify not only sediment volumes but also the major P forms stored in these sediments (Diaz et al., 2006).

Early studies in the EAA have demonstrated that farm canals have a considerable impact on TP loads discharged from agricultural farms (Stuck et al., 2001). Decades of farming and continual drainage from the EAA farms has led to accumulation of sediment in main farm and regional drainage canals, which have the potential to be transported to downstream ecosystems. Several studies have been completed utilizing sediment coring as a tool to characterize the potential impacts that stored sediments might have on the overlying water quality (Diaz et al., 2006; Das et al., 2012a and b). Diaz et al. (2006) evaluated the potential impact of stored sediments in major WCA canals used to transport low-P water discharged from functional STAs. Intact sediment cores from approximately 196 km of canal were collected at transects locations spaced at about 1.6 km intervals down from the upstream end of each canal. Sediments were characterized to calculate the total P inventory and major P forms stored in these sediments. Sediment depths ranged from < 5 cm in some transects in the L-38 Canal to > 3 m in the north part of the L-7 Canal. The total sediment volume calculated from all canal reaches was about 6.8 million m^3, with about 71 percent stored in canals from the eastern side (L7, L39, and L40) of the WCAs. Higher sediment accumulation in the eastern WCA canals is suspected to be the result of factors such as flow, canal size, and nutrient loading from the EAA and adjacent urban areas. This study reported that the total P mass calculated for the entire sediment profile in all canal reaches upstream and downstream of all STAs is estimated to be in excess of 1,800 Mg P. The P fractionation part of this study showed that the P fractions associated with Ca/Mg compounds and residual organic P were the dominant P fractions indicating that > 80% of the TP mass in surface sediments of all canals in the WCAs is fairly stable. However, the moderately available P represented by the Fe/Al and humic acid bound P pools were a considerable fraction (~ 22 percent) of the TP mass stored in the surface sediments from the eastern WCA canals, which are more susceptible to redox changes that can result in the long-term P release to the water column. In addition, sediments from the eastern side of the WCAs were highly organic with low bulk densities making them more susceptible to mobilization and transport during drainage events.

In a similar study, Das et al. (2012a and b) collected intact sediment cores from three main regional canals and three farm canals within the EAA. A physicochemical assessment, mineralogical analysis, P speciation and P storage were determined for surface and subsurface layers. Incubation and flux experiments were conducted on intact sediment cores . Results showed that sediments from main regional canals had higher TP concentrations (1,280 mg/kg) than farm canals (960 mg/kg), while farm canals sediments showed higher organic matter content compared to the regional main canals (Das et al., (2012a). It was also reported that P bound to Ca and Mg (HCl-Pi) accounted for the largest fraction (60-73 percent) of TP in all surface sediments, with the residue-P fraction accounting for the second largest (17-26 percent) storage pool in the three main canals. Although > 80 percent of P in the surface sediments in these canals is present in a relatively stable form, there is a concern that the organic nature and low bulk density of these sediments makes them highly susceptible to resuspension and transport during high flow events. The second phase of the study evaluated the potential of accumulated sediments in these canals to act as a potential P source to the overlying water (Das et al., 2012b). Results from the study indicated that in general, P release was highest from the Miami Canal sediments compared to the sediments from the Ocean and West Palm Beach (WPB) Canal. It was also reported that besides high TP concentrations others factors such as redox and the presence of carbonate precipitates (in the WPB Canal sediments) may have an overriding effect on P release. Based on the equilibrium P concentrations studies, Miami Canal sediments could behave as a source of P under certain conditions, while the Ocean and WPB Canal sediments appear to be in a state of equilibrium with the overlying water column. However, whether these sediments act as sink or sources of P depends on the P concentration in the water column, which can change widely during the rainy season.

Due to the low P concentrations needed to be achieved at the STA outflows plus the fact that PP can be a major P fraction in outflow waters leaving the STAs, it is important to understand the bioavailability and fate of this P fraction within the STAs. Dierberg and DeBusk (2008), conducted a series of laboratory studies to evaluate the stability of P in suspended particles within inflow and outflow water from selected flow-ways of a well performing (STA-2) and under-performing (STA-1W) STA. This study reported that

PP removal within the STAs can be considerable (71 percent) and the bioavailability of the particles can change during passage through the STAs. Despite this effectiveness, PP remains a major P fraction exported from the STAs on a percentage basis, even from the well performing STA-2 (~ 43 percent of TP exported). The study concluded that STA P loading history is an important factor determining the bioavailability as well as the overall PP mass discharged from the STAs. DB Environmental, Inc. (2011) characterized existing sediments in selected STA inflow and outflow canals, and investigated their potential P contribution to the overlaying floodwater. Intact sediment cores were collected from 17 transects for sediment characterization and P-flux incubation studies. Sediment characterization showed higher organic matter content in inflow canals compared to outflow canals. This finding is consistent with the previous study by Dierberg and DeBusk (2008) that showed that inflow canals in the STAs tend to accumulate more organic material than outflow canals, as most particulate matter is retained within the STAs. Sediment characterization showed that sediment P was not correlated with total Carbon, volatile solids, or total N, indicating that much of the P in these sediments may be associated with inorganic constituents such as Al, Fe, and/or Ca, rather than with organic matter. The incubation studies showed minimal P releases from STA-1W and STA-2 to moderate releases in STA-5 and STA-6 outflow canals; however, sediments from the STA-2 inflow canal showed the highest P release than any of the outflow canals, probably due to the higher organic matter content measured in inflow canals. Phosphorus release was significantly correlated with sediment redox potential, which is probably due to higher rates of organic matter decomposition and the disassociation of Fe-P complexes at the lowest redox potentials. This study observed substantial spatial variability in sediment composition in these canals; thus, caution should be used in extrapolating these findings to the entire length of the canals. In addition, time of sampling (e.g., wet season versus dry season) could have an effect on sediment P contribution to the water column.

In a study in the Lake Okeechobee watershed, Dunne et al. (2007) collected intact sediment cores from agricultural drainage ditches from three agricultural land uses to better understand P storage and P dynamics in the basin. The study reported that P content in agricultural ditches was considerably affected by land uses, such as dairy operations, improved, or unimproved pasture. It was also reported that inorganic P concentrations and water extractable P fractions in agricultural ditches were good indicators of land use impact, while soil characteristics such as organic matter and soil metal content were important in determining total P storage in these ditches. The degree of P saturation was also suggested to indicate that dairy and improved pasture soils had the potential to impact water quality. The study concluded that P is being transported from uplands to wetlands, and then to agricultural ditches during wetland flooding. In another study, Reddy et al. (1995) reported that P released from the Okeechobee basin is transported through canals, streams and wetlands before it reaches Lake Okeechobee. The interaction of high P water with vegetation in the basin results in a short-term P assimilation process; however, as the vegetation decomposed, organic P in undecomposed plant material accumulates becoming an integral part of soil/sediment P pool. The study reported that P sorption in wetlands soils and stream sediments was regulated by the amorphous forms of Fe and Al and organic matter. Phosphate interaction with Fe^{3+} at the soil/sediment-water interface in the oxidized zone can function as a sink for P moving from the water column into this layer and P diffusing from the underlying anaerobic soil layer. According to this study, stream sediments and wetland soils could potentially retain an additional 50 percent of total P in moving water through the basin, however, under current management practices, flow is primarily confined to streams and canals. The study concluded that if flow is directed throughout the wetland areas, P retention will most likely improve in the basin, with the wetland-stream system acting as a sink for P as long as P concentrations in the flow waters is lower than the EPC_W (threshold P concentration in the water column where P retention = P release).

BEST MANAGEMENT PRACTICES (BMPS)

Non-Dredging BMPs

On-farm studies have demonstrated that a substantial portion of total P loads leaving EAA farms is in the particulate form (Stuck et al., 2001; Daroub et al., 2003). Thus, efforts directed to reduce PP and sediments in drainage waters are essential to further reduce TP loads leaving the EAA. Agricultural Best Management Practices (BMPs) have been devised to help reduce PP and sediment loads exiting EAA farms and serve as an integral process to improving water quality within the agricultural area. BMPs in the EAA present a multifaceted approach to reducing PP in drainage waters as the effectiveness of traditional erosion controls practices provide limited benefits for PP export (Stuck et al., 2002). Some of the most commonly used sediment control BMPs at the farm level in the EAA include laser leveling of agricultural fields, ditch and canal berms, sediment sumps and traps, cover crops, raised culverts, vegetated banks, the use of weed booms and trash racks, and a canal cleaning program (Diaz et al. 2005). Sediment-sumps in field ditches have become one of the most common sediment control practices in the EAA with the main objective of reducing flow velocity and trapping heavier sediment materials before they are moved off agricultural lands or into main drainage canals. However, the effectiveness of sediment traps in main drainage canals of the EAA have not been fully tested and would not be expected to achieve the same success shown in other watersheds as most particulate matter transported from the EAA basin is very light and easily suspended, and would require a long residence time to settle out of the water column (Stuck et al., 2001; Diaz et al., 2005). Thus, a comprehensive canal cleaning plan is crucial to remove materials that have accumulated over time, which may have the potential to be exported from the farm.

Overall, BMPs have been successful in reducing EAA farm drainage P loads. However, additional analytical investigation of how environmental and management factors affect P loading in farm runoff may allow for additional improvements in BMP performance (Lang et al., 2010). A 10-year study encompassing 10 farm sites utilizing a Spearman Correlation, Principal Component Analysis, and stepwise multivariate regression attempted to identify these factors. The study identifies multiple water management variables (rainfall, lag rainfall, irrigation P loads, irrigation P concentration, and pump to rainfall ratio) as principal factors impacting unit area P load from the EAA. Lang et al. (2010) suggested that P load reduction and improving BMP performance can be achieved by lowering drainage volumes through improving internal drainage within the farm by the proper use of water control structures and laser land leveling.

Sediment Dredging BMPs

Dredging is a relatively common method for the removal of sediments, detritus, and other materials that may be impacting canals, streams, rivers or estuaries. Sediment nutrient loading and the accumulation of other types of chemicals justify the need for dredging activities in different areas. In the mid-west, ditch dredging is a necessary management tool to ensure adequate discharge of water from surrounding agricultural fields (Smith et al., 2006). In the organic soils of the EAA, sediment removal from main canals and field ditches is a necessary practice to reduce PP loads leaving the agricultural area (Stuck et. al., 2002, Diaz et al., 2005). In a study conducted by Smith et al., (2006), a laboratory stream simulator (fluvarium) approach was used to identify the short-term transport of soluble P in agricultural drainage ditches post dredging. Smith collected ditch sediments immediately before and after ditch dredging operations. The sediments were placed in a fluvarium and adsorption and desorption experiments were conducted. Based on the laboratory study, it was found that removal of P from the water column was greater in pre-dredged sediments than post-dredged sediments and the release of P to the water column was more rapid and in a greater amount from dredged sediments than pre-dredged sediments. This study indicated that water quality may be impaired immediately after dredging the field ditches as the newly exposed sediments buffering water column P at greater concentrations than the sediments present before dredging. Ditch dredging may also alter the downstream delivery of anthropogenic contaminants;

however, it is an essential practice to ensure adequate drainage of agricultural fields (Smith et al., 2006). This study suggested that more research is needed to identify and test potential sediment amendments to increase the P removal by dredged sediments, and decrease the concentration at which these sediments buffer water column P concentrations.

Smith and Pappas (2007) conducted a nearly identical fluvarium study with similar purpose but included a more detail approach to considering bed materials (sediments, detritus, and other organic matter). Other nutrients (ammonium and nitrate) in addition to P were taken into account. Pre-dredge and post-dredge bed material were collected and analyzed in a controlled laboratory environment. Results from this study showed that pre-dredge bed material was able to remove ammonium-N, nitrate-N, and soluble P faster than the bed materials present after dredging. Additionally, the release of soluble P from the dredged bed material to the water column was greater than those measured in the bed materials collected prior to dredging, as a result of a decrease in the specific surface area of the bed materials present after dredging, as well as the removal of organic matter and biota during the dredging process (Smith and Pappas, 2007). This study demonstrated that sediment bed materials can act as a source or sink for contaminants and their removal through dredging practices may degrade downstream water quality. This study in particular concentrates on the immediate impacts of dredging on water quality and suggests that downstream ecological impacts are not yet understood and warrant further investigation. To minimize water quality impacts, the study suggested dredging of agricultural ditches during periods when contaminate loads are expected to be low, and to minimize the use of source nutrients during and immediately after dredging activities. In the EAA, it is suggested that canal dredging should be conducted during quiescent conditions and if possible in combination with field irrigation to relocate sediment resuspended during dredging back to the farm (Stuck et al., 2002).

Contaminants in sediment accumulated in canals, streams, or any other water body can have an adverse effect on the flora and fauna of that water body and can limit the use of that water body (ASCE, 1992). Determining how to remove contaminated sediments is often an expensive and difficult undertaking. Dredging is one of several options dealing with the risk posed by contaminated sediments; however, it is expensive and sometimes controversial about its efficacy. One of the difficulties of dredging is to determine the thickness and horizontal distribution of the sediment layer that needs to be removed, considering the uneven bathymetry of the water body and the sampling intensity required to determine the thickness and horizontal distribution of the sediment layer. Another important consideration is the prediction of the future transport and effect of these sediments to downstream ecosystems (Gustavson et al., 2008). Vivona and Mooney (2000) used a truck-mounted hydraulic dredge to remediate a canal section south of Hangar 22 at Miami International Airport. This technique proved to be effective at removing loose sediment and other dense material down to the underlying limestone bedrock. They also implemented alternative dewatering techniques to achieve higher solid removal during dredging. Diaz et al. (2006) performed a comprehensive sediment inventory of major Water Conservation Area (WCA) canals in South Florida to quantify the total sediment volume and major P fractions stored in these canals. Results reported that the surface 12-cm sediment layer downstream of all active STAs had a sediment volume of about 709,000 m^3 and a total P mass of about 217 mg (megagram). Although, their results showed that > 80 percent of the TP mass in surface sediments is fairly stable, sediments stored in the eastern canals of the WCAs were high in Fe-bound P, making them susceptible to changes in redox that can result in the long-term P release to the water column. Although sediment removal was not an original objective of this study, these results indicated that further studies should be done on the eastern WCAs canals to estimate the feasibility of removing sediments from these canals to avoid the future transport of these P-rich sediments to downstream ecosystems.

Taylor Engineering, Inc. (2007) conducted a dredging feasibility evaluation of the EAA and STA-1, STA-2, and STA-5 inflow canals. The study includes a multitude of variables and information in relation to developing a canal dredging plan prior to, during, and post operation. Some of the factors considered by the study in addition of sediment quality and dredging activities included the consideration of upland staging areas, dewatering sites, and identification of dredged material management areas. As part of the dredging study, Civil Services, Inc. (2007) conducted a physical and chemical characterization of sediments in the study area to provide a preliminary characterization of sediments proposed for dredging. Sediment samples from the study area canals were collected using a one-inch diameter stainless steel tube with PVC extenders capable of sampling depths of up to 40 ft. All sediment samples were subjected to a sieve analysis to determine the grain-size distribution for physical characterization. For chemical characterization, the sediment samples were analyzed for organochlorine pesticides, eight metals, arsenic, barium, cadmium, chromium, lead, selenium, silver, and mercury, total petroleum hydrocarbons, and TP. The results from both the physical and chemical sediment characterization testing during the feasibility study suggested that any dredging operations will require greater sampling frequency to better characterize the physical and chemical sediment properties for each proposed canal section. A number of the sediment samples contained concentrations of targeted chemical constituents (arsenic, chromium, selenium, mercury, and dieldrin), but the majority of the sediment samples collected yielded high concentrations of TP indicating that these canals are significant sinks for P-rich sediments. These results were based on a limited data set; thus, further sampling may be necessary to validate these findings.

PART II: AS-BUILT DRAWING REVIEW

This section summarizes the canal configuration document review (record drawings and operation plans) efforts completed for the Evaluation of the Influence of Canal Conveyance Features on STA and FEB Inflow and Outflow TP Concentrations Study (Canal Study) under the Restoration Strategies Science Plan (SFWMD, 2013a).

AS-BUILT DRAWINGS, DESIGN DRAWING REVIEW AND FIELD OBSERVATIONS

The relevant record (as-built) drawings and STA operation plans were reviewed for all the canals studied under this project. Limited field observations werealso made at each canal. This section summarizes the canal physical characteristics including but not limited to:

- General description and design intent,
- Conveyance capacity,
- Dimensions of canal cross sections at different locations (side slope, bottom width, centerline elevation, etc.), and
- Other critical physical features and related configurations.

This information will be used in the estimation of accumulated sediment and water velocities in the canals. The cross-sections data will also be used in development of the seepage model and the hydrodynamic model to be included in Phase II of the study.

STA-1E DISCHARGE CANAL

The final STA-1E Water Control Plan (USACE, 2012), STA-1E Interim Operation Plan (Gary Goforth, Inc., 2009), STA-1E record drawings for Contract 6 (Bell Constructors), and record drawings for Contract 7 (Grundy Marine and F.R.S. and Associates, Inc.) were reviewed with respect to the STA-1E Discharge Canal (**Figure 1**). In some cases, discrepancies (noted below) were found among the record drawings, STA-1E Water Control Plan, and STA-1E Interim Operation Plan. Field verification of the inconsistent data are necessary before detailed modeling, analysis, or evaluation is conducted. A summary of the STA-1E Discharge Canal characteristics follows.

The STA-1E Discharge Canal receives outflow from Cells 2, 4S, and, 6 and conveys it to S-362. The canal is divided into three legs: (1) the east leg serving Cell 2; (2) the west leg serving Cells 6 and 4S; and (3) the S-362 intake canal, formed by the confluence of the east and west legs.

East Leg. The East Leg runs east-west along the downstream end of Cell 2 then turns 90 degrees and runs south along the eastern boundary of STA-1E to the confluence with the West Leg. The canal runs the entire width of Cell 2 to help with seepage control from the cell. The design discharge is 900 cubic feet per second (cfs), with a mean channel velocity of 0.47 feet per second (ft s^{-1}), and an invert of –6.5 to 6.0 feet National Geodetic Vertical Datum of 1929 (ft NGVD). The record drawings indicate a bottom width of 10 ft, while the STA-1E Water Control Plan and STA-1E Interim Operation Plan indicate a bottom width of 15 ft.

West Leg. The West Leg runs parallel to the L-40 levee along the downstream end of Cell 6 and Cell 4S to the confluence with the East Leg Canal. The canal terminates at the southwest boundary of Cell 6 to reduce seepage from the Refuge. The design discharge is 3,300 cfs, with a mean channel velocity of 1.23 ft s^{-1}, an invert of –6.5 to 2.5 ft NGVD. The record drawings indicate a bottom width of 25 ft, while the STA-1E Water Control Plan (USACE, 2012) and STA-1E Interim Operation Plan (Gary Goforth, Inc., 2009) indicate a bottom width varying between 25 and 50 ft.

S-362 Intake Canal. The East and West Leg Canals come together approximately 320 ft upstream of S-362 to form the Intake Canal. The design discharge is 4,200 cfs, with a mean channel velocity of 0.75 ft s^{-1}, an invert of –6.5 ft NGVD, and a bottom width of 191 ft, as documented in the STA-1E Water Control Plan (USACE, 2012) and the STA-1E Interim Operation Plan (Gary Goforth, Inc., 2009).

The STA-1E Discharge Canal features are summarized in **Table 1**.

Table 1. Summary of STA-1E Discharge Canal features.

Canal Reach	Design Discharge (cfs)[2]	Approx. Bottom Elevation (ft NGVD)[1,2]	Approx. Bottom Width (feet)
East Leg	900	Varies from -6.5 to 6.0	10[1] 15[2]
West Leg	3,300	-6.5 to 2.5	25[1] Varies between 25 and 50[2]
S-362 Intake	4,200	-6.5	191[2]

[1] STA-1E Record Drawings

[2] STA-1E Water Control Plan (USACE, 2012) and STA-1E Interim Operation Plan (Gary Goforth, Inc., 2009)

cfs = cubic feet per second; ft NGVD = feet National Geodetic Vertical Datum 1929.

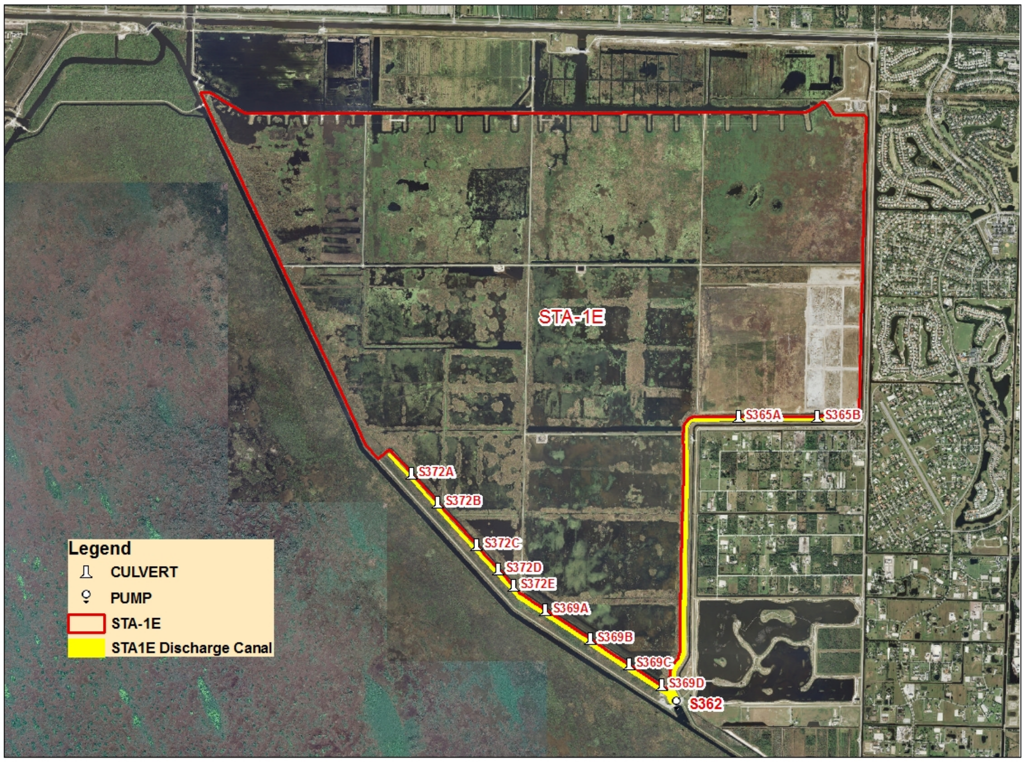

Figure 1. STA-1E Discharge Canal.

STA-1 INFLOW BASIN CANAL BETWEEN S-5A AND G-302

The STA-1W Operation Plan (SFWMD, 2007a) and Hydrographic Survey of S5A Discharge Canal and a Portion of Levee 7 and Levee 40 Borrow Canals (SFWMD, 2013b) were reviewed with respect to the STA-1 Inflow Basin Canal (**Figure 2**). A summary of the STA-1 Inflow Basin features follows.

The 272-acre STA-1 Inflow Basin provides the capability to convey discharges from the S-5A Pump Station to Stormwater Treatment Area 1 West (STA-1W), Water Conservation Area 1 (WCA-1), and Stormwater Treatment Area 1 East (STA-1E). The physical facilities of the STA-1 Inflow Basin consist of three automated control structures designated as G-300, G-301, and G-302; the L-7 and L-40 borrow canals; and a levee that separates the Inflow Basin from the north end of the WCA-1. Structures G-301 (situated on the L-7 Borrow Canal) and G-300 (situated on the L-40 Borrow Canal) are intended to act in parallel, with a discharge capacity of 4,800 cfs to provide for full conveyance of all S-5A Pump Station outflow in the event of a need to divert water directly to WCA-1 under emergency or extreme inflow and rainfall conditions. Structures G-300 and G-301 may also be operated for water supply deliveries from WCA-1 to the C-51 and L-8 canals. The separation levee has a design top elevation of 20.0 ft NGVD and a length of 6,100 ft.

Using the hydrographic survey report (SFWMD, 2013b), five canal cross-sections were selected to represent the general configuration of the STA-1 Inflow Basin Canal between S-5A and G-302. The subject canal reach is approximately 6,500 ft long, with an invert elevation varying approximately between -5 to 5 ft NGVD depending on location.

A summary of the STA-1 Inflow Basin Canal between S-5A and G-302 is shown in **Table 2**.

Table 2. Summary of STA-1 Inflow Basin Canal features between S-5A and G-302.

Canal Reach	Approx. Length (ft)	Design Capacity (cfs)	Approx. Bottom Elevation (ft NGVD)	Approx. Bottom Width (ft)
S-5A to G-302	6,500	Convey 3,250 cfs to G-302 (G-302 HW of 18.0 ft NGVD and G-302 TW of 15.8 ft NGVD)	-5 to 5 ft (varies)	Varies

HW = headwater stage; TW = tailwater stage; cfs = cubic feet per second; ft NGVD = feet National Geodetic Vertical Datum 1929.

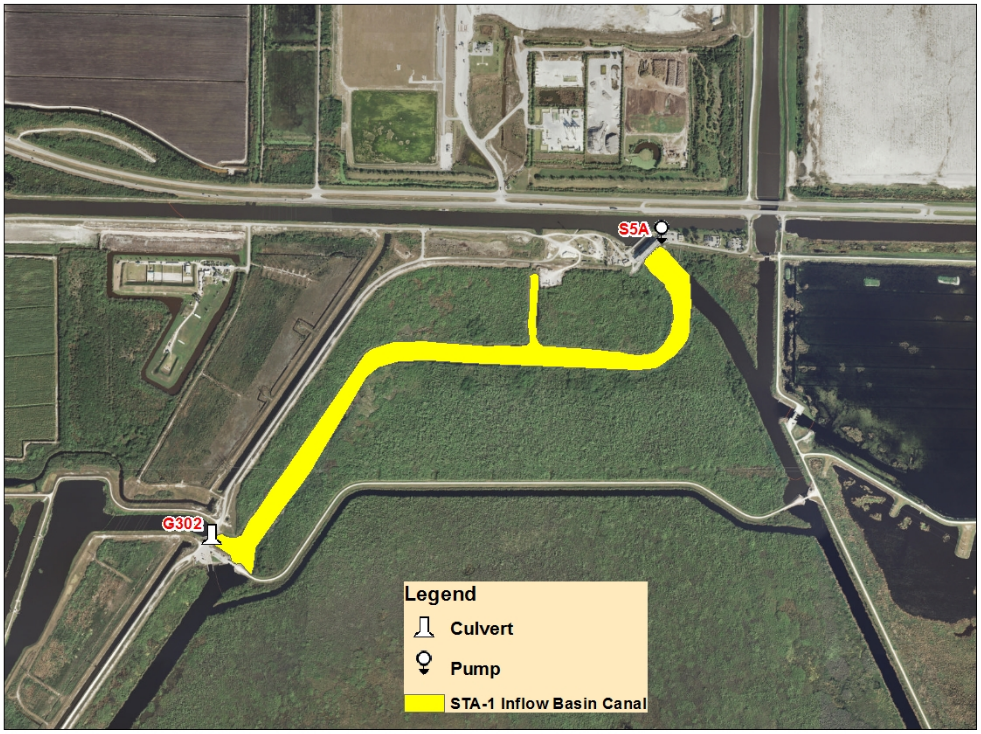

Figure 2. STA-1 Inflow Basin Canal between S-5A and G-302.

STA-1W DISCHARGE CANAL

The STA-1W Operation Plan and the STA-1W as-built drawings (Hutcheon Engineers, 2000) were reviewed with respect to the STA-1W Discharge Canal (**Figure 3**). A summary of the STA-1W Discharge Canal characteristics follows.

The total length of the Discharge Canal is approximately 30,000 ft (5.7 mi). The Discharge Canal extends along the western boundary of the project, from gated culvert G-327A located in the northwest corner of the STA south to the outflow pump station G-310. The canal conveys discharges from culverts G-306A-J, G-258, G-259, G-309, G-308, and G-307, as well as seepage from Treatment Cells 2, 3, 4, and 5 to the G-310 outflow pump station.

At its origin near the G-327A structure, the Discharge Canal was designed with a trapezoidal cross-section and with a bottom width of 50 ft at elevation –5.0 ft NGVD and side slopes 2.5:1 (H:V). South of G-306J, the Discharge Canal was designed for a bottom width of 30 ft at elevation –5.0 ft NGVD. The canal continues south with this design cross-section until it reaches just north of outflow structure G-309, at which point the canal bottom width once again widens to approximately 50 ft. This was done to accommodate the Western Flow-way flows. Just north of G-308, the design cross-section widens to 80 ft for the Eastern Flow-way flows. The design canal cross-section expands just south of G-259 to a 100 ft wide bottom width, and continues at this design cross-section to the outflow pump station.

While the as-built cross sections deviate slightly from the design cross sections, modeling conducted after construction demonstrated that the design conveyance capacity was achieved. Using the as-built canal cross sections, normal flow conditions (2,800 cfs) were modeled using HEC-2, and estimated velocities in the Discharge Canal were simulated up to 2.65 ft s^{-1} in the south end of the canal (Hutcheon Engineers, 2000). The water surface elevation during this flow condition ranged from 8.85 ft NGVD at the north end to 7.0 ft NGVD at the G-310 Pump Station. Under Standard Project Storm conditions, STA-1W inflow was limited to 1,100 cfs and project discharges reached 2,800 cfs; canal velocities varied from 0 to 1.2 ft s^{-1}, with water surface elevations ranging from 13.6 ft NGVD in the north to 13.25 ft NGVD at the G-310 Pump Station. Under Probable Maximum Storm conditions (0 cfs inflow and 2,800 cfs outflow), modeling estimates of the water surface elevations showed a level pool in the discharge canal of 16.1 ft NGVD.

A summary of the STA-1W Discharge Canal features is shown in **Table 3**.

Table 3. Summary of STA-1W Discharge Canal features.

Canal Reach (North to South)	Approx. Length (ft)	Design Capacity[1] (cfs)	Approx. Bottom Elevation (ft NGVD)	Approx. Bottom Width (ft)	Approx. Side Slopes (H:V)
G-327A to G-306J	10,000	1,470	-5.0	50	2.5:1
G-306J to G-309	8,000	1,470	-5.0	30	2.5:1
G-309 to G-308	5,100	2,170	-5.0	50	2.5:1
G-308 to G-259	5,000	2,730	-5.0	80	2.5:1
G-259 to G-310	500	2,800	-5.0	100	2.5:1

[1] These values were estimated based on the outflow structure capacity.

cfs = cubic feet per second; ft NGVD = feet National Geodetic Vertical Datum 1929.

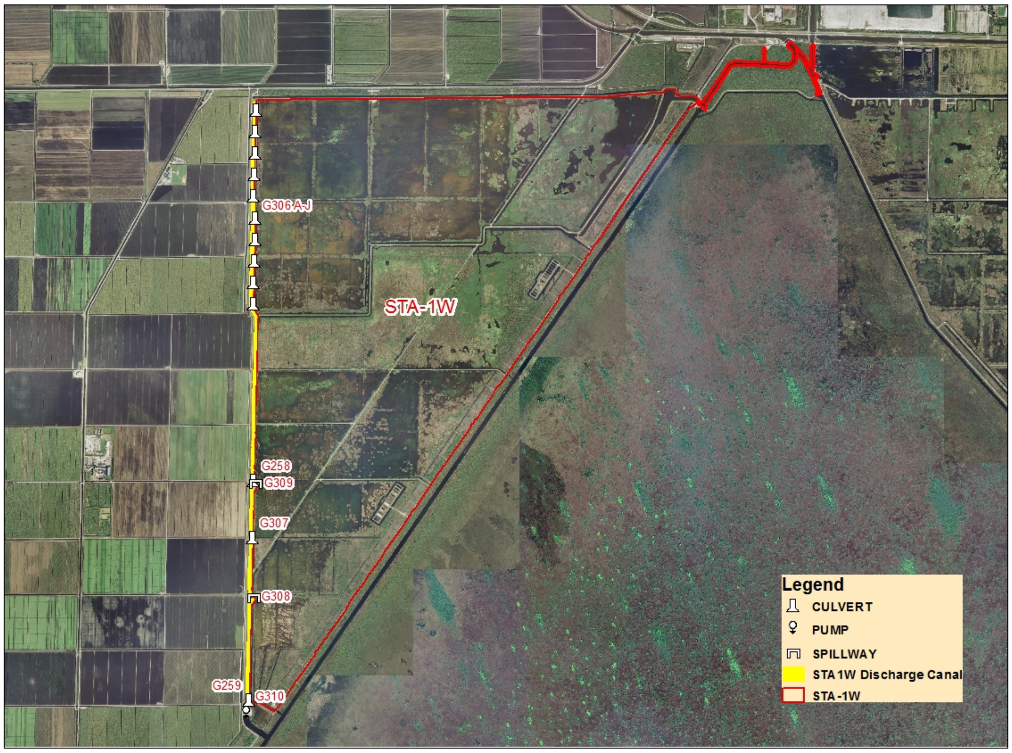

Figure 3. STA-1W Discharge Canal.

STA-2 SUPPLY AND INFLOW CANAL

The STA-2 As-Built Survey (F.R.S. & Associates, Inc. 1999) and STA-2 Operation Plan (Brown and Caldwell, 2012) were reviewed with respect to the STA-2 Supply and Inflow Canal physical characteristics (**Figure 4**). A summary of the STA-2 Supply and Inflow Canal characteristics follows.

STA-2 Supply Canal to Cells 1, 2 and 3

The STA-2 Supply Canal extends from the S-6 Pump Station to the Cells 1-3 Inflow Canal at the northeast corner of STA-2, a length of approximately 21,500 ft. The Supply Canal has a bottom width of 57.0 ft at elevation -4.0 ft NGVD and minimum side slopes of 2.5:1 (H:V). The top of the Perimeter Levee adjacent to the Supply Canal is at elevation 20.8 ft NGVD with a width of 14.0 ft and toe of the levee elevation at 10.0 ft NGVD. The Supply Canal was designed to convey the peak rates of discharge from pump stations S-6 and G-328 (3,370 cfs) without exceeding a maximum elevation of 18.3 ft NGVD at the tailwater of the S-6 Pump Station (Brown and Caldwell, 1996).

The static water elevation within the Supply Canal is generally 12.0 ft NGVD. Design flow stages range from 18.19 ft NGVD at S-6 tailwater to 17.05 ft NGVD at the end of the Supply Canal. The Standard Project Storm stages range from 18.03 ft NGVD at S-6 tailwater to 17.25 ft NGVD at the end of the Supply Canal. The Probable Maximum Storm stages ranges from 18.20 ft NGVD at S-6 tailwater to 17.79 ft NGVD at the end of the Supply Canal.

STA-2 Inflow Canal to Cells 1, 2 and 3

The STA-2 Inflow Canal extends westward from the Supply Canal along the northern boundary of Cells 1-3 to structure G-337A. The total length of the Inflow Canal is approximately 23,400 ft (Note that the canal length increased to 41,000 ft when STA-2 included Cells 1-4). The Inflow Canal in the reach along the top of Cell 1 has a bottom width of 20.0 ft at elevation -4.0 ft NGVD and side slope of 3:1 (H:V). The Inflow Canal in the reach along the top of Cells 2 and 3 has a bottom width of 20.0 ft at elevation -2.0 ft NGVD and side slope of 3:1 (H:V). A summary of the STA-2 Supply and Inflow Canal features is shown in **Table 4**.

Table 4. Summary of STA-2 Supply and Inflow Canal features.

Canal Reach	Approx. Length (ft)	Design Peak Flow Rate (cfs)	Approx. Bottom Elevation (ft NGVD)	Approx. Bottom Width (ft)	Approx. Side Slopes (H:V)
Supply Canal					
S-6 to Inflow Canal at northeast corner of Cell 1	21,500	Convey peak rate of 3,370 cfs without exceeding a maximum elevation of 18.30 ft NGVD at the S-6 TW	-4.0	57	2.5:1
Inflow Canal					
Northern boundary Cell 1	5,600	3,340[1]	-4.0	20	3:1
Northern boundary Cells 2& 3	17,800	2,556[1]	-2.0	20	3:1

[1] Inflow Canal Peak flow rates were estimated based on the treatment cell's design peak flow rates (Brown and Caldwell, 2012).

cfs = cubic feet per second; ft NGVD = feet National Geodetic Vertical Datum 1929.

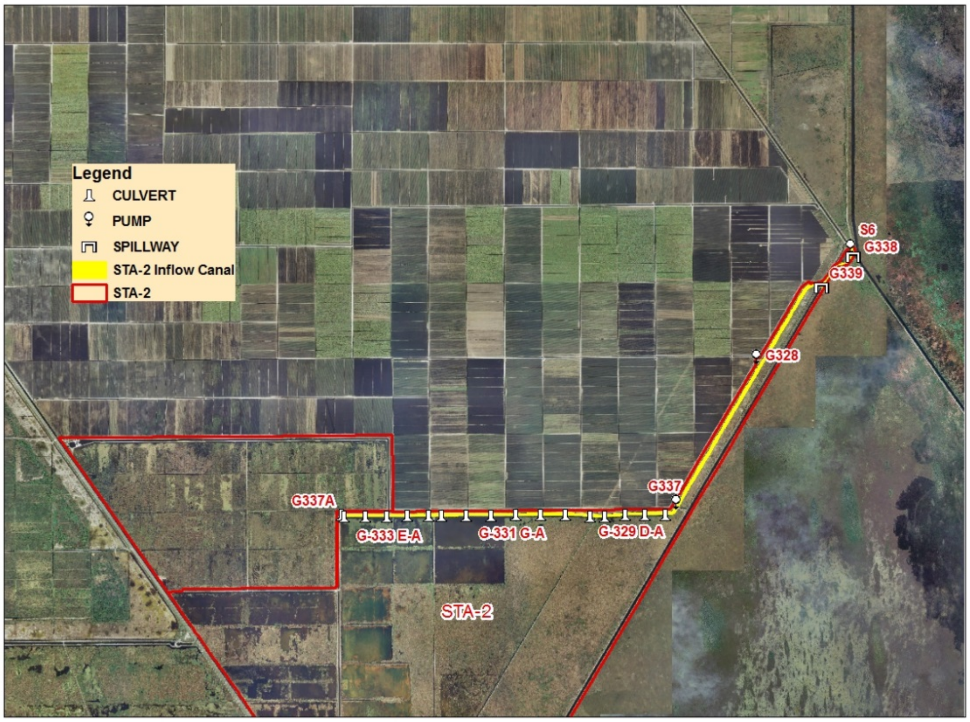

Figure 4. STA-2 Supply and Inflow Canal.

STA-2 Discharge Canal

The STA-2 record drawings (F.R.S. & Associates, Inc. 1999), STA Compartment B North Build-out Record Drawings (Brown and Caldwell, 2011a), STA Compartment B South Build-out Record Drawings (Brown and Caldwell, 2011b), and STA-2 Operation Plan (Brown and Caldwell, 2012) were reviewed with respect to the STA-2 Discharge Canal physical characteristics (**Figure 5**). A summary of the STA-2 Discharge Canal characteristics follows.

Discharge Canal Reach for Cells 1, 2 and 3

The Discharge Canal for Cells 1, 2, and 3 extends eastward from the vicinity of G-332 and G-334 to the outflow pump station G-335 for a distance of approximately 6,000 ft. The Discharge Canal has a bottom width varying from 50.0 ft to 66.0 ft at elevation –4.0 ft NGVD 29 and side slopes varying between 3H:1V and 2.5H:1V. Currently, the Discharge Canal from Cells 4 through 8 joins the Discharge Canal for Cells 1, 2, and 3 just east of G-334. This connection links pump stations G-335 and G-434 so that either or both pump station can be used to discharge the entire STA-2 system. G-335 serves as the primary outflow pump station for Cells 1, 2, and 3 and is located at the extreme southeast corner of STA-2.

Discharge Canal Reach for Cells 4 through 8

The Discharge Canal for Cells 4 through 8 extends eastward from the G-368 structure to the G-335 and G-436 outflow pump stations. The total length of the outflow canal is approximately 2.4 mi, with a bottom width of 35.0 ft at elevation -5.55 ft NGVD and side slopes of 2H:1V. The existing outflow canal from Cell 4 joins the new section of the discharge canal approximately 3,150 ft west of the G-436 outflow pump station. Currently, this Discharge Canal is connected to the Cells 1-3 Discharge Canal just east of G-334 by an existing cut through the perimeter levee. This connection links pump stations G-335 and

G-436 so that either or both pump stations can be used to discharge the entire STA-2 system. A summary of the STA-2 Discharge Canal features is shown in **Table 5**.

Table 5. Summary of STA-2 Discharge Canal features.

Canal Reach	Approx. Length (ft)	Discharge Capacity (cfs)	Approx. Bottom Elevation (ft NGVD)	Approx. Bottom Width (ft)	Approx. Side Slopes (H:V)
Cells 1-3 between G-334 and G-335	6,000	3,040[1]	-4.0	Varies: 50 - 66	Varies 3:1 to 2.5:1
Cells 4-8 between G-368 and G-436[2]	13,000	1,600[3]	-5.3 to -5.55	60 at Section A 135 at Section B, C and D	2:1

cfs = cubic feet per second; ft NGVD = feet National Geodetic Vertical Datum 1929.

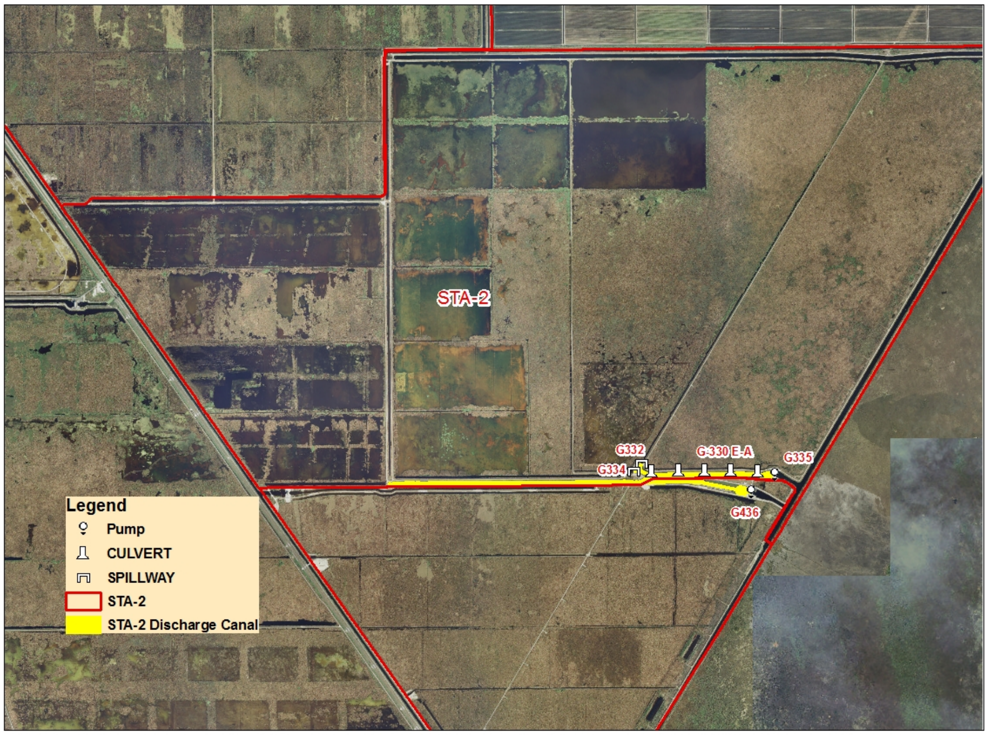

Figure 5. STA-2 Discharge Canal.

STA-3/4 INFLOW AND SUPPLY CANAL

The STA-3/4 As-built Survey of the Supply Canal (F.R.S. Associates, Inc. 2003), STA-3/4 Works, Conforming to Construction Records, (Montgomery Watson, Adair and Brady, Inc., and Gee & Jenson, 2001), and STA-3/4 Operation Plan (SFWMD, 2007b) were reviewed with respect to the STA-3/4 Inflow and Supply Canal physical characteristics (**Figure 6**). A summary of the STA-3/4 Inflow and Supply Canal characteristics follows.

The Inflow/Supply Canal system conveys discharges from G-370 and G-372 to STA-3/4. The Supply Canal is located adjacent to the northern boundary of the Holey Land and extends from G-372 eastward (7.7 miles) and then southward (2.7 miles) before joining the Inflow Canal at the northwest corner of the STA. The Inflow Canal borders the northern portion of STA-3/4 from the junction of the Supply Canal to G-370 (6.2 miles). Structure G-383 is located in the Inflow Canal adjacent to the western limit of Cell 1A. Under normal conditions, this structure will be open. However, when upstream flood protection conditions require or if needed for water quality performance optimization, G-383 can be closed to control the movement of water from the two pump stations to the three flow-ways.

The Supply Canal is flanked on both sides by levees to contain water levels that are expected to be as much as 8 ft above the surrounding grade elevation. The existing Holey Land Levee was modified to protect the Holey Land, and the Exterior Levee serves to protect farming areas located north of the canal. For the Inflow Canal, an Inflow Control Levee serves to separate the canal from the STA, while an Exterior Levee protects the farming areas to the north. Maintenance berms exist between the canal and both levees along the entire length of the Inflow/Supply Canal. A summary of the STA-3/4 Inflow and Supply Canal features is shown in **Table 6**.

Table 6. Summary of STA-3/4 Inflow and Supply Canal features.

Canal Reach	Approx. Length (ft)	Design Maximum Flow (cfs)	Approx. Bottom Elevation (ft NGVD)	Approx. Bottom Width (ft)	Approx. Side Slopes (H:V)
Supply Canal (from G-372 to NW corner of Cell 3A and the Inflow canal)	55,000	3,670	Varies between -5 to -10	Varies between 40 to 80	2.5:1
Inflow Canal (along north border of Cells 1A, 2A and 3A)	32,000	2,775[1]	-5.5	Varies between 30 to 45	2.5:1

[1] Inflow Canal section from G-380F to G-383.

cfs = cubic feet per second; ft NGVD = feet National Geodetic Vertical Datum 1929.

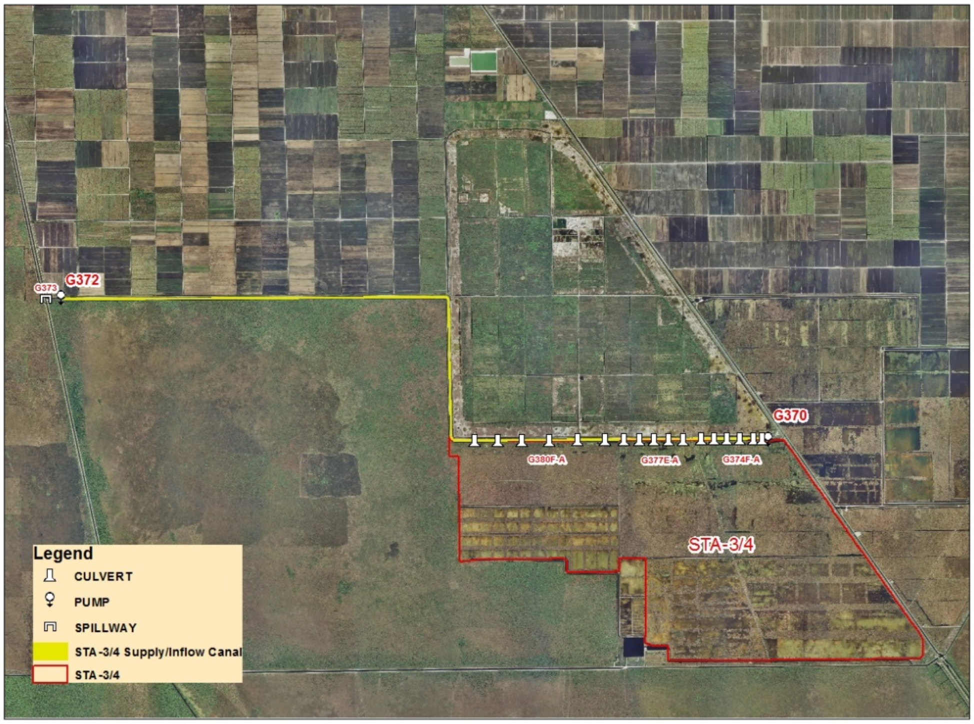

Figure 6. STA-3/4 Inflow and Supply Canal.

PART III: DATA QUERY

This section summarizes data queries completed for the Canal Study under the Restoration Strategies Science Plan (SFWMD, 2013a). The information contained in this report will support analyses conducted for the canals included in this study.

DATA QUERY BY THE NUTRIENT LOAD PROGRAM AND PRELIMINARY REVIEW

Period-of-record (POR) data ending with Water Year 2013 (WY2013; May 1, 2012–April 30, 2013) w queried for each canal to be investigated under this project, subject to availability. The beginning dates vary according to the dates that each STA began operation (see **Table 7**). Flow and water quality data, as summarized in **Table 8,** were retrieved from the District's database. Structures included in the canals studied are shown in **Appendix A**.

Table 7. Data query period.

STA	Start Date	End Date
STA-1E	5/1/2005	4/30/2013
STA-1W	5/1/2000	4/30/2013
STA-2	5/1/2001	4/30/2013
STA-3/4	5/1/2004	4/30/2013

Table 8. A list of parameters for data query.

Data	Unit	Test Number[1]
Phosphate, Total as P (TP)	µg/L	25
Phosphate, ORTHO as P (SRP)	µg/L	23
Phosphate, Dissolved as P (TDP)	µg/L	26
Particulate P (PP) (calculated)[2]	µg/L	N/A
DOP (calculated)[3]	µg/L	N/A
Total Suspended Solids (TSS)	µg/L	16
Dissolved Chloride (CLD)	µg/L	32
Turbidity (TURBI)[4]	NTU	12
Flow	CFS	N/A

[1] Numeric code used to identify individual tests within the District's DBHydro database, e.g., 25 = TPO_4 total phosphorus.

[2] PP = TP- TDP

[3] DOP = TDP – SRP

[4] Turbidity data were queried for reference (this parameter will not be analyzed).

For the water quality data retrieval, the Nutrient Load Program, a web-based tool developed by the District, was used. This program provides daily nutrient load estimates according to a user-configurable interface. Definitions of the different calculation modes used to compute flow-weighted mean concentrations, as documented in the Nutrient Load Program menu, are provided below:

- Mode 0: Use grab sample results only on days with flow, extrapolate between missing values.
- Mode 1: Use autosampler results only, extrapolate between missing values.
- Mode 2: Use autosampler results first; if missing use grab sample results only on days with flow, extrapolate between missing values.
- Mode 3: Use autosampler results first; if missing use grab sample, extrapolate between missing values.
- Mode 4: Currently not configured for use.
- Mode 5: Use grab sample results, use sample results if flow or no flow exists to extrapolate between missing values.

Calculation Modes 2, 3 and 5 were used for this study (**Table 9**) and the results from the three modes were compared for differences. Mode 0 was not used because for some sites, autosampler data are available and should not be excluded from the analysis. Mode 1 i not used because for some sites, there were no autosampler data available, and Mode 4 was currently not configured for use.

Table 9. Data queried by the Nutrient Load Program.

Calculation Mode	STA-1E	STA-1W	STA-2	STA-3/4
Mode 2	STA1E_TP_M2	STA1W_TP_M2	STA2_TP_M2	STA34_TP_M2
Mode 3	STA1E_TP_M3	STA1W_TP_M3	STA2_TP_M3	STA34_TP_M3
Mode 5	STA1E_TP_M5	STA1W_TP_M5	STA2_TP_M5	STA34_TP_M5
Mode 2	STA1E_DP_M2	STA1W_DP_M2	STA2_DP_M2	STA34_DP_M2
Mode 3	STA1E_DP_M3	STA1W_DP_M3	STA2_DP_M3	STA34_DP_M3
Mode 5	STA1E_DP_M5	STA1W_DP_M5	STA2_DP_M5	STA34_DP_M5
Mode 2	STA1E_OP_M2	STA1W_OP_M2	STA2_OP_M2	STA34_OP_M2
Mode 3	STA1E_OP_M3	STA1W_OP_M3	STA2_OP_M3	STA34_OP_M3
Mode 5	STA1E_OP_M5	STA1W_OP_M5	STA2_OP_M5	STA34_OP_M5
Mode 2	STA1E_CLD_M2	STA1W_CLD_M2	STA2_CLD_M2	STA34_CLD_M2
Mode 3	STA1E_CLD_M3	STA1W_CLD_M3	STA2_CLD_M3	STA34_CLD_M3
Mode 5	STA1E_CLD_M5	STA1W_CLD_M5	STA2_CLD_M5	STA34_CLD_M5
Mode 2	STA1E_S_Solid_M2	STA1W_S_Solid_M2	STA2_S_Solid_M2	STA34_S_Solid_M2
Mode 3	STA1E_S_Solid_M3	STA1W_S_Solid_M3	STA2_S_Solid_M3	STA34_S_Solid_M3
Mode 5	STA1E_S_Solid_M5	STA1W_S_Solid_M5	STA2_S_Solid_M5	STA34_S_Solid_M5
Mode 2	STA1E_TURB_M2	STA1W_TURB_M2	STA2_TURB_M2	STA34_TURB_M2
Mode 3	STA1E_TURB_M3	STA1W_TURB_M3	STA2_TURB_M3	STA34_TURB_M3
Mode 5	STA1E_TURB_M5	STA1W_TURB_M5	STA2_TURB_M5	STA34_TURB_M5

RAINFALL DATA QUERY

Both rain gauge-based and NEXRAD (Next-Generation Radar)-based rainfall data for the POR were queried and reviewed. The rainfall data were used in combination with STA flow data to identify different storm events when the canal structures were operated at full capacity, medium capacity, and low capacity. Active rain gauges within the study area are summarized in **Table 10**.

Table 10. Active rain gauges within the study area.

STA-1W and STA-1E			
Station	**DBKEY**	**Remark**	**Preferred DBKEY**
ENR101	15851	---	no
ENR203	15874	---	no
ENR301	15877	---	no
ENR308	15888	---	no
ENR401	15862	---	no
Average	KN809	Thiessen weighted average of available gauges	yes
STA-2			
Station	**DBKEY**	**Remark**	**Preferred DBKEY**
G331D	PT420	---	no
STA-3/4			
Station	**DBKEY**	**Remark**	**Preferred DBKEY**
S7	15204	---	yes
EAA5	15184	PREF DBKEY JW233 discontinued in 2010	no

REFERENCES

Ansar, M., R. Musalen, T. Strowd, M. Wilsnack and J. Zeng. 2014. Sedimentation control in the Central and Southern Florida project. Submitted for publication.

ASCE Task Committee on Sediment Transport and Aquatic Habitats, Sedimentation Committee. 1992. Sediment and Aquatic Habitat in River Systems, Journal of Hydraulic Engineering, Vol. 118, No. 5, pp. 669-687.

Bagnold, R.A. 1966. An approach to the sediment transport problem from general physics. *Geol. Surv. Prof. Paper*, 422-I, 42 p.

Bell Constructors. STA-1E Record Drawings for Contract 6.

Brown and Caldwell. 1996. Detailed Design Stormwater Treatment Area 2 and WCA-2A Hydropattern Restoration.

Brown and Caldwell. 2011a. Compartment B North Build-Out Record Drawings. December 2011.

Brown and Caldwell. 2011b. STA Compartment B South Build-out Record Drawings. December 2011.

Brown and Caldwell. 2012. STA-2 Operation Plan. August 2012.

Chomat, C.J. and K.S. Westphal. 2013. Enhanced understanding of sediment phosphorus dynamics in river systems with a simple supplemental mass balance tool. *J. Environ. Eng.*, 139:34-43.

Civil Services, Inc. 2007. Updated report of physical and chemical characterization of sediments – Everglades Agricultural Area (EAA), Stormwater Treatment Areas (STA) 1, 2, and 5 inflow canals. Final Project Report submitted to the South Florida Water Management District, West Palm Beach, FL.

Daroub, S.H., J.D. Stuck, T.A. Lang, and O.A.Diaz. 2002a. Particulate phosphorus in the Everglades Agricultural Area: I – Introduction and Sources. SL197. Florida Cooperative Extension Service. Inst. of Food and Agric. Sci., Univ. of Florida, Gainesville, FL.

Daroub, S.H., J.D. Stuck, T.A. Lang and O.A. Diaz. 2002b. Particulate phosphorus in the Everglades Agricultural Area: II – Transport mechanisms. University of Florida IFAS Extension, EDISSL198/SS417. http://edis.ifas.ufl.edu/SS417

Daroub, S.H., J.D. Stuck, T.A. Lang, O.A. Diaz and M. Chen. 2003. Implementation and verification of BMPs for reducing P loading in the EAA. Final Project Report submitted to the Everglades Agricultural Area Environmental Protection District and the Florida Department of Environmental Protection, Tallahassee FL.

Das, J., S.H. Daroub, J.H. Bhadha, T.A. Lang, O. Diaz and W. Harris. 2012a. Physicochemical assessment and phosphorus storage of canal sediments within the Everglades Agricultural Area, Florida. *J. Soils Sediments*, 12:952-965.

Das, J., S.H. Daroub, J.H. Bhadha, T.A. Lang and M. Josan. 2012b. Phosphorus release and equilibrium dynamics of canal sediments within the Everglades Agricultural Area, Florida. *Water Air Soil Pollut.*, 223:2865-2879.

DB Environmental, Inc. 2011. Stormwater treatment area outflow and inflow canal sediment characterization. Final Project Report submitted to the South Florida Water Management District, West Palm Beach, FL.

Diaz, O.A., S.H. Daroub, J.D. Stuck, M.W. Clark, T.A. Lang and K.R. Reddy. 2006. Sediment inventory and phosphorus fractions for Water Conservation Area canals in the Everglades. *Soil Sci. Soc. Am. J.*, 70:863-871.

Diaz, O.A., T.A. Lang, S.H. Daroub and M. Chen. 2005. Best management practices in the Everglades Agricultural Area: Controlling particulate phosphorus and canal sediments. University of Florida IFAS Extension, EDIS SL228/SS 448. http://edis.ifas.ufl.edu/SS448

Dierberg, F.E. and T.A. DeBusk. 2008. Particulate phosphorus transformations in south Florida stormwater treatment areas used for Everglades protection. *Ecol. Eng.*, 34:100-115.

Domagalski, J.L., S. Ator, R. Coupe, K. McCarthy, D. Lampe, M. Sandstrom and N. Baker. 2008. Comparative study of transport processes of nitrogen, phosphorus, and herbicides to streams in five agricultural basins, USA. *J. Environ. Qual.*, 37:1158-1169.

Dunne, E.J., K.A. McKee, M.W. Clark, S. Grunwald and K.R. Reddy. 2007. Phosphorus in agricultural ditch soil and potential implications for water quality. *J. Soil Water Conserv.*, Vol. 62(4):244-252.

Biedenham, D. S., Hubbard, L.C., Thome, C. R., and Watson, C.C. Understanding Sediment Sources, Pathways and Sinks in Regional Sediment Management: Wash Load and Bed-Material Load Concept, EU.S. Army Engineer Research and Development Center, Vicksburg, MS. RDC TN-SWWRP-06-3, March 2006.

F.R.S. & Associates, Inc. 1999. STA-2 Record Drawings. November 1999.

F.R.S. & Associates, Inc. 2003. STA-3/4 Record Survey of the Supply Canal. March 2003.

Foster, I.D.L., S.M.J. Baban, S.D. Wade, S.M. Charlesworth, P.J. Buckland and K. Wagstaff. 1996. Sediment-associated phosphorus transport in the Warwickshire River Avon, UK. Erosion and Sediment Yield: Global and Regional Perspectives. IAHS Publ. no. 236:303-312.

Gary Goforth, Inc. 2009. STA-1E Interim Operation Plan. May 2009.

Grundy Marine and F.R.S. and Associates, Inc. Record Drawings for Contract 7.

Gustavson, K.E., G.A. Burton, N.R. Francingues, Jr., D.D. Reible, D.J. Vorhees and J.R. Wolfe. 2008. Evaluating the effectiveness of contaminated-sediment dredging. *Environ. Sci. Technol.*, July 15:5042-5047.

Harvey, J.W., G.B. Noe, L.G. Larsen, D.J. Nowacki and L.E. McPhillips. 2011. Field flume aquatic vegetation's role in sediment and particulate phosphorus transport in a shallow aquatic ecosystem. *Geomorphology*, 126:297-313.

House, W.A, F.H. Denison, J.T. Smith and P.D. Armitage. 1995. An Investigation of the effects of water velocity on inorganic phosphorus influx to a sediment. *Environ. Pollut.*, Vol. 89(3):263-271.

Hutcheon Engineers. 2000. STA-1W Record Drawings. September 2000.

James, S.C., C.A. Jones, M.D. Grace and J.D. Roberts. 2010. Advances in sediment transport modelling. *J. Hydraul. Res.*, Vol. 48(6):754-763.

Karimi, Gh.H. and H. Moazed. 2012. Settling and non-settling velocities in irrigation canals, Hamidieh and Ghods irrigation network, South of Iran. *Afr. J. Agric. Res.*, 7(22):3271-3276.

Lang, T.A., O. Oladeji, M. Josan and S. Daroub. 2010. Environmental and management factors that influence drainage water P loads from Everglades Agricultural Area farms of South Florida. *Agr. Ecosyst. Environ.*, 138:170-180.

Low Hui Xiang, D., H.D. Utomo and K. Lim Zhi Hao. 2011. Correlation between turbidity and total suspended solids in Singapore rivers. *J. Water Sustainability*, 1(3):313-322.

Martin, Y. and M. Church. 2000. Re-examination of Bagnold's empirical bedload formulae. *Earth Surf. Processes*, 25:1011-1024.

Montgomery Watson, Adair and Brady, Inc., and Gee & Jenson. 2001. STA-3/4 Works, Conforming to Construction Records. April 2001.

Noe, G.B., J.W. Harvey and J.E. Saiers. 2007. Characterization of suspended particles in Everglades wetlands. *Limnol. Oceanogr.*, 52(3):1166-1178.

Osidele, O.O., W. Zeng and M.B. Beck. 2003. Coping with uncertainty: A case study in sediment transport and nutrient load analysis. *J. Water Res. Pl-ASCE*, 129:345-355.

Reddy, K.R., O.A. Diaz, L.J. Scinto and M. Agami. 1995. Phosphorus dynamics in selected wetlands and streams of the Lake Okeechobee Basin. *Ecol. Eng.*, 5:183-207.

SFWMD. 2007a. STA-1W Operation Plan. South Florida Water Management District, West Palm Beach, FL. April 2007.

SFWMD. 2007b. STA-3/4 Operation Plan. South Florida Water Management District, West Palm Beach, FL. August 2007.

SFWMD. 2013a. Restoration Strategies Regional Water Quality Plan: Science Plan for the Everglades Stormwater Treatment Areas. South Florida Water Management District, West Palm Beach, FL. June 2013. Available online at www.sfwmd.gov/rs_scienceplan.

SFWMD. 2013b. Surveyor's Report: Hydrographic Survey of S5A Discharge Canal and a Portion of Levee 7 and Levee 40 Borrow Canals and a Topographic Survey of a Portion of Levee 7, Levee 40 and the Connecting Road between G-300 and G-301 in Palm Beach County, Florida. Final Report. South Florida Water Management District, West Palm Beach, FL. April 2013.

Skhiri, A. and F. Dechmi. 2011. Irrigation return flows and phosphorus transport in the Middle Ebro River Valley (Spain). *Span. J. Agric. Res.*, 9(3):938-949.

Smith, D.R., E.A. Warnemuende, B.E. Haggard, and C. Huang. 2006. Changes in sediment-water column phosphorus interactions following sediment disturbance. Ecological Engineering 27: 71-78.

Smith, D.R. and E.A. Pappas. 2007. Effect of ditch dredging on the fate of nutrients in deep drainage ditches of the Midwestern United States. *J. Soil Water Conserv.*, 62(4):252-261.

Stuck, J.D., F.T. Izuno, K.L. Campbell, A.B. Bottcher and R.W. Rice. 2001. Farm-level studies of particulate phosphorus transport in the Everglades Agricultural Area. *American Society of Agricultural Engineers*, 44(5): 1105-1116.

Stuck, J.D., T.A. Lang, O.A. Diaz, S. Daroub and T. Aziz. 2002. Studies of particulate phosphorus sources and potential management practices for control in the Everglades Agricultural Area. Seventh Biennial Stormwater Research & Watershed Management Conference.

Surratt, D.D., M.G. Waldon, M.C. Harwell and N.G. Aumen. 2008. Time-series and spatial tracking of canal water intrusion into wetlands of a National Wildlife Refuge in Florida, USA. *Wetlands*, 28(1):176-183.

Taylor Engineering, Inc. 2007. Dredging feasibility evaluation of Everglades Agricultural Areas Stormwater Treatment Areas 1, 2, & 5 and inflow canals. Final Project Report submitted to the South Florida Water Management District, West Palm Beach, FL.

Thodsen, H., B. Hasholt and M. Pejrup. 2004. Transport of phosphorus, wash load and suspended sediments in the River Varde Å in southwest Jutland, Denmark. Sediment Transfer through the Fluvial System, Publ. 228:466-473.

USACE. 2012. Final STA-1E Water Control Plan (revised). U.S. Army Corps of Engineers, Jacksonville, FL.

Van Rijn, L.C. 1984a. Sediment transport, Part I: Bed load transport. *J. Hydraul. Eng.*, 110(10): 1431-1456.

Van Rijn, L.C. 1984b. Sediment transport, Part II: Suspended load transport. *J. Hydraul. Eng.*, 110(11):1613-1641.

Vivona, M.A. and G. Mooney. 2000. Remediation of contaminated stormwater canal at Miami International Airport. Final Report.

Walling, D.E., B.W. Webb and M.A. Russell. 1997. Sediment-associated nutrient transport in UK rivers. Freshwater Contamination, IAHS Publ. no. 243:69-81.

Zaimes, G.N. and R.C. Schultz. 2002. Phosphorus in agricultural watersheds: A literature review. Department of Forestry, Iowa State University, Ames Iowa.

Zelenakova, M., M. Carnogurska, M. Slezingr, D. Slys and P. Purcz. 2013. A model based on dimensional analysis for prediction of nitrogen and phosphorus concentrations at the river station Izkovce, Slovakia. *Hydrol. Earth Syst. Sci.*, 17:201-209.

Appendix A:

Study Structures, DBKEYS and Water Quality Sites

Structures		Preferred DBKEYS	Source DBKEYS	Water Quality Sites
STA-1E				
Outflow	S362	TP369	T0897	S362
STA-1E, Eastern Flow-way				
Outflow	S365A	W3904	SG561	S365A
	S365B	W3905	SG563	S365B
STA-1E, Central Flow-way				
Outflow	S369A	W3911	TA355	S369B
	S369B	W3912	TA356	S369B
	S369C	W3913	TA318	S369C
	S369D	W3914	TA357	S369C
STA-1E, Western Flow-way				
Outflow	S372A	W3918	TN560	S372B
	S372B	W3919	TY236	S372B
	S372C	W3920	TA330	S372B
	S372D	W3921	TN561	S372D
	S372E	W3922	TY238	S372D

Structures		Preferred DBKEYS	Source DBKEYS	Water Quality Sites
STA-1W				
Inflow	G302	JW221	JJ806	G302
Outflow	G251	JW222	15848	ENR012
	G310	M2901	PK919	G310
STA-1W, Northern Flow-way				
Inflow	G304A	W3860	V2485	G302, G303
	zG304B	W3861	V2486	G302, G303
	G304C	W3862	V2487	G302, G303
	G304D	W3863	V2488	G302, G303
	G304E	W3864	VW951	G302, G303
	G304F	W3865	VW802	G302, G303
	G304G	W3866	VW952	G302, G303
	G304H	W3867	VW876	G302, G303
	G304I	W3868	VW872	G302, G303
	G304J	W3869	VW953	G302, G303
Outflow	G306A	W3870	L9866	G306C
	G306B	W3871	L9867	G306C
	G306C	W3872	L9868	G306C
	G306D	W3873	L9869	G306C
	G306E	W3874	L9870	G306C
	G306F	W3875	L9871	G306G
	G306G	W3876	L9872	G306G
	G306H	W3877	L9873	G306G
	G306I	W3878	L9874	G306G
	G306J	W3879	L9875	G306G
STA-1W, Western Flow-way				
Outflow	G258	---	SG916	G309
	G309	W3882	L9849	G309
	G307	---	VM853	G307
STAA-1W, Eastern Flow-way				
~~Inflow~~	~~G303~~	~~W3880~~	~~L9830~~	~~G303~~
	~~G255~~	~~WF797~~	~~VM838~~	~~G255~~
Outflow	G308	W3881	L9846	G308
	G259	W3884	SG917	G259
	G251	JW222	15848	ENR012

Structures		Preferred DBKEYS	Source DBKEYS	Water Quality Sites
STA-2				
Inflow	S6	15034	06741	S6
	G328	J0718	MQ903	G328
	G328I_P	---	TA605	G328R
	G328I_C	---	TA607	G328R
	G338 from	---	MC705	S10D
	G338 to WCA-	---	MC705	S6
	G339 from	---	MC706	G335
	G339 to WCA-	---	MC706	S6
	G434	---	AI368	G434
	G435	---	AI386	G435
Outflow	G335	N0659	LG726	G335
	G436	---	AI400	G436
STA-2, Flow-way 1				
Inflow	G329A	W3926	N0748	G329B
	G329B	W3927	LG703	G329B
	G329C	W3928	LG704	G329B
	G329D	W3929	LG705	G329B
Outflow	G330A	W3930	LG706	G330D
	G330B	W3931	LG707	G330D
	G330C	W3932	LG708	G330D
	G330D	W3933	LG709	G330D
	G330E	W3934	LG710	G330D
STA-2, Flow-way 2				
Inflow	G331A	W3935	LG711	G331D
	G331B	W3936	LG712	G331D
	G331C	W3937	LG713	G331D
	G331D	W3938	LG714	G331D
	G331E	W3939	LG715	G331D
	G331F	W3940	LG716	G331D
	G331G	W3941	LG718	G331D
Outflow	G332	W3942	LG719	G332

Structures		Preferred DBKEYS	Source DBKEYS	Water Quality Sites
STA-2, Flow-way 3				
Inflow	G333A	W3943	LG720	G333C
	G333B	W3944	LG721	G333C
	G333C	W3945	LG722	G333C
	G333D	W3946	LG723	G333C
	G333E	W3947	LG724	G333C
Outflow	G334	W3948	LG725	G334
STA-2, Flow-way 4				
Inflow	G337A	90403	W1982	G337A
	G434	90327	AI368	G434
Outflow	G368	90404	VN385	G368
STA-2, Flow-way 5				
Inflow	G435	90328	AI386	G435
Outflow	G441	90406	AI621	G441

Structures		Preferred DBKEYS	Source DBKEYS	Water Quality Sites
STA-3/4				
Inflow	G370	TA438	T0973	G370
	G372	TA437	T0975	G372
STA-3/4, Eastern Flow-way				
Inflow	G374A	W3964	T8434	G374B
	G374B	W3965	T8435	G374B
	G374C	W3966	T8436	G374B
	G374D	W3967	T8437	G374E
	G374E	W3968	T8438	G374E
	G374F	W3969	T8439	G374E
STA-3/4, Central Flow-way				
Inflow	G377A	W3970	T9945	G377B
	G377B	W3971	T9946	G377B
	G377C	W3972	T9947	G377B
	G377D	W3973	T9948	G377D
	G377E	W3974	T9949	G377D
STA-3/4, Western Flow-way				
Inflow	G380A	W3975	T9955	G380B
	G380B	W3976	T9956	G380B
	G380C	W3977	T9957	G380B
	G380D	W3978	T9958	G380E
	G380E	W3979	T9959	G380E
	G380F	W3980	T9960	G380E