Chemical Treatment Followed by Solids Separation Advanced Technology Demonstration Project

FINAL REPORT

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Prepared by:

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- STSOC UNIT COST SUMMARIES (3 pages each):
  - * CTSS Post-BMP Full-Scale Treatment Facilities
    - 120 mgd
    - 150 mgd
    - 200 mgd
    - 220 mgd
    - 270 mgd
    - 380 mgd
  - * CTSS Post-STA Full-Scale Treatment Facilities
    - 80 mgd
    - 100 mgd
    - 140 mgd
    - 190 mgd
    - 260 mgd
    - 390 mgd

EXECUTIVE SUMMARY

INTRODUCTION, BACKGROUND AND OBJECTIVES

The Everglades Forever Act (EFA), Section 373.4592, Florida Statutes, enacted by the Florida Legislature in May 1994, mandates a series of state agency actions to restore the Everglades. The restoration projects mandated by the EFA include research, regulation, exotic species control and construction projects, and are collectively referred to as the "Everglades Program." As part of the Everglades Program, the EFA requires the South Florida Water Management District (SFWMD) to design and build six stormwater treatment areas (STAs) to remove phosphorus from Everglades Agricultural Area (EAA) stormwater runoff before releasing to the Everglades Protection Area (EPA). STAs are constructed wetlands that will provide water quality treatment through natural biological and physical processes. STAs will encompass approximately 47,000 acres, and are being designed to treat more than one million acre-feet per year of water received from the EAA and Lake Okeechobee. STAs will be used in combination with on-farm Best Management Practices (BMPs) to reduce phosphorus concentrations to within the Everglades Program Interim goal of 50 μg/L.

The EFA also requires SFWMD and the Florida Department of Environmental Protection (FDEP) to conduct research and rulemaking to interpret numerically the existing narrative Class III water quality standard for phosphorus. A comprehensive research program that determines the maximum phosphorus concentration that will not cause an imbalance in the natural flora or fauna of the Everglades is ongoing and targeted for completion by no later than January 1, 2001. Preliminary results from research and modeling indicate that the threshold phosphorus concentration will be below the Interim goal of 50 μg/L.

Long-term phosphorus reduction goals of the Everglades Program involve the implementation of new basin-scale treatment processes (also referred to as "advanced treatment technologies"), as stand-alone treatment systems or in series with STAs, to reduce phosphorus concentrations to within the threshold concentration. Because the threshold phosphorus concentration is expected to be less than the Interim goal of 50 μg/L and because the EFA establishes a default phosphorus criterion of 10 μg/L if FDEP does not adopt a final total phosphorus (Total P) criterion by December 31, 2003, long-term phosphorus reduction goals of the Everglades Program are focused on demonstrating water quality treatment technologies capable of reducing phosphorus concentrations to 10 μg/L. The EFA requires SFWMD to have treatment technologies on-line by December 31, 2006.

The primary objective of this project was to evaluate the technical, economic and environmental feasibility of the full-scale implementation of the chemical treatment and solids separation (CTSS) technology and assess its ability to reduce the Total P content of EAA surface waters to concentrations of 10 μg/L or less. The determination of the feasibility of full-scale CTSS implementation was to be obtained from the results of pilot and field investigations. More specific objectives of the project were to:

- Identify and demonstrate an optimized CTSS process for which operating conditions can be described and full-scale costs projected;

- Conduct sampling adequate to complete a Supplemental Technology Standard of Comparison (STSOC) evaluation as described by PEER Consultants/Brown & Caldwell Joint Venture (1998); and,

- Develop process criteria and experience needed to design a full-scale CTSS system.

CTSS pilot testing was used to determine the ability of chemical coagulation coupled with solids separation techniques (*e.g.*, solids settling/clarification and filtration) to remove Total P from representative Post-BMP and Post-STA canal surface waters within the Everglades Agricultural Area (EAA). The optimum CTSS treatment process identified would produce the lowest possible effluent Total P at the lowest capital and operating cost and have as limited as possible environmental impact on downstream marshes and wetlands.

This Final Report for the entire project includes: 1) an overview of the CTSS pilot system and a discussion of how it was operated; 2) the overall experimental design; 3) a summary of the test data; 4) data analysis and conclusions; 5) a set of recommendations and costs for scaling up the technology from demonstration-scale to full basin-scale treatment; and 6) an order of magnitude engineering cost estimate for a set of full-scale facilities for STA 2, as required by the STSOC.

METHODS AND MATERIALS

The CTSS project evaluated the feasibility of using the technology (chemical treatment followed by settling and/or filtration) as a basin-scale treatment process for reducing phosphorus loads from the EAA. The chemical treatment phase of CTSS involves the use of metal (iron or aluminum) salts to precipitate phosphorus. These metal salts are routinely used in conventional water treatment facilities for producing drinking water. Metal salts coagulate the precipitates and other particles, which allows the small particulates to be coalesced (flocculated) into larger and more readily settled or readily filtered agglomerates. Organic polymers were used to increase flocculent size, density, and strength. Solids generated from the coagulation and flocculation process were then separated from the liquid through settling and/or filtration.

The CTSS test facility was constructed under a separate contract with SFWMD and was installed at the southern end of the Everglades Nutrient Removal (ENR) site near the location of ENR effluent discharge into the Water Conservation Area. The CTSS test facility consisted of two process trains, each containing the following equipment:

- One cubic meter mix tank complete with a mechanical mixer for rapid/flash mixing;

- Two flocculation tanks (each, one cubic meter in volume) fitted with variable speed mechanical flocculating blades;

- One clarifier with a variable hydraulic capacity up to approximately 30 gallons per minute;

- One backwash tank for retaining an entire volume of backwash solids and water;

- Flow meters, sensors and composite samplers sufficient to measure the quantity and quality of feed, effluent and intermediate points throughout the pilot facility; and

- A total of nine 8-inch diameter columns to be used to test filtration media.

Operational variables that were tested and optimized included feed flow rates, flocculation retention times and mixing speeds, coagulant feed concentrations, clarifier overflow rates, residual solids recirculation rate, filter media composition and filtration rates. Some experiments included all of the process units listed above in series and others limited the treatment train to selected units. For example, direct filtration experiments were conducted using only the flocculation tanks with these flows being sent directly to the filtration columns, bypassing the clarifier.

After numerous screening tests were conducted on ENR outflow (Post-STA) waters and the more effective operating conditions had been identified, a modified pilot test facility was installed to test representative Post-BMP canal surface waters. The Post-BMP testing was conducted at the ENR North Testing Site. The source of the feed waters to at the North Test Site was the L10/L11 Canal.

The CTSS demonstration project field-testing was conducted in six stages over a period of seven months:

Stage	Duration	Dates (1999)
1 - Shakedown	2 weeks	May 10 – May 24
2 - Pre-Screening	2 weeks	May 17 – June 1
3 - Screening	17 weeks	June 2 – Sept. 25
4 - Optimization Level 1	4 weeks	Oct. 26 – Nov. 15
5 - Optimization Level 2	3 weeks	Nov. 16 – Dec. 3
6 - Demonstration	4 weeks	Dec. 4 – Dec. 23

(Note: The North Site facility was constructed from September 26 through October 25.)

In addition to the testing conducted on the pilot facilities, several vendor technologies were evaluated, including dissolved air flotation, high rate sedimentation, ballasted sand flocculation, as well as others during the May through December experimental testing period.

STUDY RESULTS

Screening Phase

The experimental setup for the screening experiments conducted at the South Test Site consisted of two essentially identical conventional water treatment trains, each train containing: 1) an in-line static mixer; 2) a coagulation tank; 3) two flocculation tanks in series; 4) a clarifier fitted with inclined plate settlers; and 5) granular media rapid filters in parallel. The chemically treated (and clarified) water could be introduced to any one or all of the filter columns of selected filter media. Various chemical tested included: 1) alum ($Al_2(SO_4)_3$)•14 H_2O; 2) ferric-sulfate ($Fe_2(SO_4)_3$); 3) anionic coagulant aid (A-1849 polyacrylamide also known as PAM); and 4) hydrated lime ($CaOH_2$). A total of 28 multiple-day experiments were conducted during the screening phase of the testing program. Screening experiments were performed from June 3, 1999 to September 26, 1999.

Conventional water treatment operations (*i.e.*, chemical addition, coagulation, flocculation, and filtration processes) produced a filtered effluent containing less than 10 μg/L Total P during three screening experiments. These results were obtained using the coagulant alum with a dose of 10 to 12 mg/L and with 0.3 to 0.5 mg/L of A-1849 (Cytec) anionic polymer. The corresponding flocculation volume was equal to a total of 400 gallons (*i.e.*, use of both flocculation tanks with total HDTs ranging from 30 to 40 minutes). These successful experimental conditions were the starting point for performing additional optimization experiments. Combining the filtrate Total P quality results with the filters displaying superior hydraulic performance (*i.e.*, the longest run times without clogging) resulted in the selection of the "GE" (an anthracite and sand dual media) and "Swiss" (an expanded shale media) filters for further testing.

Optimization Testing Results

Optimization experiments were conducted simultaneously at the North and South Test Sites from October 26 through December 3, 1999. Using a '*Bayesian*' experimental design approach, optimization testing was conducted in four unique segments with the results of earlier segments influencing the testing conditions of later experiments. During the optimization experiments, coagulation volumes were varied from 20 to 220 gallons per minute (approximately 1.5 to 18-minute retention time at a feed flow rate of 12 gallons per minute) and the hydraulic loading rates to the filters ranged from 4.9 to a high of 9.8 gpm/sq.ft. The flocculation volume was set at a constant volume of 400 gallons and the mixing velocity gradient (G) was equal to 100 G in the first stage flocculator and 40 G in the second stage. Clarifier projected-area loading rates ranged from 0.14 up to a high of 0.43 gpm/sq.ft. Both ferric-chloride and alum were tested and anionic polymers (PAM) A-130 and A-1849 were tested as well in different daily trials.

The total of 138 optimization experimental results (70 at the North Site and 68 at the South) showed varying degrees of Total P reduction. Total P removal of up to 97.5 percent (from 163 to 4 μg/L) was achieved at the North Site. The highest Total P reduction was achieved with 40 mg/L of ferric-chloride and 0.5 mg/L of Cytec anionic A-130 polymer (PAM) and with relatively low hydraulic loadings of both the clarifier and the filter columns (0.14 gpm/sq.ft. and 4.9 gpm/sq.ft., respectively. At the South Test Site, up to 87.9 percent Total P reduction (less than 4 μg/L of Total P in effluent samples) was achieved. Conditions corresponding to these removal results included 0.28 gpm/sq.ft. clarifier and 4.9 gpm/sq.ft. filter hydraulic loading rates and using 20 mg/L of alum as the chemical coagulant. The "GE" filter provided marginally higher Total P removal than the Swiss media during the optimization trials.

A relatively narrow range of pilot operating conditions produced the desired 10 μg/L or less Total P effluent results. Recommendations from the Technical Review Team (TRT) members resulted in the following conditions for demonstration testing:

	North Site	South Site
Feed Flow Rate, gpm	12	12
Clarifier Overflow, gpm/sq.ft.	0.14	0.28
Filtrate Rate, gpm/sq.ft.	4.9	9.8
Filter Media	Swiss/GE	Swiss/GE
Coagulant Type	ferric salt	Alum
Coagulant Dose, mg/L as element	40	20
Coagulation Volume, gallons	20	20
Flocculation Volume, gallons	400	400
Flocculation Blade Speed, RPM (tank 1/tank 2)	10/5	10/5
Flocculation HDT, minutes	33	33
Coagulation HDT, minutes,	1.7	1.7
Polymer Dose (A-130)	0.5	0.5
Clarifier Waste Rate, gpm	0.6	0.6

Both iron and alum coagulants produced low Total P results and testing of each of the chemicals during demonstration experiments was consequently recommended.

Demonstration Testing

For the entire demonstration testing period of December 4 through December 23, 1999, the CTSS pilot facilities at both the North and South Sites produced clarifier effluents and filtrate Total P concentrations consistently at or below 10 μg/L.

The average raw water Total P concentration at the North Site during demonstration testing was equal to 164 μg/L. Total P summary results for the North Site testing follow:

	Average Total P value (μg/L) for North Site Testing
Feed Water	164
Clarifer Effluent	7
Swiss Filtrate	6
GE Filtrate	6

The average raw water Total P concentration at the South Site during demonstration testing was equal to 22 μg/L. Total P summary results for the South Site testing follow:

	Average Total P value (μg/L) for South Site
Feed Water	22
Clarifier Effluent	7
Swiss Filtrate	6
GE Filtrate	6

Standard of Comparison Additional Demonstration Phase Testing Results

Standard of Comparison (STSOC) testing was conducted during the CTSS demonstration phase testing in accordance with the requirements specified by PEER/Brown & Caldwell (August 1999). The results of the various additional demonstration testing components are provided below.

Water Quality Testing

For both the North (Post-BMP) and the South (Post-STA) Test Sites, composite samples were collected on raw water, clarified effluent and filtrate sample several times during the December demonstration phase of testing. These samples were submitted to the contract laboratory for metals, nitrogen series, total dissolved solids (TDS), common cations and anions, total organic carbon, biotoxicity testing and algal growth potential (AGP). Average results obtained for these chemical constituents are discussed below:

- ***Total Alkalinity and pH***

  A significant amount of total alkalinity was removed from the feed waters as a result of the CTSS testing. Average alkalinity was reduced from 129 to 38 mg/L at the North Site and from 220 to 114 mg/L at the South Site. The pH was also reduced from an average of 6.8 to 6.0 at the North Site and from 7.1 to 6.4 at the South Site. Reductions of alkalinity and pH are expected with the addition of the acidic alum and ferric-chloride coagulants.

- ***Conductivity and TDS***

  The conductivity and TDS of samples are both measures of the dissolved solids content. Addition of metallic salts to EAA surface water will normally result in increases in these parameters. Due to the ferric-chloride addition at the North Site, the chlorides added will contribute to both higher conductivity and TDS results. The average TDS of the feed waters increased from 308 to 358 mg/L at the North Site, and from an average TDS of

581 to 587 mg/L at the South Site. At the South Site, the TDS increased due to the added sulfates contained in alum. The conductivity of the North Site feed samples averaged 578 micromhos/centimeter and 625 micromhos/centimeter in the pilot unit effluent samples. At the South Site, the conductivity in the feed samples averaged 1091 micromhos/centimeter and equaled 1083 in the CTSS pilot unit effluent samples.

- ***Metals***

The North Site demonstration testing was conducted using the coagulant ferric-chloride. No significant increases (*e.g.*, less than 20 percent difference) were observed in feed versus effluent average sample results for the following metallic constituents:

Boron	Calcium	Lead
Silica	Molybdenum	Magnesium
Selenium	Aluminum	Cobalt
Mercury	Potassium	Iron
Zinc	Vanadium	

At the North Test Site the following metals increased more than 20 percent following chemical treatment:

Metal	Concentration in Feed (mg/L)	Concentration in Effluent (mg/L)
Copper	0.0021	0.0042
Manganese	0.019	0.166
Nickel	0.0013	0.0056

The South Site demonstration testing was all conducted using the coagulant alum. No significant increases (*e.g.*, less than 20 percent difference) were observed in feed versus effluent average sample results for the following constituents:

Sodium	Boron	Calcium	Lead
Silica	Molybdenum	Magnesium	Potassium
Selenium	Cobalt	Copper	Manganese
Nickel	Mercury	Vanadium	Zinc

Iron was the only metal tested at the South Site that displayed a higher average value in the effluent than observed in the influent samples. The average influent iron concentration was equal to 0.07 mg/L and in the pilot unit effluent, the average iron concentration was 0.12 mg/L.

- ***Sulfate***

  There were no significant differences in the average concentrations of sulfate in feed versus CTSS effluent samples for the North Test Site. During demonstration testing, the average feed concentration was equal to 36 mg/L and the treated effluent averaged 39 mg/L. However, due to use of alum at the South Test Site, the measured CTSS effluent sulfate concentration increased from an average 50 mg/L at the inflow to 164 mg/L at the outflow.

- ***Total Organic Carbon and Color***

  The majority of the color and total organic carbon (TOC) of the EAA surface waters is attributed to the leaching of organic materials from the muck soils into the water column. Alum and ferric-chloride water treatment coagulants readily react with the organic color molecules and reductions in the TOC and color content of the treated waters would be expected.

  The average TOC of the feed water at the North Site was equal to 18 mg/L during demonstration testing. Treating these waters with ferric-chloride reduced the average TOC content to 8 mg/L. Influent color at the North Site averaged 153 APHA units. The color was reduced to an average of 22 APHA units in the treated effluent samples.

- ***Turbidity and Total Suspended Solids***

  Turbidity of the North Site influent waters averaged 26 NTUs. The treated and clarified pilot unit effluent averaged 1.7 NTUs. At the South Test Site, the average feed turbidity was equal to 0.76 NTUs and the clarified effluent average was equal to 5.5 NTUs.

  The total suspended solids (TSS) content of the feed waters at the North Test Site were reduced by the treatment process from an average 27 mg/L to 0.8 mg/L in the clarified effluent. At the South Site, the average feed TSS was equal to 5 mg/L and the clarified effluent averaged 3.3 mg/L of suspended solids. Reductions in feed water TSS content would be expected as particulate material contained in the surface waters will generally be removed during the water treatment coagulation and flocculation processes.

- ***Dissolved Oxygen***

  The mechanical aeration associated with the CTSS process increased the dissolved oxygen (DO) values of the measured effluents.

- ***Testing of Nitrogen Forms***

  Analyses for ammonia, nitrate + nitrite, and total kjeldahl nitrogen (TKN) forms were performed several times on pilot unit feed and effluent samples during demonstration testing.

  The CTSS treatment system had no observed effect on the forms of nitrogen tested during the demonstration experiments at both the North and South Test Sites.

- ***SFWMD Low Level Mercury Results***

  SFWMD staff collected feed and filtrate samples for trace level mercury analysis five times during the December Pilot Study demonstration period. Analyses were performed for filtered and total methyl mercury and filtered and total mercury on representative grab samples of feed and filtrate samples at the North and South Test Sites. Total mercury and methyl mercury analyses were also collected and performed on the clarifier underdrain solids.

  The average total mercury concentration of the feed samples was equal to 6.176 nanograms/L and 1.352 nanograms/L, while the average total mercury filtrate concentration was 0.306 nanograms/L and 0.500 nanograms/L, at the North and South Sites, respectively. Unfiltered total mercury was reduced approximately 95 percent at the North Site and 63 percent at the South Site. Filtered total mercury was reduced approximately 65 percent at the North Site and 31 percent at the South Site. Unfiltered methyl mercury was reduced approximately 66 percent at the North Site. The unfiltered methyl mercury concentration at the South Site was unchanged as was the filtered methyl mercury concentrations at both the North and South Sites. Mercury removed by CTSS is accumulated in the clarifier underdrain solids. The concentration of total mercury in the concentrated solids from the CTSS treatment system was equal to 81 nanograms/Liter at the North Test Site and 7.9 nanograms/Liter at the South.

- ***Bioassay and Algal Growth Potential Results***

  Bioassay and Algal Growth Potential (AGP) analyses were performed by the FDEP Biology Section and Hydrosphere Research on CTSS treatment technology water samples collected during the latter part of optimization and during demonstration of pilot testing (November through December 1999).

A total of three bioassay samples were performed on the CTSS feed water and filtrate sample pairs. Feed and filtrate samples were collected simultaneously to determine if any observed effects were the result of the feed waters or from the CTSS treatment process. Of all the testing conducted, there was only a slight to moderate effect on the reproduction rate of the water flea shown in two of the CTSS filtrate samples that was not observed in the feed water sample collected at the same time. On November 29, 1999, the CTSS North Site filtrate sample showed a slightly reduced rate of reproduction for the water flea test organism that was not shown in the feed sample. On this same day, a slight reduced rate of reproduction for the same organism was displayed in the filtrate sample collected at the South Site that was also not shown in the feed sample.

A significant toxicity effect was displayed in both the feed waters and CTSS filtrate samples for the fish, waterflea and algal test organism for samples collected on December 7, 1999.

The conventional treatment train did not show a significant impact identified from the bioassay sampling completed during testing that could be attributed to the CTSS treatment system.

- ***Residual Solids Characterization and Testing***

Off-site disposal of solids occurred only after toxicity analysis was conducted to ensure they contained no hazardous substances. On December 14, 1999, during demonstration testing, representative samples of these underdrain samples were collected and submitted to the FDEP laboratory in Tallahassee for full toxicity characteristic leachate procedure (TCLP) analyses. All of the analytical results on the residual solids from both the North and South Test Sites were well below respective allowed limits for TCLP parameters and, by definition, the CTSS residual solids are non-hazardous.

Based on these non-hazardous test results, arrangements were made with local EAA farmers to test the application of the residual onto agricultural land.

- ***Solids Productions Rates and Land Application Trials***

Solids production rates were calculated for the pilot units using data gathered during the demonstration period. Solids production rates ranged from 1,145 pounds of dry solids per million gallons of treated water at the ENR effluent location (Post-STA residual solids production rate using alum as the coagulant) to 1,720 pounds of dry solids per million gallons treated at the ENR influent location (Post-BMP solids production rate using ferric chloride as the coagulant).

Preliminary and short-term land application trials using CTSS aluminum-based and iron-based residuals on sweet corn plots on EAA muck soils were conduced and indicated:

a) Except for a higher aluminum and iron content, CTSS residuals are quite similar to typical Water Treatment Plant (WTP) residuals.

b) At the application rates tested, both the aluminum-based and iron-based residuals had an inhibitory effect on sweet corn crop yield. This effect was felt to be due to reactive aluminum/iron hydroxides in the residuals tying up the available soil phosphorus. The CTSS residuals used in the trials may not have been sufficiently "aged" to reduce the degree of reactive hydroxides.

c) As expected, the application of residuals increased the levels of aluminum, iron and Total P in the soil plots. There was also an increase in soil silicon levels observed. Based on the aluminum and iron content of CTSS residuals, which are 2.5 to 3 times the typical WTP residuals, lower application rates (*i.e.*, <8 tons/acre) should be considered.

d) At the application rates tested, there was no evidence of an accumulation of any of the residuals' constituents in the plant leaves/stalk or in the sweet corn ears.

VENDOR TECHNOLOGY TESTING

Vendor technologies tested during CTSS field activities included the following:

- **Krüger, Inc.** offers the ACTIFLO process using microsand as a seed for floc formation. Completed test results indicate that the ACTIFLO process can reduce the Total P concentration below the threshold limit of 10 μg/L. However, since these results could not be achieved without adding sulfuric acid and lowering the pH to the 4 to 5 range, the process would not be the first selected option if others could be identified that operate in the more native pH range of the EAA surface waters.

- **Infilco Degremont, Inc.** tested their DensaDeg high-rate clarification thickener unit at the North Test Site. Testing results indicate that the DensaDeg high-rate clarifier is capable of reducing the Total P concentration below the threshold limit of 10 μg/L. This high Total P removal efficiency was achieved however with a relatively high dosage of the treatment chemicals. Comparing to conventional technologies, the consumption of the coagulant was high. Besides the increase of operation cost, the relatively high dosage of the coagulant (ferric-chloride) will result in the generation of excessive amount of residual solids.

- **ROCHEM Environmental, Inc.** Based upon the testing of a one-gallon per minute bench scale unit, ultrafiltration could produce a less than 10 ppb Total P concentration on Post-STA waters. Larger scale pilot testing of ultrafiltration was recommended in order to obtain reliable operation and cost data on the process.

- **F.B. Leopold Company** conducted dissolved air flotation (DAF) pilot tests at both the Post-STA and Post-BMP sites. The DAF pilot unit could not reduce feed water Total P to the desired 10 microgram per Liter threshold level. Based on the DAF test results, no further consideration of this process for Total P removal of EAA surface waters is recommended.

- **Micromag Corporation** tested the CoMag treatment technology, which uses high gradient magnetic fields for the separation of floc aggregates. Test results suggest that the CoMag process can reduce the Total P concentration below the predetermined threshold limit of 10 μg/L. Although it is not clearly reported which testing conditions correspond to favorable results, it is likely that the process is economical due to the relatively low dosage concentration and reuse of process chemicals. The process appears to be more suited to treat waters with higher Total P concentration. At low raw water Total P levels, the CoMag process did not prove the capability for consistent Total P removals. The CoMag process may be considered a burgeoning, promising technology; however, no large scale systems are currently in operation. System reliability and cost verification should be made based upon larger scale testing of the technology.

FULL-SCALE CTSS APPLICATION

A process identified as the Supplemental Technology Standard of Comparison (STSOC) has been established to enable SFWMD to compare supplemental technologies. Flow and Total P data used in developing facility conceptual designs are required by the Standard of Comparison guidelines to be developed from the 10-year period of record (POR) baseline data used for preparing the detailed design for STA.

The period of record for the data series is from January 1, 1979 through September 30, 1988. The historical flow weighted mean Total P concentration for this period was equal to 163.1 ppb for S6, plus an additional 16.3 percent of S5A. The computed STA inflow mean phosphorus concentration was equal to 122 ppb for the 9.75-year POR.

Based on the STSOC guidelines, six full-scale facility scenarios were developed each for Post-BMP and Post-STA applications. These facilities were designed to achieve flow weighted average effluent Total P concentrations of 10 and 20 ppb Total P with 0 percent, 10 percent, and 20 percent flow diversion (STSOC required) of the 10-year POR flow volume. This approach resulted in a total of 12 full-scale treatment scenarios as shown below:

Location	Effluent Total P	No Diversion (mgd)	10% Diversion (mgd)	20% Diversion (mgd)
Post-BMP	10 ppb	380	270	200
	20 ppb	220	150	190
Post-STA	10 ppb	390	260	100
	20 ppb	140	100	80

Water treatment technologies generally operate best (*e.g.*, consistently produce the highest quality effluent stream) within a relatively narrow range of influent flows. Wide fluctuations of flows associated with the EAA stormwaters will require full-scale conventional water treatment systems to be coupled with flow equalization basins (FEB) in order to store runoff from peak rainfall events until they can be adequately processed. For the purposes of this Report, flow equalization was accomplished within the STA and treatment plant sizes were determined for each POR flow diversion scenario to meet the desired effluent quality. Water balances were completed to determine the treatment plant sizes. Full-scale treatment scenarios were based on a scale-up of the CTSS pilot data using coagulation, flocculation and clarification enhanced by use of inclined plate settlers. No filtration process was recommended for the full scale as Total P objectives (*i.e.*, less than 10 micrograms/Liter of Total P in treated effluent) were achieved without it.

Post-BMP Full-Scale

The Post-BMP conceptual design scenarios used 6,000 acres of the STA for flow equalization and the remaining 430 acres for the treatment plant works, residual solids thickening, and treated water conditioning using a buffer cell. The existing influent STA pump station would pump the water into the flow equalization basin (FEB), former STA, and a new pump station would be installed to pump the water from the equalization basin into the treatment plant.

Post-BMP waters would be pumped into concrete basin coagulators where ferric-chloride is fed at an average dose of 40 mg/L as Fe. Coagulated water flows into concrete flocculation basin where an anionic polymer is fed into the system at an average dose of 0.5 mg/L. The water is then clarified in concrete basins equipped with lamella plate settlers. The treated water flows into a buffer cell then into a collection canal. The existing effluent STA pumping station would be used to discharge the treated water into the conservation area.

Residual solids will be discharged to an on-site storage lagoon, using a residual solids hydraulic detention time of three days. Supernatant overflow from the solids storage area would be returned to the FEB for treatment. Settled solids in the lagoon are pumped to a dedicated land application facility. The estimated required area for this dedicated solids disposal area ranges from 1,150 to 1,680 acres and is based upon an annual solids loading criterion of 28 tons of dry solids per acre per year (USEPA, 1995).

The six full-scale Post-BMP conceptual design scenarios are summarized below:

Post-BMP Conceptual Design Summary

Effluent Total P Concentration	Diversion of 10-yr POR	Treatment Plant Design Average Daily Flow (mgd)
10 ppb	No Diversion	380
	10%	270
	20%	200
20 ppb	No Diversion	220
	10%	150
	20%	120

The existing levees would be operated using a maximum water height of 4.5 feet, allowing for 4 feet of water storage (0.5 to 4.5 feet). The treatment plant would operate at a peak load of 50 percent greater than its average daily design flow rate when the water level within the equalization basin reached 3.5 feet. The table below summarizes the Post-BMP treatment plant operation data and the corresponding FEB water level:

Post-BMP Treatment Plant Operation Summary

Treatment Plant Size (mgd)	% Operation During 10-yr POR	% Operating Time at Peak Design Flow Rate	Average Depth in FEB (feet)	Days Exceedance of 4.0 feet (days/yr.)
380	38	16	1.1	10
270	48	17	1.2	15
200	56	18	1.4	21
220	56	24	1.5	31
150	71	25	1.9	44
120	77	29	2.1	51

Post-STA Full-Scale

The Post-STA conceptual design scenarios used 4,400 acres of STA 2 as a "natural system." The natural system would produce an average effluent Total P concentration of 65 ppb. Flow equalization would occur in a 1,500-acre basin and the remaining 530 acres for the treatment plant works and buffer cell. The existing influent STA pump station would pump the water into the STA for natural treatment. A new pump station would be installed to pump the naturally treated water into the FEB. Another new pump station would be installed to pump the water from the equalization basin into the treatment plant.

Post-STA waters would be pumped into concrete basin coagulators where alum is fed at an average dose of 20 mg/L as Al. Coagulated water flows into concrete flocculation basin where an anionic polymer is fed into the system at an average dose of 0.5 mg/L. The water is then clarified in concrete basins equipped with lamella plate settlers. The treated water flows into a buffer cell then into a collection canal. The existing effluent STA pumping station would be used to discharge the treated water into the conservation area.

Residual solids will be discharged to an on-Site storage lagoon, using a residual solids hydraulic detention time of three days. Supernatant overflow from the solids storage area would be returned to the FEB for later treatment. Settled solids in the lagoon are pumped to a dedicated land application facility. The estimated required area for this dedicated solids disposal area ranges from 450 to 910 acres and is based upon an annual solids loading criterion of 28 tons of dry solids per acre per year (U.S. EPA, 1995).

The six full-scale Post-STA conceptual design scenarios are summarized below:

Post-STA Conceptual Design Summary

Effluent Total P Concentration	Diversion of 10-yr POR	Treatment Plant Design Average Daily Flow (mgd)
10 ppb	No Diversion	390
	10	260
	20	190
20 ppb	No Diversion	140
	10	100
	20	80

The existing levees would be operated using a maximum water height of 4.5 feet, allowing for 4 feet of water storage (0.5 to 4.5 feet). The treatment plant would operate at a peak load of 50 percent greater than its average daily design flow rate when the water level within the equalization basin reached 3.5 feet. The table below summarizes the treatment plant operation data and the corresponding FEB water level:

Post-STA Treatment Plant Operation Summary

Treatment Plant Size (mgd)	% Operation During 10-yr POR	% Operating Time at Peak Design Flow Rate	Average Depth in FEB (feet)	Days Exceedance of 4.0 feet (days/yr.)
390	28	31	1.2	17
260	36	38	1.4	30
190	43	43	1.5	41
140	50	50	1.8	64
100	58	54	2.0	87
80	63	56	2.2	100

Cost estimates were prepared for the 12 full-scale facility scenarios discussed for CTSS treatment plants treating Post-BMP and Post-STA waters. Each scenario includes capital, operation and maintenance (O&M), replacement, and salvage costs. A 50-year present worth cost was then calculated based on a using a net discount rate of 4 percent. The 10-year POR (1979-1988) flow and phosphorus data was used to calculate the present worth for each scenario per million gallons of treated water ($/million gallons treated) and per pound of phosphorus removed ($/pound of P removed).

The Basis for Cost Estimates of Full-Scale Alternative Treatment (Supplemental) Technology Facilities (August 1999), prepared by B&C and revised and updated by SFWMD, was used to provide various unit costs and is referenced accordingly.

Present worth calculations were performed based on capital and O&M estimates. Estimates of the 50-year present worth for the Post-BMP and Post-STA facilities, including the cost of the associated STA, are summarized below:

Full-Scale Treatment Scenarios
Present Worth Summary Including STA Costs

Application	Treatment Plant Design Average Daily Flow (mgd)	50-Year Present Worth ($ million)
Post-BMP	380	428.2
	270	378.9
	200	342.9
	220	361.6
	150	325.6
	120	304.1
Post-STA	390	433.6
	260	382.7
	190	347.9
	140	322.7
	100	295.3
	80	278.1

Estimates of the 50-year present worth for the Post-BMP and Post-STA facilities, excluding the cost of the associated STA, are summarized below:

Full-Scale Treatment Scenarios
Present Worth Summary Excluding STA Costs

Application	Treatment Plant Design Average Daily Flow (mgd)	50-Year Present Worth ($ million)
Post-BMP	380	280.2
	270	231.4
	200	196.1
	220	213.8
	150	178.4
	120	157.4
Post-STA	390	301.0
	260	250.1
	190	215.3
	140	190.1
	100	162.7
	80	145.5

The present worth cost with respect to gallons treated and phosphorus removed, including the associated STA costs, are summarized below:

Application	Treatment Plant Design Average Daily Flow (mgd)	50-Year Present Worth: Dollars per million gallons treated ($/mgal)	50-Year Present Worth: Dollars per pound of phosphorus removed ($/lb)
Post-BMP	380	154	158
	270	153	163
	200	157	169
	220	145	147
	150	150	155
	120	158	165
Post-STA	390	192	380
	260	192	385
	190	198	402
	140	209	344
	100	226	367
	80	243	394

The present worth cost with respect to gallons treated and phosphorus removed, excluding the associated STA costs, are summarized below:

Application	Treatment Plant Design Average Daily Flow (mgd)	50-Year Present Worth: Dollars per million gallons treated ($/mgal)	50-Year Present Worth: Dollars per pound of phosphorus removed ($/lb)
Post-BMP	380	101	104
	270	93	100
	200	90	97
	220	86	87
	150	82	85
	120	82	85
Post-STA	390	134	264
	260	125	252
	190	122	249
	140	123	203
	100	125	202
	80	127	206

STUDY CONCLUSIONS

1. The CTSS treatment can produce a settled, clarifier effluent of less than 10 ppb of Total P on both Post-STA and Post-BMP EAA surface waters using either ferric-chloride or alum as coagulants. The principal unit processes used in achieving these results were chemical coagulation, flocculation, and inclined plate enhanced clarification.

2. Several other vendor technologies produced treated effluent of less than 10 micrograms per Liter of Total P. These technologies should be further evaluated if the conventional CTSS system is determined not to be the most practicable scenario at some point in the future or if these technologies are proven to be more cost-effective than conventional treatment.

3. Dissolved air flotation, direct in-line filtration, direct filtration and activated alumina treatment have proved ineffective at reducing the Total P content of the stormwater and no further testing of these technologies is recommended.

4. Bioassay and AGP studies conducted on representative CTSS feed and effluent samples demonstrated no significant adverse impact on receiving waters. The CTSS process reduced the alkalinity, color and pH of treated waters and use of a treated effluent buffer cell has been suggested for incorporation in to the full-scale design for effluent conditioning.

5. Residual solids produced by the CTSS process contain no hazardous constituents as defined by the toxicity characteristic leachate procedure (TCLP). Full-scale conceptual designs have included recommendations for direct application of residual solids on land adjacent to the treatment facilities.

6. With the exception of a dedicated land application area, a full-scale CTSS treatment facility, including the cost of the associated STA could be constructed within the STA 2 footprint for a 50-year present worth preliminary total cost of $428 million (capital costs equal to $204 million). This facility would be capable of treating an average of 380 million gallons per day (mgd) of surface stormwaters with continuous production of a 10 ppb Total P effluent with no flow diversion or by-pass. The cost for a 120 mgd Post-BMP facility producing a 20 ppb Total P effluent and with a 20 percent flow diversion is equal to $304 million ($145 million in initial capital). A large portion of STA 2, as it is currently designed, would serve as a flow equalization basin for the incoming stormwaters in this scenario. A dedicated land application area of

approximately 1,681 acres would be needed outside and adjacent to the STA footprint to receive residual solids generated in the CTSS process. The estimated capital and operating costs for full-scale scenarios as reported in this document were confirmed by independent estimates.

7. Capital costs range from $1.40/gallon for 100 mgd plant to $0.50/gallon for a 350 mgd treatment plant. Operational costs range from $139.62/millon gallons treated (Post-BMP) to $216.34/millon gallons treated (Post-STA).

8. Civil work and land cost accounts for over 80 percent of the capital costs.

9. Chemical and energy costs accounts for about 80 percent of the operating costs. Any alternative to further reduce these costs should be evaluated in future research.

10. Sensitivity analysis for chemical treatment is positive compared to other technologies.

RECOMMENDATIONS

1. Prior to full-scale implementation, construction and operation of a prototype CTSS facility ranging from 100,000 to 1 million gallons per day is recommended as this would enable testing of full-scale vendor equipment unit processes and technologies. Economies of scale may very well be identified during prototype operation that would enable more cost effective (and smaller) facilities than presently conceptualized in this Report. An alternative to prototype construction would be to build a portion of a modular full-scale system to assess removal efficiencies and determine the need for additional construction requirements.

   During prototype testing, additional long-term residual solids investigations could also be completed to assess the efficacy of direct land application alternatives. A more comprehensive program should be carried out with CTSS residuals to provide more definitive information on their beneficial use for land application. These trials should look at a lower range of application rates than previously tested and using aged (one-year) residuals. In addition, further investigation should be made into using CTSS residuals (particularly aluminum) as a BMP land application for reducing Total P concentrations from EAA fallow land or canal buffer areas.

2. Cost economies may be available through the use of metal salt/acid combinations. Additional research should be performed to determine if there are viable methods of metal salt recovery and reuse.