1.0 BACKGROUND

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; they 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. The STAs will encompass approximately 46,000 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 Phase I 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 fall below the 50 μg/L goal expected from the Phase I STAs.

Phase II of the Everglades Program involves the implementation of new basin-scale treatment processes (also referred to as "Supplemental 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 Phase I 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, Phase II of the Everglades Program is focused on demonstrating water quality treatment technologies capable of reducing phosphorus concentrations to approximately 10 μg/L. Treatment technologies that can meet or surpass the Phase II goal will allow the default phosphorus criterion to be met with the most appropriately sized system. The EFA requires SFWMD to have treatment technologies on-line by December 31, 2006.

As part of the Chemical Treatment Followed by Solids Separation (CTSS) Supplemental Technology Demonstration Project carried out by HSA at the Everglades Nutrient Removal (ENR) Project site in 1999, a number of vendor technologies were evaluated (*see*, HSA’s CTSS Report to SFWMD for further detail). One of the vendor technologies evaluated was ultrafiltration (UF). The UF unit tested was a relatively small (bench scale) unit capable of producing a permeate flow of 1 gpm at a 90 percent recovery rate (*i.e.*, 1 gpm of permeate from a feedwater flow of 1.1 gpm). The nominal pore size of the UF membrane was approximately 0.03 micron. The small unit was tested for direct treatment (no chemical addition) of ENR effluent (Post-STA) over a four-week period and consistently produced a permeate of less than 10 ppb of Total P treating a feedwater varying from 17 to 39 ppb of Total P.

Based on the promising results obtained with the small unit (*i.e.*, permeate Total P consistently less than 10 ppb), larger scale testing of UF was warranted. SFWMD decided to carry out the additional work as an addendum to DB Lab's Submerged Aquatic Vegetation (SAV) Project. Accordingly, a proposal was made to DB Environmental Laboratories (DB Labs) and SFWMD to carry out a larger scale UF pilot testing program.

2.0 DESCRIPTION OF ULTRAFILTRATION (UF) PROCESS

"Ultrafiltration" is a pressure-driven, separation process where the water to be treated is separated by a porous membrane into a stream of purified filtrate/permeate and a remaining quantity of concentrate. The principle of UF is that in the presence of an external pressure or driving force, liquid flow occurs from the concentrated solution to the dilute solution across a semi-permeable membrane. The pure water (known as "product water" or "permeate") essentially emerges at near atmospheric pressure. Particulate solids contained in the water that have been rejected by the membrane are accumulated in the concentrate stream.

UF plants can be operated either in dead-end or cross-flow modes. An important difference is the direction of the flow relative to the membrane layer. In dead-end systems, all the feed flow passes through the membrane. The separated particles are concentrated at the upstream side of the membrane. This system is typically applicable for waters with low solids concentration allowing a high packing density of the membranes. Cross-flow systems, on the other hand, are more suited to treat waters with higher influent solids content. The feed flow in these systems is parallel to the membrane layers allowing only a certain portion of the feed water to pass through the membranes. Consequently, the separated particles are removed from the membrane surface with the unfiltered water flow resulting in a diluted concentrate.

3.0 OBJECTIVES

Objectives of the larger scale UF pilot testing program were to:

- Develop process design criteria for the UF technology that would enable a cost analysis to be made for full-scale application of the technology;

- More fully characterize the effluent and concentrate streams produced by a UF system; and,
- Evaluate UF membrane performance over a 10-year operational period.

4.0 DESCRIPTION OF PILOT TEST FACILITIES

FIGURE 1 shows a simplified schematic of the pilot UF treatment process employing (1) low lift pumping, (2) cartridge filtration, (3) flow equalization, (4) booster pumping, and (5) membrane separation. ROCHEM Environmental, Inc. (ROCHEM) supplied the UF systems tested at the South ENR (Post-STA) Test Site. While the smaller unit was operated in the cross-flow mode, the larger pilot treatment unit was designed to operate in the dead-end mode. Both units were tested without the addition of treatment chemicals. The "end of a filter run" is defined when the operating pressure exceeds a preset value, at which point the membrane(s) required cleaning.

Smaller Pilot Unit:

Typical operating parameters for the ROCHEM UF cross-flow mini-plant (Type CF-UF1-3) were:

Operation mode:	cross-flow
Set flow rate:	2 gpm (0.45 m^3/h)
Permeate yield:	90%
Membrane area:	3 m^2
Nominal pore size:	50,000 Dalton (nominal 0.03 μm)
Max operating temperature:	104°F (40°C)
Operating pH range:	3-11
Max operating pressure:	29 psi (2.0 bar)
Electrical power:	0.5 HP (4 kw)

A photograph of the smaller ROCHEM UF unit is shown in **FIGURE 2**.

Larger Pilot Unit:

The larger ROCHEM pilot plant (Model No. B2006) was equipped with two module blocks, each block containing three parallel membrane modules. The total membrane area of the unit was 60 m^2 (10 m^2 per module). Accumulation of solids in operating UF units typically results in increasing pressure drop through the membrane layer. In order to provide essentially constant permeate flow, the ROCHEM design automatically compensates (*i.e.*, increases) the operating pressure during a filtration cycle. The plant allows simultaneous normal operation of one block while the other block of three modules are cleaned. The permeate of an operating block is used for flushing the exhausted filter modules. While a cleaning cycle is automatically initiated upon reaching the pre-selected cut-off pressure, the optimum cleaning duration is determined for each application. Based on the prior experience with Post-STA waters with the smaller UF unit, ROCHEM suggested a 5-minute cleaning period. During flushing, the boosted permeate of the operating block is supplied with air introduced to the upstream side of the membranes to remove concentrated particles. Near the end of a cleaning cycle, a short duration cross-flow flush is initiated. The amount of permeate consumed for cleaning is about 5 percent of the total flow. In addition to routine water-air mix cleaning, UF units need chemical cleaning on a less frequent but regular basis. Typical operating UF parameters for the larger unit are listed below:

Operation mode:	dead-end
Capacity:	24.3 gpm (5.5 m^3/h)
Permeate yield:	90-95%
Membrane area:	60 m^2
Nominal pore size:	50,000 Dalton (nominal 0.03 μm)
Max operating temperature:	104°F (40°C)
Operating pH range:	3-11
Max operating pressure:	29 psi (2.0 bar)
Electrical power:	9.4 HP (7.0 kw)

A photograph of the larger ROCHEM UF unit is shown in **FIGURE 3**.

The larger UF plot unit was operated under four different sets of operational conditions as shown in **TABLE 1**.

5.0 SAMPLING AND ANALYTICAL PROCEDURES

For the smaller UF unit, a monitoring program was conducted involving collection of samples of the feed and permeate, and analyzing the samples for phosphorus forms only.

The larger UF unit was monitored more intensively with 24-hour composite samplers located on the influent and permeate, and grab composite samples being collected from the concentrate or backwash. The samples were collected at the frequencies indicated and analyzed for the parameters shown in **TABLE 2**.

Operational data were collected and recorded for the larger pilot unit, including:

- Elapsed run time;
- Flow rate through each module;
- Feed, permeate and concentrate pressures;
- Feed water temperature;
- Cleaning interval; and
- Cleaning chemical utilized (acid or caustic).

Testing for the smaller UF unit was carried out over the period of October 13 to December 7, 1999, whereas the testing for the larger unit was conducted from February 7, 2000 to April 28, 2000.

6.0 RESULTS AND DISCUSSION

Results for the entire UF pilot plant monitoring program are presented in **APPENDIX A (Analytical Data)** and **APPENDIX B (Operational Data)**. In addition to the assessment of (1) Total P, (2) total dissolved phosphorus (TDP), and (3) soluble reactive phosphorus (SRP), general water quality parameters were also monitored at specified locations (**FIGURE 1**) for the larger pilot unit. Only Total P concentrations were monitored for the smaller UF unit operation and these are reported in **TABLE 3**. Phosphorus forms are reported in **TABLE 4** for the February 7, 2000 to April 28, 2000 period (larger UF unit). Statistical parameters (mean, sample number, standard deviation) of these data are summarized in **TABLE 5**.

Raw water (Post-STA) Total P concentrations for the June 3, 1999 to April 13, 2000 period are shown in **FIGURE 4**. Total P concentration varied from 11 μg/L up to 70 μg/L during the study period. Including two values in excess of 60 μg/L, the average raw (Post-STA) water Total P concentration in the June 3, 1999 to December 23, 1999 period was 21.5 μg/L with a standard deviation of 7.7 μg/L. Corresponding values for the February 7, 2000 to April 13, 2000 period were 34.7 μg/L and 6.7 μg/L, respectively. Due to seasonal effect or some other condition such as increased hydraulic loading to the ENR, Total P values were significantly higher in the February 7 to April 13, 2000 period than in the last six months of 1999.

FIGURE 5 shows temporal UF influent and effluent (permeate) Total P concentrations for periods of UF testing. Three distinct periods are shown. The first period represents the operation of the smaller pilot treatment unit from October 13, 1999 to December 7, 1999. On average, 17 μg/L raw water Total P concentration was reduced to 6.4 μg/L by the smaller pilot UF unit. The larger scale pilot UF plant was tested from February 7, 2000 to April 28, 2000. Data in this second period (February 7, 2000 to April 28, 2000) shows that the average Total P concentration of 33.2 μg/L was reduced to 24.9 μg/L by the larger pilot UF unit. While maintaining normal operation, Total P removal efficiencies were higher in the

April 2, 2000 to April 28, 2000 period. In this last period, the average Total P concentration of 30.3 μg/L was reduced to 13.6 μg/L. Total P removal efficiency of the smaller unit exceeded the average Total P removal of the larger pilot unit (68 percent versus 39 percent). The data also shows that Total P removal efficiency of the larger pilot unit was higher in the second part (third period) of its operation (55 percent vs. 25 percent).

UF influent and effluent phosphorus species are compared in **FIGURES 6 through 9**. **FIGURE** 6 shows influent SRP and effluent Total P concentrations for the three experimental periods. Average influent SRP concentrations were 3.0 μg/L, 10.0 μg/L, and 3.1 μg/L in the three segments. The corresponding UF effluent Total P concentrations were 6.4 μg/L, 24.9 μg/L, and 13.6 μg/L, respectively. These data show higher Total P removal at reduced concentrations of influent SRPs. This is to be expected since UF will remove only particulate and colloidal P exceeding the membrane pore size. SRP will not be removed to any degree.

FIGURE 7 shows average influent TDP and effluent Total P concentrations for the three periods. Influent TDP concentrations were 11.8 μg/L, 26.1 μg/L, and 14.2 μg/L in segments 1, 2 and 3. Corresponding average effluent Total P concentrations were 6.4 μg/L, 24.9 μg/L, and 13.6 μg/L, respectively. The experimental results show similar influent TDP – effluent Total P ratios in periods 2 and 3; the same ratio was higher during the period of testing the smaller pilot unit.

FIGURE 8 shows UF influent and effluent Total P concentrations for each of the three experimental periods. The smaller pilot unit reduced the Total P concentration from 17 μg/L to 6.4 μg/L (62 percent removal). The overall removal efficiency of the larger pilot unit was 39 percent (31.8 μg/L to 19.4 μg/L). Specific removal efficiencies in the second and third periods were 25 percent and 55 percent, respectively. Comparison of the Total P data shows that the removal efficiency of the smaller pilot unit was the highest. Although the overall Total P removal efficiency of the larger pilot unit was relatively low, the unit's 55 percent Total P removal in the third segment was close to the similar value of the smaller unit. The observed differences in percentage of Total P removal by the two pilot units probably has little to do with configurational differences, but is due to changing feedwater characteristics.

FIGURE 9 shows average influent and effluent TDP concentrations for the UF testing program. The smaller pilot unit reduced the TDP concentration from 11.8 μg/L to 5.5 μg/L (53 percent removal). TDP removals in the second and third segments were 16 percent (26.1 μg/L to 22 μg/L) and 28 percent (14.2 μg/L to 10.2 μg/L), respectively. These results show that the UF units are removing colloidal P that is in a range of 0.03 μm to 0.45 μm.

Water Quality Testing

TABLE 6 provides summaries of the various chemical constituents analyzed during the larger UF pilot testing. Samples were collected of raw water, filtrate, concentrate and spent cleaning solutions and were submitted to the contract laboratory for metals, nitrogen series, TDS, common cations and anions, and TOC.

Filtrate Water Quality

As shown in **TABLE 6**, no significant differences (*e.g.*, less than 20 percent difference) were observed in feed versus filtrate (effluent) average sample results for the following constituents:

Aluminum	Alkalinity	Calcium
Chloride	Color	Dissolved Silica
Sodium	Specific Conductance	Sulfate
TKN	TOC	Total Solids
Iron	Magnesium	Mercury
Molybdenum	Nitrate	Potassium
Zinc	Total Dissolved Solids	Total Suspended Solids

Ammonia: The UF treatment system removed on average approximately 30 percent of the influent ammonia during the pilot testing. Average ammonia was reduced from 0.112 to 0.079 mg/L.

Manganese: The UF treatment system removed on average approximately 50 percent of the influent manganese during the pilot testing. Average manganese was reduced from 13 to 6.6 mg/L.

Concentrate Water Quality

Samples were collected of the concentrate stream after completion of a backwash cycle. **TABLE 6** summarizes the concentrate concentrations for various water quality parameters. The concentrations of ammonia and manganese in the concentrate are greater than the corresponding effluent concentrations. There were no significant differences (*e.g.*, less than 20 percent difference) observed in concentrate versus feed or filtrate concentrations for the remainder of the parameters tested.

Cleaning Solution Water Quality

Samples were collected of the spent chemical solution after completion of membrane cleaning with a high pH cleaning solutions (sodium hydroxide with surfactants). **TABLE 6** summarizes the cleaning solution concentrations for various water quality parameters.

There were significant differences (greater than 20 percent difference) observed in spent chemical solution versus influent average concentrations for the following parameters:

Parameter	Influent Concentration (mg/L)	Cleaning Concentration (mg/L)
Aluminum	70	530
Calcium	64	220
Manganese	13	4400
TOC	22	740
Zinc	11	96

There was no significant differences observed in the remainder of the parameters tested.

SFWMD Low Level Mercury Results

Representatives from SFWMD collected feed and filtrate samples for trace level mercury analysis on or about March 30, 2000. Analyses were performed for filtered / total filtered methyl mercury and filtered and total mercury on representative grab samples of feed and filtrate samples. The mercury data will be summarized and reported separately by SFWMD.

Bioassay and Algal Growth Potential (AGP) Results

HSA collected UF feed and effluent samples during the week of April 3, 2000, for bioassay and AGP analyses by Hydrosphere Research. Summary results for the bioassay and AGP analyses are provided in **TABLE 7**.

Feed and filtrate samples were collected simultaneously to determine if any observed effects were the result of the feed waters or from the UF treatment process. Exposure to the UF feed water significantly reduced the survival of the Bannerfin Shiner. There was no adverse effect caused by exposure to the UF filtrate.

Pilot Operations

There were seven distinct operation conditions during the test of the larger pilot unit that took place from February 1, 2000 to April 28, 2000. The applied hydraulic loading per unit surface area or flux varied from 0.016 gpm/sq.ft. to 0.22 gpm/sq.ft. The cut-off pressure was adjusted for 1.8 bar in the first three periods and 2 bar in the remaining period of the testing. The backwash duration of 5 minutes and frequency of 3/hr were not changed during the pilot scale testing. **FIGURE 10** shows that actual fluxes gradually declined during the study period. The declining trend could be partly attributed to the increased cut-off pressure (1.8 bar to 2.0 bar) in the second part of the trials or possibly the natural aging of the membrane. The change of transmembrane pressure during the study period is shown in **FIGURE 11**. A drop of pressure is typical after the chemical cleaning of the membrane. Operation data are attached in **APPENDIX B.**

7.0 CONCEPTUAL DESIGN AND PRELIMINARY COST ESTIMATE FOR A FULL-SCALE ULTRAFILTRATION APPLICATION

7.1 DEVELOPMENT OF HYDRAULIC AND TOTAL P DESIGN CRITERIA

The consulting firms of PEER Consultants (PEER) and Brown and Caldwell Consultants (B&C) jointly developed a standard of comparison for all supplemental technology demonstration projects (PEER/B&C J.V., November 1997; PEER/B&C J.V., August 1999). A process identified as the Supplemental Technology Standard of Comparison (STSOC) was 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 2. The STA 2 flow and phosphorus concentration data were provided by SFWMD.

Generating this synthetic daily time series of inflow and outflow phosphorus information was based upon re-scaling historical S5A and S6 flows and phosphorus loadings. Documentation received from SFWMD with this data indicated the following factors were not considered in developing this time series summary:

- BMP make-up water contributions to STA (October – February time period);
- Attenuation of inflow concentration peaks due to STA storage and uptake; and
- Atmospheric phosphorus loads.

The program documentation also indicates that recently implemented BMPs in the EAA have reduced the baseline historical phosphorus concentrations by 25 percent. Input assumptions (as described in the program documentation) made in creating these summaries included:

- The STA average outflow concentration will be equal to 50 μg/L of phosphorus;
- The BMP load reduction, as indicated above, is equal to 25 percent; and
- The fraction of S5A flow diverted to STA 2 was equal to 0.163.

The POR 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 μg/L for S6, plus an additional 16.3 percent of S5A. The computed STA inflow, mean phosphorus concentration was equal to 122 μg/L for the 9.75-year POR.

All of the Supplemental Treatment Technology Demonstration Projects will be evaluated using this POR data and these same assumptions. The approach utilized herein for UF conceptual design and cost estimation is similar to the methodologies used for the recently completed CTSS and Microfiltration Projects (*see,* HSA's CTSS Final Report, Dec. 2000, and Microfiltration Report, Jan. 2001).

7.2 DEVELOPMENT OF CONCEPTUAL DESIGN FOR FULL-SCALE POST-STA TREATMENT FACILITY

7.2.1 Analysis of the Baseline Period of Record Data and its Application to the UF Conceptual Design

The UF process was only tested on Post-STA waters and the conceptual design for a full-scale treatment facility is based on the scale-up of the pilot data collected for the testing period. Accordingly, a UF conceptual design was only developed for the Post-STA treatment scenario.

FIGURE 12 provides a graphical representation of the estimated baseline STA 2 effluent flow (Post-STA) for the 10-year POR, and **FIGURE 13** shows the corresponding phosphorus concentrations for the same time period. The average flow is equal to 536 acre-feet per day (175 million gallons per day [mgd]).

The STSOC guidelines require development of six full-scale facility scenarios for each Post-BMP and Post-STA application. These facilities would be designed to achieve flow weighted average effluent Total P concentrations of 10 ppb and 20 ppb Total P with 0 percent, 10 percent, and 20 percent flow diversion (STSOC required) of the 10-year POR flow volume. The UF pilot testing showed that UF could periodically produce a treated effluent of less than 10 mg/L Total P when SRP levels in the influent were in range of 5 mg/L. However, subsequently based on the larger pilot trials, UF when treating Post-STA water may be expected to consistently produce an effluent Total P in the order of 20 mg/L. For this reason only one scenario was evaluated for UF (*i.e.,* a treatment system producing a flow weighted effluent Total P concentration of 20 ppb with 20 percent diversion of flow volume).

7.2.2 *Full-Scale Conceptual Design Fundamental Approach*

Water treatment technologies generally operate best (*e.g.*, consistently produce the highest quality effluent stream) within a relatively narrow range of influent flows. The wide fluctuations of flows associated with the EAA stormwaters will require full-scale water treatment systems to be coupled with flow equalization basins (FEB) in order to store runoff from peak rainfall events until it can be adequately processed. For purposes of this Report, flow equalization was assumed to be accomplished within the STA. A water balance was completed to determine the treatment plant size. The assumptions and the basis for the balance are summarized below:

- "Natural treatment," flow equalization, and UF treatment would occur within the footprint of the existing STA 2. Based on the pilot data, it was estimated that the UF treatment process could treat Post-STA water with an outflow Total P concentration to 65 ppb.

- The required size of STA 2 acres to provide an effluent Total P concentration of 65 ppb was estimated using an exponential decay relationship between the STA 2 area and the outflow Total P concentration. This relationship is represented by $C=Co*e-^{kA}$ ("C" is the outflow concentration, "Co" is the inflow concentration, "K" is a constant, and "A" is the STA area). Using the assumed inflow concentration (122 ppb) and the outflow concentration (50 ppb), the exponential relationship becomes, $50=122e-^{kA}$. If the UF plant would treat Post-STA water with an outflow concentration of 65 ppb, a preceding 4,540-acre "natural system" would be required.

- The Post-STA full-scale conceptual design uses Cell No. 2 and Cell No. 3 of STA 2 (combined area of 4,440 acres) as a "natural system."

- 1,500 acres of STA 2 will be used as a FEB. The levees will not be modified and will be used to store water up to a maximum depth of 4.5 feet.

- Bypass will occur when the FEB has reached capacity.

- Rainfall and evapotranspiration from FEB were not considered.

- Total P removal within the FEB is estimated at 20 percent.

- The full-scale UF system would be able to operate at a peak hydraulic capacity of 50 percent greater than its average daily design flow rate for short time periods.

- The UF technology would produce an average effluent Total P concentration of at least 0.02 mg/L as P.

- Full-scale treatment scenarios were based on a scale-up of the UF pilot data.

The water balance calculations resulted in a treatment facility sized for an average flow rate of 95 mgd. **TABLE 8** presents the detailed conceptual design criteria developed for the Post-STA UF full-scale facility design.

7.2.3 Post-STA Full-Scale UF Treatment System Conceptual Design

The Post-STA conceptual design scenario was based on using 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 backwash solids and chemical cleaning lagoons. The existing influent STA pump station would pump the water into the STA for wetland 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 UF treatment plant.

FIGURE 14 shows the layout of the full-scale Post-STA facility within the STA 2 footprint. The conceptual design for the full-scale Post-STA facility is illustrated in **FIGURE 15**.

Post-STA waters after flow splitting would be pumped through coarse screen filters and into the UF treatment plant. The existing effluent STA pumping station would be used to discharge the treated water into the conservation area.

Flux restoration of the membranes would be accomplished by periodically cleaning the membranes with a combination of citric acid and sodium hydroxide. The spent cleaning solutions would be discharged to onsite neutralization and treatment lagoons. Lagoon effluent would be discharged into the seepage canal with the backwash solids and blowdown from the coarse screen and returned to the front end of the STA.

The existing levees would be operated using a maximum water height of 4.5 feet, allowing for 4 feet of water storage (0.5 feet 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. **TABLE 9** summarizes the treatment plant operation data and the corresponding FEB water level.

TABLE 10 summarizes the 10-year POR quantities of stormwater and phosphorus pumped into the FEB, UF treated flow volume, phosphorus removed, and volume of stormwater and phosphorus untreated for blending for the full-scale treatment facility.

7.3 COST ESTIMATES FOR FULL-SCALE IMPLEMENTATION

SFWMD provided unit costs for selected capital, operation and maintenance (O&M), replacement, and salvage items. The cost estimate data were developed from equipment supplier quotations and prior engineering experience. **Note that all operation and maintenance costs are based on the number of actual operation days and the actual volume of treated water, and are not based upon 365-days per year operation. The percentage of operation for the UF facility can be found in the TABLE 9.** These unit costs were used to prepare a cost estimate for the 95 mgd full-scale UF treatment facility treating Post-STA waters. "The Basis for Cost Estimates of Full-Scale Alternative Treatment (Supplemental) Technology Facilities" (August 1999), prepared by B&C for SFWMD, was also used to source various unit costs and is referenced where appropriate.

The full-scale facility estimate includes costs associated with construction and maintenance of an STA/FEB. These costs were included because all of the Supplemental Treatment Technology Demonstration Projects will be required to provide full-scale estimates, which includes the costs to construct, operate and maintain the associated STA. However, costs are also shown excluding the STA associated costs. The full-scale treatment plant costs are summarized in **TABLE 11**. The detailed cost estimate is included in **APPENDIX C**.

Further details on the development of costs for the major categories identified in the detailed cost estimate tables follow:

7.3.1 Capital Costs

- *Equipment, Tankage, and Piping*

  The equipment, tankage, and piping cost includes capital costs associated with membranes, membrane tanks, permeate pumps, backpulse pumps, air scour blowers, PLCs and MCC, permeate and air scour headers, backpulse chemical feed system, treatment plant piping, and excavation.

ROCHEM provided capital costs for installed UF units at 100 mgd, 250 mgd, and 400 mgd full-scale treatment plants. The capital cost for installed UF units at the 95 mgd facility was extrapolated from the ROCHEM supplied information. **FIGURE 16** shows the UF capital costs versus plant design capacity.

Piping costs were calculated based on typical unit costs ($ per linear feet of piping) to purchase and install treatment plant piping.

TABLE 12 summarizes the equipment, tankage, and piping capital costs for the full-scale treatment plant.

- *Instrumentation and Electrical*

HSA estimated a capital cost for the treatment plant instrumentation and electrical of 10 percent of the treatment plant equipment, tankage, and piping costs.

- *Power Distribution*

SFWMD provided a unit cost for the electrical power distribution to the treatment plant of $80,000 per mile. The treatment plant will be fed electrical power from the STA 2 effluent pump station, which is located approximately one-half of one mile from the UF treatment plant.

- *Civil Work*

One water control structure will be installed in the UF influent/discharge canal. This structure will control the amount of untreated water to be blended with the UF effluent water, prior to discharge to the conservation area. SFWMD provided a unit cost of $300,000 for a gated water control structure.

- *Pumping Stations*

SFWMD provided unit construction costs for pumping stations based upon the pump capacity (cfs).

- *Land*

Land acquisition costs were calculated at a price of $4,655 per acre. An additional 10 percent more land was allowed for easements, right-of-ways, and buffers (B&C, August 1996).

7.3.2 Operating Costs

- *Labor*

Labor costs were estimated assuming a projected staffing plan for 24-hour per day operation and a unit cost of $30 per hour (includes fringe benefits) per employee.

- *Maintenance*

Mechanical - SFWMD provided unit costs for maintenance of selected mechanical items. Operating costs were calculated using these unit costs for pumping stations (influent, effluent, and seepage) and for the treatment plant building/support facilities.

Levees - Levee operating costs were calculated for the 18 miles of levees surrounding the STA, treatment plant, and buffer cell using the SFWMD-provided unit cost for levee maintenance ($1,500/mile/year).

- *Chemicals*

Membrane chemical cleaning would occur every 21 days using citric acid and sodium hydroxide solutions. One reuse was estimated for the citric acid solution and no reuse of the sodium hydroxide solution.

The estimated membrane chemical cleaning cost for the full-scale facility is based on the average number of days of treatment per year (215 days) and the subsequent frequency of membrane cleaning.

- *Energy*

Electricity - ROCHEM provided an estimated power consumption of 1 kwh per 1000 gallons of treated water. The electrical costs were based on the average annual volume of treated water and a unit cost of $0.08 per kwh (SFWMD).

Fuel Consumption - The pumping stations included in the full-scale facility conceptual design would be diesel power. SFWMD provided a unit rate of $0.55 gallons of diesel fuel consumed per acre-foot of water pumped. Using a unit rate of $0.90 per gallon of diesel fuel, the annual fuel consumption was calculated based on the total volume of water pumped by the pumping stations.

- *Membrane Replacement*

It was assumed that the UF membranes would be replaced every 10 years. ROCHEM provided membrane replacement costs at 100, 250 and 400 mgd UF facilities. The membrane replacement cost for the 95 mgd UF plant was extrapolated from the ROCHEM-supplied information.

- *Total Annual Operating Cost*

The total annual operating cost of a 95 mgd full-scale facility would be approximately $5,840,000. **TABLE 13** summarizes the estimated operating costs and these same costs are shown graphically in **FIGURE 17**.

The operating costs are itemized in **APPENDIX C**.

7.3.3 Demolition / Replacement Costs

- *Demolition Costs*

Demolition costs were estimated at 20 percent of the treatment plant and pumping station's construction costs (B&C, August 1996).

- *Replacement Costs*

The following replacement costs items were considered (B&C, August 1999):

- FEB pump stations - 25 percent of costs replaced once at 25 years;
- Treatment plant pumping stations - 50 percent of costs replaced once at 25 years;
- Treatment plant equipment - 25 percent of plant cost replaced at 20th and 40th years.

The UF membranes will be replaced every ten years. These costs are discussed in Section 5.3.2 “Operating Costs.”

7.3.4 Salvage Costs

Salvage estimates were prepared considering both salvage value and salvage costs (B&C, August 1996). These costs include restoration costs, and land value. It was assumed that the land purchased for residuals solids disposal was dedicated and no land value or restoration costs were assigned (B&C, August 1996).

7.3.5 Lump Sum Items

- Telemetry

  SFWMD provided a lump sum telemetry cost of $100,000.

- Sampling and Monitoring

  It was assumed that sampling and monitoring of the treatment plant would cost approximately $500,000 per year (SFWMD).

- Treatment Plant Building / Support Facilities

  The treatment plant building and support facilities would be constructed to house the membrane tanks and ancillary equipment and to provide rooms for chemical storage, office space, and instrumentation and controls. ROCHEM provided capital costs for a roofed plant superstructure with a concrete slab, open walls and electrical, at 100 mgd, 250 mgd, and 400 mgd full-scale treatment plants. The capital cost for the treatment plant building for the 95 mgd facility was extrapolated from the ROCHEM-supplied information.

7.4 PRESENT WORTH ANALYSIS AND ECONOMIC ANALYSIS

Fifty-year present worth costs were calculated using a net discount rate of 4 percent. **TABLE 14** includes the 50-year present worth for the 95 mgd full-scale treatment facility. These costs include the costs to construct, operate and maintain the associated STA.

The 50-year present worth excluding the STA costs is included in **TABLE 11**. The 10-year POR (1979-1988) flow and phosphorus data provided by SFWMD was used to calculate a present worth for each scenario per million gallons of treated water ($/million gallons treated) and per pound of phosphorus removed ($/pound of P removed). **TABLE 14** also shows the 50-year present worth cost per million gallons of treated water and per pound of phosphorus removed.

7.5 SENSITIVITY ANALYSIS

The STSOC (PEER/B&C) requires that a series of qualitative criteria be addressed for each advanced treatment technology. Although this technology was tested over a relatively short period and all of the STSOC criteria were not met, some qualitative criteria are addressed in the following:

- *Level of Phosphorus Concentration Reduction*

  The UF treatment technology employed during the pilot unit operations was found to reduce phosphorus, contained in representative Post-STA waters, to less than 20 micrograms of P per liter on a routine basis. UF, without chemical addition, could not be expected to produce an effluent Total P of less than 10 μg/L unless influent SRP concentrations could be consistently maintained below 5 ppb.

- *Total P Load Reduction*

  With 20 percent flow diversion, the UF technology, coupled with a natural treatment component and a flow equalization basin, can reduce the incoming phosphorus load to a level that routinely produces a treated effluent of less than 20 micrograms of P per liter. UF plant produced 67 percent reduction in Total P over a 10-year POR.

- *Cost Effectiveness of Technology*

  The cost effectiveness of the UF technology can only be adequately evaluated when the comparative costs of the other advanced treatment technologies (*e.g.,* SAV, Periphyton STA, etc.) are available. Decisions related to the benefit of achieving the 10 microgram per liter P threshold versus cost of full-scale implementation will need to be closely assessed.

- *Compliance with Water Quality Criteria*

  This Report provides a review of the water quality produced by the treatment technology in terms of specific chemical parameters as well as bioassay toxicity testing. There appears to be no adverse impact on downstream flora and fauna based upon bioassay toxicity testing.

- *Implementation Schedule*

  It is estimated that the following approximate time periods would be required for implementation of a full-scale UF facility:

  - Finalize process design criteria - 3 months.
  - Prepare detailed plans and specifications - 9 months.
  - Prepare, submit and obtain Environmental and Construction Permits - 6 months.
  - Prepare contractor bid packages, advertise and award project to general contractor - 6 months.
  - Project construction – 9-12 months.
  - Full-scale shakedown, start up and troubleshooting of constructed facility - 6 months.

- *Operational Flexibility*

  The UF full-scale conceptual design proposed has been coupled with the operation of an equalization basin to attenuate peak flows and store water during high rainfall events. Based upon the 10-year POR flow data used for developing the facility conceptual design, the technology can adequately attenuate identified peak hydraulic flows and consistently produce an acceptable effluent water quality. As indicated previously, the treated effluents tested during pilot studies and had no identified adverse impact on downstream flora and fauna.

- *Sensitivity to Fire, Flood, Drought and Hurricane*

  The UF full-scale treatment technology would be affected for a short time period due to fires occurring at the facility. A severe fire on-site would adversely affect electrical wiring, damage instrumentation, controls and motors, and require as much as six months for repair. Area muck fires are anticipated to have little affect on the system as the plant area would be protected by berms and fire protection equipment.

  Flooding within the treatment plant would have little impact upon the system and the facility could be operational within days of flood subsidence. Extensive flooding would impact some pump motors and electrical components associated with facility instrumentation. Repairs and complete return to normal operation in this instance could be as long as three months.

Prolonged droughts would have no anticipated adverse impact on the UF treatment system or the ability of the facility to produce a 20 microgram per of liter Total P effluent. In fact, during drought periods the system would be inactive due to limited water in the FEB.

Due to hurricane construction codes established in Palm Beach County, a Class 5 hurricane would have limited adverse impact relative to wind damage to the facility. The impact of tornadoes associated with hurricanes is difficult to determine; however, in most instances, it is anticipated that normal operation could be returned within no more than two months after a storm. Repairs and complete return to normal operation if significant flooding occurred is estimated at three months. Diesel standby generators included in the conceptual design could be used to operate critical electrical equipment at the facility until electrical service was restored.