Chemical Treatment Followed by Solids Separation Advanced Technology Demonstration Project

FINAL REPORT

December 2000

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Prepared by:

HSA Engineers & Scientists
(A member of the CRA Family of Companies)

Milian, Swain & Associates
Lockhart AG Technologies

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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 $(Al_2(SO_4)_3)\bullet 14\ H_2O$; 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.

1.0 PROJECT BACKGROUND, OBJECTIVES AND OVERVIEW

1.1 PROJECT 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. 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 be 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 "advanced 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.

The advanced technologies must be demonstrated sufficiently to establish their technical, economic and environmental feasibility for basin scale application. Furthermore, the treatment may supplement the STAs as part of a treatment train, to meet the interim (default) phosphorus concentration limit of 10 μg/L, unless a future alternate limit is negotiated. The EFA specifies that the evaluation process must address an initial set of technology criteria, which are set forth below:

- Technical feasibility;
- Levels of load reduction;
- Levels of discharge concentration reduction;
- Water quantity, distribution and timing for the EPA;
- Compliance with water quality standards;
- Compatibility of treated water with the balance in natural populations of aquatic flora and fauna in the EPA (*i.e.*, marsh readiness of effluents);
- Environmental acceptability;
- Cost effectiveness; and
- Schedule for implementation.

Based on an extensive series of evaluations of numerous alternative water treatment technologies performed by Brown and Caldwell (B&C, 1992, 1993 and 1996) under previous contracts with SFWMD, one of the most promising basin-scale processes for application in the EAA is chemical treatment followed by solids separation (CTSS). The specific CTSS processes identified by B&C include direct filtration, high-rate settling and dissolved air flotation. CTSS offers the potential advantages of low land requirement, flexibility, reliability, and ability to reduce phosphorus to levels substantially lower than could be achieved using STAs alone. This project will demonstrate CTSS as a potential technology for meeting the Phase II phosphorus reduction goals. Before implementing CTSS as a basin-scale treatment process, the technology must be demonstrated sufficiently to establish its technical feasibility, economic viability, and environmental compatibility.

The United States Environmental Protection Agency (USEPA) is cost-sharing a portion of the CTSS project through its Section 319h grant program, which is being administered by the FDEP. All deliverable requirements of the Section 319h grant will be incorporated as part of this CTSS project. Final deliverables from this project will be

shared with members of the Section 319h project team, including the USEPA, the United States Army Corps of Engineers and the Florida Department of Agriculture and Consumer Services.

1.2 PROJECT OBJECTIVES

The primary objective of this project was to evaluate - for full-scale implementation - the technical, economic and environmental feasibility of the CTSS technology. The specific objectives of the operations 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 and Caldwell Joint Venture; 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 EAA. The optimum CTSS treatment process will produce the lowest possible effluent Total P at the lowest capital and operating cost and have a benign environmental impact on downstream marshes and wetlands.

1.3 PROJECT OVERVIEW

The CTSS project evaluated the feasibility of using the technology (chemical treatment followed by high rate 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 dissolved phosphorus. These metal salts are routinely used in conventional water treatment facilities for producing drinking water. Metal salts also coagulate the precipitates and other particles, which allows small particulates to be coalesced (flocculated) into larger and more readily settled or readily filtered agglomerates. The precipitation and coagulation reactions are pH dependent, and acids and bases were also tested in combination with the metallic salts to vary pH within the desired ranges. Organic polymers were used to increase flocculent

size, density, and strength. The polymers employed all met National Sanitary Foundation (NSF) Standard 61 for use in drinking water applications. Solids generated from the coagulation and flocculation process were then separated from the liquid through settling and/or filtration.

The CTSS Pilot Unit facility was initially located at the southern end of the Everglades Nutrient Removal (ENR) Project. The ENR is a prototype, constructed wetlands developed to determine the effectiveness of filter marshes/wetland systems to reduce the phosphorus content of the EAA surface waters. The pilot unit had been established adjacent to the ENR exit canal to test Post-STA surface waters. **FIGURE 1.1** shows a map of the EAA and provides the location of the ENR.

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 1-cubic meter flocculation tanks 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 dual and triple media filter columns. All of the columns were 10 feet in height: 6 columns for filtration and 3 columns for adsorption (adsorption columns were tested on Post-BMP waters only).

FIGURE 1.2 provides a schematic diagram of the CTSS pilot facility. Further details on the pilot facility are provided in Section 2.

Operational variables that were screened and optimized included feed flow rates, flocculation retention times and mixing speeds, coagulant feed concentrations, clarifier overflow rates, sludge recirculation rate, filter media composition and filtration rates. Some tests included all of the process units listed above in series and others limited the treatment train to selected units. For example, direct filtration tests 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 effluent (Post-STA) waters and the more effective testing options 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 Test Site.

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: From September 26 through October 25, the North Site facility was constructed.)

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 testing period. **TABLE 1.1** provides a chronology of the major activities completed during the CTSS project.

This Final Report includes the following for the entire project: 1) an overview of the CTSS system and a discussion of how it was operated; 2) the overall 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) order of magnitude engineering cost estimate for a full-scale facilities.

1.4 TECHNICAL REVIEW TEAM PARTICIPATION

A Technical Review Team (TRT) was established at the onset of the project and the members included internationally recognized authorities in water treatment technology. TRT members included: Dr. Jack Cleasby (a water treatment filtration expert); Dr. Gary Amy (an environmental engineering professor at the University of Colorado and an authority on the characterization and treatment of natural organic matter [NOM]); Dr. Petr Dolejs (environmental consultant and expert on the interaction of temperature and operation variables on the treatment of humic containing waters); and Dr. Earl Shannon (who served as the chairperson of the TRT and a recognized water treatment and water quality expert). The TRT convened a total of three times during the course of the project and provided valuable guidance at the project onset and throughout the field investigations.

1.5 'BAYESIAN' APPROACH TO INVESTIGATION

Statistical design of scientific investigation was first introduced by Fisher in the 1920s (Ollos, 1998). Factorial tests often involve several variables examined at multiple design levels. The completion of a large number of tests is generally not possible, or at least not practical, due to time and material constraints. The later-developed fractional factorial design technique necessitates a reduced number of test trials, but has the disadvantage of confounding between potentially important main effects and/or interactions. Strictly speaking, (complete or fractional) factorial tests should be designed when nothing is known about a process. In fact, some prior knowledge is almost always available (about everything) which allows design according to a 'Bayesian'-type of investigation (Reilly, 1993).

Thomas Bayes developed his famous theorem in the 1750s. After his death in 1761, the 'Bayesian' approach to scientific investigation was published in 1762 by his friend, Richard Price. Before a test is performed, the scientist or engineer has a certain level of knowledge about the result, which will be obtained. This knowledge may stem from (1) previous experience in the subject area or (2) from the findings of other researchers. Bayes' theorem describes in a fundamental way the process of learning from experience. Besides easy management of common problems, such as dropped or altered design levels during the course of testing, the 'Bayesian' approach also minimizes testing efforts (*i.e.*, provides the most new information with the least amount of test trials). This is accomplished by the use of a sequential design technique and the typical update of prior covariances (*i.e.*, assumed knowledge) before the design of each new segment. Unlike conventional factorial design, the number of 'Bayesian'-designed tests is not restricted.

Typically, the variances in a 'Bayesian' design are higher than those of a fractional/factorial design test. On the other hand, no complete confounding of the various factors exists in a 'Bayesian'-designed test. Further details on the mathematical basis of the 'Bayesian' approach are provided in **APPENDIX 1.1**.

The CTSS project was well suited to using 'Bayesian' testing design techniques due to the significant amount of previous jar testing data available for input during model development. The 'Bayesian' technique was used to assist the CTSS project team in developing daily test conditions during the course of the field investigations. Actual testing matrices developed showing daily conditions (*e.g.*, chemical type, dosage rates, clarifier overflow rate, etc.) are provided.

CHAPTER 1 - REFERENCES

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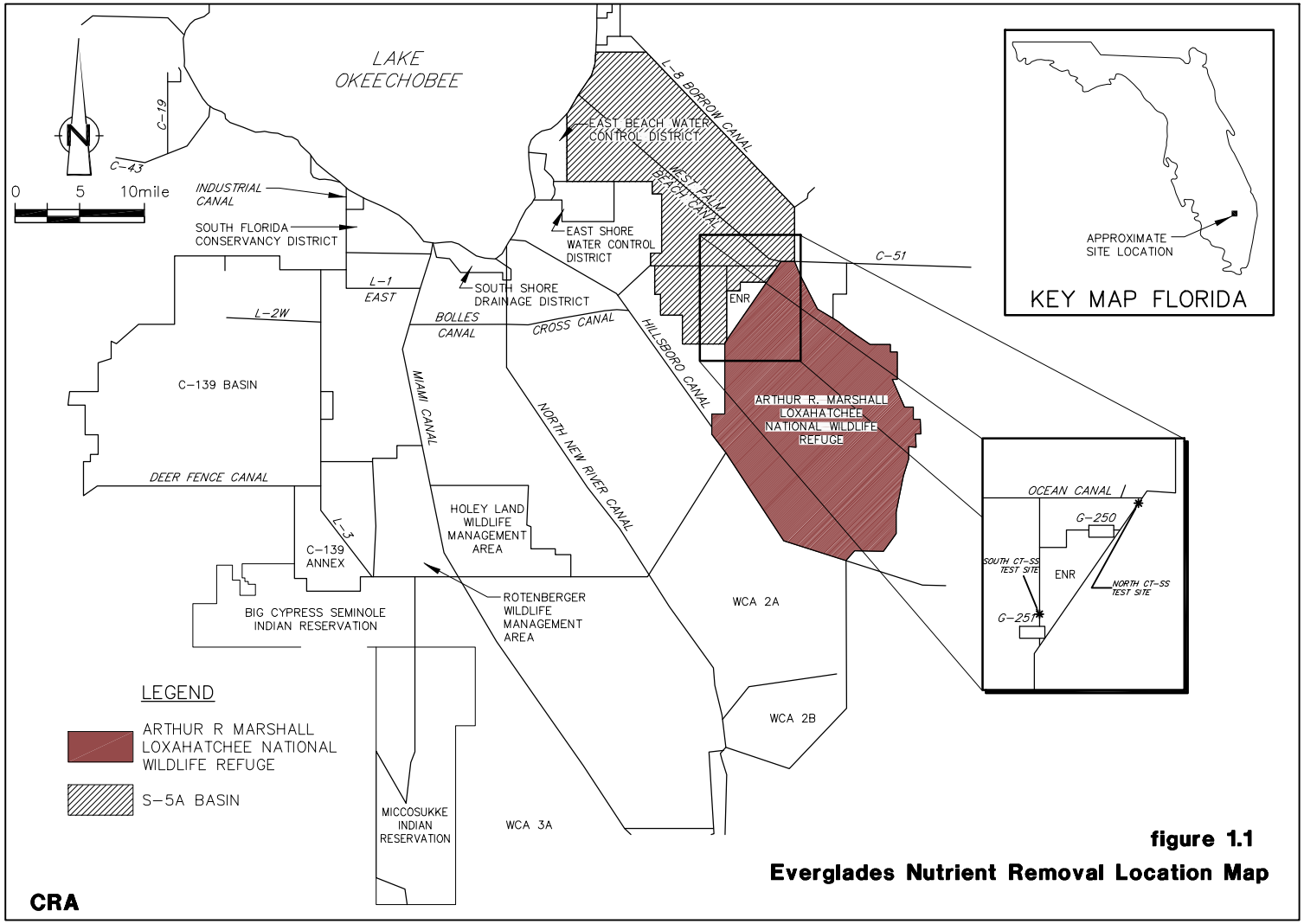


figure 1.1

Everglades Nutrient Removal Location Map

FIGURE 1.2
Schematic Diagram of CTSS Pilot Facility

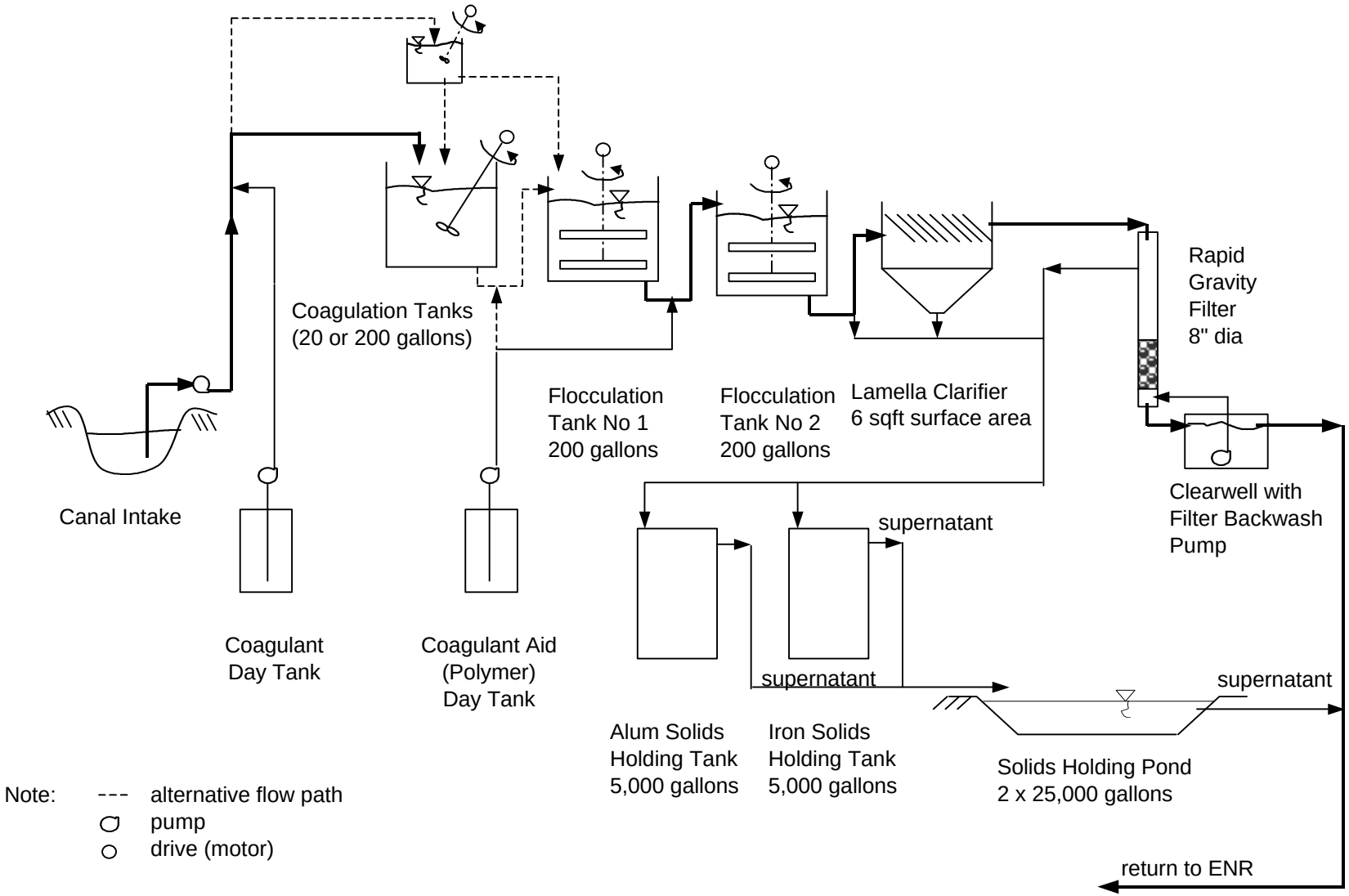


TABLE 1.1
CTSS Field Activities Chronological Sequence of Events

1. Event	2. Organization	3. Scope	4. Duration (1999)	
			From:	To:
TRT Meeting #1	Technical Review Team	General directions	May 3	May 3
CTSS Preliminary Phase	HSA	Equipment setup, etc.	May 17	June 2
CTSS Screening Phase	HSA	Assessment of filtration and dosages	June 3	September 25
Jar Testing No. 1	HSA / Dr. Dolejs	Pilot optimization	June 22	June 25
Bench Scale Filtration	University of Florida / HSA	Bench scale filtration with coated granular media	July 6 and September 8	July 6 and September 8
Bench Scale Filtration	Syracuse University, NY / HSA	Bench scale filtration with glass-sand filter media	July 7	July 21
Vendor Testing	Biochem Technologies Inc. / HSA	Dolomitic lime fixed film bio-reactor pilot test	August 3	December 23
Jar Testing No. 2	Etus Inc. / HSA	Jar testing of vendor supplied coagulant aids	August 17	August 17
Jar Testing No. 3	HSA / Dr. Dolejs	Lake Okeechobee settling	August 18	August 23
TRT Meeting #2	Technical Review Team	Screening review and optimization planning	August 20	August 20
Vendor Testing	HSA / Rochem Environmental Inc.	2 gpm Ultrafiltration pilot test	September 14	November 24
Vendor Testing	HSA / Zenon Environmental Inc.	10 gpm Microfiltration pilot test	September 27	November 22
Vendor Testing	F.B. Leopold Company / HSA	Dissolved air flotation pilot test	October 11	October 24
Vendor Testing	HSA / Infilco Degremont Inc.	DensaDeg high rate clarification and thickening pilot test	October 11	December 12
CTSS Optimization Phase	HSA	Process optimization	October 26	December 3
Vendor Testing	Krüger Inc. / HSA	ACTIFLO (ballasted sand) process pilot test	November 7	November 26
Solids Leaching Study	HSA / SFWMD	Phosphorus release	November 11	December 17
Jar Testing No. 4	HSA / Dr. Dolejs	Lake Okeechobee discharges settling	November 19	November 24
TRT Meeting #3	Conference Call	Technical Review Team – Confirm demonstration conditions	November 18	November 18 (2 hours)
Vendor Testing	MicroMag Corporation / HSA	CoMag process pilot test	November 28	December 21
CTSS Demonstration Phase	HSA	Demonstration of process performance	December 4	December 23
Pilot Scale Filtration	HSA	Activated alumina filter media test	December 17	December 22

2.0 DESCRIPTION OF CHEMICAL TREATMENT PILOT UNITS, METHODS AND MATERIALS

The CTSS treatment technology is a conventional chemically assisted sedimentation water treatment process utilizing coagulation, flocculation, clarification, and rapid granular media filtration process units.

2.1 PROCESS DESCRIPTION

As shown schematically in **FIGURE 1.2**, raw water enters the system in the coagulation tank. Chemical coagulant and pH adjusting agents can be added into or prior to this tank to destabilize suspended solids and colloidal matter. The dispersion of these process chemicals could be achieved either by an inline static mixer or by a mechanical mixer located in the coagulation tank.

There were two coagulant tanks of different volume available in the pilot units, in which the hydraulic detention times were about 2 minutes and 20 minutes, respectively, at a flow rate of 10 gallons per minute. The tanks could be utilized either in series or singularly. Both tanks were equipped with mechanical mixers to enhance the dispersion of the added process chemical(s).

The aggregation of flocs continues as water enters the flocculation process using two tanks in series. The two identical flocculation tanks were equipped with variable speed mechanical mixers. The relatively low energy input agitation of the pretreated water provides ideal conditions for the formation of larger size aggregates. This process was typically further augmented by the dosage of a coagulant aid (polymer) into either of the flocculation cells. The hydraulic detention time in each flocculator tank is 20 minutes (at a feed flow rate of 10 gpm).

The separation of fully formed flocs takes place in the downstream clarifier unit. The 6-square foot plan area clarifier is equipped with 28 inclined settling plates with a total projected surface area of 28 ft^2. Each plate was one-foot deep by two-feet wide and inclined 60 degrees from vertical. Clarifier surface loading rates were investigated in the 0.14 gpm/sq.ft. to 0.71 gpm/sq.ft. range of projected area. The clarified water exited the unit through a collector trough or weir. By the discharge of calculated amount of pretreated water from the clarifier influent, the clarifier surface loading rate and the hydraulic detention time in the upstream treatment units could be maintained

independently. Underdrain residual solids from the clarifier were periodically discharged to the residual solids holding tank/pond. A portion of the solids could be recycled to either of the upstream tanks, if desired.

The final treatment process was rapid granular filtration achieved in eight inches diameter filter columns. Several filter media were tested, including 1) anthracite, 2) expanded shale, 3) sand, 4) granular activated carbon, and 5) polystyrene. Declining rate filtration and constant-rate filtration operation modes were primarily tested. Hydraulic filter loadings were investigated in the range of 4 gpm/sq.ft. to 10 gpm/sq.ft. In-ground steel tanks stored water for filtrate use during filter backwashing. Both filtrate and air scour was used for the periodic backwash of the filter columns.

FIGURES 2.1 through **FIGURE 2.3** provide various photographs of the CTSS pilot facility including pictures inside the treatment trailers showing the process tanks and outside shots of the filter columns and the solids retention storage tanks.

There are essentially two sources of residuals in the treatment process, (1) clarifier solids discharge and (2) filter backwash. These residual lines are connected to a collector header, which discharges to either one of two holding tanks. The 2,500-gallon tanks are used alternately to receive residuals depending on the type of coagulant in use (*i.e.*, aluminum or iron salt).

2.1.1 Process Chemicals

The two primary functions of coagulant chemicals are particle destabilization and strengthening of flocs to reduce floc breakup. The coagulant must form highly insoluble compounds or be strongly adsorbed on particulate surfaces, thus minimizing the concentration of soluble residuals that might pass through the treatment plant.

Selection of the type and dose of coagulant depends on the characteristics of the coagulant, the particles, and the water quality. Because of the complex nature of coagulation, each coagulation problem must be solved empirically. Due to the negative surface charge of most naturally occurring particles, the most effective coagulants are compounds that have a positive charge of high valence. The two principal inorganic coagulants used in water treatment are salts of aluminum and ferric ions. Lime is also used for coagulation when high pH values are desired.

The CTSS pilot tests included the use of water treatment grade lime, ferric-chloride, alum and Cytec anionic polymers A-1849 and A-130. The ferric-sulfate used for the project was donated by KEMIRON and General Chemicals provided the alum.

2.1.2 Coagulation, Flocculation

"Coagulation" is a process of chemically altering colloids so that they will be able to approach each other and form larger particles. "*Flocculation"* is the physical process of bringing the coagulant particles into contact to promote floc formation.

Fine particles (usually less than 10 micron), do not settle out of suspension by settling alone in an economical time frame, requiring the production of larger size aggregates. The aggregation of particulate matter, which allows cost-effective separation, is a two-step sequential process. In the initial step, the interparticle forces responsible for the stability of the particulates are reduced or eliminated by addition of suitable chemicals. Subsequently, particulate collisions occur due to transport by molecular motion or mechanical mixing.

There are four basic mechanisms of *destabilization*:

1. Compression of the electrical double layer;
2. Electrostatic attraction;
3. Interparticle bridging; and
4. Sweep floc or enmeshment.

Double Layer Compression. Increasing the ionic strength compresses the double layer causing a decrease in its thickness. When the zeta potential is $< \pm 20$ mV, rapid coagulation is likely to occur.

Electrostatic Attraction. Many particulates in waters have surface charges dependent on the solution pH and can exhibit both positive and negative surface charges. The pH corresponding to a surface charge of zero is defined as the *zero point of charge (ZPC)*. Above, the ZPC the surface charge is negative; below, it is positive.

Interparticle Bridging. Long chain polymers carrying negative charges can form bridges between particulates, thus destabilizing the suspension.

Enmeshment (Sweep Floc). Some soluble cations such as aluminum, iron or magnesium hydrolize and form an insoluble precipitate, thereby minimizing the concentration of ions added to the water.

The three principal modes of particulate transport are:

1. *'Brownian'* motion (perikinetic flocculation);
2. Differential movement due to fluid shear (orthokinetic flocculation); and
3. Differential movement from particulate sedimentation.

The '*Brownian'* motion affects the movement of colloidal particles (5 nm to 1 μm) only.

Fluid flow in mechanically mixed flocculation system is rarely laminar. Under turbulent flow conditions, the velocity gradient is not well defined and can vary locally in the flocculation reactor. When flow conditions are turbulent, floc breakup cannot be neglected. Small particles are sheared from larger aggregates when the local shear stress exceeds the internal binding forces of the aggregate. The principal mechanisms of aggregate or floc breakup are surface erosion.

The velocity of particles of similar densities settling in a water column is proportional to the size squared. For suspensions containing a wide range of particle size, differential sedimentation can be a significant transport mechanism.

2.1.3 Clarification

Sedimentation of aqueous suspensions can be accelerated by increasing particle size or by decreasing the distance a particle must fall prior to removal. The first

is achieved by coagulation and flocculation prior to sedimentation. The second can be achieved by making the settling distance of floc aggregates as small as possible or practical. The design of shallow settling basins is limited by practical aspects. The application of inclined parallel plates in either newly designed or existing basins is an economical way of enhancing clarification efficiency. The parallel plates reduce the vertical settling distance to a few inches and allow the settled sludge to flow in a countercurrent direction from the suspension flow passing upward through the plate. Thus, solids drop to the bottom of the clarifier and are removed by conventional removal techniques.

The range of projected area overflow rates used during test was from 0.14 to 0.71 gallons per square feet per minute. Underdrain solids were pumped at a regular basis to a residual solids storage tank. The underdrain pumping rate was set at 0.6 gallons per minute during pilot unit operations.

2.1.4 Filtration

Filtration through granular media is a widely used phase separation process. The type and physical characteristics of the media has an effect on filter operation and performance, including 1) approach velocity, 2) headloss, 3) surface or depth filtration, and 4) effluent water quality.

The two basic mechanisms of granular filtration are the transport and attachment of solids. Under most conditions, transport is not rate limiting. Destabilization of suspended particles is essential for the attachment process to occur. Depending on filter design, particulate materials either accumulate on the surface of the medium or are collected through its depth.

Optimum filter performance occurs when the time to reach a limiting headloss is reached at the same moment that the effluent quality exceeds the specified standards. Granular filters need backwashing before reaching any of the limiting conditions (*i.e.*, headloss or breakthrough). Filtration assisted by air scour is typically used for filter backwash.

For the CTSS tests, numerous filtration media were used including shale, anthracite, sand, polystyrene beads and activated carbon. These media were installed in eight-inch diameter, 10-foot tall plexiglass filter columns. Filtration hydraulic loading testing rates ranging from 5 to 10 gallons per minute per square

feet of filter media were tested. A combination of air scouring and backwashing using collected filtered water was routinely used to clear the filters. Air scour and water backwash rates were adjusted to each filter columns containing different media to provide approximately 30 percent fluidization of the filter bed. Filter media characteristics used during the CTSS screening phase are reported in **TABLE 2.1**.

A total of six filter configurations were tested. Five of these filters were operated in the conventional downflow mode. Filter 1C, utilizing polystyrene filter media, was operated in the upflow mode. Filter media selected for testing were chosen based upon the consensus recommendations the TRT members. Modes of filter operation and ranges of recommended filtration rates were also agreed upon by the TRT members.

As solids accumulate in the media, column filtration rates decline. Periodic cleaning of these solids off the media is accomplished by reversing the flow direction (backwashing). A brief summary of the backwashing steps employed during pilot testing follows:

1. Provided approximately 6 inches (15 cm) water coverage over filter.

2. Applied 10 cfm (0.93 m^3/min) air scour for a 5-minute duration.

3. Kept applying 10 cfm air scour and initiated backwash at a flow rate of 2 gpm (7.6 L/min) for 2 minutes (the time required for the water level to reach 12 inches (300 mm) below the backwash water discharge line).

4. Before reaching the aforementioned water level (12 inches below discharge), gradually reduced the air scour rate to provide the stratified settling and prevent the loss of filter media.

5. After the adjustment of proper scour rates, backwash flow rates were increased to values indicated in **TABLE 2.2**.

6. Visual observations confirmed that no filter media was lost during backwash. The duration of each backwash phase is also shown in **TABLE 2.2.**

Filter 1C was the only filter column operated in the upflow mode. The applied filter media in this column was polystyrene. Due to its specific gravity, that media is buoyant. Steps for the backwashing of the polystyrene media include:

1. Dropped water level to approximately 12 inches (300 mm) over bottom discharge line.

2. Re-established normal filtration mode at 1.7 gpm (6.5 L/min) flow rate. In addition, applied air scour at 10 scfm (0.93 m^3/min) for approximately 2 minutes (the time required for the water level to reach 12 inches (300 mm) below the filtrate discharge line).

3. Shut off air scour.

4. Repeated steps 1 to 3 a minimum of 5 times.

The required frequency of filter backwash was a function of hydraulic as well as suspended solids loading rates. Filter backwash was initiated before either:

- Breakthrough (rapid increase of solids and/or phosphorus concentration in the filtrate), or
- Increased headloss resulting in a vacuum in the filter media.

2.1.5 Sampling Measurements and Analytical Techniques

Sampling Locations. Composite samplers were used to collect an approximate 75 milliliter aliqouts of sample at 15-minute intervals extending over an approximate 24-hour total compositing period. Ice was added to the outside jacket of each composite sampler and all samples were kept at 4 degrees Centigrade until collection. The unpreserved composite containers were then retrieved and carried into the on site field trailer for processing and preparing for shipment to the contract laboratory.

Composite sampling locations (ISCO programmable sampler) are shown in **FIGURE 2.4** and include:

1. Raw water;
2. Clarified water; and
3. Each filtrate stream.

Grab sampling locations (including grab composite sampling) are also shown in **FIGURE 2.4** and include:

1. Coagulants (alum, ferric-chloride, ferric-sulphate);
2. Coagulant aids (A-130 and A-1849 polyacrylamids); and
3. Residuals (clarifier sludge blow-down, filter backwash).

Flow metering (water and air) locations are provided as well in **FIGURE 2.4** and include:

1. Raw water (1 instantaneous and totalizer meter per trailer);
2. Filtrate (6 instantaneous and totalizer meters);
3. Instantaneous filter backwash; and
4. Instantaneous air scour.

Laboratory Analyses. There were three off-site laboratories involved in the analysis of the collected samples during the study period, including 1) DB Environmental Laboratories (DB Labs), 2) DEP Laboratories, and 3) Hydrosphere. DB Labs analyzed the phosphorus forms and suspended solids analyses. The DEP Laboratory was responsible for analyzing all metals, pesticides nitrogen tests and bioassay samples, with Hydrosphere Laboratory handling the bioassay overflow analyses. Specific analytical methods for each test performed by the laboratories during the CTSS testing are provided in **TABLE 4.4**, **TABLE 4.5** and **TABLE 4.6** of this Report's **APPENDIX 2**.

2.2 TEST DESIGN

There are numerous factors that have a potentially significant impact on the reduction of phosphorus concentration in aquatic environments using a chemical treatment

technology. In such cases one of the main objectives of a test design is to screen the large number of potential variables and select the most important ones for detailed analysis. From among the numerous potentially important operational, environmental and water quality variables, seven system variables were selected for detailed investigation. The selection of key variables was reviewed and agreed to by the TRT. These variables or design factors include:

- Clarifier surface loading [a];
- Hydraulic filter loading [b];
- Coagulation hydraulic detention time [c];
- Coagulant dosage concentration [d];
- Polymer dosage concentration [e];
- Coagulant type [f]; and
- Filter media [g].

The design factors will be referred to in later parts of this Report by their designating letter shown in the brackets. The primary system response measured was the steady-state net reduction of Total P concentration reported as "μg/L."

There were a total of 201 trials (87 at the North Test Site and 114 at the South Test Site) conducted throughout the testing program. The large number of tests was grouped into 1) screening, 2) optimization, and 3) demonstration.

2.2.1 Screening Tests

A series of screening phase trials were conducted to investigate a broad range of potentially significant variables. The outcome of these screening trials answered some fundamental questions with pronounced impact on later optimization and demonstration trials. In particular, the preliminary tests were concerned with:

1. Familiarization with the pilot scale treatment system and sampling procedures;

2. Establishment of reduction kinetics of phosphorus species (*i.e.*, time required to establish steady-state net reduction of Total P in the system);

3. Recommendation of most effective filter media for a testing research phase(s);

4. Assessment of treatment chemical types and dosage concentrations;

5. Assessment of system performance at lowered pH (charge neutralization) conditions;

6. Establishment of sampling reproducibility (variance); and

7. Reporting correlation results between Total P concentrations and other environmental factors.

Design concepts and the setup of new trials, a few at a time, were developed as the testing progressed. Coded system variables for all 31 screening trials are shown in **TABLE 2.3**. Most of the screening tests were conducted for multipurpose analysis and they varied from 2 to 8 days. The actual length of each trial is shown in the second column ("days") in **TABLE 2.3**. All these screening tests are assigned with the capital letter "S" followed by the trial number.

2.2.2 Optimization Tests

After establishing baseline conditions with the screening tests, the primary objective of optimization was to generate data that could be used for optimizing phosphorus removal.

Since other phosphorus reduction projects (*e.g.*, CRA conducted microfiltration project) during the past several years had generated a significant amount of data, it was decided to use the '*Bayesian'* design approach. The principles of the '*Bayesian'* approach (which allows prior knowledge to testing) are outlined in Section 1.4 and described in detail elsewhere (Reilly, 1993). The capital letter "M" followed by either "N" for the North Test Site or "S" for the South Test Site followed by the trial number were assigned to each optimization test. The design of the optimization program is described below.

Based on the results of screening phase trials and with the review and concurrence of the TRT, the initially tested 6 filter media were reduced to the two best performing filter configurations, which were the "Swiss" and "Green Everglades" media. The Green Everglades or "GE" filter is somewhat similar to the formerly tested "LA" filter configuration. **TABLE 2.4** provides a summary of the media used during the optimization testing.

'Bayesian' testing is based on the principle of learning from experience as stated previously. It is common practice to design approximately 25 percent of the anticipated number of trials at a time. Accordingly, a total of 70 trials at the North Test Site and 68 trials at the South Test Site were designed. Both of these series of trials were designed in four distinct segments. Screening phase results and a review of published literature provided the prior information for the design of the first segment. The total number of trials was 22 in this segment, 16 of those were designed according to '*Bayesian'* principles. The additional six trials addressed specific testing conditions. The coded design matrices for the North and South Test Sites are shown in **TABLE 2.5** and **TABLE 2.6**, respectively. After the completion of the first design segment, the results were evaluated and supplemented to the previous prior distribution resulting in improved prior information for the design of the second segment. The second segment consisted of 16 additional trials designed according to the '*Bayesian'* approach (**TABLE 2.7** and **TABLE 2.8**).

The total number of tests in the third segment was 14 at both Test Sites. The coded design matrices for the North and South Test Sites are shown in **TABLE 2.9** and **TABLE 2.10**, respectively. Trials in this segment were designed to investigate specific testing conditions (*e.g.*, direct filtration) and could not be used for model building. Two tests were performed with higher than the intended coagulant dosage concentration in the previous segment. These trials were repeated with the correct dosage concentration in this segment (Tests MN39 and MN40).

Before the design of the fourth segment, the design level of two of the factors (coagulation volume and clarifier surface loading) were increased from 2 to 3 (*e.g.*, 20, 200 and 220 gallons). In addition, all the '*Bayesian'*-designed tests were grouped together and considered as the prior information for the design of the last segment. Since the design of the fourth segment is typical, the design of

this segment is provided in **APPENDIX 1.2**. **TABLE 2.11** and **TABLE 2.12** provide the resulting Segment #4 test protocols for the North and South Test Sites, respectively.

2.2.3 Demonstration Tests

The primary objective of the last testing phase was two-fold: 1) to demonstrate that the conventional water treatment process can be operated in such condition(s) that its final effluent meets, on a consistent basis, the Total P criteria of 10 micrograms per liter, and 2) to obtain process design data for developing full scale conceptual treatment systems.

After reviewing data obtained during the optimization phase, conditions for the demonstration phase testing were selected with input from members of the CTSS project team and from the technical review team members. **TABLE 2.13** shows the coded design matrix for the demonstration testing.

Demonstration testing was conducted during the time period December 4 through December 23, 1999.

2.2.4 Residual Solids Management and Testing

Residual solids generated from the CTSS flocculation process were allowed to concentrate via gravity settling in the clarifier underdrain chamber. During clarifier operation, these underdrain solids were periodically pumped at an average rate of 0.6 gallons per minute into the two 2500-gallon residual solids storage facilities (one dedicated for alum residuals and the other for iron) located adjacent to the treatment trailers. Solids were allowed to settle in these tanks using a minimum hydraulic retention time of approximately two days and the supernatant overflow was returned to the ENR. Long-term storage of additional residual solids was also accomplished in two lined, in-ground basins each possessing approximately 20,000-gallon capacity.

At the end of the CTSS demonstration phase, all of the solids were chemically tested for the full suite of toxicity characteristics leaching procedure (TCLP) organic and metal parameters and then portions were used for additional residuals testing including:

- Dewatering testing by means of belt press, filter press and centrifugation; and
- Land application trials at EAA sweet corn test plots.

Details of these land application trials and dewatering and testing results are provided in Section 3 of this Report.

2.2.5 Vendor Technologies

Aside from the CTSS pilot facility, other technologies have been identified as being potentially able to substantially reduce the Total P content of the EAA surface waters. Throughout the course of the field testing trials lasting from June to December of 1999, various vendor technologies were tested to determine their phosphorus removal potential. Some of these trials were limited to HSA personnel testing proprietary polymer mixes using the onsite jar testing apparatus and submitting resulting water samples to the lab for assessment. Other vendors were contracted to conduct pilot testing trials at the ENR North and South Test Sites for periods of time. **TABLE 2.14** provides a summary of all of the vendor technologies that were testing during the CTSS field trials**. TABLE 2.14** also provides the size of the pilot facilities (if any) used and the dates testing occurred. Details of vendor trials and associated results are provided in Section 4 of the report.

2.2.6 Additional Testing

During the CTSS field trials, testing of influent and effluent samples for low level mercury and for biotoxicity testing was also completed.

SFWMD field personnel collected samples for the low level mercury analyses during the CTSS Demonstration testing period. Analyses were performed for:

- Total mercury;
- Filtered total mercury;
- Total methyl mercury; and
- Filtered methyl mercury.

Biotoxicity and Algal Growth Potential (AGP) analyses were collected on representative influent and effluent CTSS samples and analyzed by the FDEP Laboratory in Tallahassee, Florida. During the latter phase of demonstration testing, Hydrosphere Laboratory (located in Gainesville, Florida) served as an overflow bioassay lab and also conducted a few of the biotoxicity tests as well. Tests conducted include the following:

- Seven-day chronic estimator (screening) tests using the bannerfin shiner (*Cyprinella Leedsi*) test;
- Seven-day chronic estimator (screening) tests using the water flea (*Ceriodaphnia Dubia*) test; and
- A 96-hour growth test using the unicellular green alga (*Selenastrum Capricornutum*) test.

Tests were performed following USEPA guidelines, but substituting *C. Leedsi* for the fathead minnow, *Pimephales Promelas* (EPA/600/4-91/002). Algal Growth Potential (AGP) tests were performed on the influent and were conducted following USEPA guidelines (EPA/600/9-78-018).

FIGURE 2.1a - Pilot Unit Filter Columns

FIGURE 2.1b - Laboratory Trailer Testing Equipment

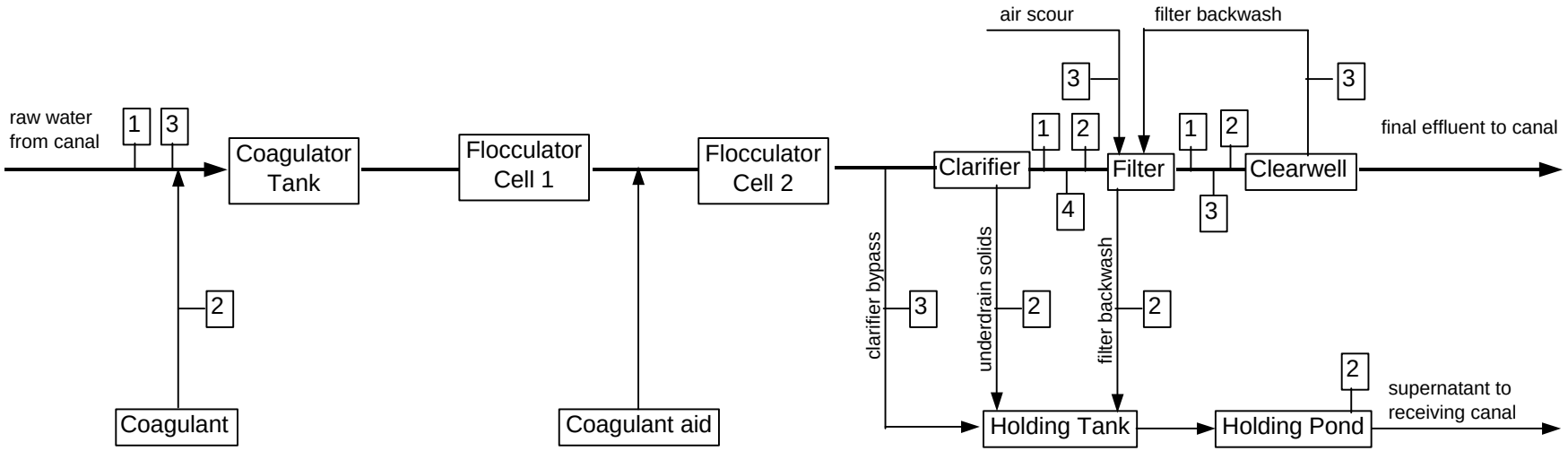
FIGURE 2.2a - Residual Solids Storage

FIGURE 2.2b - Pilot Unit Treatment Trailer

FIGURE 2.3a - Treatment Trailer and Process Tanks

FIGURE 2.3b - Residuals Holding Ponds

FIGURE 2.4
Schematic Diagram of CTSS Pilot Facility Showing Various Sampling Locations



Legend:

1 *composite sampling*

2 *grab sampling*

3 *flow metering*

TABLE 2.1
DESCRIPTION OF FILTERS USED DURING SCREENING TRIALS

FILTER			FILTER MEDIA							
No.	**Designation**	**Layer**	**Type**	**Depth (inches)**	**ES* (mm)**	**UC** (-)**	**d_{60} (mm)**	**Description *****	**Sphericity (φ)**	**Porosity (n)**
1A	LA	mono	Anthracite	77.5	1.5	1.6	2.4	'sharp'	0.81	0.40
1B	Swiss	top	Expanded shale	40	N/A	N/A	2 – 3	'crushed'	0.70	0.48
		bottom	Sand	12	1.5	1.5	2.25	'spherical'	1.00	0.38
1C	Polystyrene ****	mono	Polystyrene	96	N/A	N/A	2 – 3	'spherical'	1.00	0.38
2A	Humics	top	Anthracite	16 ½	2.0	1.5	3.0	'sharp'	0.81	0.40
		bottom	Sand	31	1.5	1.5	2.25	'spherical'	1.00	0.38
2B	Wahnbach	top	GAC	15	N/A	N/A	3 – 5	'angular'	0.78	0.43
		middle	Anthracite	47	1.5	1.6	2.4	'sharp'	0.81	0.40
		bottom	Sand	20	0.8	1.6	1.28	'spherical'	1.00	0.38
2C	Shale	mono	Expanded shale	70 ½	N/A	N/A	2 – 3	'worn'	0.94	0.39

Notes: * *effective size (d_{10}) as reported by Metcalf & Eddy Ltd.*
** *uniformity coefficient (d_{60}/d_{10}) as reported by Metcalf & Eddy Ltd.*
*** *as observed by CRA*
**** *upflow filtration (all other reported filters are operated in downflow mode)*

TABLE 2.2
FILTER BACKWASH PROCEDURES

Filter No.	Initial Water Coverage over Media (inches)	Step #1		Step #2			Step #3		
		Air Scour Flow Rate (scfm)	Duration (minutes)	Air Scour Flow Rate (scfm)	Filtrate Flow Rate (gpm)	Duration* (minutes)	Air Scour Flow Rate (scfm)	Filtrate Flow Rate (gpm)	Duration (minutes)
1A	6	10	5	10	2	2	**no air scour**	22 gpm	10
1B	6	10	5	10	2	2	0.2	22 gpm	10
1C**	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A
2A	6	10	5	10	2	2	0.2	22 gpm	10
2B	6	10	5	10	2	2	**no air scour**	22 gpm	10
2C	6	10	5	10	2	2	0.4	22 gpm	10

Notes: * *approximate time of rising water level to reach 12 inches (30 cm) below waste discharge line*
** *special filter backwash procedure applies*

TABLE 2.3
Design Matrix – Screening Phase Trials
South Test Site (June 03, 1999 to September 25, 1999)

Exp #	Days	Operational Variables							
		Dosage Concentration of Treatment Chemicals				Sludge Discharge		Hydraulic Loading	
		$Al_2(SO_4)_3$ (mg/L) as AL	$Fe_2(SO_4)_3$ (mg/L) as Fe	$Ca(OH)_2$ (mg/L)	A-1849 (mg/L)	Wasted (%)	Recycled (%)	Clarifier* (gpm/sq.ft.)	Filter (gpm/sq.ft.)
S1	1 - 6	none	none	none	none	2	none	0.43	4.9
S2	1 - 6	12	none	none	none	2	none	0.71	-
S3	7 - 15	12	none	none	0.5	2	none	0.43	4.9
S4	7 - 15	none	3.5	50	none	2	none	0.43	4.9
S5	16–19	10	none	none	0.5	2	none	0.43	6.0
S6	16-19	none	1.5	50	none	2	none	0.43	6.0
S7	20-27	10	none	none	0.3	2	none	0.43	6.0
S8	20-27	none	10	none	none	2	none	0.71 **	-
S9	28-30	10	none	none	none	-	-	-	6.0
S10	28-30	none	10	none	0.3	2	none	0.28	-
S11	31-34	10	none	none	none	-	-	-	4.9
S12	32-35	10	none	none	0.3	2	none	0.28	-
S13	31-34	none	10	none	none	-	-	-	4.9
S14	33-35	none	10	none	0.3	2	none	0.28	-
S15	36-39	none	10	none	none	-	-	-	4.9
S16	36-39	10	none	none	0.3	2	16	0.28	-
S17	36-39	10	none	none	none	-	-	-	4.9
S18	36-39	none	10	none	0.3	1	16	0.28	-
S19	41-42	10	none	none	none	-	-	-	4.9
S20	40-44	10	none	none	0.3	2	33	0.14	-
S21	41-42	none	10	none	none	-	-	-	4.9
S22	40-44	none	10	none	0.3	2	33	0.14	-
S23	45-49	10	none	none	0.1	2	33	0.14	4.9
S24	45-49	none	20	none	0.1	2	33	0.14	4.9
S25	50-56	10	none	none	0.1	-	-	-	4.9
S26	51-56	none	20	none	0.1	-	-	-	4.9
S27	57-61	10	none	none	0.1	2	none	0.43	4.9
S28	57-61	none	20	none	0.1	2	none	0.43	4.9
S29	62-64	10	none	none	0.3	5	none	0.43	4.9
S30	65-67	none	20	none	0.3	5	none	0.43	4.9
S31***	66-67	none	none	none	none	none	none	0.43	4.9

Notes:

Tests 1, 3, and 4 — *suction filtration (constant rate filtration provided by downstream pumping)*

Tests 5, 6, 7, 9 — *downstream controlled gravity filtration (constant rate followed by declining rate filtration provided by gradual opening of effluent va*

Tests 11, 13, 15, 17, 19, 21, 23, 24, 25, 26, 27, 28, 29, 30, and 31 — *declining rate gravity filtration (constant valve setting; operation from 1.3Q to 0.6Q, where Q is the target hydraulic loading)*

* — *based on 28 ft^2 projected lamella area*

** — *0.43 gpm/sq.ft. in days 23 to 26*

*** — *North Test Site data*

S — *South Test Site*

TABLE 2.4
Filters and Filter Media Parameters for
Optimization and Demonstration Trials

Filter			Filter Media						
No.	**Designation**	**Layer**	**Type**	**Depth (inches)**	**ES* (mm)**	**UC** (-)**	**Description *****	**Sphericity (φ)**	**Porosity (n)**
North Test Site									
1A	GE	top	anthracite	24	2.0	1.4	'sharp'	0.81	0.40
		middle	sand	31	1.1	1.4	'spherical'	1.00	0.38
		bottom	gravel	4	N/A	N/A	'crushed'	0.70	0.48
1B	Swiss	top	expanded shale	43	2-3	N/A	'crushed'	0.70	0.48
		middle	sand	12	1.5	1.4	'spherical'	1.00	0.38
		bottom	gravel	4	N/A	N/A	'crushed'	0.70	0.48
1C	GE****	top	anthracite	24	2.0	1.4	'sharp'	0.81	0.40
		middle	sand	31	1.1	1.4	'spherical'	1.00	0.38
		bottom	gravel	4	N/A	N/A	'crushed'	0.70	0.48
South Test Site									
2A	Swiss	top	expanded shale	43	2-3	N/A	'crushed'	0.70	0.48
		middle	sand	12	1.5	1.4	'spherical'	1.00	0.38
		bottom	gravel	4	N/A	N/A	'crushed'	0.70	0.48
2B	Swiss****	top	expanded shale	43	2-3	N/A	'crushed'	0.70	0.48
		middle	sand	12	1.5	1.4	'spherical'	1.00	0.38
		bottom	gravel	4	N/A	N/A	'crushed'	0.70	0.48
2C	GE	top	anthracite	24	2.0	1.4	'sharp'	0.81	0.40
		middle	sand	31	1.1	1.4	'spherical'	1.00	0.38
		bottom	gravel	4	N/A	N/A	'crushed'	0.70	0.48

Notes: * *effective size (d_{10}) as reported by Metcalf & Eddy Ltd.*
** *uniformity coefficient (d_{60}/d_{10}) as reported by Metcalf & Eddy Ltd.*
*** *as observed by CRA*
**** *filters were not used during demonstration*
N/A *not available*

TABLE 2.5
Coded Design Matrix – Optimization Trials
North Test Site - Segment #1 (October 26, 1999 to November 7, 1999)

Date 1999	Exp #	Variable						
		Filter Media - 'Swiss' + 'GE'	**Hydraulic Filter Loading*** - 4.9 gpm/sq.ft. + 9.8 gpm/sq.ft.	**Coagulation Volume** - 220 gallons + 200 gallons	**Clarifier Surface Loading**** - 0.28 gpm/sq.ft. + 0.43 gpm/sq.ft.	**Coagulant Type** - alum + ferric-chloride	**Coagulant Dosage Concentration** alum: - 10 mg/L as Al + 20 mg/L as Al ferric-chloride: - 20 mg/L as Fe + 40 mg/L as Fe	**Polymer (A-130) Dosage Concentration** - 0.3 mg/L + 0.5 mg/L
October 26	**MN1**	-	-	+	-	-	-	+
(Tuesday)	**MN2**	+	-	+	-	-	-	+
October 27	**MN3**	-	+	+	+	+	+	+
(Wednesday)	**MN4**	+	+	+	+	+	+	+
October 28•••	**MN5**	-	+	-***	-	+	+	-
(Thursday)	**MN6**	+	+	-***	-	+	+	-
October 29	**MN7**	-	+	-	-	+	+	-
(Friday)	**MN8**	+	+	-	-	+	+	-
November 1	**MN9**	-	+	-	-	+	-	+
(Monday)	**MN0**	+	+	-	-	+	-	+
November 2	**MN11**	-	+	-	-	-	+	+
(Tuesday)	**MN12**	+	+	-	-	-	+	+
November 3	**MN13**	-	+	+	-	-	-	-
(Wednesday)	**MN14**	+	+	+	-	-	-	-
November 4	**MN15**	-	-	-	-	+	+	+
(Thursday)	**MN16**	+	-	-	-	+	+	+
November 5	**MN17**	-	-	+	-	-	+	-
(Friday)	**MN18**	+	-	+	-	-	+	-
November 6•••	**MN19**	-	-	-	-	-	+	+****
(Saturday)	**MN20**	+	-	-	-	-	+	+****
November 7•••	**MN21**	-	-	-	-	+	+	+****
(Sunday)	**MN22**	+	-	-	-	+	+	+****

Notes:
- * *4.9 gpm/sq.ft. (1.7 gpm hydraulic filter loading)*
- ** *projected lamella area*
- *** *20 gallons*
- **** *A-1849 polyacrylamide*
- • *lab duplicate*
- •• *filter duplicate*
- ••• ***tests*** *in addition to Bayesian designed trials*
- *M* *model building or optimization trials*
- *N* *North Test Site*

Constant flocculation volume is 400 gallons
Even number tests will be conducted in duplicate using the Green Everglades (GE) filter media
Filter 1A: 'Green Everglades'; filter 1B: 'Swiss'; filter 1C: 'Green Everglades'

The "-" and "+" signs designate the variable to be used in a given test. For instance, in Test in N1, the "-" under filter media means that the 'Swiss' filter was used; the "-" under hydraulic filter loading means that 4.9 gpm/sq.ft. was used.

TABLE 2.6
Coded Design Matrix – Optimization Trials
South Test Site - Segment #1 (October 26, 1999 to November 7, 1999)

Date	Exp #	Variable						
1999		Filter Media - 'Swiss' + 'GE'	Hydraulic Filter Loading* - 4.9 gpm/sq.ft. + 9.8 gpm/sq.ft.	Coagulation Volume - 220 gallons + 200 gallons	Clarifier Surface Loading** - 0.28 gpm/sq.ft. + 0.43 gpm/sq.ft.	Coagulant Type - alum + ferric-chloride	Coagulant Dosage Concentration alum: - 10 mg/L as Al + 20 mg/L as Al ferric-chloride: - 20 mg/L as Fe + 40 mg/L as Fe	Polymer (A-130) Dosage Concentration - 0.3 mg/L + 0.5 mg/L
October 26	**MS1**	-	-	+	-	-	-	+
(Tuesday)	**MS2**	+	-	+	-	-	-	+
October 27	**MS3**	-	+	+	+	+	+	+
(Wednesday)	**MS4**	+	+	+	+	+	+	+
October 28♦♦♦	**MS5**	-	+	-***	-	+	+	-
(Thursday)	**MS6**	+	+	-***	-	+	+	-
October 29	**MS7**	-	+	-	-	+	+	-
(Friday)	**MS8**	+	+	-	-	+	+	-
November 1	**MS9**	-	+	-	-	+	-	+
(Monday)	**MS10**	+	+	-	-	+	-	+
November 2	**MS11**	-	+	-	-	-	+	+
(Tuesday)	**MS12**	+	+	-	-	-	+	+
November 3	**MS13**	-	+	+	-	-	-	-
(Wednesday)	**MS14**	+	+	+	-	-	-	-
November 4	**MS15**	-	-	-	-	+	+	+
(Thursday)	**MS16**	+	-	-	-	+	+	+
November 5	**MS17**	-	-	+	-	-	+	-
(Friday)	**MS18**	+	-	+	-	-	+	-
November 6♦♦♦	**MS19**	-	-	-	-	-	+	+****
(Saturday)	**MS20**	+	-	-	-	-	+	+****
November 7♦♦♦	**MS21**	-	-	-	-	+	+	+****
(Sunday)	**MS22**	+	-	-	-	+	+	+****

Notes:
- * *4.9 gpm/sq.ft. (1.7 gpm hydraulic filter loading)*
- ** *projected lamella area*
- *** *20 gallons*
- **** *A-1849 polyacrylamide*
- ♦ *lab duplicate*
- ♦♦ *filter duplicate*
- ♦♦♦ ***tests*** *in addition to 'Bayesian' designed trials*
- *M model building or optimization trials*
- *S South Test Site*

Constant flocculation volume is 400 gallons
Uneven number tests will be conducted in duplicate using the 'Swiss' filter media
Filter 2A: 'Swiss'; filter 2B: 'Swiss'; filter 2C: 'Green Everglades'

TABLE 2.7
Coded Design Matrix – Optimization Trials
North Test Site - Segment #2 (November 8, 1999 to November 15, 1999)

Date	Exp #	Variable						
1999		Filter Media - 'Swiss' + 'GE'	Hydraulic Filter Loading* - 4.9 gpm/sq.ft. + 9.8 gpm/sq.ft.	Coagulation Volume - 220 gallons + 200 gallons	Clarifier Surface Loading** - 0.28 gpm/sq.ft. + 0.43 gpm/sq.ft.	Coagulant Type - alum + ferric-chloride	Coagulant Dosage Concentration alum: - 10 mg/L as Al + 20 mg/L as Al ferric-chloride: - 20 mg/L as Fe + 40 mg/L as Fe	Polymer (A-130) Dosage Concentration - 0.3 mg/L + 0.5 mg/L
November 8	**MN23**	-	+	+	-	-	+	+
(Monday)	**MN24**	+	+	+	-	-	+	+
November 9	**MN25**	-	+	+	-	-	-	+
(Tuesday)	**MN26**	+	+	+	-	-	-	+
November 10	**MN27**	-	+	+	+	+	-	+
(Wednesday)	**MN28**	+	+	+	+	+	-	+
November 11♦♦♦	**MN29**	-	+	+	+	+	+***	-
(Thursday)	**MN30**	+	+	+	+	+	+***	-
November 12	**MN31**	-	-	+	+	+	+	+
(Friday)	**MN32**	+	-	+	+	+	+	+
November 13	**MN33**	-	-	+	-	+	-	-
(Saturday)	**MN34**	+	-	+	-	+	-	-
November 14	**MN35**	-	+	-	+	-	+	+
(Sunday)	**MN36**	+	+	-	+	-	+	+
November 15	**MN37**	-	-	-	-	+	+	-
(Monday)	**MN38**	+	-	-	-	+	+	-

Notes:
- * *4.9 gpm/sq.ft. (1.7 gpm hydraulic filter loading)*
- ** *projected lamella area*
- *** *100 mg/L as Fe*
- ♦ *lab duplicate*
- ♦♦ *filter duplicate*
- ♦♦♦ ***test**(s), in addition to 'Bayesian' designed trials*
- *M model building or optimization trials*
- *N North Test Site*

Constant flocculation volume is 400 gallons
Even number tests will be conducted in duplicate using the Green Everglades (GE) filter media
Filter 1A: 'Green Everglades'; filter 1B: 'Swiss'; filter 1C: 'Green Everglades'

TABLE 2.8
Coded Design Matrix – Optimization Trials
South Test Site - Segment #2 (November 8, 1999 to November 15, 1999)

Date	Exp #	Variable						
1999		Filter Media - 'Swiss' + 'GE'	Hydraulic Filter Loading* - 4.9 gpm/sq.ft. + 9.8 gpm/sq.ft.	Coagulation Volume - 220 gallons + 200 gallons	Clarifier Surface Loading** - 0.28 gpm/sq.ft. + 0.43 gpm/sq.ft.	Coagulant Type - alum + ferric-chloride	Coagulant Dosage Concentration alum: - 10 mg/L as Al + 20 mg/L as Al ferric-chloride - 20 mg/L as Fe + 40 mg/L as Fe	Polymer (A-130) Dosage Concentration - 0.3 mg/L + 0.5 mg/L
November 8	**MS23**	-	+	+	-	-	+	+
(Monday)	**MS24**	+	+	+	-	-	+	+
November 9	**MS25**	-	+	+	-	-	-	+
(Tuesday)	**MS26**	+	+	+	-	-	-	+
November 10	**MS27**	-	+	+	+	+	-	+
(Wednesday)	**MS28**	+	+	+	+	+	-	+
November 11	**MS29**	-	+	+	+	+	+	-
(Thursday)	**MS30**	+	+	+	+	+	+	-
November 12	**MS31**	-	-	+	+	+	+	+
(Friday)	**MS32**	+	-	+	+	+	+	+
November 13	**MS33**	-	-	+	-	+	-	-
(Saturday)	**MS34**	+	-	+	-	+	-	-
November 14	**MS35**	-	+	-	+	-	+	+
(Sunday)	**MS36**	+	+	-	+	-	+	+
November 15	**MS37**	-	-	-	-	+	+	-
(Monday)	**MS38**	+	-	-	-	+	+	-

Notes:
- * *4.9 gpm/sq.ft. (1.7 gpm hydraulic filter loading)*
- ** *projected lamella area*
- ⬥ *lab duplicate*
- ⬥⬥ *filter duplicate*
- *M* *model building or optimization trials*
- *S* *South Test Site*

Constant flocculation volume: 400 gallons
Uneven number tests will be conducted in duplicate using the 'Swiss' filter media
Filter 2A: 'Swiss'; filter 2B: 'Swiss'; filter 2C: 'Green Everglades'

TABLE 2.9
Coded Design Matrix – Optimization Trials
North Test Site - Segment #3 (November 16, 1999 to November 21, 1999)

Date	Exp #	Variable						
1999		Filter Media - 'Swiss' + 'GE'	Hydraulic Filter Loading* - 4.9 gpm/sq.ft. + 9.8 gpm/sq.ft.	Coagulation Volume - 20 gallons 0.8 200 gallons + 220 gallons	Clarifier Surface Loading** -2 none - 0.14 gpm/sq.ft. 0 0.28 gpm/sq.ft. + 0.43 gpm/sq.ft.	Coagulant Type - alum + ferric-chloride	Coagulant Dosage Concentration alum: - 10 mg/L as Al + 20 mg/L as Al ferric-chloride: - 20 mg/L as Fe + 40 mg/L as Fe	Polymer (A-130) Dosage Concentration - 0.3 mg/L + 0.5 mg/L
November 16	**MN39**	-	+	0.8	+	+	+	-
(Tuesday)* **	**MN40**	+	+	0.8	+	+	+	-
**November 17••• **	**MN41**	-	-	+	-2	+	-	-
(a.m.)	**MN42**	+	-	+	-2	+	-	-
**November 17••• **	**MN43**	-	-	+	-2	+	+	-
(p.m.)	**MN44**	+	-	+	-2	+	+	-
**November 18••• **	**MN45**	-	-	+	-2	-	-	-
(a.m.)	**MN46**	+	-	+	-2	-	-	-
**November 18••• **	**MN47**	-	-	+	-2	-	+	-
(p.m.)	**MN48**	+	-	+	-2	-	+	-
**November 19••• **	**MN49**	-	-	+	-	-	+	+
(Friday)	**MN50**	+	-	+	-	-	+	+
**Nov ember 20••• **	**MN51**	-	-	+	-	+	+	+
(Saturday)	**MN52**	+	-	+	-	+	+	+
**November 21••• **	**MN53**	-	-	+	-	+	+	+
(Sunday)	**MN54**	+	-	+	-	+	+	+

Notes: *Constant flocculation volume: 400 gallons*
HDT in a single flocculator cell: 49 min 30 sec (Q_{feed} = 4 gpm) unless noted
* *4.9 gpm/sq.ft. (1.7 gpm hydraulic filter loading)*
** *projected lamella area*
*** *HDT in a single flocculator cell: 16 min 30 sec (Q_{feed} = 12 gpm)*
• *lab duplicate*
•• *filter duplicate*
••• ***tests*** *in addition to 'Bayesian' designed trials*
M *model building or optimization trials*
N *North Test Site*
Even number tests will be conducted in duplicate using the Green Everglades (GE) filter media
Filter 1A: 'Green Everglades'; filter 1B: 'Swiss'; filter 1C: 'Green Everglades'

TABLE 2.10
Coded Design Matrix – Optimization Trials
South Test Site - Segment #3 (November 17, 1999 to November 21, 1999)

Date	Exp #	Variable						
1999		Filter Media - 'Swiss' + 'GE'	Hydraulic Filter Loading* - 4.9 gpm/sq.ft. + 9.8 gpm/sq.ft.	Coagulation Volume - 20 gallons 0.8 200 gallons + 220 gallons	Clarifier Surface Loading** -2 none - 0.14 gpm/sq.ft. 0 0.28 gpm/sq.ft. + 0.43 gpm/sq.ft.	Coagulant Type - alum + ferric-chloride	Coagulant Dosage Concentration alum: - 10 mg/L as Al + 20 mg/L as Al ferric-chloride: - 20 mg/L as Fe + 40 mg/L as Fe	Polymer (A-130) Dosage Concentration - 0.3 mg/L + 0.5 mg/L
November 16♦♦♦♦ (Tuesday)								
November 17♦♦♦ (a.m.)	**MS39**	-	-	+	-2	+	-	-
	MS40	+	-	+	-2	+	-	-
November 17♦♦♦ (p.m.)	**MS41**	-	-	+	-2	+	+	-
	MS42	+	-	+	-2	+	+	-
November 18♦♦♦ (a.m.)	**MS43**	-	-	+	-2	-	-	-
	MS44	+	-	+	-2	-	-	-
November 18♦♦♦ (p.m.)	**MS45**	-	-	+	-2	-	+	-
	MS46	+	-	+	-2	-	+	-
November 19♦♦♦ (Friday)	**MS47**	-	-	+	-	-	+	+
	MS48	+	-	+	-	-	+	+
November 20♦♦♦ (Saturday)	**MS49**	-	-	+	-	+	+	+
	MS50	+	-	+	-	+	+	+
November 21♦♦♦ (Sunday)	**MS51**	-	-	+	-	+	+	+
	MS52	+	-	+	-	+	+	+

Notes: *Constant flocculation volume is 400 gallons unless noted*
Constant HDT in a single flocculator cell: 49 min 30 sec (Q_{feed} = 4 gpm) unless noted
* *4.9 gpm/sq.ft. (1.7 gpm hydraulic filter loading)*
** *projected lamella area*
♦ *lab duplicate*
♦♦ *filter duplicate*
♦♦♦ *test(s), in addition to 'Bayesian' design*
♦♦♦♦ *test was not conducted*
M *model building or optimization trials*
S *South Test Site*
Uneven number tests will be conducted in duplicate using the 'Swiss' filter media
Filter 2A: 'Swiss'; filter 1B: 'Swiss'; filter 1C: 'Green Everglades'

TABLE 2.11
Coded Design Matrix – Optimization Trials
North Test Site - Segment #4 (November 22, 1999 to December 3, 1999)

Date	Exp #	Variable						
1999		Filter Media - 'Swiss' + 'GE'	Hydraulic Filter Loading* - 4.9 gpm/sq.ft. + 9.8 gpm/sq.ft.	Coagulation Volume - 20 gallons 0.8 200 gallons + 220 gallons	Clarifier Surface Loading** - 0.14 gpm/sq.ft. 0 0.28 gpm/sq.ft. + 0.43 gpm/sq.ft.	Coagulant Type - alum + ferric-chloride	Coagulant Dosage Concentration alum: - 10 mg/L as Al + 20 mg/L as Al ferric-chloride: - 20 mg/L as Fe + 40 mg/L as Fe	Polymer (A-130) Dosage Concentration - 0.3 mg/L + 0.5 mg/L
November 22	MN55	-	-	-	+	-	-	-
(Monday)	MN56	+	-	-	+	-	-	-
November 23	MN57	-	-	-	-	-	+	+
(Tuesday)	MN58	+	-	-	-	-	+	+
November 24	MN59	-	-	-	-	+	-	+
(Wednesday)	MN60	+	-	-	-	+	-	+
November 29♦♦♦	MN61	-	-	+	-	-	-	-
(Monday)	MN62	+	-	+	-	-	-	-
November 30♦♦♦	MN63	-	+	+	-	-	+	-
(Tuesday)	MN64	+	+	+	-	-	+	-
December 1♦♦♦	MN65	-	-	+	-	+	+	+
(Wednesday)	MN66	+	-	+	-	+	+	+
December 2♦♦♦	MN67	-	+	+	-	+	-	+
(Thursday)	MN68	+	+	+	-	+	-	+
December 3♦♦♦	MN69	-	+	+	-	+	-	-
(Friday)	MN70	+	+	+	-	+	-	-

Notes: * *4.9 gpm/sq.ft. (1.7 gpm hydraulic filter loading)*
** *projected lamella area*
♦ *lab duplicate*
♦♦ *filter duplicate*
♦♦♦ *tests in addition to 'Bayesian' designed trials*
M model building or optimization trials
N North Test Site
Constant flocculation volume: 400 gallons
Even number tests will be conducted in duplicate using the Green Everglades (GE) filter media
Filter 1A: 'Green Everglades'; filter 1B: 'Swiss'; filter 1C: 'Green Everglades'

TABLE 2.12
Coded Design Matrix – Optimization Trials
South Test Site - Segment #4 (November 22, 1999 to December 3, 1999)

Date	Exp #	Variable						
1999		Filter Media - 'Swiss' + 'GE'	Hydraulic Filter Loading* - 4.9 gpm/sq.ft. + 9.8 gpm/sq.ft.	Coagulation Volume - 20 gallons 0.8 200 gallons + 220 gallons	Clarifier Surface Loading** - 0.14 gpm/sq.ft. 0 0.28 gpm/sq.ft. + 0.43 gpm/sq.ft.	Coagulant Type - alum + ferric-chloride	Coagulant Dosage Concentration alum: - 10 mg/L as Al + 20 mg/L as Al ferric-chloride: - 20 mg/L as Fe + 40 mg/L as Fe	Polymer (A-130) Dosage Concentration - 0.3 mg/L + 0.5 mg/L
November 22	**MS53**	-	-	-	+	-	-	-
(Monday)	**MS54**	+	-	-	+	-	-	-
November 23	**MS55**	-	-	-	-	-	+	+
(Tuesday)	**MS56**	+	-	-	-	-	+	+
November 24	**MS57**	-	-	-	-	+	-	+
(Wednesday)	**MS58**	+	-	-	-	+	-	+
November 29♦♦♦	**MS59**	-	-	+	-	-	-	-
(Monday)	**MS60**	+	-	+	-	-	-	-
November 30♦♦♦	**MS61**	-	+	+	-	-	+	-
(Tuesday)	**MS62**	+	+	+	-	-	+	-
December 1♦♦♦	**MS63**	-	-	+	-	+	+	+
(Wednesday)	**MS64**	+	-	+	-	+	+	+
December 2♦♦♦	**MS65**	-	+	+	-	+	-	+
(Thursday)	**MS66**	+	+	+	-	+	-	+
December 3♦♦♦	**MS67**	-	+	+	-	+	-	-
(Friday)	**MS68**	+	+	+	-	+	-	-

Notes:
- * *4.9 gpm/sq.ft. (1.7 gpm hydraulic filter loading)*
- ** *projected lamella area*
- ♦ *lab duplicate*
- ♦♦ *filter duplicate*
- ♦♦♦ *tests in addition to 'Bayesian' designed trials*
- *M* *model building or optimization trials*
- *S* *South Test Site*

Constant flocculation volume: 400 gallons
Uneven number tests will be conducted in duplicate using the Green Everglades (GE) filter media
Filter 2A: 'Swiss'; filter 2B: 'Swiss'; filter 2C: 'Green Everglades'

TABLE 2.13
Coded Design Matrix – Demonstration Trials
North and South Test Sites (December 4, 1999 to December 23, 1999)

Test Site	Variable					
	Hydraulic Filter Loading (gpm/sq.ft.) - 4.9 gpm/sq.ft. + 9.8 gpm/sq.ft.	**Coagulation Volume (gallons)** - 20 gallons 0.8 200 gallons + 220 gallons	**Clarifier Surface Loading (gpm/sq.ft.)** - 0.14 gpm/sq.ft. 0 0.28 gpm/sq.ft. + 0.43 gpm/sq.ft.	**Coagulant Type** - alum + ferric-chloride	**Coagulant Dosage Concentration (mg/L)*** alum: - 10 mg/L + 20 mg/L ferric-chloride: - 20 mg/L + 40 mg/L	**Polymer** Dosage Concentration (mg/L)** - 0.3 mg/L + 0.5 mg/L
North	-	-	-	+	+	+
South	+	-	0	-	+	+

Notes: * *as metal*
** *A-130 polyacrylamide*

TABLE 2.14
Vendor Technologies Tested During CTSS Field Investigations

Vendor	Treatment Process		Test Location	Test Duration (1999)	Area (L x W x H) (feet)	Electrical	Hydraulic Loading (gpm)*		Process Chemicals
	Name	Description					Max	Tested	
F.B. Leopold Company	Dissolved Air Flotation (DAF)	solids-liquid separation process that transfers solids to the liquid surface through attachment of fine bubbles to solid particles	South Site North Site	Oct 11 - Oct 15 Oct 18 – Oct 24	11' x 54' x 13'2"	460/3/100 or 230/3/200	36	36	Coagulants coagulant aids
Kruger Inc.	ACTIFLO Process	conventional-type water treatment process that utilizes microsand as a seed for floc formation	South Site North Site	Nov 8 – Nov 12 Nov 15 – Nov 21	39.3' x 8' x 13.5'	480/3/75	330	360	Coagulants coagulant aids acid (pH control)
Infilco Degremont Inc.	DensaDeg High Rate Clarifier	compact solids contact high rate clarification	North Site	Oct 11 – Nov 10	20' x 8' x 22'	480/3/100	200	140	Coagulants coagulant aids
ROCHEM Environmental Inc.	Ultrafiltration	pressure driven separation process, in which liquid flow occurs from the concentrated solution to the dilute solution across a semi-permeable membrane	South Site	Sep 30 – Nov 30	4'5" x 2'x 1'4"	480/3	2.2	2.0	None
Zenon Environmental Inc.	Microfiltration	'cross-flow with concentrate recycle' solids separation system removing particles greater than 0.1 micron	South Site	Sep 30 – Nov 30	6' x 6' x 6'	480/3	10	10	Coagulants or None
BIOCHEM Technologies Inc.	Dolomitic Lime Fixed Film Bio-Reactor	biological treatment technology utilizing an indigenous sessile bacteria for the uptake of nutrients such as phosphorus and nitrogen.	South Site	Aug 4 – Dec 31	35' x 5' x 3'	120/1/5	10	10	None
MicroMag Corporation	CoMag Process	innovative technology utilizing magnetite seed and high gradient magnetic fields for the separation of floc aggregates.	South Site North Site	Nov 15 – Nov 19 Nov 22 – Nov 26	40' x 8' x 13.5'	480/3/50 KVA 240/3/25	20	20	Coagulants coagulant aids
University of Florida	Bench Scale Coated Media Filtration	patented phase separation technique utilizing metallic hydroxide coated granular filter media	Off Site	July 18, and Sept 10	N/A	N/A	N/A	10 mL/sec to 25 mL/sec	None
Syracuse University / HSA	Bench Scale Glass Sand Filtration	separation technique utilizing 50/50 mix of two washed size fractions (0.6 – 1.18 mm and 0.295 – 0.6 mm) of filter media	South Site	July 20 - Aug 15	mounted on clarifier outside wall	120/1/5	N/A	10 mL/sec	Coagulants coagulant aids
ETUS Inc. / HSA	Jar Testing with Supplied Treatment Chemicals	conventional phase separation technique utilizing vendor supplied treatment chemicals	HSA Lab at South Site	November 18	6' x 2' x 1' (jar test unit)	120/1/5	N/A	N/A	Coagulant aids

Notes: *N/A* *not applicable*
- *unless noted otherwise*

gpm *gallons per minute*

3.0 CTSS PILOT STUDY RESULTS AND MAJOR FINDINGS

Study results for the six months of pilot studies conducted on the CTSS pilot facility have been summarized below for information during the screening, optimization and demonstration phases of testing, respectively.

For the demonstration data results, more detailed discussions are provided related to phosphorus removal rates through the pilot unit and also for residual solids characterization and dewatering, bioassay testing and low level mercury assessments. Detailed discussions related to all Standard of Comparison water quality data obtained during the demonstration testing is also provided.

3.0.1 Phosphorus Forms Tested and Reporting Conventions

In all, three distinct forms of phosphorus were analyzed during the CTSS studies. A brief summary of the three forms are provided below:

- ***Soluble Reactive Phosphorus (SRP)***

  Upon collection, samples are prepared in the field by filtering through a 0.45 micron filter and placing in an unpreserved sample bottle. Upon receipt in the laboratory, a direct colorimetric analysis is conducted without any sample digestion. The analytical result from this test is defined as the SRP content and typically represents the ortho phosphorus fraction and a small portion of the condensed phosphorus that is unavoidably hydrolized during the analytical procedure. Soluble Reactive Phosphorus results are described below using the acronym "SRP" and the data is all reported on an elemental phosphorus weight basis (*i.e.,* mg/L or μg/L as P).

- ***Total Dissolved Phosphorus (TDP)***

  Upon collection, samples are prepared in the field by filtering through a 0.45 micron filter and then preserving the sample to pH 2 or less using sulfuric acid. In the laboratory, the sample is digested using strong acid solutions converting all of the phosphorus forms contained in the sample to dissolved orthophosphate. Total Dissolved Phosphorus results are described below using the acronym "TDP" and the data is all reported on an elemental phosphorus weight basis (*i.e.,* mg/L or μg/L as P).

- ***Total Phosphorus (Total P)***

  Upon collection, the samples are immediately chemically preserved to a pH of 2 or less using sulfuric acid. In the laboratory, the sample is digested using strong acid solutions. The objective of the Total P analysis is to obtain the Total P of the sample regardless of the form (*e.g.*, reactive, dissolved, etc.). Total P results are described below using Total P and this data is all reported on an elemental phosphorus weight basis (*i.e.,* mg/L or µg/L as P).

3.0.2 South Test Site (Post-STA) General Water Quality Characteristics

The variation of Total P in the raw water supply of the South (Post-STA) Test Site during the study period is shown in **FIGURE 3.1.** Total P at the South Test Site generally ranged from between 15 to 30 micrograms/liter (µg/L) during the entire study period (June through December, 1999). The average Total P concentration recorded at the South Site was equal to 22.4 µg/L during this time, and elevated Total P data was only observed during the September time period as shown in **FIGURE 3.1**. Total P spikes as high as 70 µg/L were observed during this time and were attributed to the release of high concentrations of particulate phosphorus attributed to the SAV harvesting activities which were occurring upstream of the CTSS intake structure. SAV harvesting was performed in order to transplant SAV from the ENR into the newly flooded Cell 5 of STA 1 West.

Based upon the average monthly data shown in **FIGURE 3.2**, the SRP component of the Total P at the South Site was typically quite low and represented less than 20 percent of the total. The SRP was, in actuality, even lower than shown in **FIGURE 3.2** as all SRP data reported by the laboratory to be less than 2 µg/L were averaged as if they were 2. **FIGURE 3.2** also provides a summary of the dissolved phosphorus data and shows the TDP content of the South Site ranging from approximately 66 to as high as high as 87 percent of the Total P content.

In general, the ENR effluent, or South Test Site, water quality observed during the CTSS study period can be characterized as a highly colored water (derived naturally from area muck soils) possessing an approximate neutral pH, relatively high total dissolved solids (TDS) (exceeding drinking water standards), and containing relatively high concentrations of total organic carbon (TOC). Representative analytical values observed during CTSS testing for select parameters at the South Test Site are provided below:

Parameter	South Site Average Value	Range
pH, pH units	7.1	6.5 – 7.6
Color, PCU	113	89 – 144
TDS, mg/L	581	524 – 688
TOC, mg/L	29	13 – 37

3.0.3 North Test Site (Post-BMP) General Water Quality Characteristics

The variation of Total P in the raw water supply of the North (Post-BMP) Test Site during the study period is shown in **FIGURE 3.3**. The Total P content of the North Test Site generally ranged from between 110 to 160 μg/L during the entire study period (October 26 through December 23, 1999). The average Total P concentration recorded at the North Site was equal to 149 μg/L.

Based upon the average monthly data shown in **FIGURE 3.4**, the SRP component of the Total P at the North Site varied considerably and ranged from 39 to as high as 71 percent. **FIGURE 3.4** also provides a summary of the dissolved phosphorus data and shows the TDP content of the North Site ranging from approximately 59 to 82 percent of the Total P content.

Representative analytical values observed during CTSS testing for select parameters at the North Test Site are provided below:

Parameter	North Site Average Value	Range
pH, pH units	6.8	6.2 – 7.5
Color, PCU	145	114 – 236
TDS, mg/L	308	278 – 343
TOC, mg/L	18	4.5 – 30

3.1 SUMMARY OF SCREENING TEST RESULTS

The screening phase investigation consisted of a total of 28 tests performed from June 3, 1999 to September 26, 1999. **TABLE 3.1** shows the test conditions and the resulting filtrate Total P concentration of each screening phase trial. Each trial was conducted for several days as shown in **TABLE 3.1**. **FIGURE 3.5** provides a schematic diagram of the pilot facility and shows the various process units used during the screening tests.

The screening phase investigation consisted of a total of 28 tests performed from June 3, 1999 to September 26, 1999. **TABLE 3.1** shows the test conditions and the resulting

filtrate Total P concentration of each screening phase trial. Each trial was conducted for several days as shown in **TABLE 3.1**.

Two essentially identical conventional water treatment trains were used during the testing at the South Site with each train containing 1) an in-line static mixer, 2) an extended time 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. 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 ($CaOH_2$).

Filtration tests were conducted with 1) anthracite; 2) expanded shale; 3) sand; 4) granular activated carbon (GAC); and 5) 'Polystyrene' granular filter media. Both up and downflow filtration modes were performed. Three filtration methods were tested, which were 1) downstream controlled 'suction' filtration; 2) downstream controlled gravity filtration; and 3) declining rate gravity filtration. Besides the conventional treatment process, direct in-line filtration and direct filtration processes were investigated as well. The clarification process was tested at four distinct surface loading values from 0.14 gpm/sq.ft. to 0.71 gpm/sq.ft. Hydraulic filter loadings were investigated in the range of 2.9 gpm/sq.ft. to 6.3 gpm/sq.ft. Actual clearwater filter headlosses were measured regularly and contrasted to theoretical headloss values.

A description of the three different filter hydraulic control techniques used the screening phase is provided below:

1) ***Downstream Controlled Suction Filtration (Tests 1, 3, and 4)***

   Each filter unit consisted of the filter column, a centrifugal pump, and a flow meter device. Both the pump and the flowmeter were located downstream of the filter. A 4-20 mA flowmeter signal output and the preset value of the target flow provided a feedback system for the control of the variable rate pumping.

2) ***Downstream Controlled Gravity Filtration (Tests 5, 6, 7, and 9)***

   A manually operated control valve was located downstream of the filter. The intended initial hydraulic loading of a filter could be generally achieved at a partially restricted valve position. The manual opening of the valve provided an essentially constant filtration rate after the filter is put into operation. Upon

reaching the fully open position of the valve, the filtration rate could not be maintained resulting in a decline of filter throughput. In summary, the downstream controlled gravity filtration is a quasi-constant rate followed by a declining rate filter operation.

3) ***Declining Rate Gravity Filtration (Tests 11, 13, 15, 17, 19, 21, 23, 24, 25, 26, 27, and 28)***

A manually operated control valve was located downstream of the filter. The initial hydraulic filter loading of 1.3 x Q (where Q is the intended throughput) was adjusted at a partially restricted position of the control valve. The initially adjusted valve position was maintained resulting in a monotone declining rate filtration rate throughout a filter run. A filter run was typically terminated when the actual hydraulic filter loading has declined to about 60 percent of the intended value (0.6 x Q).

Direct in-line and direct filtration tests were also conducted during the screening phase and a brief description of the specific testing protocols used for each of these is provided below:

- ***Direct In-line Filtration***

The coagulant and coagulant aid, if applied, are dosed prior to the coagulation process. After coagulation, which is generally achieved by static mixing the chemically pretreated water is introduced directly to the granular filter units. While some flocculation may take place in the conduits, conventional flocculation in agitated chamber(s) and a clarification process are excluded from the direct in-line filtration process. The precipitated aggregates are relatively small in size and often referred to as "pinflocs."

- ***Direct Filtration***

The treatment chemicals are dosed to the raw incoming water. After coagulation and flocculation, the chemically pretreated water is introduced directly to the granular media separation process. In other words, clarification is not used in a direct filtration process. As a result of the absence of clarification, mass filter loading values typically exceed those accounted for in conventional treatment processes. Screening phase tests typically utilized a static mixer for coagulation and a single stage flocculator chamber for flocculation.

Used throughout the discussion of results are the following reporting conventions:

- Clarifier surface loadings are reported in terms of a gallons-per-minute per-square-foot (gpm/sq.ft.) unit based on a projected lamella area; and

- Reported dosage concentrations of alum and ferric-sulphate process chemicals are based on a metallic equivalent (*e.g.,* 20 mg/L alum always refers to a dosage of 20 mg/L alum as Al).

A tabular summary of the results for the individual screening tests is provided in **TABLE 3.1 - Screening**. Results are described below:

TRIAL 1 (days 1 to 6):

Baseline testing was completed using all unit processes with no feed chemicals followed by a granular filtration process. After passing through the flocculator tanks and the clarifier, the settled raw water was distributed to the six filters. The hydraulic detention time (HDT) in a single flocculator cell varied from 17 to 20 minutes. The surface loading rate to the clarifier was 0.43 gpm/sq.ft. based on the 28 ft^2 projected lamella area. *Downstream controlled 'suction' filtration* was utilized to achieve the hydraulic filter loading of 4.9 gpm/sq.ft.

As shown in **TABLE 3.1**, approximately 30 percent of Total P was removed through clarification; however, little or no Total P was removed by any of the filters. During this baseline period of operation, clean water headloss was determined for each of the filter medias and all pumps, flow meters and mixing equipment were calibrated and tested. Details of the clean water headloss calculations may be found in **APPENDIX 3** in the handouts provided at the second Technical Review Team meeting.

TRIAL 2 (days 1 to 6):

Trial 2 investigated the Total P removal efficiency of the clarification process at relatively high hydraulic loading rates. After the introduction of 12 mg/L alum ($Al_2(SO_4)_3$), the coagulant was dispersed by means of an in-line static mixer. Energy (mixing) input was applied by means of mechanical mixers in the three, flocculator chambers that were operated in series. The HDT varied from 10 to 13 minutes in a single flocculator cell. The intended clarifier surface loading was

0.71 gpm/sq.ft. Process solids were at a rate of 1.2 to 1.5 percent of the unit throughput. The clarified water was wasted bypassing the filter columns.

Testing results suggest that at the applied conditions, limited or no Total P removal was achieved by the clarification process alone under the specified conditions.

TRIAL 3 (days 7 to 15):

Chemical coagulation and polymer addition, to enhance settling, followed by filtration was investigated in the third trial. The two treatment chemicals were alum ($Al_2(SO_4)_3$) coagulant, and A-1849 polyacrylamide coagulant aid. A-1849 polymer is manufactured by Cytec Chemical Corporation. The targeted alum dosage was 12 mg/L. The anionic polymer was dosed at a concentration of 0.5 mg/L. While alum was introduced upstream of the static mixer, the polymer was applied just downstream of flocculator tank #2.

The clarified water was distributed to Filters 1A, 1B, and 1C. Targeted clarifier surface and hydraulic filter loadings were 0.43 gpm/sq.ft. and 4.9 gpm/sq.ft., respectively. HDT in a single flocculator cell varied from 16 to 18 minutes. *Downstream controlled 'suction' filtration* was applied.

Analytical results suggest that approximately 40 percent of Total P could be removed by clarification and the average Total P concentration of the clarified effluent was equal to 11.3 µg/L. The 'Swiss' dual media filter configuration, utilizing expanded shale and sand media, demonstrated that under the conditions tested Total P concentration could be reduced below the threshold 10 µg/L level. During this trial, the average Total P content of the 'Swiss' filtrate was equal to 8.2 µg/L.

TRIAL 4 (days 7 to 15):

Testing included the use of the ferric-sulfate and calcium hydroxide. Ferric-sulfate ($Fe_2(SO_4)_3$), was dosed at 3.5 mg/L and the hydrated lime was applied at a target concentration of 40 mg/L. As a result of both the natural alkalinity of the raw canal water and the application of the lime, the pH was typically raised to about 9. While ferric-sulfate was introduced upstream of the static mixer, hydrated lime was dosed directly into flocculator tank #1.

The clarified water was distributed to Filters 2A, 2B, and 2C and the clarifier surface and hydraulic filter loadings were 0.43 gpm/sq.ft. and 4.9 gpm/sq.ft., respectively. HDT in the flocculator cells varied from 15 to 17 minutes. *Downstream controlled 'suction' filtration* was applied.

Under the conditions tested, there was virtually no Total P removal in the clarifier as the average Total P influent concentration was equal to 17.7 μg/L and that of the clarifier effluent was 17.2 μg/L. Approximately 30 percent of Total P was removed through filtration and the lowest average Total P of 12.3 μg/L and was produced by the 'Wahnbach' media.

TRIAL 5 (days 16 to 19):

In the presence of both a coagulant and a coagulant aid, Total P removal efficiencies of clarification and granular media filtration were investigated. The applied treatment chemicals were alum and A-1849 polyacrylamide. The alum dosage was 10 mg/L and the anionic polymer was dosed at 0.5 mg/L. While alum was introduced upstream of the static mixer, the polymer was applied just downstream of flocculator tank #2. The clarified water was discharged to Filters 1A, 1B, and 1C. The granular filters were operated in the *downstream controlled gravity filtration* mode. Targeted clarifier surface and hydraulic filter loadings were 0.43 gpm/sq.ft. and 6.0 gpm/sq.ft., respectively. HDT in a single flocculator cell varied from 17 to 20 minutes.

Approximately 40 percent of the influent Total P was removed by clarification. Filtration removed an additional 20 to 30 percent Total P in this trial. Filtered effluents produced average Total P data of less than 10 μg/L in both 'LA' (9.8 μg/L) and the 'Swiss' (8.0 μg/L) filter columns, respectively.

TRIAL 6 (days 16 to 19):

In the presence of both a coagulant and a pH-adjusting agent, Total P removal efficiencies of clarification and granular media filtration were investigated. The applied treatment chemicals were ferric-sulfate and hydrated lime. The dosage of ferric-sulfate was 1.5 mg/L. The targeted dosage concentration of hydrated lime was 50 mg/L, which raised the effluent pH to about 9. While ferric-sulfate was introduced upstream of the static mixer, hydrated lime was dosed directly into flocculator tank #1. The clarified water was distributed to Filters 2A, 2B, and 2C. The granular filters were operated in the *downstream controlled gravity*

filtration mode. Targeted clarifier surface and hydraulic filter loadings were 0.43 gpm/sq.ft. and 6.0 gpm/sq.ft., respectively. HDT in the flocculator cells varied from 17 to 21 minutes.

Influent Total P for this trial averaged 17 µg/L and the lowest filtrate average value was equal to 13.7 µg/L.

TRIAL 7 (days 20 to 27):

In the presence of both a coagulant and a coagulant aid, Total P removal efficiencies of clarification and granular media filtration were investigated. The applied treatment chemicals were alum and A-1849 polyacrylamide. The alum dosage was 10 mg/L. The anionic polymer was dosed at 0.3 mg/L. While alum was introduced upstream of the static mixer, the polymer was applied just downstream of flocculator tank #2. The clarified water was discharged to the filters. The granular filters were operated in the *downstream controlled gravity filtration* mode. Targeted clarifier surface and hydraulic filter loadings were 0.43 gpm/sq.ft. and 6.0 gpm/sq.ft., respectively. HDT in a single flocculator cell varied from 15 to 23 minutes (10 to 12 gpd feed flow rate).

The clarification process reduced the Total P concentration by about 40 percent. Total P was further reduced by all the tested filters. With the exception of the 'Polystyrene' filter column, effluent Total P concentrations of all filters were below 10 µg/L Total P.

TRIAL 8 (days 20 to 27):

The objective of this trial was to test Total P removal efficiency of the clarification process at high hydraulic loading rates. The only treatment chemical was ferric-sulfate added prior to static mixing at a dosage concentration of about 10 mg/L. The performance of the lamella clarifier was tested at 0.71 gpm/sq.ft. Corresponding to this flow rate, individual HDT in three flocculator chambers varied from 10 to 18 minutes (roughly 10 to 20 gpm feed rate).

At the applied testing conditions, the high rate clarification process has shown no Total P removal.

TRIAL 9 (days 28 to 30):

Trial 9 evaluated *direct in-line filtration.* Alum was dosed at a concentration of 10 mg/L prior to static mixing and following coagulation, the chemically treated water was sent to the 'Humics', 'Wahnbach' and 'Shale' filters. The hydraulic filter loading rate was 6.0 gpm/sq.ft. The filters were operated in the *downstream controlled gravity filtration* mode. Only the 'Humics' configuration showed appreciable (approximately 20 percent) Total P removal and the average filtrate concentration from this filter during Trial 9 was equal to 16.8 μg/L.

TRIAL 10 (days 28 to 30):

The two treatment chemicals employed were ferric-sulfate and the anionic polymer, and the coagulant was dosed at a concentration of 10 mg/L with the coagulant aid being applied at 0.3 mg/L. After in-line mixing and 3-stage flocculation, the treated water was introduced to the lamella clarifier. The hydraulic loading of the clarifier was 0.29 gpm/sq.ft. Corresponding to this loading, HDT in each flocculator varied from 25 to 26 minutes. These trials tested the ability of the coagulation, flocculation and clarification processes alone to remove Total P. No Total P was removed during this testing.

TRIAL 11 (days 31 to 34):

Similar to Trial 9, this trial investigated *direct in-line declining rate filtration*. Alum was dosed at a concentration of 10 mg/L prior to static mixing. Following coagulation, the chemically treated water was delivered to the 'LA', 'Swiss' and 'Polystyrene' filters. The applied approach velocity was 4.9 gpm/sq.ft. These tests resulted in no Total P removal from the incoming waters.

TRIAL 12 (days 32 to 35):

This 'clarification only' trial was designed with similar testing conditions as Trial 10. Conditions in this trial included the dosage of 10 mg/L alum and 0.3 mg/L A-1849 polyacrylamide. After coagulation and 3-stage flocculation, the treated water was clarified. HDT in each of the flocculator cells varied from 24 to 25 minutes and a 0.29 gpm/sq.ft. clarifier loading was applied.

In excess of 30 percent Total P was removed by the clarification process. The Total P feed concentration for this test was equal to 25.7 µg/L and the clarified effluent was equal to 17.5 µg/L.

TRIAL 13 (days 31 to 34):

Direct in-line filtration was investigated. The coagulant ferric-sulfate was dosed prior to static mixing. The applied dosage concentration was 10 mg/L. Following coagulation, the chemically pretreated water was distributed to the 'Humics', 'Wahnbach' and 'GE' filters. The applied hydraulic filter loading was 4.9 gpm/sq.ft. The granular media filters were operated in the *declining rate gravity* mode. No Total P was removed from the incoming waters during this test.

TRIAL 14 (days 33 to 35):

Trial 14 investigated the clarification process without filtration. Ferric-sulfate was introduced prior static mixing at a concentration of 10 mg/L. The anionic polymer was dosed at 0.3 mg/L level. A 0.29 gpm/sq.ft. clarifier loading was adjusted and the clarified water was wasted. HDT in an individual flocculator chamber varied from 24 to 25 minutes (equivalent to a feed flow rate of approximately 8 gpm). No Total P was removed during this test.

TRIAL 15 (days 36 to 39):

Total P removal efficiency of different filter media in the absence of both flocculation and chemically assisted sedimentation processes was evaluated. The *direct in-line declining rate gravity filtration* process was identical to the one used in Trial 13, with the exception of the tested filters. The chemically treated water was discharged to the 'LA', 'Swiss' and 'GE' filters. No Total P was removed from the incoming waters during this test.

TRIAL 16 (days 36 to 39):

Trial 16 tested Total P removal efficiency of the clarification process using 10 mg/L alum, and 0.3 mg/L A-1849 polyacrylamide. The clarifier loading and HDT in a flocculator chamber were 0.29 gpm/sq.ft. and 25.5 minutes, respectively. Trial 16 is a duplication of Trial 12 with the exception of clarifier underdrain recycling. While no recycling was used in Trial 12, this test applied

solids recycling from the clarifier to flocculator #2 at a rate corresponding to approximately 16 percent of the raw water feed. No Total P was removed form the feed waters during this test.

TRIAL 17 (days 36 to 39):

Trial 17 is a replicate of Trial 11 with the exception of using different filters. *Direct in-line declining rate gravity filtration,* with an alum dosage concentration of 10 mg/L, was used in both of these tests. No polymer was added. The hydraulic filter loading was 4.9 gpm/sq.ft. The chemically treated water was introduced to the 'Humics', 'Wahnbach' and 'Shale' filters. No Total P was removed from the incoming waters during these tests.

TRIAL 18 (days 36 to 39):

Total P removal efficiency by clarification was investigated in Trial 18. Ferric-sulfate and A-1849 polyacrylamide were dosed at 10 mg/L and 0.3 mg/L concentrations, respectively. While the coagulant was injected prior to static mixing, the coagulant aid was applied prior to flocculator #3. Corresponding to the targeted clarifier loading of 0.29 gpm/sq.ft., the HDT in a single flocculator unit varied from 25 to 38 minutes (equivalent to 5 to 8 gpm feed flow rate). Clarifier underdrain solids were recycled at a rate equal to 16 percent of the raw water feed. Under the conditions tested, the clarification process could not remove any Total P.

TRIAL 19 (days 41 to 42):

Direct in-line declining rate gravity filtration was the tested treatment process in Trial 19. Alum was added at a dosage of 10 mg/L. The targeted hydraulic filter loading was 4.9 gpm/sq.ft. The chemically-treated water was filtered by the 'LA', 'Swiss' and 'Polystyrene' media.

The 'LA' filter column reduced the Total P concentration from an average of 19 μg/L in the feed waters to 15.5 μg/L in the filtrate. The removal efficiency was approximately 20 percent.

TRIAL 20 (days 40 to 44):

Trial 20 investigated Total P removal achieved by the clarification process. Alum and A-1849 polyacrylamide treatment chemicals were added at 10 mg/L and 0.3 mg/L concentrations, respectively. The coagulant was injected prior to static mixing. The coagulant aid was added downstream of flocculator tank #2. The targeted clarification surface loading was 0.14 gpm/sq.ft. No Total P was removed from the feed waters during these tests.

TRIAL 21 (days 41 to 42):

Direct in-line declining rate gravity filtration was investigated in Test 21. Ferric-sulfate was added at 10 mg/L concentration prior the static mixer. The pretreated water was introduced to the 'LA', 'Swiss' and 'GE' filters. No Total P was removed from the feed waters during these tests.

TRIAL 22 (days 40 to 44):

Trial 22 tested clarification without filtration. Testing conditions included 10 mg/L targeted-dosage of ferric-sulfate and 0.3 mg/L addition of the anionic polyelectrolite. The 0.14 gpm/sq.ft. clarifier surface loading was aimed. The HDT in a flocculator cell varied from 50 to 51 minutes (equal to an approximate 4 gpm feed flow rate). Residual solids were recycled from the clarifier into flocculator #2 at a rate corresponding to approximately 33 percent of the hydraulic unit loading. Besides recycling, residual solids were also wasted at a rate corresponding to 0.2 to 3.0 percent of the unit throughput. Trial results suggest no Total P removal by this clarification process.

TRIAL 23 (days 45 to 49):

Alum and A-1849 polyacrylamide were used for these tests. The coagulant was dosed at a concentration of 10 mg/L prior to flocculator #1. The anionic coagulant aid was applied at 0.1 mg/L just prior to flocculator #3. The clarified water was introduced to 'LA', 'Swiss' and 'Polystyrene' filters. The clarifier and hydraulic filter loadings were 0.14 gpm/sq.ft. and 4.9 gpm/sq.ft., respectively. The accumulated solids were both wasted and recycled from the clarifier. Wastage rate was adjusted to correspond to approximately 6 percent of the unit throughput. Recycling of clarifier underdrain solids into flocculator #2 occurred

at a rate of 30 to 34 percent of the hydraulic unit loading of approximately 4 gpm.

Up to 20 percent Total P could be removed by the 'LA' and 'Swiss' filter configurations. The lowest average filtrate Total P produced was 'LA' filter and equaled 18 μg/L with the average feed Total P concentration equal to 22.6 μg/L.

TRIAL 24 (days 45 to 49):

Ferric-sulfate was dosed at 20 mg/L prior to flocculator #1 and A-1849 polyacrylamide was applied at the 0.1 mg/L level for Trial 24. Treated water was filtered using the 'Humics', 'Wahnbach' and 'Shale' columns. The clarifier surface loading was 0.14 gpm/sq.ft. Approach velocity of the filters was adjusted to 4.9 gpm/sq.ft. Solids from the clarifier bottom discharge were both wasted and recycled. While approximately three percent of the daily throughput was wasted, 30 to 40 percent of the underdrain residuals were recycled back to flocculator #2. No Total P was removed from the feed waters during this test.

3.1.1 Screening Results Recommendations Based Upon TRT Input

On August 20, 1999, the second meeting of the Technical Review Team took place and several conclusions and recommendations were made based upon the completed screening testing. **APPENDIX 3.1** and **APPENDIX 3.2** provide copies of the complete meeting minutes from the TRT meeting. The TRT recommendations included the following:

Reconfiguration of Filter Columns

After completing Trial 24 on September 1, 1999, the filter media in the six columns should be removed and replaced.

- ***Filters 1A and 2A***: 'LA' utilizing 200 cm of anthracite (ES = 1.5; UC = 1.4) on top of a 10 cm gravel support layer.

- ***Filters 1B and 2B***: 'Swiss' utilizing 110 cm of expanded shale (ES = 2 to 3) on top of 30 cm sand (ES = 1.5; UC = 1.4) supported by a 10 cm gravel layer.

- ***Filters 1C and 2C***: 'GE' utilizing 60 cm anthracite (ES = 2.0; UC = 1.4) on top of 80 cm sand (ES = 1.1; UC = 1.4) supported by 10 cm gravel layer.

These filter media recommendations were made by the TRT based upon the relative filter run times observed during the screening tests coupled with the ability of the filters to achieve the 10 μg/L Total P target. Headloss measurements were routinely taken during screening tests at multiple depths from each filter column. Headloss increases with respect to length of filter runs were graphically summarized for all screening filter columns (*see* **APPENDIX 3.3**). An example of a typical headloss curve is shown in **FIGURE 3.6** for Filter 1B, the 'Swiss' media. As shown in **FIGURE 3.6**, the filter was run for a total of approximately 30 hours.

During the screening tests, the 'Swiss' expanded shale media and the 'LA' anthracite displayed the longest filter run times (on the order of 30 hours) compared to maximums of 5 to 15-hour runs for the other media (*i.e.*, 'Polystyrene' and 'Humics'). Both 'Swiss' and 'LA' filters produced filtered effluents containing less than 10 μg/L of Total P. Due to this fact and also the ability of these columns to operate longer without backwash cleaning, these were the ones recommended for further testing. A dual media anthracite and sand filter, given the name of 'Green Everglades' (GE) was also recommended for testing to see if the rapid filtration characteristics displayed by the anthracite material coupled with finer enhanced sand filtration ability could be produce long filter runs and enhanced solids separation.

Reconfiguration of Pretreatment Units

After completing Trial 24 on September 1, 1999, the TRT Team also recommended that the coagulation-flocculation-sedimentation process be reconfigured. Flocculator tank #1 was taken out of service and flocculator cell #2 was converted to an extended flash mix chamber. In summary, for Trials 25 through 28, discussed below, coagulation is accomplished using the static mixer and the reconfigured flash mixer tank. The chemically treated water was introduced into the sole flocculator cell (formerly called flocculator #3). While the coagulant was typically introduced prior to the static mixer unit, the coagulant aid was added to the treated water prior entering to the flocculator cell. The utilization of the clarifier depends on the process design. TRT committee suggestions were intended to determine effects of conducting a series of tests using a single stage (only one of the 200-gallon flocculation tanks). Total flocculation time would be reduced from 30 minutes or more to a range of 15 to 20 minutes. Additional screening tests aimed at

simultaneous evaluation of the effectiveness of alum versus ferric-salts and direct filtration tests were also recommended by the TRT for future screening tests as well.

The recommended pilot unit reconfigurations were completed within a one-week period and Trial 25 testing commenced on September 9, 1999. **TABLE 3.1** provides a summary of the test results for screening Trials 25 through 28.

3.1.2 Screening Trials 25 though 28

TRIAL 25 (days 50 to 56):

Trial 25 evaluated *direct filtration*. After dispersion of the applied coagulant in the static and flash mixer units, the coagulated water was introduced to a single flocculation cell. Alum was dosed prior static mixing at concentration of 10 mg/L. The anionic coagulant aid was applied to the water prior its entering the flocculator tank at 0.1 mg/L concentration. In the absence of a clarification process, the pretreated water was introduced directly to the 'LA', 'Swiss' and 'GE' filter columns. The applied hydraulic loading of each of these filters was 4.9 gpm/sq.ft.

Testing results suggest that under the conditions tested, all three filters removed Total P with a removal efficiency of 10 to 35 percent. The lowest average Total P concentration was observed in the 'GE' column and equaled 20.3 µg/L. The average Total P concentration in the feed waters during this test was 30.4 µg/L.

TRIAL 26 (days 50 to 56):

Direct filtration was tested using ferric-sulfate as the coagulant. Ferric-sulfate was dosed prior to static mixing at a concentration of 20 mg/L. The A-1849 polyacrylamide coagulant aid was introduced prior to the flocculation process at a target concentration of 0.1 mg/L. In the absence of a clarification process the pretreated water was introduced directly to the 'LA', 'Swiss' and 'GE' reconfigured filter columns. The target hydraulic filter loading was 4.9 gpm/sq.ft. Testing results indicated that the ferric-salt assisted phase separation process could not remove more than 5 percent of the raw water Total P concentration.

Direct filtration tests using ferric-chloride and alum could not produce filtrate Total P results at or near the 10 μg/L target value.

TRIAL 27 (days 57 to 61):

The treatment train consisted of 1) a static mixer; 2) a flash mixer; 3) a single flocculator tank; 4) a lamella clarifier; and 5) the three granular filter columns. The applied treatment chemicals were alum and A-1849 polyacrylamide. While the coagulant was dosed prior to static mixing at a concentration of 10 mg/L, the coagulant aid was applied at the 0.1 mg/L level prior to the flocculator. The pretreated water was introduced to the 'LA', 'Swiss' and 'GE' filter columns. Hydraulic clarifier and filter loading was 0.43 gpm/sq.ft. and 4.9 gpm/sq.ft., respectively.

Testing results show that while approximately 20 percent of the Total P could be removed by the clarifier, two of the operating filters could remove no Total P. The 'LA' filter removed less than 6 percent Total P. The lowest filtrate Total P concentration obtained during this test was in the 'LA' filtrate at a concentration of 27.2 μg/L.

TRIAL 28 (days 57 to 61):

Instead of alum, Trial 28 used ferric-sulfate coagulant at 20 mg/L dosage level. The treatment train consisted of 1) a static mixer; 2) a flash mixer; 3) a single flocculator tank; 4) a lamella clarifier; and 5) the three tested granular filter columns. While the ferric-sulfate was dosed prior to the static mixer, the anionic coagulant aid was applied at 0.1 mg/L level prior to the flocculator. The treated water was filtered using the 'LA', 'Swiss' and 'GE' columns. Hydraulic clarifier and filter loading was 0.43 gpm/sq.ft. and 4.9 gpm/sq.ft., respectively. Approximately 2 percent of the unit throughput was wasted.

Results from these tests suggest that no Total P could be removed by clarification and only small amounts of Total P could be removed through filtration.

3.1.3 Screening Trials Conclusions and Recommendations

Based upon a review of the screening trial results by the TRT members and the CTSS project team, the following conclusions and recommendations were developed from the screening trials:

1) 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 screening Trials 3, 5 and 7 on Post-STA feed waters as shown in **TABLE 3.1**. These results were obtained using the coagulant alum at a dose of 10 mg/L to 12 mg/L and with 0.3 mg/L 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). Flocculation tank velocity gradients as a function of mixing intensity were empirically determined and the results of this relationship are provided in **FIGURE 3.7**. A velocity gradient of 100 (equivalent to 10 RPM in the first stage flocculation tank) and 40 (5 RPM in the second stage tank) were used during Trials 3, 5 and 7. These successful testing conditions should be the starting point for performing additional optimization tests.

2) Combining the superior 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' (a dual media anthracite and sand media) and 'Swiss' (expanded shale media) filters for further testing. As a quality assurance measure, duplicate columns were recommended for testing during the optimization phase with the 'Swiss' column being duplicated at the South Test Site and the 'GE' at the North Site.

3) Repeated testing of the direct in-line treatment process did not produce significant reductions in the feed water Total P concentration. Direct in-line filtration was eliminated from further consideration as a treatment option.

4) No significant Total P removal was obtained during trials employing residual solids recirculation. Solids recirculation was eliminated from further consideration as a treatment option.

5) Using the 'Bayesian' design approach previously described in Section 2 of this Report, additional testing during the optimization phase would be conducted using selected combinations of the variables and specific conditions provided in **TABLE 3.2**.

6) Due to some anomalous results obtained during the last 10 days of screening tests (*see* Section 3.2 below), additional direct filtration tests should be conducted during optimization testing.

3.2 OPERATIONAL MODIFICATIONS PLANNED FOR ENHANCING PILOT PLANT PERFORMANCE AND PREPARATIONS FOR OPTIMIZATION AND DEMONSTRATION TESTING

The last 10 days of screening tests, represented as Trials 25 through 28 in **TABLE 3.1**, compared the results of direct filtration and conventional water treatment using iron and aluminum salts as coagulants. Testing results showed little, if any, phosphorus removal and on a number of individual tests, filtrate phosphorus concentrations were higher than the feed phosphorus content for the same testing period.

After a thorough review of the pilot unit design and its operations, it was confirmed that the existing facility was capable of producing representative results but that certain operating procedures would need to be incorporated into future testing to compensate for identified pilot facility design peculiarities. The testing results obtained, particularly during the last 10 days of screening, were thought to be adversely impacted by several conditions including:

- Build-up of solids in the flocculation tanks causing excess solids carry over into effluent samples thus contributing to elevated effluent Total P values;

- Dead space regions in the clarifier resulting in solids accumulation and periodic solids carry over; and,

- Non-continuous operation of the CTSS facility which potentially allowed solids to settle and accumulate in the process basins.

Solids build-up in the pilot unit process unit was confirmed during this September time period when all of the tanks were drained and inspected. As much as one inch of accumulated solids (estimated 4 to 6 percent solids content) were observed in the bottoms of the coagulation, flocculation and clarifier process units. Remedial measures incorporated into future testing included the following:

- All treatment trailer process units (*i.e.*, chemical metering, coagulation, flocculation and clarification) would be run as continuously as possible (*i.e.*, 24 hours per day) during all downstream testing in order to reduce the potential for accumulation of settled solids in the process tanks.

- Between each set of test conditions, all coagulation and floc tanks and clarifiers would be drained and thoroughly flushed out to remove any accumulated solids.

- All new sample collection tubing would be installed.

- The sample intake location for the clarifier would be moved into the discharge end of the effluent collection weir box, the point of highest velocity in this process unit.

During the period of September 27 through October 26, 1999, no CTSS testing was conducted in order to prepare for the optimization and demonstration testing. Activities completed during this time included the construction of additional test facilities that involved moving portions of the South Site CTSS Pilot Unit to the North Site. One of the two treatment trailers and three of the nine filter columns were moved to the North Test Site at this time. Splitting up the equipment between the two locations would enable optimization and demonstration testing to be conducted concurrently on Post-BMP and Post-STA representative feed waters. Also at this time, SFWMD was relocating the pump station that would provide feed water to the North Test Site. Relocation of this pumping facility to the Ocean Canal was required due to STA 1 West construction activities. After the North Site construction was completed, optimization testing commenced at both the North and South ENR Test Sites on October 26, 1999.

3.3 OPTIMIZATION PHASE TESTING RESULTS

Using the 'Bayesian' test design approach, optimization testing was conducted in four unique segments. Results of the testing completed in the initial segments were used to optimize the test conditions of latter segments. **FIGURE 3.8** provides a representative schematic diagram of the pilot facilities for both the North and South Testing Sites, showing test configurations for process units employed during optimization testing. During the optimization tests, 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 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.

TABLES 3.2 through 3.9 provide a detailed summary of all daily trials and the corresponding test conditions used for each process unit.

Segment 1 optimization testing was conducted between October 26 through November 7, 1999, at both the North (Post-BMP) and South (Post-STA) Test Sites. **TABLE 3.2** provides the testing conditions used daily at the North Site and also provides the filtrate and clarified effluent Total P results obtained during the daily trials. **TABLE 3.3** provides the South Site data (the same testing conditions were used as for the North Site) and shows the Total P results obtained in the clarifier and filtrate samples. The conditions producing the lowest Total P results during this first segment of testing follow:

	North Site	South Site
Feed Flow Rate, gpm	12	12
Clarifier overflow, gpm/sq.ft.	0.28	0.28
Filtrate rate, gpm/sq.ft.	4.9	4.9
Filter media	'GE'	'GE'
Coagulant type	Alum	Alum
Coagulant dose, mg/L as element	20	20
Coagulation volume, gallons	220	220
Polymer dose	0.5	0.3
Total P Feed content, µg/L	141	33
Clarifier Total P content, µg/L	58	6
Filtrate, Total P content, µg/L	13.5	<4
Date of Test	11/6/99	11/5/99

Using the test conditions shown above, the South Test Site produced a clarified effluent of 6 µg/L Total P and a filtered effluent of less than 4 µg/L.

The second segment of optimization tests was conducted from November 8 through November 15, 1999. **TABLE 3.4** and **TABLE 3.5** provide the summaries of daily trial testing conditions and Total P filtrate and clarifier results. The conditions producing the lowest Total P results during this segment 2 testing follow:

	North Site	South Site
Feed Flow Rate, gpm	12	12
Clarifier overflow, gpm/sq.ft.	0.28	0.28
Filtrate rate, gpm/sq.ft.	9.8	9.8
Filter media	'GE'	'Swiss'
Coagulant type	Alum	Alum
Coagulant dose, mg/L as element	20	20
Coagulation volume, gallons	200	200
Polymer dose	0.5	0.5
Total P Feed content, µg/L	115	19
Clarifier Total P content, µg/L	30	6
Filtrate, Total P content, µg/L	13	6
Date of Test	11/8/99	11/5/99

During the second segment of optimization testing, North Site tests were again unable to produce a filtrate or clarified Total P value of less than or equal to 10 µg/L. However, the South Site facility produced a filtered effluent of less than 10 µg/L on three different testing days (November 8, 9 and 11) as shown in **TABLE 3.5**. Both ferric-chloride and alum coagulants produced less than 10 µg/L Total P results at the South Site; however, 40 mg/L of the iron salt was required produce a filtrate concentration of 8 µg/L during the November 8 testing trial.

As part of segment 3 testing, the direct filtration treatment technique was evaluated during approximately half of the trials. **TABLE 3.6** provides testing conditions and Total P results for these direct filtration tests conducted during November 17 and 18, 1999, at the North Site. Direct filtration testing was conducted using both alum and ferric-chloride coagulants and both produced marginal results. The lowest Total P concentration obtained in the filtrate samples was equal to 67 µg/L and this value was obtained on a North Site Total P feed concentration of 169 µg/L.

Direct filtration treatment proved no more effective at the South Site than observed during the North Site testing (**TABLE 3.7**). No Total P was removed during these tests as the feed averaged 18 µg/L and direct filtration effluent was equal to 19 µg/L.

Based upon the marginal Total P reductions of the direct filtration tests conducted at both the North and South Sites during this time period, this treatment technique was eliminated from further consideration and was determined to not be a viable technique for removing Total P in EAA surface waters.

The fourth segment of optimization testing produced Total P clarified and filtrate results of less than or equal to 10 μg/L at both the North and South Test Sites. **TABLE 3.8** and **TABLE 3.9** provide the segment 4 pilot unit testing conditions for each daily trial and also show the corresponding Total P effluent results. The conditions producing the lowest Total P results during this segment four optimization testing follow:

	North Site	South Site
Feed Flow Rate, gpm	12	12
Clarifier overflow, gpm/sq.ft.	0.14	0.14
Filtrate rate, gpm/sq.ft.	4.9	4.9
Filter media	'Swiss'	'GE'
Coagulant type	ferric-salt	ferric-salt
Coagulant dose, mg/L as element	40	40
Coagulation volume, gallons	220	200
Polymer dose	0.5	0.5
Total P Feed content, μg/L	163	18
Clarifier Total P content, μg/L	10	10
Filtrate, Total P content, μg/L	4	5
Date of Test	12/1/99	12/1/99

3.3.1 Conclusions Developed from Optimization Testing and Recommendations for the Demonstration Phase

As discussed above, optimization tests were conducted simultaneously at the North and South Test Sites from October 26 through December 3, 1999. The 138 test results (70 at the North Site and 68 at the South Site) 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 the use of 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. 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 did during the optimization trials.

During the optimization period, direct filtration tests were also performed at the North and South Test Sites. Direct filtration tests consistently provided high, final effluent Total P results at both Sites and, consequently, no further testing of this treatment technique is proposed.

A relatively narrow range of pilot operating conditions have provided the desired 10 μg/L or less Total P effluent results and, based upon the input from the TRT members, the following conditions were recommended 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	4.9
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), mg/L	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 trials was consequently recommended.

3.4 DEMONSTRATION TESTING RESULTS

3.4.1 Total P Testing Results

FIGURE 3.9 provides a schematic diagram of the CTSS pilot facility showing the process unit configuration employed during demonstration phase testing. **TABLE 3.10** and **TABLE 3.11** provide the daily test conditions and Total P clarifier and effluent results for the North Site tests for the 'Swiss' and 'GE' columns, respectively. For the entire demonstration testing period of December 4 through December 23, 1999, all clarifier effluent and filtrate Total P analyses were reported 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 Testing Site follow:

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

FIGURE 3.10 provides a graphical summary of the Total P results obtained at the North Test Site during demonstration testing and provides a comparison of the raw Total P daily results and the pilot facility clarified effluent and filtered analyses. **FIGURE 3.11** provides an expanded scale detail of the North Test Site results and provides the effluent Total P time series data for the filtered samples and the clarified effluent.

TABLE 3.12 and **TABLE 3.13** provide the daily test conditions and Total P clarifier and effluent results for the South Site tests for the 'Swiss' and 'GE' columns, respectively. For the entire demonstration testing period of December 4 through December 23, 1999, all clarifier effluent and filtrate Total P analyses were reported at or below 10 μg/L. 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 Testing Site follow:

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

FIGURE 3.12 provides a graphical summary of the Total P results obtained at the South Test Site during demonstration testing and provides a comparison of the raw Total P daily results and the pilot facility clarified effluent and filtered analyses.

3.4.2 Standard of Comparison Additional Demonstration Phase Testing Results

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

3.4.3 Water Quality Testing

TABLE 3.14 and **TABLE 3.15** provide summaries of the various chemical constituents tested during the demonstration trials for both the North (Post-BMP) and the South (Post-STA) Test Sites. Composite samples were collected on raw water, clarified effluent and filtrate samples several times during the December demonstration phase of testing and were submitted to the contract laboratory for metals, nitrogen series, TDS, common cations and anions, and TOC.

- ***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 to be 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 will 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. Due to the alum addition as the South Site, the TDS increased due to the added sulfates contained in the coagulant. Conductivity was measured in the field on both feed and effluent samples during demonstration testing as shown in **TABLE 3.15**. 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/centimeters and equaled 1083 in the CTSS pilot unit effluent samples.

- ***Metals***

The North Site demonstration testing was all conducted using the coagulant ferric-chloride. As shown in **TABLE 3.14**, 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	

Metals at the North Test Site displaying a 20 percent increase or more in the average results when comparing the feed to the CTSS effluent content included:

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. As shown in **TABLE 3.14**, 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.

  The use of alum at the South Test Site resulted in an increase in the CTSS effluent average effluent sulfate concentration to 164 mg/L from an average feed water content of 50 mg/L.

- ***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 feedwater 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***

  During the several months of screening and optimization testing at the South Site, the clarified effluent averaged 6.6 mg/L (number of observations = 79) of DO, and the influent averaged 4.7 mg/L (number of observations = 100). The increase in DO is attributed to the aeration resulting from the mechanical mixing of the coagulant with the feed waters. Since DO levels are artificially increased via mechanical aeration associated with the CTSS process, limited significance can be assigned to the DO readings and the only conclusion that can be made is that the CTSS process increase the DO of the treated surface waters.

- ***Testing of Nitrogen Forms***

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

  For the North Test Site pilot unit, the average TKN influent and effluent value equaled 1.6 mg/L as N (**TABLE 3.14)**. Nitrate + nitrite data was equally comparable as the feed samples averaged 0.54 mg/L as N and the clarified effluent samples averaged 0.53 mg/L. Average ammonia values in the influent were equal to 0.045 mg/L as N and in the clarified effluent from the pilot system, ammonia values were somewhat higher and averaged 0.089 mg/L as N.

  South Test Site influent versus effluent data for ammonia, nitrate + nitrite and TKN all recorded virtually identical results.

  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.

3.4.4 SFWMD Low Level Mercury Results

Representatives from SFWMD collected feed and filtrate samples for trace level mercury analysis five times during the December Pilot Study demonstration period. Analyses were performed for filtered/total filtered 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 analyzed 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 as shown in the **TABLE 3.16**. 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.

3.4.5 Bioassay and Algal Growth Potential (AGP) Results

Bioassay and 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). Summary results for the bioassay and AGP analyses are provided in **TABLE 3.17**.

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. No immediate cause for this significant toxicity on both the feed water and effluent samples could be identified.

There was no significant impact identified from the bioassay sampling completed during testing that could be attributed to the CTSS treatment system.

3.4.6 Residual Solids Characterization and Testing

Clarifier underdrain solids and filter backwash solids were pumped to nearby aboveground storage tanks and lagoons. The solids were allowed to settle to the bottom of the tanks and the supernatant overflowed the top of the tanks and flowed to the lagoons and ultimately was returned to the ENR. Solids were routinely drained from the storage tanks into the lagoons for long term storage to assess settling properties and until they could be chemically characterized. Offsite disposal of solids occurred only after full 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. The results of the samples collected from both the North and South Testing Sites are provided in **TABLE 3.18**. As shown in **TABLE 3.18**, 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 upon these non-hazardous test results, arrangements were made with local EAA farmers for application of the solids onto agricultural land. The results of these land application trials are provided in **APPENDIX 7**.

- ***Underdrain Solids Characterization***

  Clarifier underdrain solids were sampled three times during demonstration tests. **TABLE 3.19** provides the average analytical results for the settled solids at the North (Post-BMP) and South (Post-STA) locations. These samples were collected during the time that solids were being pumped from the bottom of the clarifier process tank. Even though these settled materials are referred to as "solids," the results of the analyses are provided in units of "mg/L" due to their dilute nature. As shown in **TABLE 3.19**, the suspended solids content of these underdrain solids range from 0.1 to 0.2 percent (1,480 to 1,980 mg/L TSS).

  As shown in **TABLE 3.19**, the Total P content of the underdrain solids ranged from a low 0.69 mg/L to 1.99 mg/L, and the TKN concentration varied from 6 mg/L as N to 12 mg/L as N.

- ***Clarifier Underdrain Solids Production Rates***

  Clarifier underdrain solids production rates were calculated for the pilot units using data gathered during the demonstration period. The effective clarifier blowdown rate was 0.6 gallons per minute. Using clarifier loading rates, the blowdown rate and average TSS concentrations, solids production rates ranged from 1145 pounds of dry solids per million gallons of treated water at the ENR effluent location (Post-STA residual solids production rate) to 1720 pounds of dry solids per million gallons treated at the ENR influent (Post-BMP) site.

- ***Residual Solids Dewatering Trials***

  HSA contracted two laboratories to assess the dewatering characteristics of supplied residual solids. These laboratories were:

  1. ASHBROOK Laboratories, and
  2. USFilter, Dewatering Systems Group.

  HSA provided four distinct, five-gallon samples of residual solids samples to both laboratories. The samples were 1) North Test Site – alum solids; 2) North Test Site – ferric-solids; 3) South Test Site – alum solids; and 4) South Test Site – ferric-solids.

ASHBROOK Laboratories assessed the dewatering efficiency of a belt filter press and USFilter evaluated the performance of both a belt filter press and a centrifuge.

ASHBROOK Laboratories conducted four belt filter press tests using the supplied residual solids samples on January 18, 2000. Due to the relatively low solids concentration, the samples were typically gravity settled and decanted before each analysis was performed. The reported solids capture efficiency was 95 percent or higher in each test. Tabular results of these tests are provided below:

Residual Solids Dewatering Characteristics - ASHBROOK Laboratories

Residual Solids / Site	Raw Residual Solids*					Dewatered Residual Solids							
	pH	Temp	Ash	VSS	Feed Solids	Hydraulic Loading	Solids Loading	Cake Solids	Belt Speed	Polymer			
										Type	Dosage Conc	Dosage Rate	Cost
	(-)	(°F)	(%)	(%)	(%)	(gpm/m)	(lb/hr/m)	(-)	(m/min)	(-)	(lbs./ton)	(gpm)	($/ton)
Alum Solids / North	6.85	75	49.7	50.3	12.6	22.5	1,419	28.5	3.05	Percol 712	1.0	0.57	2.0
Alum Solids / South	7.10	50	49.9	50.1	4.32	42.5	919	29.5	2.15	Percol 727	1.5	1.15	3.0
Ferric-Solids / North	7.30	50	65.7	34.3	1.41	65	459	36.5	1.55	Percol 727	3.0	1.3	6.0
Ferric-Solids / South	7.26	75	57.4	42.6	3.60	37.5	676	29.5	1.85	Percol 712	2.0	0.75	3.0

Notes: * gravity settled and decanted before analysis
30 psi belt tension was applied in all tests

Each of the tests resulted in a minimum of 95 percent solids capture. The reported data suggests that dewatering characteristics of solids (both alum and ferric) produced at the North Test Site are better than those produced at the South Site. The ASHBROOK tests indicate that the CTSS residuals can be dewatered and produce solids cakes in the range of 28 to 37 percent.

USFilter conducted eight tests using the supplied residual solids samples. Dewatering characteristics of each of the four supplied solids sample was assessed by both a belt filter and a centrifuge. USFilter concluded that all the tested solids are the "difficult to dewater."

Belt filter dewatering tests utilized two distinct polymer dosage ranges, 8 to 12 and 8 to 14 pounds per ton of solids. While the lower polymer dosage range was applied to the two alum solids, the higher dosage values were related to the ferric-solids. The treatment efficiency was evaluated in

terms of the estimated cake solids percentage content. In terms of this response parameter, residual solids of alum origin (both sites) showed a marginally higher value (11 to 13 percent) when compared to the ferric-solids (10 to 12 percent).

The dewatering efficiency of the centrifuge was 10 to 12 percent in terms of estimated cake solid content. For that efficiency the dosage of 10 to 14 lbs./ton of solids polymer dosage was required. The applied polymer in all the tests was a Cytec anionic emulsion.

Comparison of the test results suggests that the belt filter loaded with alum solids resulted in the highest cake solid content. Because of the experienced operation problems (sticking of solids to the belt filter), USFilter recommended centrifuge as the preferred dewatering equipment. The centrifuge resulted in less operation problems and offers the additional benefits of (1) continuous operation, (2) relatively high hydraulic loading rates, and (3) minimal maintains requirements.

3.4.7 Total Phosphorus Mass Balance Results

The CTSS pilot facilities were intensively monitored, particularly for phosphorus forms throughout the screening, optimization and demonstration phases of the project. Although data was collected during all phases that could have been used for the calculation of Total P mass balances, the pilot conditions were changed frequently during the screening and optimization phases. It was only during the demonstration phase that the pilot facilities operated with a defined set of conditions for an extended period of time (*i.e.*, 25 days). Accordingly, the demonstration phase was selected to be the appropriate phase for calculation of Total P mass balances.

The average experimental conditions for the two demonstration tests were as follows:

(a) ***Post-BMP***:

- Mass Balance Run Time = 15 days
- Pilot Plant Throughput @ 4 gpm = 86,400 gal.
- Average Influent Total P Concentration = 0.158 mg/L
- Average Clarifier Effluent Total P Concentration = 0.006 mg/L
- Volume of Residual Solids Wasted from Clarifier = 10,800 gal.
- Average Clarifier Residual Solids Total P Concentration = 1.49 mg/L
- Total P In = 0.1138 lbs.
- Total P Out In Effluent = 0.0038 lbs.
- Total P Out In Clarifier Residual Solids = 0.1342 lbs.

Difference In-Out -.0242 lbs.
or –21.3%

(b) ***Post-STA***:

- Demonstration Run Time = 15 days
- Pilot Plant Throughput @ 8 gpm = 172,800 gal.
- Average Influent Total P Concentration = 0.027 mg/L
- Average Clarifier Effluent Total P Concentration = 0.006 mg/L
- Volume of Residual Solids Waste from Clarifier = 10,800 gal.
- Average Clarifier Residual Solids Concentration = 0.57 mg/L
- Total P In = 0.0389 lbs.
- Total P Out In Effluent = 0.0081 lbs.
- Total P Out In Clarifier Residual Solids = 0.0513 lbs.

Difference In-Out -.0205 lbs.
or –52.6%

The differences in the mass balances are outside the generally acceptable range of ±15%. Both the Post-BMP and Post-STA results indicated that more phosphorus was being removed from the system with the clarifier residual solids than could be explained by the difference between the influent and effluent from the system.

A post-mortem review of the project residual-solids sampling procedures shows that the clarifier residuals solids sampling port (located in a dead-end section of the clarifier withdrawal pipe) likely produced samples with higher solids and

Total P concentrations than the solids actually removed from the clarifier by the withdrawal pump. The residual solids withdrawal pump, with a capacity of 30 gpm, removed solids for a 7-second interval every 7 minutes of operation. The residual solids sampling port for each clarifier was sampled three times during the demonstration phase -- a factor that probably also contributed to the non-representative sludge results. The residual solids sampling technique is, by far, the most likely area effecting the goodness of the balance as feed flow rates were measured continuously and calibrated several times, and phosphorus influent and effluent values were obtained daily during demonstration testing.

One of the CTSS pilot trailers is currently being operated at an urban stormwater test site (Wellington) as part of another SFWMD project. The other trailer will be operated at one of the ENR Test Cells for a four-month period. A revised sludge sampling protocol will be employed for these projects which will enable the collection of more representative sludge samples and also will allow comparisons to the CTSS procedures. Potentially, a correction factor can be derived that can be applied to the CTSS demonstration Total P mass balances.

Since the residual solids data used to compute the mass balances was also used to determine residual solids production rates for the full-scale system, the worst case implication of the mass balance results is the over-estimation of residual solids generated. If less solids were, in reality, produced by a full-scale system than estimated here, the area requirements for the full-scale land application management program would be less than estimated. For instance, the area estimated for designated land application for a 200 mgd is 1,326 acres (*see* **TABLE 5.1)**. If less residuals were produced, the land application area would be on the order of 700 to 900 acres.

FIGURE 3.1
Raw Water Total Phosphorus Concentration
South Test Site
June 3, 1999 - December 23, 1999

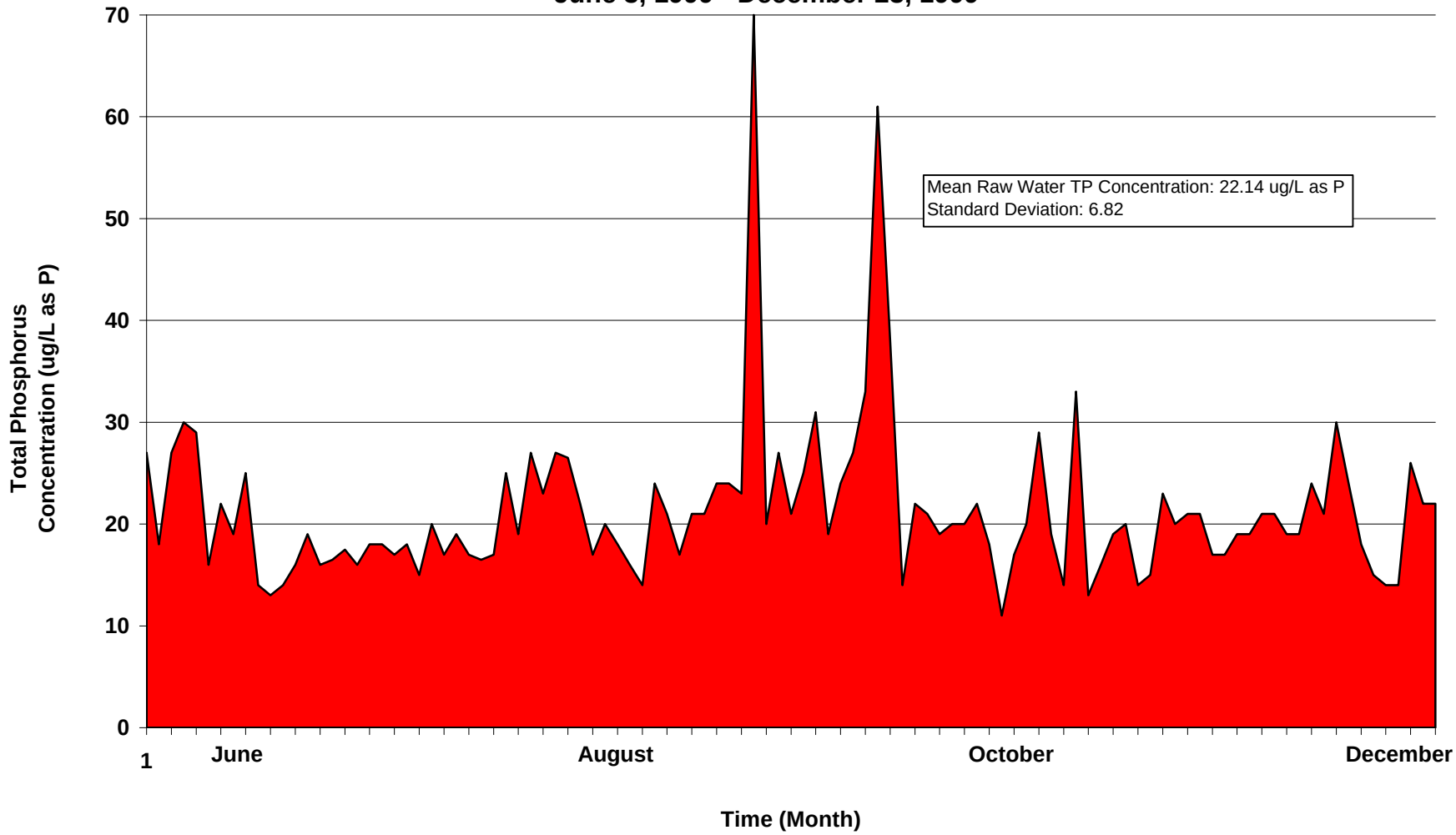


FIGURE 3.2
Average Monthly Raw Water Phosphorus Data
South Test Site
June 3, 1999 - December 23, 1999

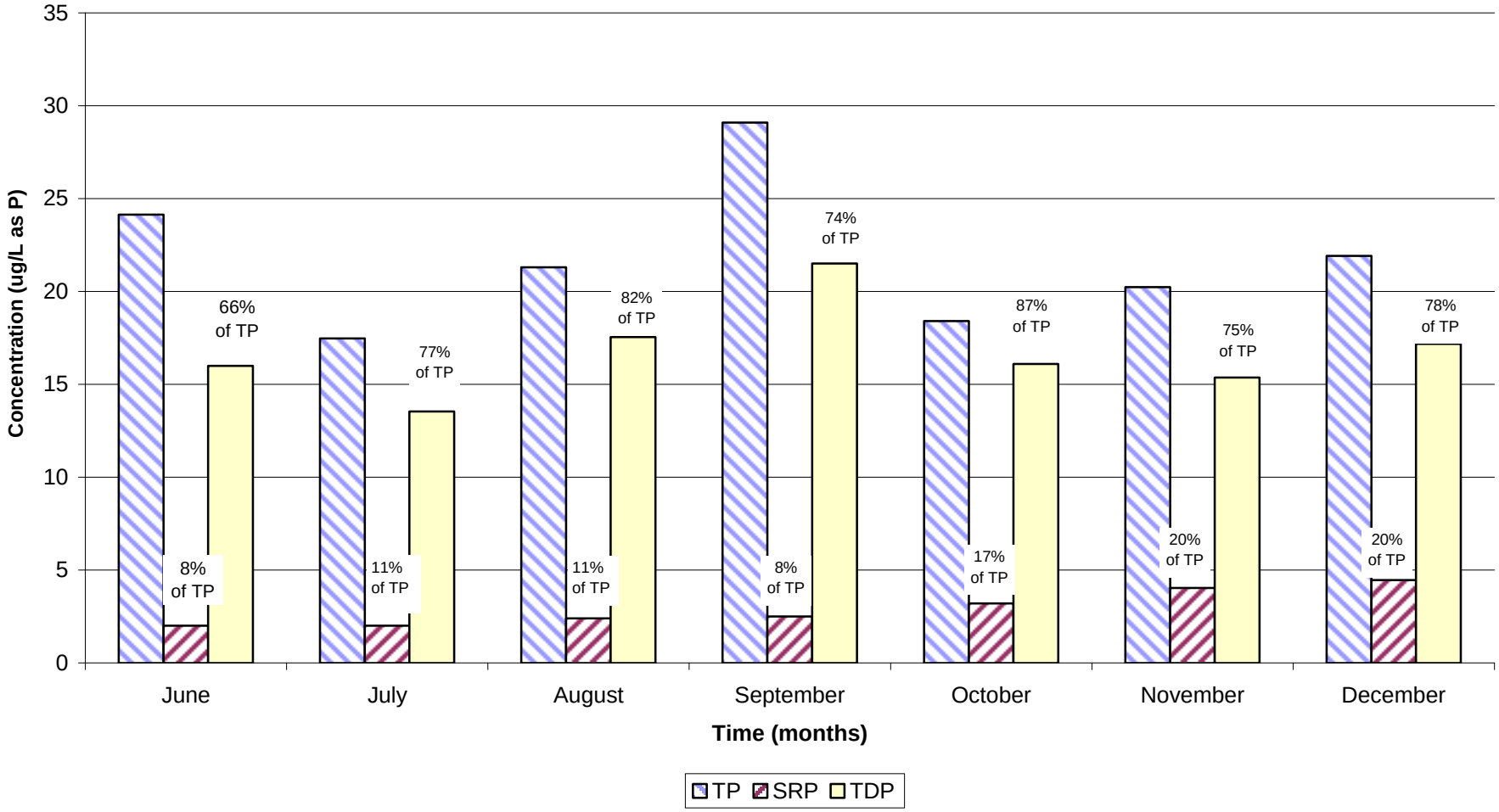


FIGURE 3.3
Raw Water Total Phosphorus (Total P) Concentration
North Test Site
October 26, 1999 - December 23, 1999

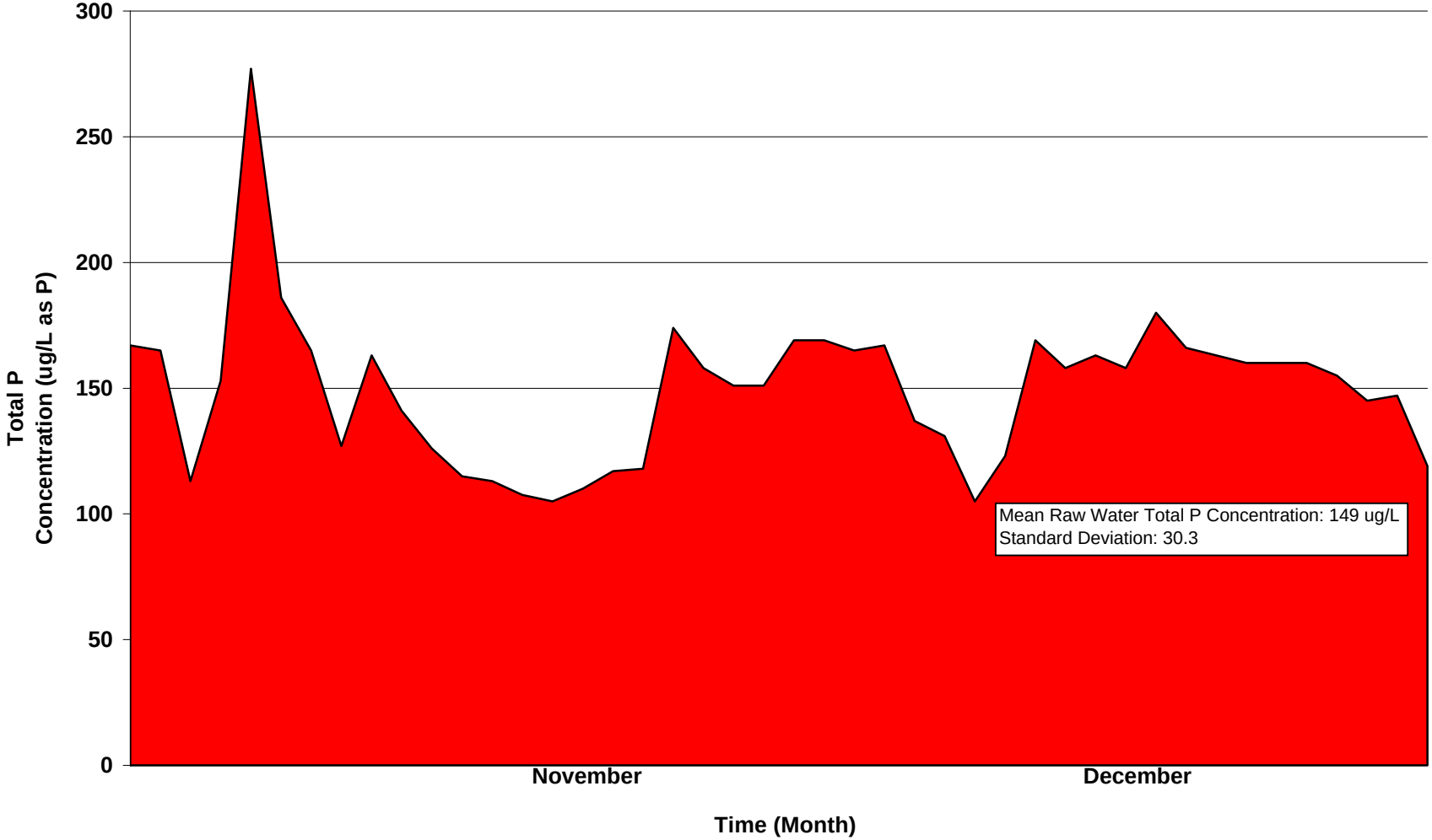


FIGURE 3.4
Average Monthly Raw Water Phosphorus Data
North Test Site
October 26, 1999 - December 23, 1999

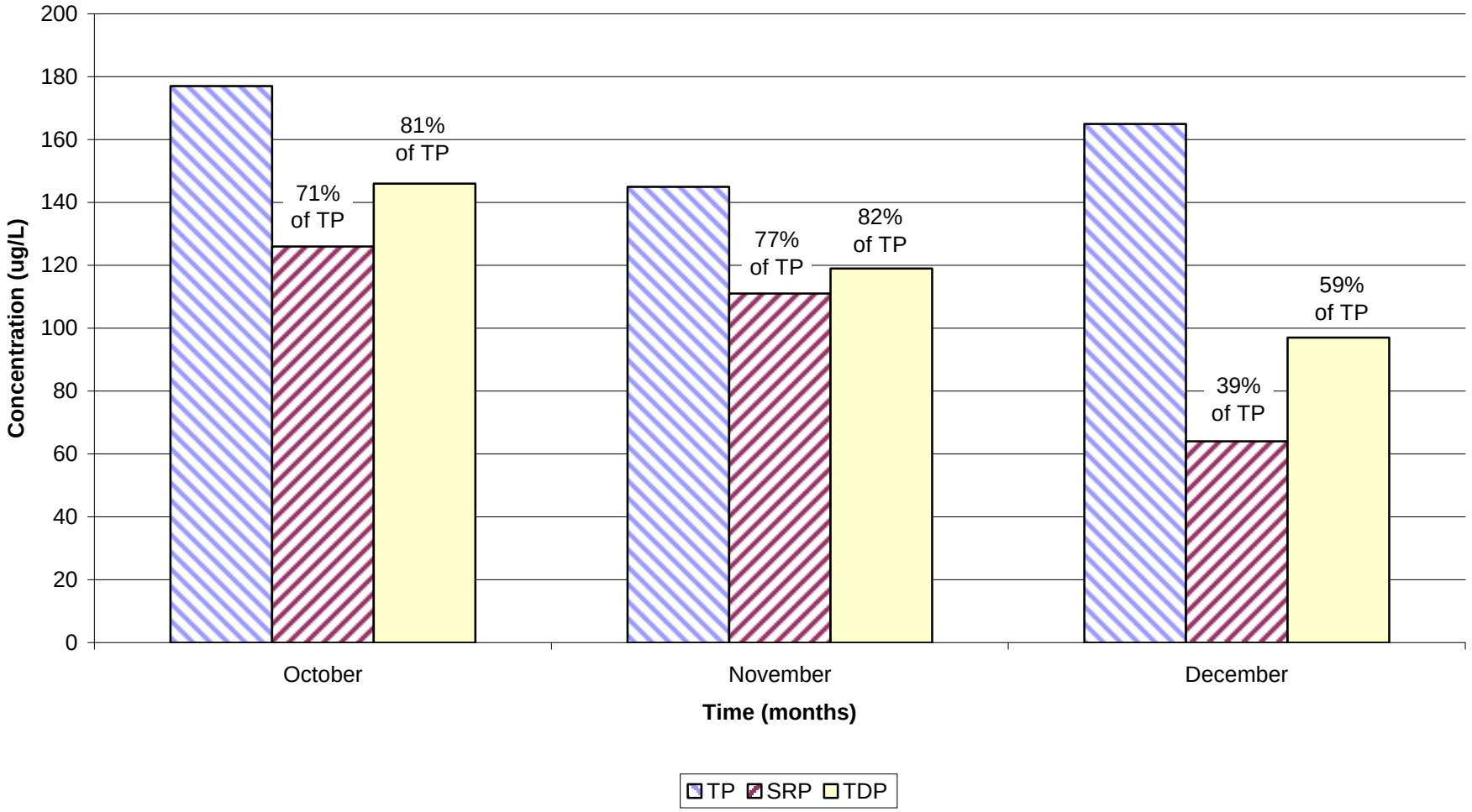


FIGURE 3.5
CTSS Pilot Facility Process During Screening

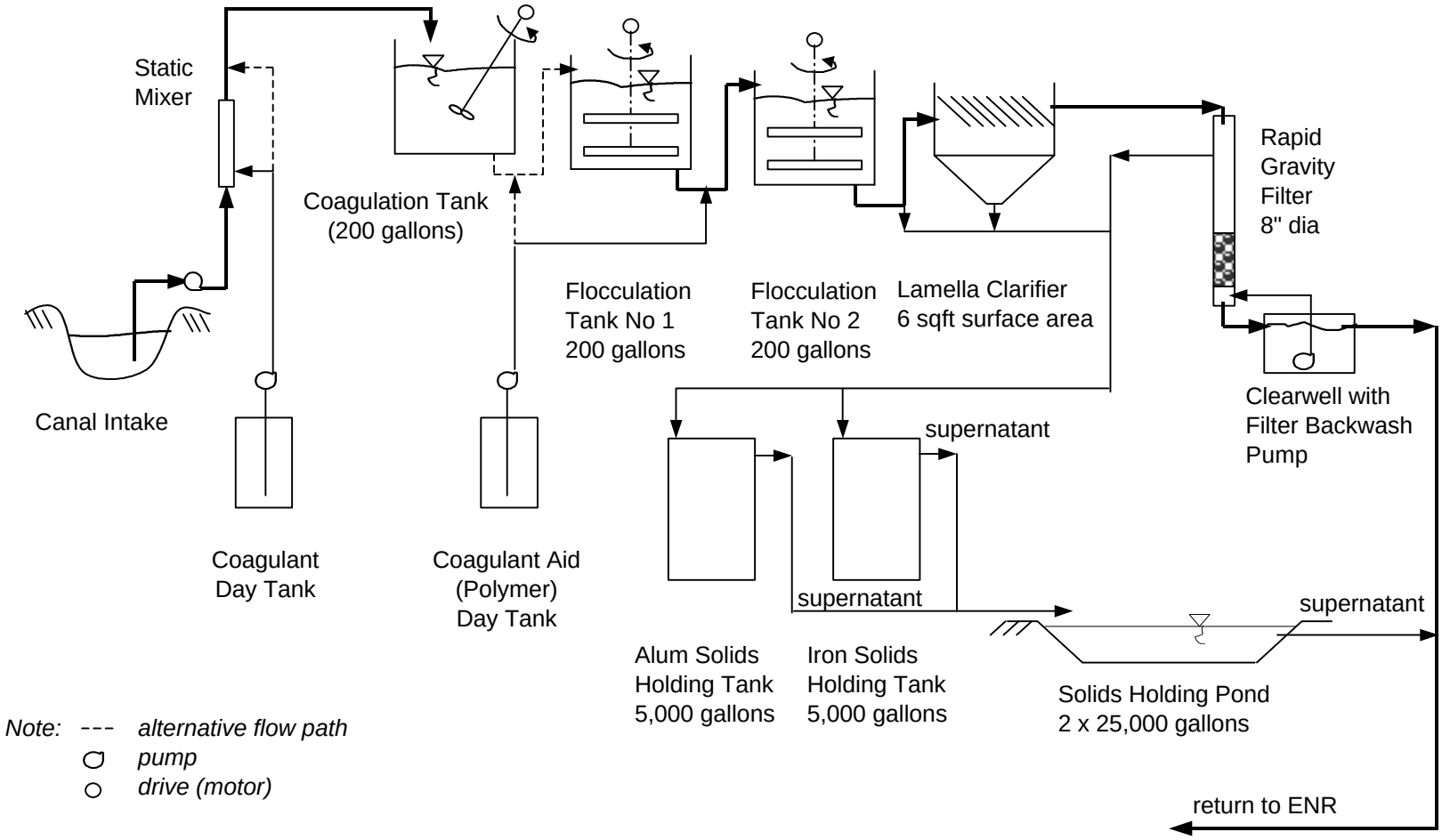


FIGURE 3.6
Headloss - Filter 1B ('Swiss' - dual media)
expanded shale: 102 cm depth, d= 2-3 mm, n = 0.48, Fi = 0.70
sand: 30 cm depth, ES(d_{10}) = 1.5 mm, UC = 1.5, n = 0.38, Fi = 1.00
Days 36, 37, 38, and 39

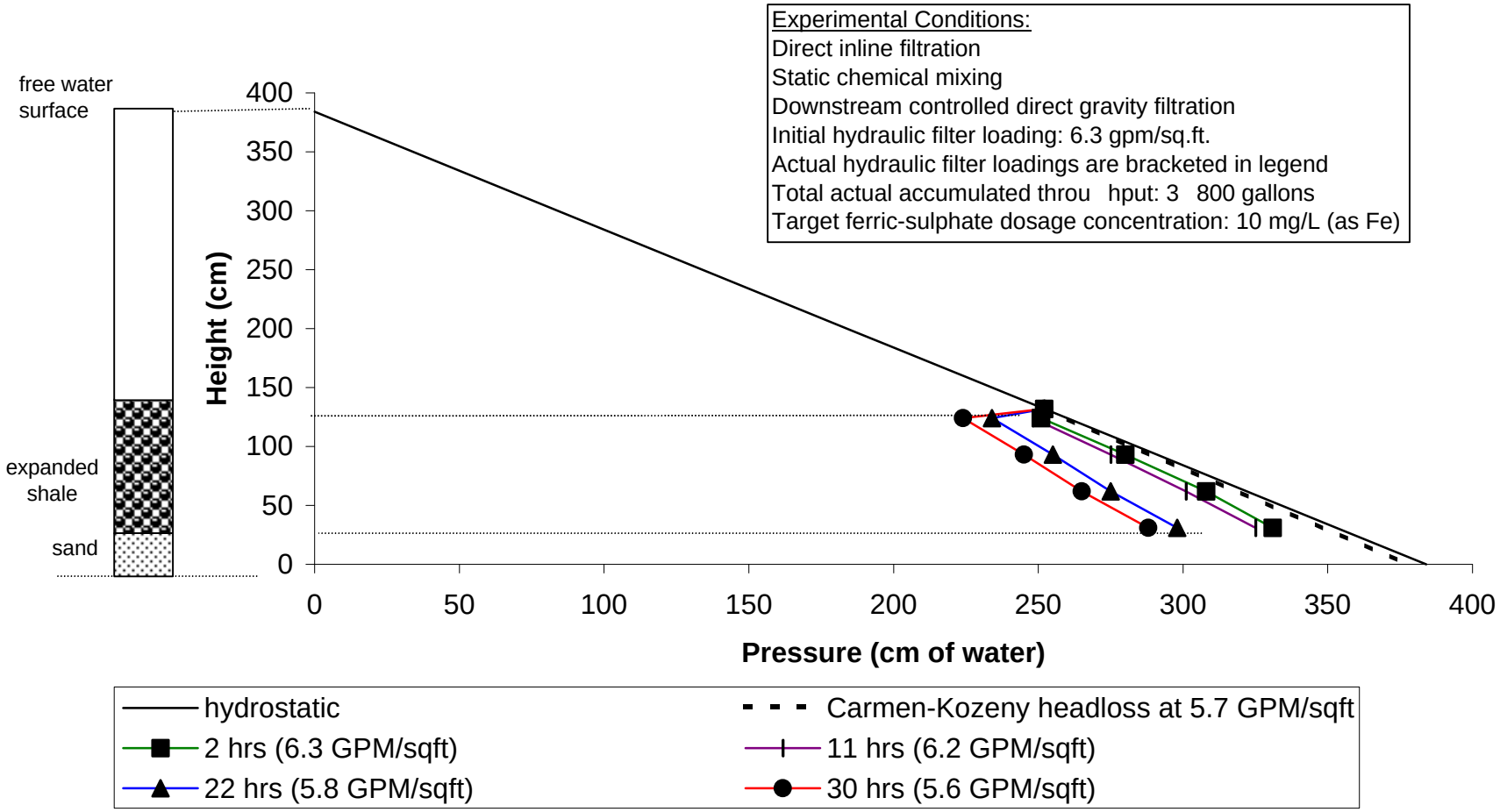


FIGURE 3.7
Velocity Gradient as a Function of
Agitation Intensity and Temperature
for 10 minutes HDT in a 200-gallon usable volume flocculator tank

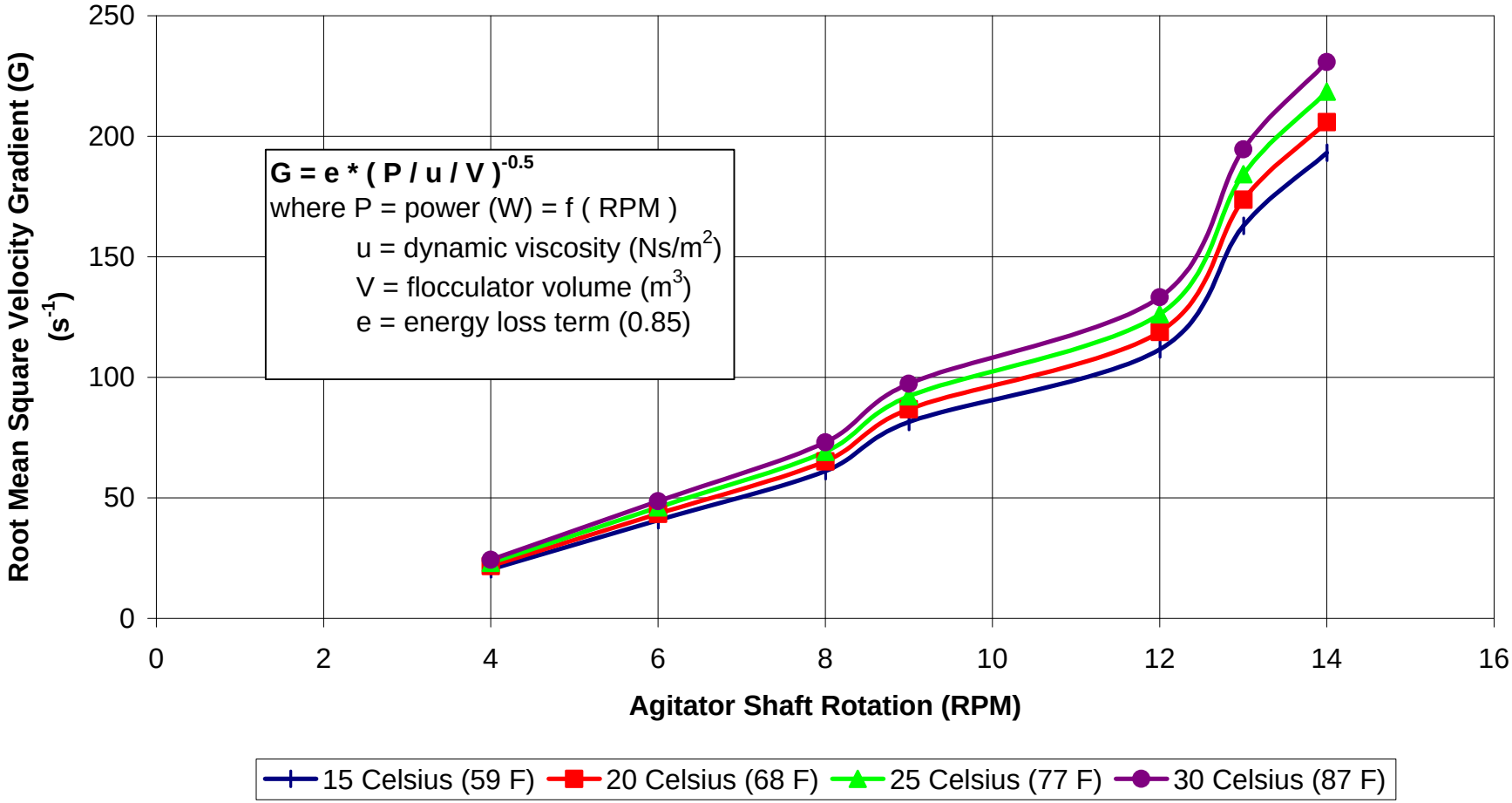


FIGURE 3.8
CTSS Pilot Facility Process During Optimization

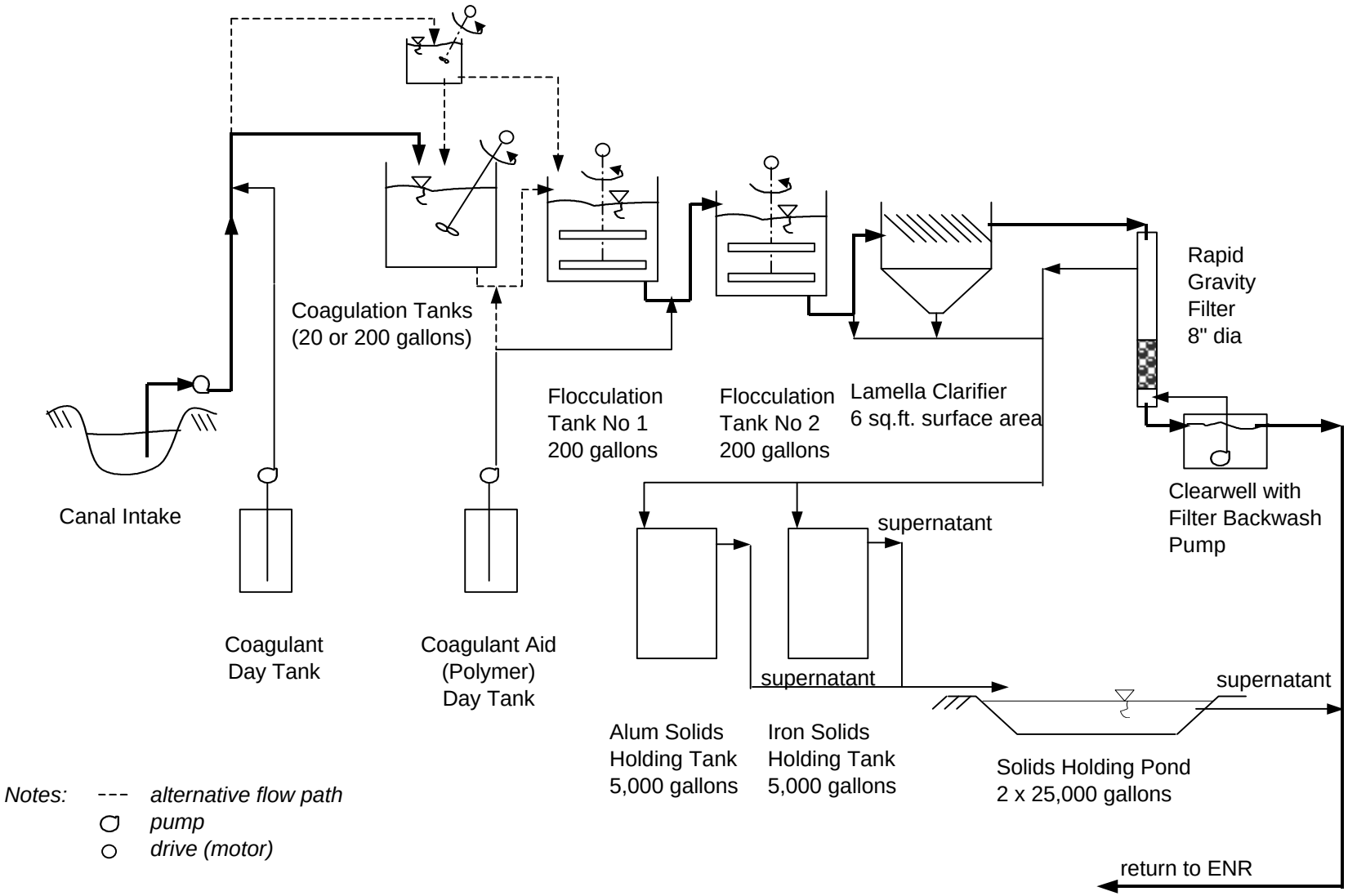


FIGURE 3.9
CTSS Pilot Facility Process During Demonstration

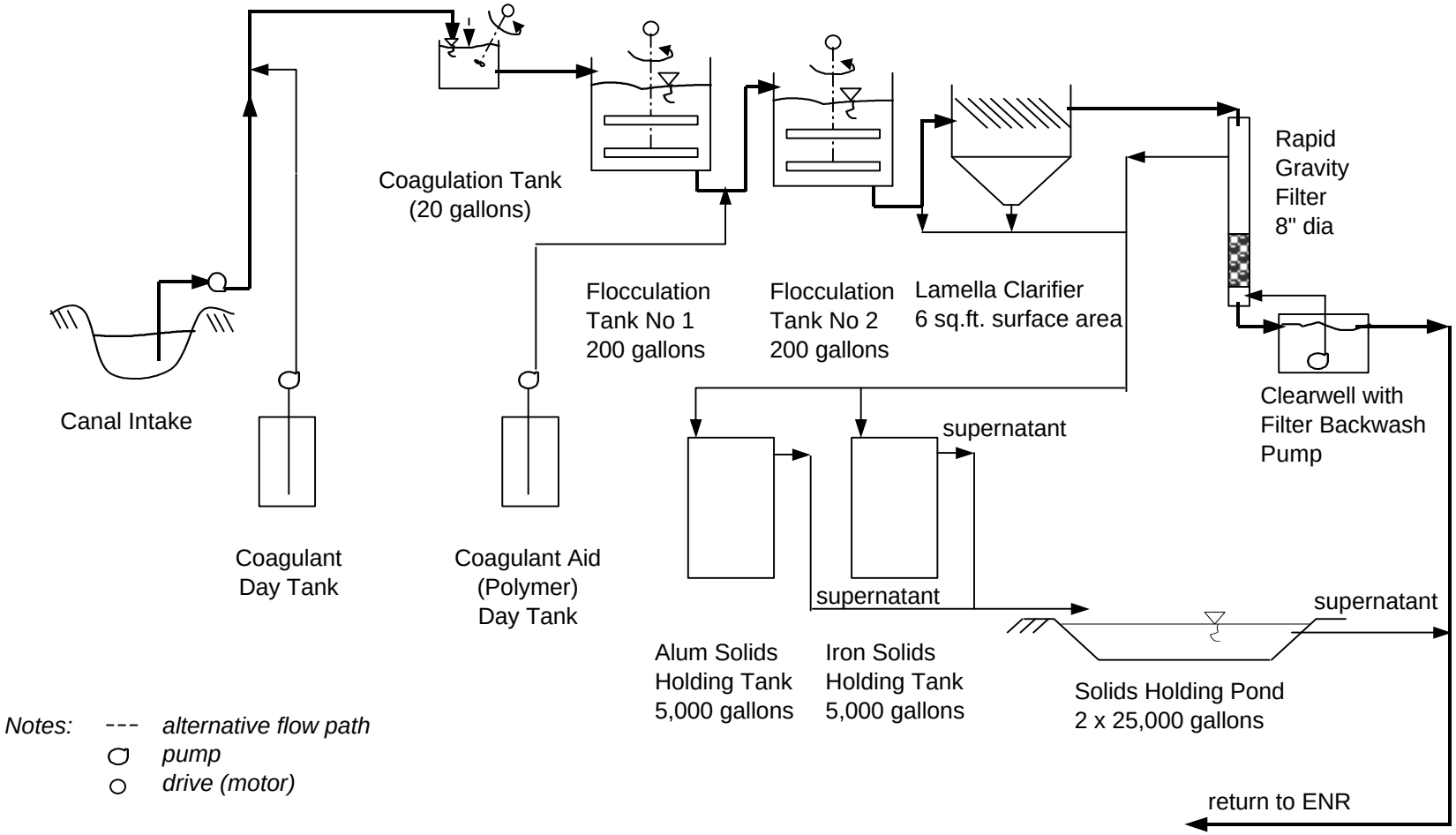


FIGURE 3.10
Concentration of Total Phosphorus (Total P)
in North Test Site Influent (I1)

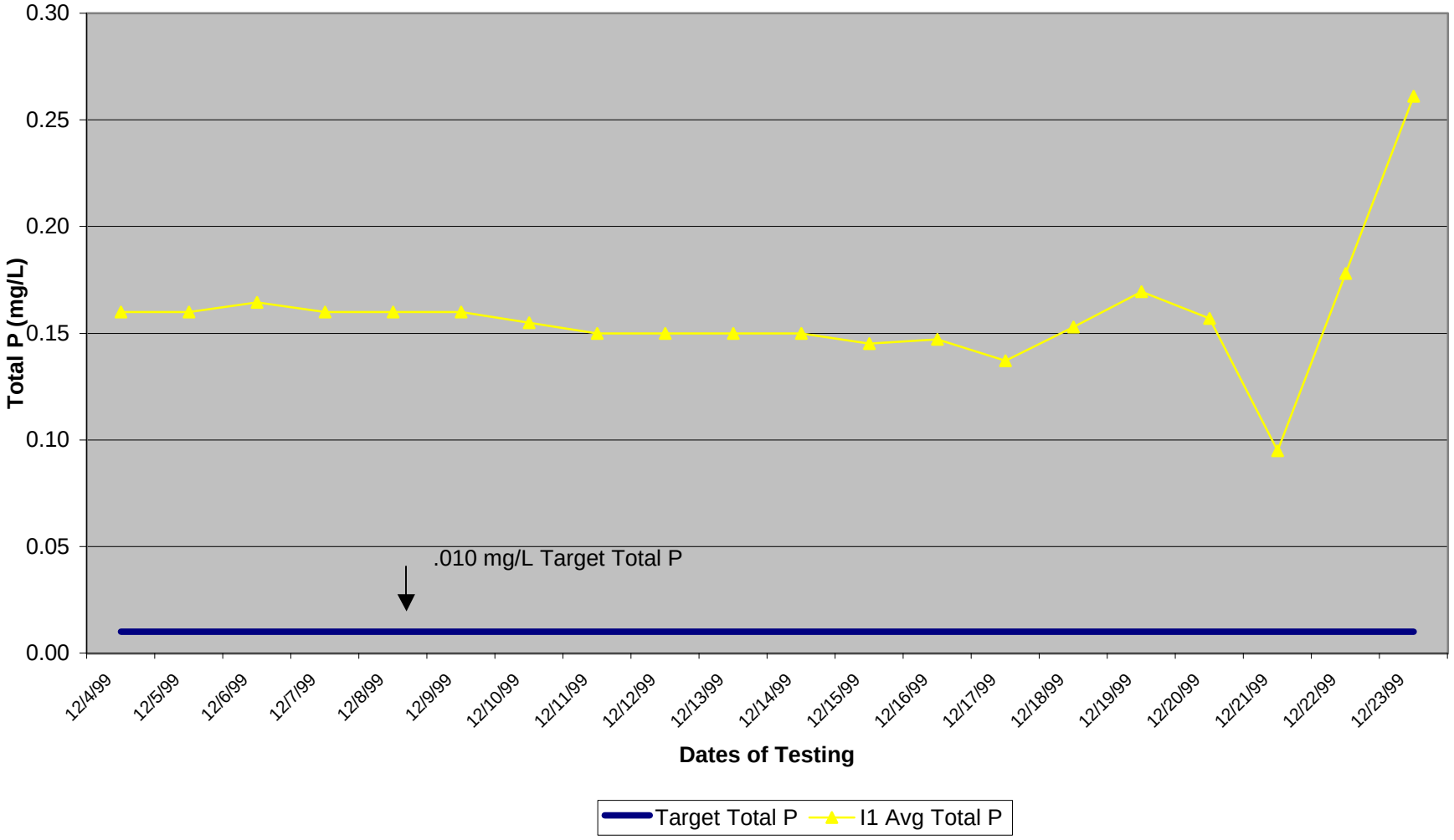


FIGURE 3.11
Expanded Scale Total Phosphorus (Total P) Results of Clarifier Effluent (C1) and Filtrates (F1A and F1B) for the North Test Site

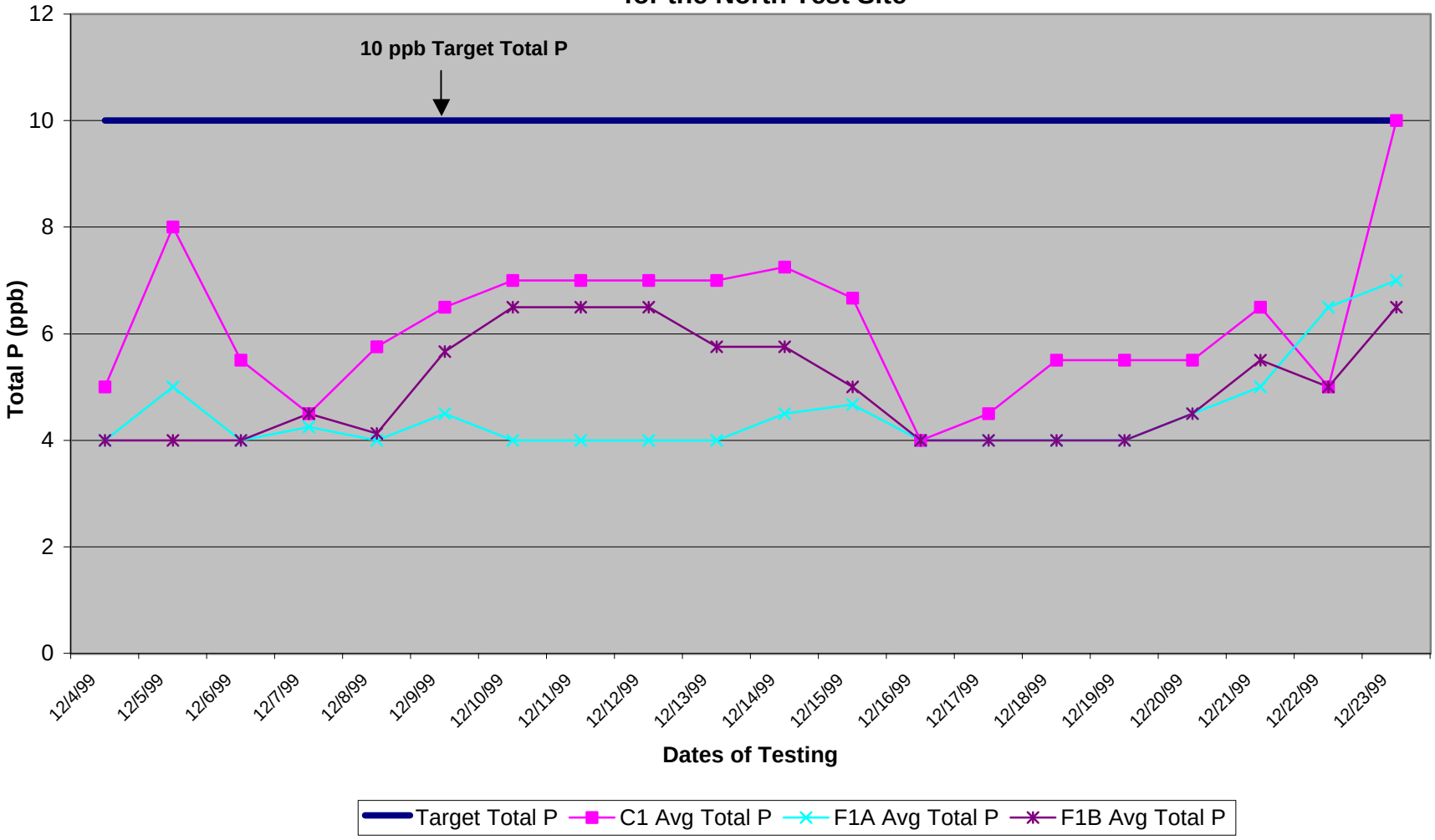


FIGURE 3.12
Total Phosphorus (Total P) Comparison
of Influent (I2) vs. Clarifier Effluent (C2) and Filtrates (F2A and F2C)
for the South Test Site

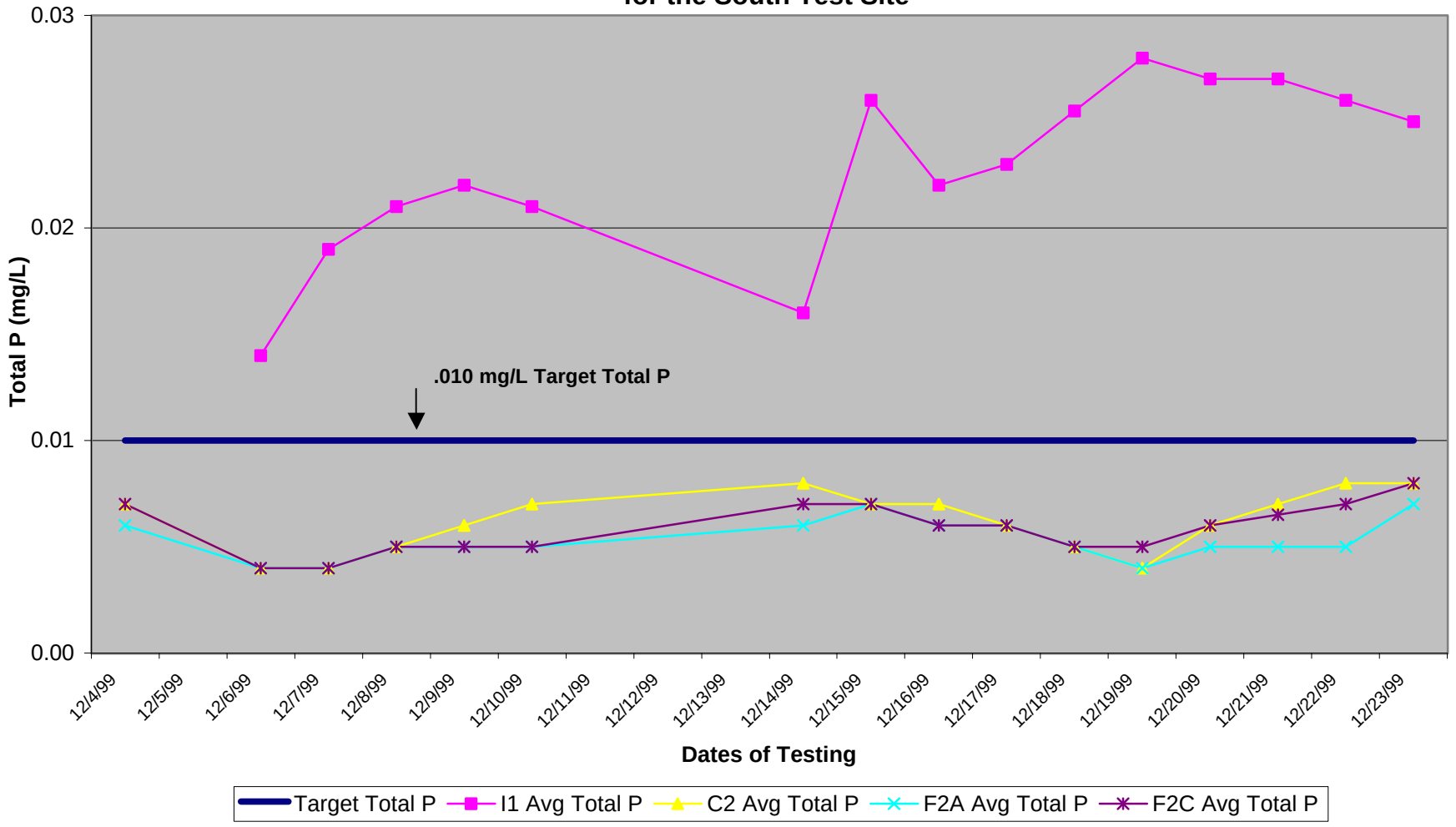


TABLE 3.1
Screening Tests – Variables and System Responses (September 10, 1999)

Test	Days	Operational Variables								Total Phosphorus Concentration (µg/L as P)							
		Treatment Chemicals (mg/L)				Sludge		Hydraulic Loading		Raw Water	Clarifier Effluent	Filtrate***					
		$Al_2(SO_4)_3$	$Fe_2(SO_4)_3$	$Ca(OH)_2$	A-1849	Wasted (%)	Recycled (%)	Clarifier* (gpm/sq.ft.)	Filter gpm/sq.ft.)			1A	1B	1C	2A	2B	2C
1	1 - 6	none	none	none	none	2	none	0.43	4.9	24.5	18.0	19.0	21.3	N/A	20.3	19.8	19.5
2	1 - 6	12	none	none	none	2	none	0.71	-	24.5	25.8	-	-	-	-	-	-
3	7 - 15	12	none	none	0.5	2	none	0.43	4.9	17.7	11.3	N/A	8.2	14.0	-	-	-
4	7 - 15	none	3.5	50	none	2	none	0.43	4.9	17.7	17.2	-	-	-	14.3	12.3	17.5
5	16–19	10	none	none	0.5	2	none	0.43	6.0	17.0	12.0	9.8	8.0	N/A	-	-	-
6	16-19	none	1.5	50	none	2	none	0.43	6.0	17.0	16.0	-	-	-	13.7	13.8	15.5
7	20-27	10	none	none	0.3	2	none	0.43	6.0	17.7	12.3	9.0	9.9	11.3	8.3	9.0	8.7
8	20-27	none	10	none	none	2	none	0.71**	-	17.6	20.3	-	-	-	-	-	-
9	28-30	10	none	none	none	-	-	-	6.0	19.5	-	-	-	-	16.8	19.3	23
10	28-30	none	10	none	0.3	2	none	0.29	-	19.5	26.3	-	-	-	-	-	-
11	31-34	10	none	none	none	-	-	-	4.9	24	-	34.2	36.5	33.3	-	-	-
12	32-35	10	none	none	0.3	2	none	0.29	-	25.7	17.5	-	-	-	-	-	-
13	31-34	none	10	none	none	-	-	-	4.9	24	-	-	-	-	29.8	30	32.5
14	33-35	none	10	none	0.3	2	none	0.29	-	25	34	-	-	-	-	-	-
15	36-39	none	10	none	none	-	-	-	4.9	19.3	-	21.5	22.0	23.5	-	-	-
16	36-39	10	none	none	0.3	2	16	0.29	-	19.3	24	-	-	-	-	-	-
17	36-39	10	none	none	none	-	-	-	4.9	19.3	-	-	-	-	33.5	32.0	32.0
18	36-39	none	10	none	0.3	1	16	0.29	-	19.3	28	-	-	-	-	-	-
19	41-42	10	none	none	none	-	-	-	4.9	19	-	15.5	25.5	24	-	-	-
20	40-44	10	none	none	0.3	2	33	0.14	-	18.4	20.5	-	-	-	-	-	-
21	41-42	none	10	none	none	-	-	-	4.9	19	-	-	-	-	21.8	22.0	23.5
22	40-44	none	10	none	0.3	2	33	0.14	-	18.4	27.2	-	-	-	-	-	-
23	45-49	10	none	none	0.1	2	33	0.14	4.9	22.6	31.0	18.0	21.3	N/A	-	-	-
24	45-49	none	20	none	0.1	2	33	0.14	4.9	22.6	29.6	-	-	-	27.9	N/A	30.0
25	50-56	10	none	none	0.1	-	-	-	4.9	30.4	-	26.7	24.9	20.3	-	-	-
26	51-56	none	20	none	0.1	-	-	-	4.9	23.8	-	-	-	-	22.8	36.3	23.0
27	57-61	10	none	none	0.1	2	none	0.43	4.9	36.6	29.0	27.2	38.8	35.0	-	-	-
28	57-61	none	20	none	0.1	2	none	0.43	4.9	36.6	42.0	-	-	-	42.6	42.6	38.7

Notes:
Tests 1, 3, and 4 suction filtration (constant rate filtration provided by downstream pumping)
Tests 5, 6, 7, 9 downstream controlled gravity filtration (constant rate followed by declining rate filtration provided by gradual opening of effluent valve)
Tests 11, 13, 15, 17, 19, 21, 23, 24, 25, 26, 27, and 28 declining rate gravity filtration (constant valve setting; operation from 1.3Q to 0.6Q, where Q is the target hydraulic loading)

N/A no data available
- not applicable
** based on 28 ft^2 projected lamella area*
*** 12 gpm in days 23 to 26*

Test	Filter					
	1A	1B	1C	2A	2B	2C
1 - 24	'LA'	'Swiss'	polystyrene	'Humics'	'Wahnbach'	shale
25 - 28	'LA'	'Swiss'	'GE'	'LA'	'Swiss'	'GE'

TABLE 3.2
Decoded Design Matrix and System Responses – Optimization Trials
North Test Site - Segment #1 (October 26, 1999 to November 7, 1999)

Date 1999	Exp #	Variable							Total Phosphorus Concentration (µg/L)		
		Filter media	Hydraulic filter loading* (gpm/sq.ft.)	Coagulation Volume (gallons)	Clarifier Surface Loading** (gpm/sq.ft.)	Coagulant Type	Coagulant Dosage Concentration (mg/L)	Polymer (A-130) Dosage Concentration (mg/L)	Raw Water	Clarifier Effluent	Filtrate
October 26	**MN1**	Swiss	4.9	200	0.28	alum	10	0.5	167	98	48.5
(Tuesday)	**MN2**	GE	4.9	200	0.28	alum	10	0.5	167	98	28
October 27	**MN3**	Swiss	9.8	200	0.43	ferric-chloride	40	0.5	165	103	86
(Wednesday)	**MN4**	GE	9.8	200	0.43	ferric-chloride	40	0.5	165	103	68
October 28•••	**MN5**	Swiss	9.8	20	0.28	ferric-chloride	40	0.3	113	76	68
(Thursday)	**MN6**	GE	9.8	20	0.28	ferric-chloride	40	0.3	113	76	48
October 29	**MN7**	Swiss	9.8	220	0.28	ferric-chloride	40	0.3	153	96	76
(Friday)	**MN8**	GE	9.8	220	0.28	ferric-chloride	40	0.3	153	96	63
November 1	**MN9**	Swiss	9.8	220	0.28	ferric-chloride	20	0.5	277	209	188
(Monday)	**MN10**	GE	9.8	220	0.28	ferric-chloride	20	0.5	277	209	168
November 2	**MN11**	Swiss	9.8	220	0.28	alum	20	0.5	186	93	65.5
(Tuesday)	**MN12**	GE	9.8	220	0.28	alum	20	0.5	186	93	48
November 3	**MN13**	Swiss	9.8	200	0.28	alum	10	0.3	165	146	89
(Wednesday)	**MN14**	GE	9.8	200	0.28	alum	10	0.3	165	146	52
November 4	**MN15**	Swiss	4.9	220	0.28	ferric-chloride	40	0.5	127	55	37
(Thursday)	**MN16**	GE	4.9	220	0.28	ferric-chloride	40	0.5	127	55	30
November 5	**MN17**	Swiss	4.9	200	0.28	alum	20	0.3	163	100	52
(Friday)	**MN18**	GE	4.9	200	0.28	alum	20	0.3	163	100	33
November 6•••	**MN19**	Swiss	4.9	220	0.28	alum	20	0.5****	141	58	20
(Saturday)	**MN20**	GE	4.9	220	0.28	alum	20	0.5****	141	58	13.5
November 7•••	**MN21**	Swiss	4.9	220	0.28	ferric-chloride	40	0.5****	126	86	59
(Sunday)	**MN22**	GE	4.9	220	0.28	ferric-chloride	40	0.5****	126	86	46

Notes:
- * *4.9 gpm/sq.ft. ≡ 1.7 gpm hydraulic filter loading*
- ** *projected lamella area*
- *** *20 gallons*
- **** *A-1849 polyacrylamide*
- ♦ *lab duplicate*
- ♦♦ *filter duplicate*
- ♦♦♦ ***tests in** addition to 'Bayesian' designed trials*

Constant flocculation volume is 400 gallons
Even number tests will be conducted in duplicate using the Green Everglades (GE) filter media
Filter 1A: 'GE'; filter 1B: 'Swiss'; filter 1C: 'GE'

TABLE 3.3
Decoded Design Matrix and System Responses – Optimization Trials
South Test Site - Segment #1 (October 26, 1999 to November 7, 1999)

Date 1999	Exp #	Variable							Total Phosphorus Concentration (µg/L)		
		Filter Media	Hydraulic Filter Loading* (gpm/sq.ft.)	Coagulation Volume (gallons)	Clarifier Surface Loading** (gpm/sq.ft.)	Coagulant Type	Coagulant Dosage Concentration (mg/L)	Polymer (A-130) Dosage Concentration (mg/L)	Raw Water	Clarifier Effluent	Filtrate
October 26	**MS1**	Swiss	4.9	200	0.28	alum	10	0.5	22	10	7.5
(Tuesday)	**MS2**	GE	4.9	200	0.28	alum	10	0.5	22	10	7
October 27	**MS3**	Swiss	9.8	200	0.43	ferric-chloride	40	0.5	18	13	8.5
(Wednesday)	**MS4**	GE	9.8	200	0.43	ferric-chloride	40	0.5	18	13	6
October 28•••	**MS5**	Swiss	9.8	20	0.28	ferric-chloride	40	0.3	11	14	10
(Thursday)	**MS6**	GE	9.8	20	0.28	ferric-chloride	40	0.3	11	14	8
October 29	**MS7**	Swiss	9.8	220	0.28	ferric-chloride	40	0.3	17	20	14
(Friday)	**MS8**	GE	9.8	220	0.28	ferric-chloride	40	0.3	17	20	9
November 1	**MS9**	Swiss	9.8	220	0.28	ferric-chloride	20	0.5	20	18	17
(Monday)	**MS10**	GE	9.8	220	0.28	ferric-chloride	20	0.5	20	18	18
November 2	**MS11**	Swiss	9.8	220	0.28	alum	20	0.5	29	10	6
(Tuesday)	**MS12**	GE	9.8	220	0.28	alum	20	0.5	29	10	8
November 3	**MS13**	Swiss	9.8	200	0.28	alum	10	0.3	19	24	13
(Wednesday)	**MS14**	GE	9.8	200	0.28	alum	10	0.3	19	24	27
November 4	**MS15**	Swiss	4.9	220	0.28	ferric-chloride	40	0.5	14	19	21.5
(Thursday)	**MS16**	GE	4.9	220	0.28	ferric-chloride	40	0.5	14	19	14
November 5	**MS17**	Swiss	4.9	200	0.28	alum	20	0.3	33	6	5.5
(Friday)	**MS18**	GE	4.9	200	0.28	alum	20	0.3	33	6	< 4
November 6•••	**MS19**	Swiss	4.9	220	0.28	alum	20	0.5****	13	6	6
(Saturday)	**MS20**	GE	4.9	220	0.28	alum	20	0.5****	13	6	5
November 7•••	**MS21**	Swiss	4.9	220	0.28	ferric-chloride	40	0.5****	16	17	12.5
(Sunday)	**MS22**	GE	4.9	220	0.28	ferric-chloride	40	0.5****	16	17	12

Notes:
- * *4.9 gpm/sq.ft. ≡ 1.7 gpm hydraulic filter loading*
- ** *projected lamella area*
- *** *20 gallons*
- **** *A-1849 polyacrylamide*
- • *lab duplicate*
- •• *filter duplicate*
- ••• ***tests*** *in addition to 'Bayesian' designed trials*

Constant flocculation volume is 400 gallons
Uneven number tests will be conducted in duplicate using the 'Swiss' filter media
Filter 2A: 'Swiss'; filter 2B: 'Swiss'; filter 2C: 'Green Everglades'

TABLE 3.4
Decoded Design Matrix and System Responses – Optimization Trials
North Test Site - Segment #2 (November 8, 1999 to November 15, 1999)

Date 1999	Exp #	Variable							Total Phosphorus Concentration (µg/L)		
		Filter Media	Hydraulic Filter Loading* (gpm/sq.ft.)	Coagulation Volume (gallons)	Clarifier Surface Loading** (gpm/sq.ft.)	Coagulant Type	Coagulant Dosage Concentration (mg/L)	Polymer (A-130) Dosage Concentration (mg/L)	Raw Water	Clarifier Effluent	Filtrate
November 8	**MN23**	Swiss	9.8	200	0.28	alum	20	0.5	115	30	17
(Monday)	**MN24**	GE	9.8	200	0.28	alum	20	0.5	115	30	13
November 9	**MN25**	Swiss	9.8	200	0.28	alum	10	0.5	113	41	25
(Tuesday)	**MN26**	GE	9.8	200	0.28	alum	10	0.5	113	41	20
November 10	**MN27**	Swiss	9.8	200	0.43	ferric-chloride	20	0.5	107.5	67	43
(Wednesday)	**MN28**	GE	9.8	200	0.43	ferric-chloride	20	0.5	107.5	67	39.5
November 11•••	**MN29**	Swiss	9.8	200	0.43	ferric-chloride	40	0.3	105	49	29
(Thursday)	**MN30**	GE	9.8	200	0.43	ferric-chloride	40	0.3	105	49	43
November 12	**MN31**	Swiss	4.9	200	0.43	ferric-chloride	40	0.5	110	34	28
(Friday)	**MN32**	GE	4.9	200	0.43	ferric-chloride	40	0.5	110	34	19.5
November 13	**MN33**	Swiss	4.9	200	0.28	ferric-chloride	20	0.3	117	92	50
(Saturday)	**MN34**	GE	4.9	200	0.28	ferric-chloride	20	0.3	117	92	34
November 14	**MN35**	Swiss	9.8	220	0.43	alum	20	0.5	118	88	75
(Sunday)	**MN36**	GE	9.8	220	0.43	alum	20	0.5	118	88	50.5
November 15	**MN37**	Swiss	4.9	220	0.28	ferric-chloride	40	0.3	174	47	42
(Monday)	**MN38**	GE	4.9	220	0.28	ferric-chloride	40	0.3	174	47	34.5

Notes: * *4.9 gpm/sq.ft. ≡ 1.7 gpm hydraulic filter loading*
** *projected lamella area*
*** *100 mg/L as Fe*
• *lab duplicate*
•• *filter duplicate*
••• *tests in addition to 'Bayesian' designed trials*

Constant flocculation volume is 400 gallons; feed flow rate of 12 gpm was maintained
Filter 1A: 'GE'; filter 1B: 'Swiss'; filter 1C: 'GE'

TABLE 3.5
Decoded Design Matrix and System Responses – Optimization Trials
South Test Site - Segment #2 (November 8, 1999 to November 15, 1999)

Date 1999	Exp #	Variable							Total Phosphorus Concentration (µg/L)		
		Filter Media	Hydraulic Filter Loading* (gpm/sq.ft.)	Coagulation Volume (gallons)	Clarifier Surface Loading** (gpm/sq.ft.)	Coagulant Type	Coagulant Dosage Concentration (mg/L)	Polymer (A-130) Dosage Concentration (mg/L)	Raw Water	Clarifier Effluent	Filtrate
November 8	**MS23**	Swiss	9.8	200	0.28	alum	20	0.5	19	6	6
(Monday)	**MS24**	GE	9.8	200	0.28	alum	20	0.5	19	6	13
November 9	**MS25**	Swiss	9.8	200	0.28	alum	10	0.5	20	12	10
(Tuesday)	**MS26**	GE	9.8	200	0.28	alum	10	0.5	20	12	10
November 10	**MS27**	Swiss	9.8	200	0.43	ferric-chloride	20	0.5	14	16	15
(Wednesday)	**MS28**	GE	9.8	200	0.43	ferric-chloride	20	0.5	14	16	14
November 11	**MS29**	Swiss	9.8	200	0.43	ferric-chloride	40	0.3	15	14	9.5
(Thursday)	**MS30**	GE	9.8	200	0.43	ferric-chloride	40	0.3	15	14	8
November 12	**MS31**	Swiss	4.9	200	0.43	ferric-chloride	40	0.5	23	15	14.5
(Friday)	**MS32**	GE	4.9	200	0.43	ferric-chloride	40	0.5	23	15	12
November 13	**MS33**	Swiss	4.9	200	0.28	ferric-chloride	20	0.3	20	21	22
(Saturday)	**MS34**	GE	4.9	200	0.28	ferric-chloride	20	0.3	20	21	20
November 14	**MS35**	Swiss	9.8	220	0.43	alum	20	0.5	21	15	17
(Sunday)	**MS36**	GE	9.8	220	0.43	alum	20	0.5	21	15	13
November 15	**MS37**	Swiss	4.9	220	0.28	ferric-chloride	40	0.3	21	15	17
(Monday)	**MS38**	GE	4.9	220	0.28	ferric-chloride	40	0.3	21	15	12

Notes: * *4.9 gpm/sq.ft. ≡ 1.7 gpm hydraulic filter loading*
** *projected lamella area*
♦ *lab duplicate*
♦♦ *filter duplicate*

Constant flocculation volume: 400 gallons
Uneven number tests will be conducted in duplicate using the 'Swiss' filter media
Filter 2A: 'Swiss'; filter 2B: 'Swiss'; filter 2C: 'Green Everglades'

TABLE 3.6
Decoded Design Matrix and System Responses – Optimization Trials
North Test Site - Segment #3 (November 16, 1999 to November 21, 1999)

Date 1999	Exp #	Variable							Total Phosphorus Concentration (µg/L)		
		Filter Media	Hydraulic Filter Loading* (gpm/sq.ft.)	Coagulation Volume (gallons)	Clarifier Surface Loading** (gpm/sq.ft.)	Coagulant Type	Coagulant Dosage Concentration (mg/L)	Polymer (A-130) Dosage Concentration (mg/L)	Raw Water	Clarifier Effluent	Filtrate
November 16	**MN39**	Swiss	9.8	200	0.43	ferric-chloride	40	0.3	158	N	34
(Tuesday)* **	**MN40**	GE	9.8	200	0.43	ferric-chloride	40	0.3	158	N	44
November 17♦♦♦	**MN41**	Swiss	4.9	220	0	ferric-chloride	20	0.3	151	N/A	129
(a.m.)	**MN42**	GE	4.9	220	0	ferric-chloride	20	0.3	151	N/A	123
November 17♦♦♦	**MN43**	Swiss	4.9	220	0	ferric-chloride	40	0.3	151	N/A	131
(p.m.)	**MN44**	GE	4.9	220	0	ferric-chloride	40	0.3	151	N/A	108
November 18♦♦♦	**MN45**	Swiss	4.9	220	0	alum	10	0.3	169	N/A	134
(a.m.)	**MN46**	GE	4.9	220	0	alum	10	0.3	169	N/A	98
November 18♦♦♦	**MN47**	Swiss	4.9	220	0	alum	20	0.3	169	N/A	89
(p.m.)	**MN48**	GE	4.9	220	0	alum	20	0.3	169	N/A	67
November 19♦♦♦	**MN49**	Swiss	4.9	220	0.14	alum	20	0.5	165	75	44
(Friday)	**MN50**	GE	4.9	220	0.14	alum	20	0.5	165	75	35
November 20♦♦♦	**MN51**	Swiss	4.9	220	0.14	ferric-chloride	40	0.5	167	53	41
(Saturday)	**MN52**	GE	4.9	220	0.14	ferric-chloride	40	0.5	167	53	35
November 21♦♦♦	**MN53**	Swiss	4.9	220	0.14	ferric-chloride	40	0.5	137	84	61
(Sunday)	**MN54**	GE	4.9	220	0.14	ferric-chloride	40	0.5	137	84	44

Notes: *Constant flocculation volume: 400 gallons*
HDT in a single flocculator cell: 49 min 30 sec (Q_{feed} = 4 gpm) unless noted
* *4.9 gpm/sq.ft. ≡ 1.7 gpm hydraulic filter loading*
** *projected lamella area*
*** *HDT in a single flocculator cell: 16 min 30 sec (Q_{feed} = 12 gpm)*
N/A *not applicable*
N *not available*

Even number tests will be conducted in duplicate using the Green Everglades (GE) filter media
Filter 1A: 'GE'; filter 1B: 'Swiss'; filter 1C: 'GE'
♦ *lab duplicate*
♦♦ *filter duplicate*
♦♦♦ ***tests*** *in addition to 'Bayesian' designed trials*

TABLE 3.7
Decoded Design Matrix and System Responses – Optimization Trials
South Test Site - Segment #3 (November 17, 1999 to November 21, 1999)

Date 1999	Exp #	Variable							Total Phosphorus Concentration (µg/L)		
		Filter Media	Hydraulic Filter Loading* (gpm/sq.ft.)	Coagulation Volume (gallons)	Clarifier Surface Loading** (gpm/sq.ft.)	Coagulant Type	Coagulant Dosage Concentration (mg/L)	Polymer (A-130) Dosage Concentration (mg/L)	Raw Water	Clarifier Effluent	Filtrate
November 16♦♦♦♦											
(Tuesday)											
November 17♦♦♦	**MS39**	Swiss	4.9	220	0	ferric-chloride	20	0.3	17	N/A	17
(a.m.)	**MS40**	GE	4.9	220	0	ferric-chloride	20	0.3	17	N/A	16
November 17♦♦♦	**MS41**	Swiss	4.9	220	0	ferric-chloride	40	0.3	17	N/A	19
(p.m.)	**MS42**	GE	4.9	220	0	ferric-chloride	40	0.3	17	N/A	19
November 18♦♦♦	**MS43**	Swiss	4.9	220	0	alum	10	0.3	19	N/A	17
(a.m.)	**MS44**	GE	4.9	220	0	alum	10	0.3	19	N/A	16
November 18♦♦♦	**MS45**	Swiss	4.9	220	0	alum	20	0.3	19	N/A	23
(p.m.)	**MS46**	GE	4.9	220	0	alum	20	0.3	19	N/A	23
November 19♦♦♦	**MS47**	Swiss	4.9	220	0.14	alum	20	0.5	21	16	13
(Friday)	**MS48**	GE	4.9	220	0.14	alum	20	0.5	21	16	11
November 20♦♦♦	**MS49**	Swiss	4.9	220	0.14	ferric-chloride	40	0.5	21	19	18
(Saturday)	**MS50**	GE	4.9	220	0.14	ferric-chloride	40	0.5	21	19	16
November 21♦♦♦	**MS51**	Swiss	4.9	220	0.14	ferric-chloride	40	0.5	19	16	17
(Sunday)	**MS52**	GE	4.9	220	0.14	ferric-chloride	40	0.5	19	16	14

Notes: *Constant flocculation volume is 400 gallons unless noted*
Constant HDT in a single flocculator cell: 49 min 30 sec (Q_{feed} = 4 gpm) unless noted
* *4.9 gpm/sq.ft. ≡ 1.7 gpm hydraulic filter loading*
** *projected lamella area*
N/A *not applicable*

Uneven number tests will be conducted in duplicate using the 'Swiss' filter media
Filter 2A: 'Swiss'; filter 1B: 'Swiss'; filter 1C: 'Green Everglades'
♦ *lab duplicate*
♦♦ *filter duplicate*
♦♦♦ ***test**s in addition to 'Bayesian' design*
♦♦♦♦ *test was not conducted*

TABLE 3.8
Decoded Design Matrix and System Responses – Optimization Trials
North Test Site - Segment #4 (November 22, 1999 to December 3, 1999)

Date 1999	Exp #	Variable							Total Phosphorus Concentration (µg/L)		
		Filter Media	Hydraulic Filter Loading* (gpm/sq.ft.)	Coagulation Volume (gallons)	Clarifier Surface Loading** (gpm/sq.ft.)	Coagulant Type	Coagulant Dosage Concentration (mg/L)	Polymer (A-130) Dosage Concentration (mg/L)	Raw Water	Clarifier Effluent	Filtrate
November 22	**MN55**	Swiss	4.9	20	0.43	alum	10	0.3	131	41	27
(Monday)	**MN56**	GE	4.9	20	0.43	alum	10	0.3	131	41	23
November 23	**MN57**	Swiss	4.9	20	0.14	alum	20	0.5	105	10	5
(Tuesday)	**MN58**	GE	4.9	20	0.14	alum	20	0.5	105	10	7
November 24	**MN59**	Swiss	4.9	20	0.14	ferric-chloride	20	0.5	123	66	35
(Wednesday)	**MN60**	GE	4.9	20	0.14	ferric-chloride	20	0.5	123	66	28
November 29♦♦♦	**MN61**	Swiss	4.9	220	0.14	alum	10	0.3	169	35	22
(Monday)	**MN62**	GE	4.9	220	0.14	alum	10	0.3	169	35	22
November 30♦♦♦	**MN63**	Swiss	9.8	220	0.14	alum	20	0.3	158	22	12
(Tuesday)	**MN64**	GE	9.8	220	0.14	alum	20	0.3	158	22	16
December 1♦♦♦	**MN65**	Swiss	4.9	220	0.14	ferric-chloride	40	0.5	163	10	4
(Wednesday)	**MN66**	GE	4.9	220	0.14	ferric-chloride	40	0.5	163	10	4
December 2♦♦♦	**MN67**	Swiss	9.8	220	0.14	ferric-chloride	20	0.5	158	42	18
(Thursday)	**MN68**	GE	9.8	220	0.14	ferric-chloride	20	0.5	158	42	24
December 3♦♦♦	**MN69**	Swiss	9.8	220	0.14	ferric-chloride	20	0.3	180	30	19
(Friday)	**MN70**	GE	9.8	220	0.14	ferric-chloride	20	0.3	180	30	14

Notes:
* *4.9 gpm/sq.ft. ≡ 1.7 gpm hydraulic filter loading*
** *projected lamella area*
♦ *lab duplicate*
♦♦ *filter duplicate*
♦♦♦ *tests in addition to 'Bayesian' designed trials*

Constant flocculation volume: 400 gallons
Even number tests will be conducted in duplicate using the Green Everglades (GE) filter media
Filter 1A: 'GE'; filter 1B: 'Swiss'; filter 1C: 'GE'

TABLE 3.9
Decoded Design Matrix and System Responses – Optimization Trials
South Test Site - Segment #4 (November 22, 1999 to December 3, 1999)

Date 1999	Exp #	Variable							Total Phosphorus Concentration (µg/L)		
		Filter Media	Hydraulic Filter Loading* (gpm/sq.ft.)	Coagulation Volume (gallons)	Clarifier Surface Loading** (gpm/sq.ft.)	Coagulant Type	Coagulant Dosage Concentration (mg/L)	Polymer (A-130) Dosage Concentration (mg/L)	Raw Water	Clarifier Effluent	Filtrate
November 22	**MS53**	Swiss	4.9	20	0.43	alum	10	0.3	19	18	14
(Monday)	**MS54**	GE	4.9	20	0.43	alum	10	0.3	19	18	14
November 23	**MS55**	Swiss	4.9	20	0.14	alum	20	0.5	24	15	10
(Tuesday)	**MS56**	GE	4.9	20	0.14	alum	20	0.5	24	15	10
November 24	**MS57**	Swiss	4.9	20	0.14	ferric-chloride	20	0.5	21	18	16
(Wednesday)	**MS58**	GE	4.9	20	0.14	ferric-chloride	20	0.5	21	18	21
November 29♦♦♦	**MS59**	Swiss	4.9	220	0.14	alum	10	0.3	30	24	19
(Monday)	**MS60**	GE	4.9	220	0.14	alum	10	0.3	30	24	16
November 30♦♦♦	**MS61**	Swiss	9.8	220	0.14	alum	20	0.3	24	11	12
(Tuesday)	**MS62**	GE	9.8	220	0.14	alum	20	0.3	24	11	7
December 1♦♦♦	**MS63**	Swiss	4.9	220	0.14	ferric-chloride	40	0.5	18	10	8
(Wednesday)	**MS64**	GE	4.9	220	0.14	ferric-chloride	40	0.5	18	10	5
December 2♦♦♦	**MS65**	Swiss	9.8	220	0.14	ferric-chloride	20	0.5	15	13	16
(Thursday)	**MS66**	GE	9.8	220	0.14	ferric-chloride	20	0.5	15	13	13
December 3♦♦♦	**MS67**	Swiss	9.8	220	0.14	ferric-chloride	20	0.3	14	17	17
(Friday)	**MS68**	GE	9.8	220	0.14	ferric-chloride	20	0.3	14	17	14

Notes:
* *4.9 gpm/sq.ft. ≡ 1.7 gpm hydraulic filter loading*
** *projected lamella area*
♦ *lab duplicate*
♦♦ *filter duplicate*
♦♦♦ *tests in addition to 'Bayesian' designed trials*

Constant flocculation volume: 400 gallons
Uneven number tests will be conducted in duplicate using the Green Everglades (GE) filter media
Filter 2A: 'Swiss'; filter 2B: 'Swiss'; filter 2C: 'GE'

TABLE 3.10
Coded Design Matrix and System Responses
Demonstration Trials (December 4, 1999 to December 23, 1999)
North Test Site – 'Swiss' Filter

Date 1999	Time	Variable						Total Phosphorus Concentration (µg/L)		
		Hydraulic Filter Loading* (gpm/sq.ft.)	Coagulation Volume (gallons)	Clarifier Surface Loading** (gpm/sq.ft.)	Coagulant Type	Coagulant Dosage Concentration (mg/L as Fe)	Polymer (A-130) Dosage Concentration (mg/L)	Raw Water	Clarifier Effluent	Filtrate
December 4	16:00	4.9	20	0.14	Ferric-chloride	40	0.5	166		< 4
(Saturday)	19:00	4.9	20	0.14	Ferric-chloride	40	0.5	166	5	< 4
December 5	12:30	4.9	20	0.14	Ferric-chloride	40	0.5	166	8	< 4
(Sunday)		4.9	20	0.14	Ferric-chloride	40	0.5	166		
December 6	10:00	4.9	20	0.14	Ferric-chloride	40	0.5	166		
(Monday)	14:00	4.9	20	0.14	Ferric-chloride	40	0.5	163	7	4
	17:00	4.9	20	0.14	Ferric-chloride	40	0.5	163	4	< 4
December 7	13:00	4.9	20	0.14	Ferric-chloride	40	0.5	163	< 4	6
	16:00	4.9	20	0.14	Ferric-chloride	40	0.5	163	5	< 4
(Tuesday)	19:30	4.9	20	0.14	Ferric-chloride	40	0.5		5	< 4
	23:10	4.9	20	0.14	Ferric-chloride	40	0.5		< 4	< 4
December 8	01:00	4.9	20	0.14	Ferric-chloride	40	0.5	160	6	5
(Wednesday)	04:00	4.9	20	0.14	Ferric-chloride	40	0.5	160	5	< 4
	07:30	4.9	20	0.14	Ferric-chloride	40	0.5	160	< 4	< 4
	10:30	4.9	20	0.14	Ferric-chloride	40	0.5	160	5	< 4
	13:30	4.9	20	0.14	Ferric-chloride	40	0.5	160	7	4
	16:30	4.9	20	0.14	Ferric-chloride	40	0.5	160	7	4
	20:00	4.9	20	0.14	Ferric-chloride	40	0.5	160	6	4
	22:30	4.9	20	0.14	Ferric-chloride	40	0.5	160	6	4
December 9	01:00	4.9	20	0.14	Ferric-chloride	40	0.5	160	6	4
(Thursday)	06:30	4.9	20	0.14	Ferric-chloride	40	0.5	160	7	7
	10:00	4.9	20	0.14	Ferric-chloride	40	0.5	160	7	7
	13:30	4.9	20	0.14	Ferric-chloride	40	0.5	160	9	6
	16:00	4.9	20	0.14	Ferric-chloride	40	0.5	160	4	4
	16:30	4.9	20	0.14	Ferric-chloride	40	0.5	160	6	6
December 10	10:00	4.9	20	0.14	Ferric-chloride	40	0.5	155	7	6
(Friday)	13:00	4.9	20	0.14	Ferric-chloride	40	0.5	155	7	7
December 11		4.9	20	0.14	Ferric-chloride	40	0.5	155		
(Saturday)		4.9	20	0.14	Ferric-chloride	40	0.5	155		
December 12		4.9	20	0.14	Ferric-chloride	40	0.5			
(Sunday)		4.9	20	0.14	Ferric-chloride	40	0.5			
December 13		4.9	20	0.14	Ferric-chloride	40	0.5			
(Monday)		4.9	20	0.14	Ferric-chloride	40	0.5			
December 14	9:40	4.9	20	0.14	Ferric-chloride	40	0.5		9	6
(Tuesday)	12:45	4.9	20	0.14	Ferric-chloride	40	0.5	145	4	4
	16:00	4.9	20	0.14	Ferric-chloride	40	0.5	145	6	6
	22:15	4.9	20	0.14	Ferric-chloride	40	0.5	145	10	7
December 15	10:00	4.9	20	0.14	Ferric-chloride	40	0.5	145	9	7
(Wednesday)	13:00	4.9	20	0.14	Ferric-chloride	40	0.5	145	7	4
	15:30	4.9	20	0.14	Ferric-chloride	40	0.5		4	4
December 16	10:00	4.9	20	0.14	Ferric-chloride	40	0.5	147		
(Thursday)	11:00	4.9	20	0.14	Ferric-chloride	40	0.5		4	4
	14:30	4.9	20	0.14	Ferric-chloride	40	0.5		4	< 4
December 17	00:05	4.9	20	0.14	Ferric-chloride	40	0.5		5	< 4
(Friday)	08:45	4.9	20	0.14	Ferric-chloride	40	0.5		< 4	4
	12:00	4.9	20	0.14	Ferric-chloride	40	0.5	119	5	<
	15:00	4.9	20	0.14	Ferric-chloride	40	0.5	155	4	< 4
December 18	11:30	4.9	20	0.14	Ferric-chloride	40	0.5		4	< 4
(Saturday)	14:00	4.9	20	0.14	Ferric-chloride	40	0.5		7	4
December 19	11:30	4.9	20	0.14	Ferric-chloride	40	0.5	152	7	4
(Sunday)	15:30	4.9	20	0.14	Ferric-chloride	40	0.5	187	4	< 4
December 20	11:45	4.9	20	0.14	Ferric-chloride	40	0.5	157	< 4	< 4
(Monday)	15:00	4.9	20	0.14	Ferric-chloride	40	0.5	157	7	5
December 21	8:30	4.9	20	0.14	Ferric-chloride	40	0.5	157	5	4
(Tuesday)	14:00	4.9	20	0.14	Ferric-chloride	40	0.5	157	8	7
December 22	10:45	4.9	20	0.14	Ferric-chloride	40	0.5		5	5
(Wednesday)	15:00	4.9	20	0.14	Ferric-chloride	40	0.5		5	5
December 23	9:00	4.9	20	0.14	Ferric-chloride	40	0.5	261	13	8
(Thursday)	10:45	4.9	20	0.14	Ferric-chloride	40	0.5	261	7	5
AVERAGE								161	6	5

Notes: * *4.9 gpm/sq.ft. ≡ 1.7 gpm hydraulic filter loading*
** *projected lamella area*
♦ *lab duplicate*
♦♦ *filter duplicate*
Constant flocculation volume is 400 gallons

TABLE 3.11
Coded Design Matrix and System Responses
Demonstration Trials (December 4, 1999 to December 23, 1999)
North Test Site – 'GE' Filter

Date 1999	Time	Variable						Total Phosphorus Concentration (µg/L)		
		Hydraulic Filter Loading* (gpm/sq.ft.)	Coagulation Volume (gallons)	Clarifier Surface Loading** (gpm/sq.ft.)	Coagulant Type	Coagulant Dosage Concentration (mg/L as Fe)	Polymer (A-130) Dosage Concentration (mg/L)	Raw Water	Clarifier Effluent	Filtrate
December 4	16:00	4.9	20	0.14	Ferric-chloride	40	0.5	166		< 4
(Saturday)	19:00	4.9	20	0.14	Ferric-chloride	40	0.5	166	5	< 4
December 5	12:30	4.9	20	0.14	Ferric-chloride	40	0.5	166	8	5
(Sunday)		4.9	20	0.14	Ferric-chloride	40	0.5	166		
December 6	10:00	4.9	20	0.14	Ferric-chloride	40	0.5	166		
(Monday)	14:00	4.9	20	0.14	Ferric-chloride	40	0.5	163	7	< 4
	17:00	4.9	20	0.14	Ferric-chloride	40	0.5	163	4	< 4
December 7	13:00	4.9	20	0.14	Ferric-chloride	40	0.5	163	< 4	5
	16:00	4.9	20	0.14	Ferric-chloride	40	0.5	163	5	< 4
(Tuesday)	19:30	4.9	20	0.14	Ferric-chloride	40	0.5		5	< 4
	23:10	4.9	20	0.14	Ferric-chloride	40	0.5		< 4	< 4
December 8	01:00	4.9	20	0.14	Ferric-chloride	40	0.5	160	6	< 4
(Wednesday)	04:00	4.9	20	0.14	Ferric-chloride	40	0.5	160	5	< 4
	07:30	4.9	20	0.14	Ferric-chloride	40	0.5	160	< 4	< 4
	10:30	4.9	20	0.14	Ferric-chloride	40	0.5	160	5	< 4
	13:30	4.9	20	0.14	Ferric-chloride	40	0.5	160	7	4
	16:30	4.9	20	0.14	Ferric-chloride	40	0.5	160	7	4
	20:00	4.9	20	0.14	Ferric-chloride	40	0.5	160	6	< 4
	22:30	4.9	20	0.14	Ferric-chloride	40	0.5	160	6	< 4
December 9	01:00	4.9	20	0.14	Ferric-chloride	40	0.5	160	6	< 4
(Thursday)	06:30	4.9	20	0.14	Ferric-chloride	40	0.5	160	7	4
	10:00	4.9	20	0.14	Ferric-chloride	40	0.5	160	7	< 4
	13:30	4.9	20	0.14	Ferric-chloride	40	0.5	160	9	4
	16:00	4.9	20	0.14	Ferric-chloride	40	0.5	160	4	4
	16:30	4.9	20	0.14	Ferric-chloride	40	0.5	160	6	7
December 10	10:00	4.9	20	0.14	Ferric-chloride	40	0.5	155	7	4
(Friday)	13:00	4.9	20	0.14	Ferric-chloride	40	0.5	155	7	4
December 11		4.9	20	0.14	Ferric-chloride	40	0.5	155		
(Saturday)		4.9	20	0.14	Ferric-chloride	40	0.5	155		
December 12		4.9	20	0.14	Ferric-chloride	40	0.5			
(Sunday)		4.9	20	0.14	Ferric-chloride	40	0.5			
December 13		4.9	20	0.14	Ferric-chloride	40	0.5			
(Monday)		4.9	20	0.14	Ferric-chloride	40	0.5			
December 14	9:40	4.9	20	0.14	Ferric-chloride	40	0.5		9	4
(Tuesday)	12:45	4.9	20	0.14	Ferric-chloride	40	0.5	145	4	< 4
	16:00	4.9	20	0.14	Ferric-chloride	40	0.5	145	6	6
	22:15	4.9	20	0.14	Ferric-chloride	40	0.5	145	10	4
December 15	10:00	4.9	20	0.14	Ferric-chloride	40	0.5	145	9	6
(Wednesday)	13:00	4.9	20	0.14	Ferric-chloride	40	0.5	145	7	< 4
	15:30	4.9	20	0.14	Ferric-chloride	40	0.5		4	4
December 16	10:00	4.9	20	0.14	Ferric-chloride	40	0.5	147		
(Thursday)	11:00	4.9	20	0.14	Ferric-chloride	40	0.5		4	< 4
	14:30	4.9	20	0.14	Ferric-chloride	40	0.5		4	< 4
December 17	00:05	4.9	20	0.14	Ferric-chloride	40	0.5		5	< 4
(Friday)	08:45	4.9	20	0.14	Ferric-chloride	40	0.5		< 4	4
	12:00	4.9	20	0.14	Ferric-chloride	40	0.5	119	5	4
	15:00	4.9	20	0.14	Ferric-chloride	40	0.5	155	4	< 4
December 18	11:30	4.9	20	0.14	Ferric-chloride	40	0.5		4	<4
(Saturday)	14:00	4.9	20	0.14	Ferric-chloride	40	0.5		7	4
December 19	11:30	4.9	20	0.14	Ferric-chloride	40	0.5	152	7	< 4
(Sunday)	15:30	4.9	20	0.14	Ferric-chloride	40	0.5	187	4	< 4
December 20	11:45	4.9	20	0.14	Ferric-chloride	40	0.5	157	< 4	< 4
(Monday)	15:00	4.9	20	0.14	Ferric-chloride	40	0.5	157	7	5
December 21	8:30	4.9	20	0.14	Ferric-chloride	40	0.5	157	5	5
(Tuesday)	14:00	4.9	20	0.14	Ferric-chloride	40	0.5	157	8	5
December 22	10:45	4.9	20	0.14	Ferric-chloride	40	0.5		5	8
(Wednesday)	15:00	4.9	20	0.14	Ferric-chloride	40	0.5		5	5
December 23	9:00	4.9	20	0.14	Ferric-chloride	40	0.5	261	13	7
(Thursday)	10:45	4.9	20	0.14	Ferric-chloride	40	0.5	261	7	7
AVERAGE								161	6	4

Notes: * *4.9 gpm/sq.ft. ≡ 1.7 gpm hydraulic filter loading*
** *projected lamella area*
♦ *lab duplicate*
♦♦ *filter duplicate*
Constant flocculation volume is 400 gallons

TABLE 3.12
Coded Design Matrix and System Responses
Demonstration Trials (December 4, 1999 to December 23, 1999)
South Test Site – 'Swiss' Filter

Date 1999	Time	Variable						Total Phosphorus Concentration (µg/L)		
		Hydraulic Filter Loading* (gpm/sq.ft.)	Coagulation Volume (gallons)	Clarifier Surface Loading** (gpm/sq.ft.)	Coagulant Type	Coagulant Dosage Concentration (mg/L as Al)	Polymer (A-130) Dosage Concentration (mg/L)	Raw Water	Clarifier Effluent	Filtrate
December 4	16:15	9.8	20	0.28	alum	20	0.5	14	8	6
(Saturday)	18:00	9.8	20	0.28	alum	20	0.5	14	6	6
December 5		9.8	20	0.28	alum	20	0.5	14		
(Sunday)		9.8	20	0.28	alum	20	0.5	14		
December 6	10:00	9.8	20	0.28	alum	20	0.5	14		
(Monday)	15:00	9.8	20	0.28	alum	20	0.5	19	4	< 4
	18:00	9.8	20	0.28	alum	20	0.5	19	4	4
December 7	09:30	9.8	20	0.28	alum	20	0.5	19	4	4
(Tuesday)	12:30	9.8	20	0.28	alum	20	0.5	21	< 4	4
	15:30	9.8	20	0.28	alum	20	0.5	21	< 4	< 4
	18:45	9.8	20	0.28	alum	20	0.5	21	< 4	< 4
	21:30	9.8	20	0.28	alum	20	0.5	21	< 4	< 4
December 8	00:30	9.8	20	0.28	alum	20	0.5	21	5	< 4
(Wednesday)	03:30	9.8	20	0.28	alum	20	0.5	21	< 4	< 4
	07:00	9.8	20	0.28	alum	20	0.5	21	< 4	< 4
	10:30	9.8	20	0.28	alum	20	0.5	21	< 4	< 4
	13:30	9.8	20	0.28	alum	20	0.5	21	6	5••
	16:00	9.8	20	0.28	alum	20	0.5	22	6	4
	19:20	9.8	20	0.28	alum	20	0.5	22	6	6
	22:00	9.8	20	0.28	alum	20	0.5	22	7	6
December 9	04:00	9.8	20	0.28	alum	20	0.5	22	6	6
(Thursday)	07:00	9.8	20	0.28	alum	20	0.5	22	6	6
	10:30	9.8	20	0.28	alum	20	0.5	22	7	4
	16:30	9.8	20	0.28	alum	20	0.5	21	4	< 4
December 10	12:00	9.8	20	0.28	alum	20	0.5	21	7	
(Friday)	13:00	9.8	20	0.28	alum	20	0.5	21	6	4
	16:00	9.8	20	0.28	alum	20	0.5	16	7	6
December 11		9.8	20	0.28	alum	20	0.5	16		
(Saturday)		9.8	20	0.28	alum	20	0.5	16		
December 12		9.8	20	0.28	alum	20	0.5	16		
(Sunday)		9.8	20	0.28	alum	20	0.5			
December 13		9.8	20	0.28	alum	20	0.5			
(Monday)		9.8	20	0.28	alum	20	0.5			
December 14	10:15	9.8	20	0.28	alum	20	0.5		7	4
(Tuesday)	15:10	9.8	20	0.28	alum	20	0.5		7	6
	21:00	9.8	20	0.28	alum	20	0.5		9	9
December 15	12:00	9.8	20	0.28	alum	20	0.5	26	7	7
(Wednesday)	15:00	9.8	20	0.28	alum	20	0.5	26	7	7
	16:30	9.8	20	0.28	alum	20	0.5	26	6	6
December 16	10:00	9.8	20	0.28	alum	20	0.5	22		
	12:10	9.8	20	0.28	alum	20	0.5	22	7	7
(Thursday)	15:10	9.8	20	0.28	alum	20	0.5	22	7	6
	17:45	9.8	20	0.28	alum	20	0.5	22	7	5
December 17	00:45	9.8	20	0.28	alum	20	0.5	22	7	7
(Friday)	09:50	9.8	20	0.28	alum	20	0.5		5	5
	10:00	9.8	20	0.28	alum	20	0.5	22		
	12:00	9.8	20	0.28	alum	20	0.5		8	8
	14:00	9.8	20	0.28	alum	20	0.5	24	5	5
December 18	13:00	9.8	20	0.28	alum	20	0.5		5	5
(Saturday)		9.8	20	0.28	alum	20	0.5		5	
December 19	12:30	9.8	20	0.28	alum	20	0.5	28	4	5
(Sunday)	15:00	9.8	20	0.28	alum	20	0.5		4	5
December 20	10:30	9.8	20	0.28	alum	20	0.5		4	5
(Monday)	15:00	9.8	20	0.28	alum	20	0.5		4	4
December 21		9.8	20	0.28	alum	20	0.5			
(Tuesday)		9.8	20	0.28	alum	20	0.5			
December 22	13:30	9.8	20	0.28	alum	20	0.5		8	5
(Wednesday)	16:30	9.8	20	0.28	alum	20	0.5	25	8	4
December 23	8:50	9.8	20	0.28	alum	20	0.5	25	5	7
(Thursday)	12:00	9.8	20	0.28	alum	20	0.5		10	7
AVERAGE								26	6	5

Notes:
* *9.8 gpm/sq.ft. ≡ 3.4 gpm hydraulic filter loading*
** *projected lamella area*
• *lab duplicate*
•• *filter duplicate*
Constant flocculation volume is 400 gallons

TABLE 3.13
Coded Design Matrix and System Responses
Demonstration Trials (December 4, 1999 to December 23, 1999)
South Test Site – 'GE' Filter

Date 1999	Time	Variable						Total Phosphorus Concentration (µg/L)		
		Hydraulic Filter Loading* (gpm/sq.ft.)	Coagulation Volume (gallons)	Clarifier Surface Loading** (gpm/sq.ft.)	Coagulant Type	Coagulant Dosage Concentration (mg/L as Al)	Polymer (A-130) Dosage Concentration (mg/L)	Raw Water	Clarifier Effluent	Filtrate
December 4	16:15	9.8	20	0.28	alum	20	0.5	14	8	8
(Saturday)	18:00	9.8	20	0.28	alum	20	0.5	14	6	5
December 5		9.8	20	0.28	alum	20	0.5	14		
(Sunday)		9.8	20	0.28	alum	20	0.5	14		
December 6	10:00	9.8	20	0.28	alum	20	0.5	14		
(Monday)	15:00	9.8	20	0.28	alum	20	0.5	19	4	4
	18:00	9.8	20	0.28	alum	20	0.5	19	4	< 4
December 7	09:30	9.8	20	0.28	alum	20	0.5	19	4	< 4
(Tuesday)	12:30	9.8	20	0.28	alum	20	0.5	21	< 4	< 4
	15:30	9.8	20	0.28	alum	20	0.5	21	< 4	< 4
	18:45	9.8	20	0.28	alum	20	0.5	21	< 4	< 4
	21:30	9.8	20	0.28	alum	20	0.5	21	< 4	< 4
December 8	00:30	9.8	20	0.28	alum	20	0.5	21	5	< 4
(Wednesday)	03:30	9.8	20	0.28	alum	20	0.5	21	< 4	< 4
	07:00	9.8	20	0.28	alum	20	0.5	21	< 4	< 4
	10:30	9.8	20	0.28	alum	20	0.5	21	< 4	9
	13:30	9.8	20	0.28	alum	20	0.5	21	6	< 4
	16:00	9.8	20	0.28	alum	20	0.5	22	6	6
	19:20	9.8	20	0.28	alum	20	0.5	22	6	6
	22:00	9.8	20	0.28	alum	20	0.5	22	7	7
December 9	04:00	9.8	20	0.28	alum	20	0.5	22	6	
(Thursday)	07:00	9.8	20	0.28	alum	20	0.5	22	6	
	10:30	9.8	20	0.28	alum	20	0.5	22	7	
	16:30	9.8	20	0.28	alum	20	0.5	21	4	
December 10	12:00	9.8	20	0.28	alum	20	0.5	21	7	6
(Friday)	13:00	9.8	20	0.28	alum	20	0.5	21	6	4
	16:00	9.8	20	0.28	alum	20	0.5	16	7	6
December 11		9.8	20	0.28	alum	20	0.5	16		
(Saturday)		9.8	20	0.28	alum	20	0.5	16		
December 12		9.8	20	0.28	alum	20	0.5	16		
(Sunday)		9.8	20	0.28	alum	20	0.5			
December 13		9.8	20	0.28	alum	20	0.5			
(Monday)		9.8	20	0.28	alum	20	0.5			
December 14	10:15	9.8	20	0.28	alum	20	0.5		7	4
(Tuesday)	15:10	9.8	20	0.28	alum	20	0.5		7	7
	21:00	9.8	20	0.28	alum	20	0.5		9	9
December 15	12:00	9.8	20	0.28	alum	20	0.5	26	7	7
(Wednesday)	15:00	9.8	20	0.28	alum	20	0.5	26	7	7
	16:30	9.8	20	0.28	alum	20	0.5	26	6	7
December 16	10:00	9.8	20	0.28	alum	20	0.5	22		
	12:10	9.8	20	0.28	alum	20	0.5	22	7	7
(Thursday)	15:10	9.8	20	0.28	alum	20	0.5	22	7	5
	17:45	9.8	20	0.28	alum	20	0.5	22	7	7
December 17	00:45	9.8	20	0.28	alum	20	0.5	22	7	7
(Friday)	09:50	9.8	20	0.28	alum	20	0.5		5	5
	10:00	9.8	20	0.28	alum	20	0.5	22		
	12:00	9.8	20	0.28	alum	20	0.5		8	5
	14:00	9.8	20	0.28	alum	20	0.5	24	5	7
December 18	13:00	9.8	20	0.28	alum	20	0.5		5	4
(Saturday)		9.8	20	0.28	alum	20	0.5		5	5
December 19	12:30	9.8	20	0.28	alum	20	0.5	28	4	5
(Sunday)	15:00	9.8	20	0.28	alum	20	0.5		4	4
December 20	10:30	9.8	20	0.28	alum	20	0.5		4	5
(Monday)	15:00	9.8	20	0.28	alum	20	0.5		4	7
December 21		9.8	20	0.28	alum	20	0.5			
(Tuesday)		9.8	20	0.28	alum	20	0.5			
December 22	13:30	9.8	20	0.28	alum	20	0.5		8	7
(Wednesday)	16:30	9.8	20	0.28	alum	20	0.5	25	8	7
December 23	8:50	9.8	20	0.28	alum	20	0.5	25	5	5
(Thursday)	12:00	9.8	20	0.28	alum	20	0.5		10	11
AVERAGE								26	6	6

Notes: * *9.8 gpm/sq.ft. ≡ 3.4 gpm hydraulic filter loading*
♦ *lab duplicate*
♦♦ *filter duplicate*
** *projected lamella area*
Constant flocculation volume is 400 gallons

TABLE 3.14
SUMMARY OF DEMONSTRATION TEST RESULTS

	METHOD DETECTION LIMIT	Post-BMP ENR Influent				Post-STA ENR Effluent			
		I1	C1	F1A	F1B	I2	C2	F2A	F2C
Alkalinity (mg/L as $CaCO_3$)	**1.0**	*mg/L*	*mg/L*	*mg/L*	*mg/L*	*mg/L*	*mg/L*	*mg/L*	*mg/L*
Mean		129	38	45	43	220	114	133	114
Max		203	66	68	68	244	132	200	128
Min		106	12	28	26	210	100	104	100
N		13	5	5	5	9	4	5	5
S.D.		26	21	17	18	12	15	38	11
Aluminum	**0.05**	*mg/L*	*mg/L*	*mg/L*	*mg/L*	*mg/L*	*mg/L*	*mg/L*	*mg/L*
Mean		0.82	0.06	0.05	0.05	0.12	1.0	0.63	0.49
Max		0.96	0.08	0.05	0.05	0.40	1.6	1.2	1.1
Min		0.57	0.05	0.05	0.05	0.05	0.61	0.35	0.13
N		7	4	5	5	8	7	7	7
S.D.		0.17	0.01	0	0	0.14	0.32	0.33	0.33
Ammonia	**0.01**	*mg/L*	*mg/L*	*mg/L*	*mg/L*	*mg/L*	*mg/L*	*mg/L*	*mg/L*
Mean		0.045	0.089	0.081	0.087	0.036	0.028	0.028	0.027
Max		0.078	0.120	0.110	0.120	0.057	0.032	0.034	0.037
Min		0.010	0.046	0.041	0.034	0.023	0.021	0.025	0.021
N		7	5	6	5	8	5	5	6
S.D.		0.026	0.029	0.024	0.033	0.012	0.005	0.004	0.006
Boron	**5.0**	*ug/L*	*ug/L*	*ug/L*	*ug/L*	*ug/L*	*ug/L*	*ug/L*	*ug/L*
Mean		61	64	65	65	96	95	94	93
Max		67	71	75	74	108	105	106	102
Min		53	56	56	56	91	90	89	89
N		6	5	5	5	7	5	5	5
S.D.		5	5	7	6	6	6	8	5

TABLE 3.14
SUMMARY OF DEMONSTRATION TEST RESULTS

		METHOD DETECTION LIMIT	Post-BMP ENR Influent				Post-STA ENR Effluent			
			I1	C1	F1A	F1B	I2	C2	F2A	F2C
Calcium		**0.10**	*mg/L*	*mg/L*	*mg/L*	*mg/L*	*mg/L*	*mg/L*	*mg/L*	*mg/L*
	Mean		46	47	48	47	69	68	68	67
	Max		51	48	50	49	78	77	78	75
	Min		39	44	45	45	64	65	62	63
	N		6	5	5	5	7	5	5	5
	S.D.		4	2	2	2	5	5	6	4
Chloride		**0.20**	*mg/L*	*mg/L*	*mg/L*	*mg/L*	*mg/L*	*mg/L*	*mg/L*	*mg/L*
	Mean		64	146	148	148	151	150	150	152
	Max		77	190	190	190	180	180	180	180
	Min		52	130	130	130	140	140	140	140
	N		6	5	5	5	7	5	5	5
	S.D.		9	25	25	25	15	17	17	16
Cobalt		**0.70**	*ug/L*	*ug/L*	*ug/L*	*ug/L*	*ug/L*	*ug/L*	*ug/L*	*ug/L*
	Mean		0.7	0.8	0.9	0.9	0.7	0.7	0.7	0.7
	Max		0.7	1.2	1.1	1.2	0.7	0.7	0.7	0.7
	Min		0.7	0.7	0.7	0.7	0.7	0.7	0.7	0.7
	N		6	5	5	5	7	5	5	5
	S.D.		0	0.2	0.1	0.2	0	0	0	0
Copper		**2.0**	*ug/L*	*ug/L*	*ug/L*	*ug/L*	*ug/L*	*ug/L*	*ug/L*	*ug/L*
	Mean		2.1	4.2	3.9	4.0	2.6	2.1	2.0	2.0
	Max		2.3	5.2	5.0	4.8	6.0	2.7	2.0	2.0
	Min		2.0	3.1	2.2	2.9	2.0	2.0	2.0	2.0
	N		6	5	5	5	7	5	5	5
	S.D.		0.1	0.8	1.2	0.8	1.5	0.3	0	0

TABLE 3.14
SUMMARY OF DEMONSTRATION TEST RESULTS

	METHOD DETECTION LIMIT	Post-BMP ENR Influent				Post-STA ENR Effluent			
		I1	C1	F1A	F1B	I2	C2	F2A	F2C
Iron	**0.01**	*mg/L*	*mg/L*	*mg/L*	*mg/L*	*mg/L*	*mg/L*	*mg/L*	*mg/L*
Mean		2.2	0.81	0.29	0.23	0.07	0.12	0.11	0.10
Max		8.9	1.2	1.2	0.33	0.321	0.17	0.16	0.14
Min		0.9	0.62	0.05	0.17	0.012	0.07	0.06	0.05
N		8	5	8	5	9	5	3	5
S.D.		2.7	0.21	0.40	0.07	0.10	0.04	0.05	0.03
Lead	**2.0**	*ug/L*	*ug/L*	*ug/L*	*ug/L*	*ug/L*	*ug/L*	*ug/L*	*ug/L*
Mean		2.2	2.0	2.0	2.0	2.0	2.0	2.0	2.0
Max		2.3	2.0	2.0	2.0	2.0	2.0	2.0	2.0
Min		2	2.0	2.0	2.0	2.0	2.0	2.0	2.0
N		2	2	2	2	2	2	2	2
S.D.		0.21	0	0	0	0	0	0	0
Magnesium	**0.012**	*mg/L*	*mg/L*	*mg/L*	*mg/L*	*mg/L*	*mg/L*	*mg/L*	*mg/L*
Mean		13	13	13	13	21	20	20	20
Max		15	14	14	14	24	24	25	24
Min		11	11	12	12	18	19	18	18
N		6	5	5	5	7	5	5	5
S.D.		1.2	0.9	0.9	0.8	2.4	2.2	2.6	2.1
Manganese	**0.25**	*ug/L*	*ug/L*	*ug/L*	*ug/L*	*ug/L*	*ug/L*	*ug/L*	*ug/L*
Mean		19	129	128	128	4.9	4.4	4.4	4.4
Max		26	171	175	171	5.9	4.9	4.9	5.0
Min		12	104	101	101	3.3	3.6	3.8	3.6
N		6	5	5	5	7	5	5	5
S.D.		5.1	27	30	28	0.9	0.5	0.5	0.5

TABLE 3.14
SUMMARY OF DEMONSTRATION TEST RESULTS

	METHOD DETECTION LIMIT	Post-BMP ENR Influent				Post-STA ENR Effluent			
		I1	C1	F1A	F1B	I2	C2	F2A	F2C
Mercury	**0.10**	*ug/L*	*ug/L*	*ug/L*	*ug/L*	*ug/L*	*ug/L*	*ug/L*	*ug/L*
Mean		0.10	0.10	0.10	0.10	0.10	0.10	0.10	0.10
Max		0.10	0.10	0.10	0.10	0.10	0.10	0.10	0.10
Min		0.10	0.10	0.10	0.10	0.10	0.10	0.10	0.10
N		6	5	5	5	7	5	5	5
S.D.		0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Molybdenum	**1.0**	*ug/L*	*ug/L*	*ug/L*	*ug/L*	*ug/L*	*ug/L*	*ug/L*	*ug/L*
Mean		1.4	1.1	1.1	1.1	1.2	1.1	1.4	1.4
Max		2.0	1.4	1.3	1.4	1.7	1.5	2.0	1.6
Min		1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0
N		6	5	5	5	7	5	5	5
S.D.		0.37	0.17	0.13	0.18	0.25	0.22	0.39	0.26
Nickel	**1.3**	*ug/L*	*ug/L*	*ug/L*	*ug/L*	*ug/L*	*ug/L*	*ug/L*	*ug/L*
Mean		1.3	5.65	5.95	5.2	1.3	1.3	1.3	1.3
Max		1.3	6.4	6.8	6	1.3	1.3	1.3	1.3
Min		1.3	4.9	5.1	4.4	1.3	1.3	1.3	1.3
N		2	2	2	2	2	2	2	2
S.D.		0	1.1	1.2	1.1	0	0	0	0
NO_2NO_3-N	**0.004**	*mg N/L*	*mg N/L*	*mg N/L*	*mg/L*	*mg N/L*	*mg N/L*	*mg N/L*	*mg N/L*
Mean		0.54	0.53	0.56	0.55	0.06	0.06	0.06	0.06
Max		0.58	0.56	0.59	0.59	0.08	0.08	0.07	0.08
Min		0.49	0.49	0.52	0.52	0.04	0.05	0.05	0.05
N		6	5	5	5	7	5	5	5
S.D.		0.03	0.03	0.03	0.03	0.01	0.01	0.01	0.01

TABLE 3.14
SUMMARY OF DEMONSTRATION TEST RESULTS

	METHOD DETECTION LIMIT	Post-BMP ENR Influent				Post-STA ENR Effluent			
		I1	C1	F1A	F1B	I2	C2	F2A	F2C
Potassium	**0.01**	*mg/L*	*mg/L*	*mg/L*	*mg/L*	*mg/L*	*mg/L*	*mg/L*	*mg/L*
Mean		5.0	5.2	5.2	5.2	8.3	8.2	8.2	8.1
Max		5.5	5.8	5.9	5.9	9.3	9.2	9.4	9.0
Min		4.5	4.7	4.8	4.8	7.8	7.9	7.7	7.8
N		6	5	5	5	7	5	5	5
S.D.		0.4	0.5	0.4	0.4	0.6	0.5	0.7	0.5
Reactive Silica	**0.30**	*mg SiO2/L*	*mg SiO2/L*	*mg SiO2/L*	*mg SiO2/L*	*mg SiO2/L*	*mg SiO2/L*	*mg SiO2/L*	*mg SiO2/L*
Mean		13	12	12	12	15	13	13	13
Max		15	14	14	14	18	17	16	17
Min		12	11	11	11	13	12	12	12
N		6	5	5	5	7	5	5	5
S.D.		1.1	1.2	1.2	1.2	2.2	2.2	1.6	2.1
Selenium	**3.0**	*ug/L*	*ug/L*	*ug/L*	*ug/L*	*ug/L*	*ug/L*	*ug/L*	*ug/L*
Mean		3.7	3.0	3.0	3.0	3.0	3.0	3.0	3.0
Max		7.0	3.0	3.0	3.0	3.0	3.0	3.0	3.0
Min		3.0	3.0	3.0	3.0	3.0	3.0	3.0	3.0
N		6	5	5	5	7	5	5	5
S.D.		1.6	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Sodium	**0.30**	*mg/L*	*mg/L*	*mg/L*	*mg/L*	*mg/L*	*mg/L*	*mg/L*	*mg/L*
Mean		40	50	50	50	103	101	101	99
Max		53	65	66	64	121	118	119	115
Min		31	39	39	39	93	95	91	93
N		6	5	5	5	7	5	5	5
S.D.		8	10	11	10	12	10	11	9

TABLE 3.14
SUMMARY OF DEMONSTRATION TEST RESULTS

	METHOD DETECTION LIMIT	Post-BMP ENR Influent				Post-STA ENR Effluent			
		I1	C1	F1A	F1B	I2	C2	F2A	F2C
Sulfate	**0.20**	*mg/L*	*mg/L*	*mg/L*	*mg/L*	*mg/L*	*mg/L*	*mg/L*	*mg/L*
Mean		36	39	39	39	50	164	166	166
Max		39	44	43	44	62	200	200	200
Min		33	35	36	35	43	140	150	150
N		6	5	5	5	7	5	5	5
S.D.		1.9	3.4	2.9	3.9	7.4	23	21	21
TKN	**0.06**	*mg/L*	*mg/L*	*mg/L*	*mg/L*	*mg/L*	*mg/L*	*mg/L*	*mg/L*
Mean		1.6	1.6	1.6	1.6	1.6	1.6	1.6	1.6
Max		2.1	2.1	2.1	2.1	2.1	2.1	2.1	2.1
Min		1.1	1.1	1.1	1.1	1.1	1.1	1.1	1.1
N		7	7	7	7	7	7	7	7
S.D.		0.4	0.4	0.4	0.4	0.4	0.4	0.4	0.4
Total Dissolved Solids	**0.50**	*mg/L*	*mg/L*	*mg/L*	*mg/L*	*mg/L*	*mg/L*	*mg/L*	*mg/L*
Mean		308	357	353	354	581	587	596	579
Max		343	423	433	412	688	705	698	707
Min		278	303	298	288	524	537	551	533
N		6	5	5	5	7	5	5	5
S.D.		23	44	50	44	59	71	61	75
Total Organic Carbon	**2.75**	*mg/L*	*mg/L*	*mg/L*	*mg/L*	*mg/L*	*mg/L*	*mg/L*	*mg/L*
Mean		18	8.0	7.2	8.0	29	17	13	11
Max		30	14	14	20	37	30	14	13
Min		4.5	4.4	4.4	4.1	13	12	12	3.9
N		13	5	5	5	9	5	5	5
S.D.		5.6	3.5	3.9	6.7	6.6	7.7	1.1	3.8

TABLE 3.14
SUMMARY OF DEMONSTRATION TEST RESULTS

	METHOD DETECTION LIMIT	Post-BMP ENR Influent				Post-STA ENR Effluent			
		I1	C1	F1A	F1B	I2	C2	F2A	F2C
Total Suspended Solids	**0.50**	*mg/L*	*mg/L*	*mg/L*	*mg/L*	*mg/L*	*mg/L*	*mg/L*	*mg/L*
Mean		27	0.8	0.5	0.5	5	3.3	0.7	0.7
Max		68	1.1	0.5	0.5	21	4.0	1.2	0.8
Min		11	0.5	0.5	0.5	0.6	2.4	0.5	0.6
N		11	3	3	3	7	3	3	3
S.D.		17	0.3	0	0	7.8	0.8	0.4	0.1
Vanadium	**0.50**	*ug/L*	*ug/L*	*ug/L*	*ug/L*	*ug/L*	*ug/L*	*ug/L*	*ug/L*
Mean		3.2	0.5	0.5	0.5	0.5	4.4	4.2	4.0
Max		3.5	1	0.5	0.5	0.5	5.0	5.1	4.7
Min		2.7	0.5	0.5	0.5	0.5	3.3	3.5	3.3
N		6	5	5	5	7	5	5	5
S.D.		0.3	0	0	0	0	0.68	0.58	0.50
Zinc	**10.0**	*ug/L*	*ug/L*	*ug/L*	*ug/L*	*ug/L*	*ug/L*	*ug/L*	*ug/L*
Mean		10	10	10	10	10	10	10	10
Max		10	10	10	10	10	10	10	10
Min		10	10	10	10	10	10	10	10
N		6	5	5	5	7	5	5	5
S.D.		0.0	0.0	0	0	0	0	0	0

Notes: 1. *Nitrogen forms reported as mg/L as N.*

2. *I1 = Influent samples at the Post-BMP (North Test) Site.*
C1 = Clarifier effluent samples at the Post-BMP (North Test) Site.
F1A = 'GE' filtrate samples at the Post-BMP (North Test) Site.
F1B = 'Swiss' filtrate samples at the Post-BMP (North Test) Site.
I2 = Influent samples at the Post-STA (South Test) Site.
C2 = Clarifier effluent samples at the Post-STA (South Test) Site.
F2A = 'Swiss' filtrate samples at the Post-STA (South Test) Site.
F2C = 'GE' filtrate samples at the Post-STA (South Test) Site.

TABLE 3.15
Analytical Field Data - Demonstration Testing Summary

	Post-BMP ENR Influent				Post-STA ENR Effluent			
	I1	**C1**	**F1A**	**F1B**	**I2**	**C2**	**F2A**	**F2C**
Color	*color units*	*color units*	*color units*	*color units*	*color units*	*color units*	*color units*	*color units*
Mean	153	22	12	13	113	69	61	64
Max	236	60	38	37	144	434	369	350
Min	82	<1	<1	<1	89	3	6	11
N	14	9	9	9	15	15	15	14
S.D.	42	21	14	13	18	142	118	119
Conductivity	*micro S*	*micro S*	*micro S*	*micro S*	*micro S*	*micro S*	*micro S*	*micro S*
Mean	578	625	616	625	1091	1083	1079	1076
Max	763	803	811	806	1465	1226	1228	1232
Min	456	529	540	539	919	952	955	954
N	17	11	11	11	17	17	17	16
S.D.	83	70	74	74	168	94	94	97
pH	*pH*	*pH*	*pH*	*pH*	*pH*	*pH*	*pH*	*pH*
Mean	6.8	6.0	6.0	6.0	7.1	6.4	6.4	6.5
Max	7.5	6.6	6.5	6.7	7.6	7.2	7.2	7.2
Min	6.2	5.7	5.6	5.4	6.5	5.8	5.8	5.8
N	17	12	12	13	18	18	18	17
S.D.	0.39	0.31	0.29	0.37	0.28	0.42	0.34	0.42
Turbidity	*NTU*	*NTU*	*NTU*	*NTU*	*NTU*	*NTU*	*NTU*	*NTU*
Mean	26	1.7	0.59	0.68	0.76	5.5	4.2	4.0
Max	53	6.1	2.3	2.2	1.9	24	21	21
Min	14	0.27	0.08	0.09	0.42	0.25	0.38	0.45
N	17	11	11	11	17	17	17	16
S.D.	10	2.0	0.76	0.73	0.40	8.5	7.1	6.9

Note: One color value (35) was deleted from the mean and considered an outlier.

TABLE 3.16

MEAN SFWMD LOW LEVEL MERCURY WATER QUALITY RESULTS

Test Site	Feed				Filtrate				Solids	
	THg UF	MeHg UF	THg F	MeHg F	THg UF	MeHg UF	THg F	MeHg F	THg UF	MeHg UF
North	6.176	0.132	0.883	0.052	0.306	0.045	0.313	0.048	81.06	0.861
South	1.352	0.045	0.578	0.045	0.500	0.045	0.400	0.045	7.994	0.113

Notes: 1. *All units in nanograms/liter (ng/L)*

2. *THg UF = total mercury unfiltered; MeHg UF = methyl mercury unfiltered; THg F = total mercury filtered; MeHg F = methyl mercury filtered*
3. *North Site feed total mercury filtered result from 12/20 (63.77 ng/L) appeared to be an outlier and was not used in calculating the mean.*

TABLE 3.17
TOXICITY AND AGP TESTING SUMMARY

Process	Test Date	Laboratory	Sample ID	Sample Description	Algal Growth Potential[1]	Chronic Tests		
						fish	waterflea	algae
DAF (Leopold)	10/26/99	FDEP	I1	North feed	51.091	IC20-41.4%	no effect	no effect
			F2-DAF	North filtrate	1.353	IC20-76.2%	no effect	no effect
ACTIFLO (Kruger)	11/15/99	FDEP	LK	South feed	0.306	no effect	no effect	no effect
			CLK	South filtrate	0.100	no effect	IC20-76.13%	no effect
CTSS	11/29/99	FDEP	096-I1	North feed	18.978	no effect	no effect	no effect
			096-F1A	North filtrate	0.100	no effect	IC20=73.4%[2]	no effect
			096-I2	South feed	0.116	no effect	no effect	no effect
			096-F2C	South filtrate	0.131	no effect	IC20-59.5%[2]	no effect
	12/7/99	FDEP	102-I2	South feed	0.102	no effect	no effect	no effect
			102-F2C	South filtrate	0.100	no effect	no effect	no effect
	12/7/99	Hydrosphere	102-I1	North feed	1[3]	significantly reduced survival	significantly reduced reproduction but not survival	significantly reduced growth
			102-F1A	North filtrate	-1[3]	no effect	no effect	no effect
MicroMag	12/9/99	Hydrosphere	MIT-I	South feed	no effect	no effect	no effect	no effect
			MIT-E	South filtrate	no effect	no effect	no effect	no effect
	12/21/99	Hydrosphere	MIT-I	North feed	no effect	significantly reduced survival and growth	significantly reduced reproduction but not survival	no effect
			MIT-E	North filtrate	no effect	significantly reduced survival and growth	no effect	no effect

Notes:

1. *Algal Growth Potential is in milligrams dry weight per liter.*
2. *IC20 is the concentration of sample which afffected reproduction in 20% of the population.*
3. *The laboratory control produced an average maximum standing crop (MSC) of 117 mg/L. Samples produced similar MSC's of -1 and 1 mg/L.*

TABLE 3.18
TOXICITY CHARACTERISTIC LEACHING PROCEDURE

TCLP Analysis - The Toxicity Characteristic Leaching Procedure (TCLP) is used to characterize wastes as hazardous or non-hazardous based on the Toxicity Characteristic Rule published in the Federal Register (40CFR 261.24) in 1990. The rule lists 39 toxic substances and maximum concentrations for each.

The table below lists the federal limits for the Toxicity Rule and the results of samples collected on December 14, 1999, from the North Test Site (Post-BMP) using ferric chloride and the South Test Site (Post-STA) using alum.

PARAMETERS	EPA METHOD REFERENCE	FEDERAL LIMITS (mg/L)	N.Sludge-Fe (mg/L)	S.Sludge-Al (mg/L)	REPORTING LIMIT (mg/L)
Metals (mg/L):					
Arsenic	6010	5.0	<0.04	<0.04	0.04
Barium	6010	100.0	0.75*	0.30	0.3
Cadmium	6010	1.0	<0.009	<0.009	0.009
Chromium	6010	5.0	<0.032	<0.032	0.032
Lead	6010	5.0	<0.050	<0.050	0.05
Mercury	245.1	0.2	<0.001	<0.001	0.001
Selenium	6010	1.0	<0.035	<0.035	0.035
Silver	6010	5.0	<0.010	<0.010	0.01
Volatiles (mg/L):					
Benzene	8260	0.5	<0.0002	<0.0002	0.0002
Carbon tetrachloride	8260	0.5	<0.0002	<0.0002	0.0002
Chlorobenzene	8260	100.0	<0.0002	<0.0002	0.0002
Chloroform	8260	6.0	<0.0002	<0.0002	0.0002
1,2-Dichloroethane	8260	0.5	<0.0002	<0.0002	0.0002
1,1-Dichloroethylene	8260	0.7	<0.0002	<0.0002	0.0002
Methyl ethyl ketone	8260	200.0			
Tetrachloroethylene	8260	0.7			
Trichloroethylene	8260	0.5	<0.0002	<0.0002	0.0002
Vinyl chloride	8260	0.2	<0.0005	<0.0005	0.0005
Semivolatiles (mg/L):					
o-Cresol	625/8270 mod.	200.00	<0.0025	<0.0027	0.0025, 0.0027**
m, p-Cresols	625/8270 mod.	200.00	<0.0025	<0.0027	0.0025, 0.0027**
1,4-Dichlorobenzene	625/8270 mod.	7.5	<0.0012	<0.0013	0.0012, 0.0013**
2,4-Dinitrotoluene	625/8270 mod.	0.13	<0.0012	<0.0013	0.0012, 0.0013**
Hexachlorobenzene	625/8270 mod.	0.130	<0.0012	<0.0013	0.0012, 0.0013**
Hexachlorobutadiene	625/8270 mod.	0.5	<0.0037	<0.004	0.0037, 0.004**
Hexachloroethane	625/8270 mod.	3.0	<0.0037	<0.004	0.0037, 0.004**
Nitrobenzene	625/8270 mod.	2.0	<0.0025	<0.0027	0.0025, 0.0027**
Pentachlorophenol	625/8270 mod.	100.0	<0.0037	<0.004	0.0037, 0.004**
Pyridine	625/8270 mod.	5.0	<0.0049	<0.0053	0.0049, 0.0053**
2,4,5-Trichlorophenol	625/8270 mod.	400.0	<0.0012	<0.0013	0.0012, 0.0013**
2,4,6-Trichlorophenol	625/8270 mod.	2.0	<0.0012	<0.0013	0.0012, 0.0013**
Pesticides (mg/L):					
Chlordane	8080	0.030	<0.0002	<0.0002	0.0002
Lindane	8080	0.4	<0.00001	<0.00001	0.00001
Methoxychlor	8080	10.0	<0.00005	<0.00005	0.00005
Toxaphene	8080	0.5	<0.00075	<0.00075	0.00075
Endrin	8080	0.02	<0.00005	<0.00005	0.00005
Heptachlor	8080	0.008	<0.00002	<0.00002	0.00002
Herbicides (mg/L):					
2,4-D	1311	10.0	<0.002	<0.002	0.002
2,4,5-TP (Silvex)	1311	1.0	<0.002	<0.002	0.002

*Notes: * Reported value is between the laboratory method detection limit and the laboratory practical quantitation limit.*

*** Different laboratory reporting limits - first listed limit is for "N.Sludge-Fe" and the second "S.Sludge-Al".*

TABLE 3.19
AVERAGE OF BACKWASH SOLIDS RESULTS

PARAMETER		Post-BMP ENR Influent		Post-STA ENR Effluent	
(mg/L) unless otherwise noted	*Method Detection Limit*	F1A	F1B	F2A	F2C
Total Phosphorus	0.004	0.18	0.20	0.09	0.04
Soluble Reactive Phosphorus	0.002	0.01	0.01	0.01	0.01
Total Dissolved Phosphorus	0.004	0.02	0.01	0.02	0.02
Total Suspended Solids	0.50	107	98	319	87
Total Organic Carbon	2.75	16	16	40	28
Alkalinity	1.0	67	68	175	132
Total Dissolved Solids	0.50	333	323	584	612
Sulfate	0.20	38	38	125	167
Reactive Silica (mg SiO2/L)	0.30	10	10	11	10
Chloride	0.20	121	124	147	150
Aluminum	0.05	0.84	0.91	22	18
Iron	0.01	34	26	1.9	1.0
Calcium	0.10	49	50	75	72
Magnesium	0.012	13	14	21	21
Potassium	0.01	5.0	5.1	8.5	8.3
Sodium	0.30	44	45	104	104
TKN	0.06	2.0	1.7	2.6	1.8
Nitrate/Nitrite (mg N/L)	0.004	0.37	0.39	0.06	0.06
Ammonia	0.01	0.08	0.08	0.04	0.03

4.0 VENDOR TECHNOLOGIES

Vendor technologies tested during CTSS field activities included the following:

- Krüger, Inc. (pilot unit shown in **FIGURE 4.1**)
- Infilco Degremont, Inc. (pilot unit shown in **FIGURE 4.2**)
- ROCHEM Environmental, Inc. (pilot unit shown in **FIGURE 4.3**)
- F.B. Leopold Company (*see* **FIGURE 4.4** for pilot unit view)
- Micromag Corporation (*see* **FIGURE 4.5**)
- Biochem Technologies, Inc.
- ZENON Environmental, Inc.
- Syracuse University / HSA Engineers & Scientists
- University of Florida
- ETUS Inc. / HSA Engineers & Scientists

A review of the vendor testing conducted during the CTSS field activities is provided below. Vendor-supplied summary reports that provide additional detail on specific processes and scientific investigation design details are provided in **APPENDIX 6**.

4.1 ACTIFLO PROCESS (Krüger Inc.)

The ACTIFLO process is a compact, conventional-type water treatment process that utilizes microsand as a seed for floc formation. The microsand provides surface area that enhances flocculation and acts as a ballast or weight, which enhances settling. This allows clarifier design with high overflow rates (or short detention times).

4.1.1 Process Description

Raw water enters the ACTIFLO system in the first coagulation tank. Here, chemical coagulant is added to destabilize suspended solids and colloidal matter in the influent stream. The intensive mixing provided in this step of the process serves to thoroughly disperse the coagulant into the raw water. Hydraulic detention time in the coagulation tank is around two minutes.

The coagulated water passes into the second (injection) tank where coagulant aid (polymer) and microsand are added to initiate floc formation. This serves as a 'seed' for floc formation and development in the next process step. Hydraulic detention time in the injection tank is around two minutes.

The aggregation of flocs continues as water passes through the underflow passage from the injection tank into the flocculation (maturation) tank. In the flocculation tank, a relatively small energy input agitation provides ideal conditions for the formation of polymer bridges between microsand and the destabilized suspended solids. The process is further augmented by the large specific surface area of the microsand provides an enhanced opportunity for polymer bridging and enmeshment of floc particles. Hydraulic detention time in the flocculation tank is around six minutes.

The fully formed ballasted flocs leave the flocculation tank and enter the settling tank. Here, laminar upflow through the tube settlers equipped settling zone provides effective removal of the flocs. Clarified water exits the ACTIFLO system via a series of collection troughs or weirs.

The ballasted floc-sand-sludge mixture is collected at the bottom of the settling tank. The sand-sludge mixture is then pumped to the hydrocyclone for separation. Energy from pumping is effectively converted to centrifugal forces within the body of the hydrocyclone causing chemical sludge to be separated from the higher density microsand. Once separated, the microsand is concentrated and discharged from the bottom of the hydrocyclone and re-injected into the ACTIFLO process for re-use. The lighter density sludge is discharged out of the top of the hydrocyclone and sent for thickening in holding ponds. Both the pond supernatant and the treated water are discharged into the receiving stream, which is the canal.

4.1.2 Scientific Investigation Protocol

There are numerous factors that have a significant or potentially significant impact on the reduction of phosphorus. In such cases one of the main objectives of a scientific investigation design is to screen the large number of potential variables and select the most important ones for detailed analysis. From among the potentially important operational, environmental, and water quality variables, six system variables were selected for detailed analysis. These variables are:

- coagulant type;
- coagulant dosage concentration;
- polymer type;

- polymer dosage concentration;
- pH; and,
- hydraulic loading.

Krüger Inc. developed a one-variable-at-a-time type of testing approach to investigate the effect of the change of individual system variables on the response. Besides the primary system response of Total P concentration, total dissolved phosphorus (TDP), turbidity, and apparent color were also analyzed.

4.1.3 Summary of Investigation Results

The major conclusions of Krüger's conducted pilot study are summarized below:

1) From among the investigated cationic polymers, CIBA LT22S appeared to support most effectively the removal of Total P in the chemically assisted sedimentation process. Optimum dosage concentration range was found to be 0.6 mg/L to 0.8 mg/L.1.

2) Testing results suggested that the removal efficiency of Total P was pH dependent. While low removal efficiencies were typically observed at naturally occurring marginally basic pH levels (7.2 to 7.6), higher Total P removals were obtained in the acidic pH range of 4.2 to 5.7.

3) Under the conditions tested, the Total P removal efficiency of the two tested coagulants, alum and ferric-chloride, were similar.

4) Testing results suggested that under the conditions tested 10 mg/L to 12.5 mg/L ferric-chloride (as Fe) dosage concentration was required to reduce Total P concentrations below the threshold level of 10 μg/L at the south test site. At the North Test Site, 17 mg/L to 21 mg/L ferric-chloride (as Fe) dosage concentration was necessary for similar results.

5) Completed testing results suggested that 75 mg/L to 80 mg/L alum (as Al) dosage concentration was required for highest Total P removal efficiency at the south test site. Results with the coagulant alum are not available at the North Test Site.

6) In the investigated range of 25 gpm/sq.ft. to 33 gpm/sq.ft., the sensitivity of hydraulic unit loading was higher at North Test Site.

7) The reduction of Total P and the reduction of color show little correlation.

8) Optimum operating conditions at both test sites are tabulated below:

Test Site	Coagulant Type	Coagulant Dosage (mg/L)	Rise Rate (gpm/sq.ft.)	Polymer LT22S (mg/L)	pH (-)	Average Total P Concentration (µg/L)	
						Influent	Effluent
South	Ferric-Chloride	10 – 12.5	25 – 33	0.80	4.2 – 4.4	16	5
South	Alum	75 - 80	25	0.80	5.3 – 5.7	23	8
North	Ferric-Chloride	17 - 21	25 – 30	0.80	4.2	156	8

4.1.4 Conclusions and Recommendation

Completed test results suggest 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.

4.2 DENSADEG HIGH-RATE CLARIFIER AND THICKENER (Infilco Degremont, Inc.)

4.2.1 Process Description

The DensaDeg treatment technology is a compact solids contact clarification process.

The DensaDeg clarifier incorporates three integral process zones: 1) reactor zone, 2) presettling/thickening zone, and 3) clarification zone. In the reactor zone, influent water is combined with reactants and preformed solids that have been recirculated from a downstream, presettling/thickening zone. As they flow upwards in a draft tube, the raw water, reactants, and thickener solids are mixed by a turbine. Existing the draft tube, the flocculated mixture, or slurry, moves downwards. Near the bottom of the reactor, a portion of the slurry re-enters the draft tube. This process of internal recirculation produces the optimum slurry density.

Located near the bottom of the reactor is a baffled opening that allows the slurry to exit the presettling/thickener zone of the reactor. As the slurry moves downward through the presettling zone, to a point near the bottom of the vessel, it is forced to make a 180 degree turn beneath a baffle. Due to the density of the solids within the slurry, nearly all are deposited on the bottom of the vessel. Aided by a slow moving rake, which facilitate the release of entrained water, the deposited solids continue to thicken. The thickened sludge is periodically blown down from the bottom of the thickener and introduced by gravity to the holding pond. The supernatant flows upward. Lamella tubes, through which all the supernatant must pass, provide for high rate removal of the remaining solids. A series of weir troughs, located above the tubes, collect the clarified effluent.

The pilot plant is rated for 75 gpm to 100 gpm throughput, which allows up to 10 gpm/sq.ft. surface loading in the tube settler.

4.2.2 Scientific Investigation Protocol

Infilco Degremont Inc. (IDI) tested their DensaDeg high-rate clarification and thickener unit at the North Test Site. The pilot scale testing program was conducted in two segments from October 11, 1999 to November 10, 1999, and from November 28, 1999 to December 12, 1999, respectively. In order to assess optimum conditions for the pilot testing, IDI conducted jar testing of the actual raw water source on October 13 and 14, 1999.

4.2.3 Summary of Investigation Results

- ***Jar Testing***

  The purpose of the jar testing program was to assess the effectiveness of different process chemicals on Total P removal. The investigated coagulants were 1) ferric-sulphate ($Fe_2(SO_4)_3$), and 2) ferric-chloride ($FeCl_3$) and alum ($Al_2(SO_4)_3$). The results clearly suggested that the efficiency of phosphorus removal versus coagulant dosage follows the order: $FeCl_3 > Al_2(SO_4)_3 > Fe_2(SO_4)_3$. The relative removals of total organic carbon (TOC) and color followed this same trend in almost identical ratios to phosphorus removal. Based on the completed jar test results, IDI recommended

the use of the two best performing coagulants, $FeCl_3$ and $Al_2(SO_4)_3$ for the later phase of the pilot scale test.

- ***Pilot Scale Testing – Phase #1***

  A 2^3 factorial design was the basis of testing in the first segment of the pilot scale study. The three variables were 1) coagulant type, 2) coagulant dosage concentration, and 3) hydraulic unit loading. Each of these variables was investigated at two design levels. These 'levels' were alum and ferric-sulphate for the qualitative variable. Investigated dosage concentrations were 10 mg/L and 20 mg/L for alum, and 20 mg/L and 40 mg/L for ferric-sulphate. The two tested hydraulic loadings were 50 gpm and 100 gpm, respectively.

  Besides the primary system response of Total P concentration, TDP, soluble reactive phosphorus (SRP), and total suspended solids (TSS) were also monitored. The response parameters were typically evaluated for 1) raw water, 2) clarifier effluent, and 3) the filtrate.

  The results of the first segment of the pilot study suggest a varying performance of the IDI supplied treatment package, which contained the DensaDeg high-rate clarifier and a granular media filter column. In terms of overall Total P removal, the removal efficiency varied from 65 percent to 92 percent. Similar removal efficiency ranges for SRP and TDP were 86 percent to 98 percent, and 73 percent to 91 percent, respectively. TSS removal efficiency showed a wide range of variation. The reported data suggests that the DensaDeg treatment unit removed the investigated constituents with a relatively high efficiency. On the other hand, filtration performance was poor.

- ***Pilot Scale Testing – Phase #2***

  The second phase of the investigation was designed and conducted by IDI personnel. IDI prepared and submitted a report on the findings as summarized below:

  > From among the important or potentially important system variables, IDI has investigated the effect of 1) coagulant dosage concentration, 2) polymer dosage concentration, and

3) hydraulic unit loading. The sole system response was the total concentration of phosphorus in the final unit effluent. While the applied coagulant was ferric-chloride, the type of polymer was not identified in the report. The variables were tested at multiple levels. Hydraulic loading was investigated from 50 gpm to 125 gpm in 25 gpm increments. $FeCl_3$ dosage concentration was tested at 116 mg/L, 125 mg/L, and 140 mg/L. The polymer dosage concentration was designed at two levels: 0.5 mg/L and 1.0 mg/L, respectively.

Reported research results suggested a relatively good performance of the DensaDeg treatment unit. The average raw water Total P concentration of 165 μg/L (during the study period) could be reduced to 4 μg/L 75 percent of the time. Essentially, any combination of system variable setting provided satisfactory results. Since Total P removal efficiency was 97 percent, even at the highest tested hydraulic loading of 140 gpm, the overall optimum performance of the unit still needs to be determined.

4.2.4 Conclusions and Recommendations

Testing results suggest 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 competing 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 sludge.

4.3 ULTRAFILTRATION (ROCHEM Environmental Inc.)

4.3.1 Process Description

"Ultrafiltration" (UF) is a pressure-driven, separation process where the water to be treated is separated by a porous membrane into a stream of purified filtrate 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, while the waste (known as concentrate or brine) practically remains at its original pressure. In the concentrate are accumulated the suspended solids contained in the water which have been rejected by the membrane.

The ROCHEM modules for UF have been developed specifically for the separation of particles in the sub-micron range from water with high fouling potential. The combination of open channel construction and narrow gap technology with an efficient cleaning method allows for high filtrate fluxes with relatively low energy demand. The easy modification of the free path feed side (distance between membrane cushions) makes possible the application of this module in a wide range of suspended solids concentrations.

4.3.2 Summary of Investigation Results

The Rochem UF unit is a relatively small (sub-pilot scale) unit capable of producing a permeate/filtrate flow of 1 gpm at a 90 percent recovery rate. The nominal pore size of the UF membranes was 0.03 microns. The unit was tested for direct treatment without chemical addition of ENR effluent (Post-STA) water over a four-week period and consistently produced a permeate of less than 10 µg/L of Total P from a feed water varying from 14 µg/L to 39 µg/L of Total P. Results are summarized below:

Testing Date	Feed Total P (ppb)	Permeate Total P (ppb)
10/13/99	14	7
10/19/99	19	8
10/20/99	19	8
10/27/99	15	5
10/28/99	16	<4
10/29/99	15	6
11/7/99	39	5

4.3.3 Conclusions and Recommendations

The results are significant in that it is apparent that UF is capable of producing a treated effluent with less than 10 µg/L without the use of chemicals or the

generation of a chemical residuals side stream (*i.e.*, a so-called 'Green Technology'). Testing of a larger, pilot scale UF system is recommended.

4.4 DISSOLVED AIR FLOTATION PROCESS (F.B. Leopold Company)

Dissolved air flotation (DAF) is a solids-liquid separation process that transfers solids to the liquid surface through attachment of fine bubbles to solid particles. The phenomenon of DAF consists of three processes: 1) bubble generation, 2) attachment of solids to the bubbles, and 3) solids separation.

4.4.1 Process Description

Before introducing the raw water to the DAF cell, a chemical coagulant and a pH-adjusting agent can be introduced to the raw water. The dispersion of these treatment chemicals is completed in an inline static mixer unit. The chemically conditioned water then enters the flocculation cell where the destabilized suspended solids and colloidal matter start forming aggregates. Mechanical vertical axle gate flocculators are used to supply energy to induce optimum size floc formation. Since the particles are not removed by gravity, their density does not have to be higher than that of water allowing the relatively low dosage of the coagulant.

The flocculated process water flows under a baffle into the dispersion zone where mechanical vertical axle gate flocculators are used and pressurized recycle water is injected. The recycle water - around 10 percent of the total flow – is taken from the final effluent (clarified water) and pumped into a packed tower saturator (pressure vessel), in which 60 psi to 90 psi pressure is maintained. Air is dissolved into the water through the packing. The minimum amount of air required is 8 grams/m^3. The saturated air-water mixture is introduced in the bottom of the dispersion cell. Due to the sudden drop of pressure, air comes out of solution in minute, 10 μm to 100 μm, bubbles.

The aerated water enters a flotation tank, where the air bubbles commence to rise. The 9-square-foot surface area flotation tank is designed for a hydraulic unit loading of 4 gpm/sq.ft. These micro-bubbles inherently carry an electrical charge, which allows them to attach to the destabilized floc particles. Three mechanisms of bubble attachment are known: 1) adhesion to the floc particle, 2) absorption within the floc structure, and 3) capture or enmeshment within the floc structure. The micro-bubble floc aggregates float to the surface forming a

stable sludge blanket. The solid content of a steady-state floating sludge blanket is about 2 percent to 4 percent. The float is then removed mechanically with a chain and flight scraper (or surface skimmer) device. The treated or clarified water is drawn from the DAF tank through a number of underflow collectors located near the bottom of the basin.

The on-line instrumentation of the pilot plant include 1) turbidity, 2) pH, 3) ORP, 4) particle counting, 5) flow rate, and 6) saturator pressure measurement and recording.

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.

4.5 COMAG PROCESS (Micromag Corporation)

The CoMag treatment technology utilizes high gradient magnetic fields for the separation of floc aggregates. The Micromag pilot-scale water treatment unit is designed for up to 20 gpm hydraulic loadings.

4.5.1 Process Description

Raw water enters the system in the first coagulation tank, where a chemical coagulant can be added to destabilize suspended solids and colloidal matter. The dispersion of the coagulant is achieved by mechanical mixing. The chemically pretreated raw water enters an electromagnetic device followed by a second coagulation tankage, where a nucleation aid is dosed. This vessel is also equipped with a high intensity chemical mixer.

The aggregation of flocs continues as water enters the flocculation process utilizing two tanks in series. The two identical flocculation tanks are equipped with mechanical mixers providing a relatively low energy input agitation of the pretreated raw water. A fine magnetic powder (magnetic seed) is added to the first flocculator tank. Throughout the coagulation-flocculation processes, a significant portion of the added magnetic particles get enmeshed into the floc aggregates. These magnetic particles have the property to be magnetized when placed in a magnetic field. The magnetized particles become tiny magnets (magnetic dipoles) having north and south poles.

The magnetic powder dispersed process water enters a second flocculator tank in which, if necessary, a coagulant aid can be added. Similarly to upstream-applied dispersion methods, repulsion forces between particles are to overcome by a low energy input mechanical agitation of the water in the tankages.

The magnetic seed enmeshed floc containing raw water enters the 'heart' of the process, which is the high gradient magnetic separator. On the basis of electromagnetic principles, the generated magnetic field in the separator exerts a force on the magnetic seed particles. On the basis of electromagnetic and centrifugal forces, the phase separation of floc aggregates takes place.

After phase separation, the liquid phase is discharged from the unit as final effluent. Forced by centrifugal forces, the separated solids enter an energized section of the separator. In the de-energized stage of this device, the floc aggregates and the magnetic seed particles can be separated. The flocs or sludge is wasted and the magnetic seed are returned to the first flocculator cell.

4.5.2 Scientific Investigation Protocol

Micromag conducted their pilot-scale testing at both Test Sites from November 20, 1999 to December 21, 1999. A total of 96 samples were collected and analyzed during this period.

The CoMag process incorporates the following steps:

- Magneto-chemical pretreatment;
- Chemical coagulation;
- Addition of finely divided clay;
- Addition of finely divided magnetide;
- Flocculation; and,
- Magnetic separation.

The investigated system variables were: 1) coagulant type, 2) coagulant dosage concentration, 3) bentonite dosage concentration, 4) coagulant aid (Cytec A-130 polymer) dosage concentration, and 5) pH. The system response was the concentration of Total P in the final effluent. Alum and ferric-chloride coagulants were tested. While the dosage concentration of alum was investigated at four levels (5 mg/L, 10 mg/L, 20 mg/L, and 40 mg/L), the dosage

concentration of ferric-chloride was tested at multiple levels (2 mg/L, 4 mg/L, 8 mg/L, 10 mg/L, 20 mg/L, and 40 mg/L). Bentonite was dosed at 12.5 mg/L and 50 mg/L concentrations. The 4 tested polymer dosage concentrations were 0.5 mg/L, 1.0 mg/L, 1.5 mg/L, and 2.0 mg/L. Several pH levels were tested. Hydraulic unit loading was held constant at 10 gpm during the study period.

4.5.3 Summary of Investigation Results

The comparison of Total P removal efficiencies at the two test sites clearly show higher and more consistent removals at the North Test Site where raw water Total P concentrations are an order of magnitude higher than at the South Test Site.

4.5.4 Conclusions and Recommendations

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. Until system reliability and cost verification can be made based upon full scale operating data, the technology cannot be recommended for further current assessment.

4.6 DOLOMITIC LIME FIXED FILM BIO-REACTOR PROCESS (BIOCHEM Technologies Inc.)

The dolomitic lime fixed film bioreactor (DLBR) process is a biological treatment technology utilizing an indigenous sessile bacteria for the uptake of nutrients such as phosphorus and nitrogen. Dolomitic lime and lava rock layers provide the supporting surface for the growth of biofilm. BTI conducted scientific investigation with pilot-scale prototype at the South Test Site from September 28, 1999 to November 30, 1999, followed by similar trials at the North Test Site from December 1, 1999 to February 15, 2000.

4.6.1 Process Description

Raw water enters the DLBR system into an aeration tank where the incoming water is aerated through a fine bubble diffuser device. The increased dissolved oxygen concentration raw water then enters the first of three reactor cells. Each of the reactors is packed with dolomitic lime and lava rock media, which surfaces support the growth of biofilm layers.

It is hypothesized that the biofilm structure is not a chance occurrence but represents an optimal arrangement for the influx of nutrients. Substrate conversion rates in biofilms are controlled by growth kinetics and mass transport processes. The overall rate of reaction is equal to the rate of the slowest therefore rate limiting step in the mechanism. The following steps may represent the overall diffusion with bioreaction process for nutrients:

1) Mass transfer of the nutrients from the bulk liquid to the external surface of the biofilm;
2) Diffusion of nutrients from the external biofilm surface to a specific cell in the matrix;
3) Adsorption of nutrients onto the cell surface;
4) Cell metabolism;
5) Desorption of waste products;
6) Diffusion of waste products from the matrix interior to the biofilm surface; and
7) Mass transfer of waste products from the biofilm surface to the bulk liquid.

Predominantly aerobic conditions prevail in the first reaction cell. Besides supporting the growth of an aerobic biofilm habitat, the lower oxidation level nitrogen forms (*e.g.*, ammonia) are oxidized by *Nitrosomonas* bacteria. Assimilative reduction of nitrate then takes place in the downstream reaction cells with reduced DO levels.

4.6.2 Summary of Investigation Results

The results obtained suggest that the overall phosphorus removal efficiency of the BTI technology is relatively low.

4.6.3 Conclusions and Recommendations

Due to its relatively low Total P removal efficiency, the BTI developed treatment technology is not recommended for further considerations.

4.7 MICROFILTRATION (ZENON Environmental, Inc.)

The "microfiltration" (MF) process is a membrane solids separation technique that can be used to remove suspended solids, large macromolecular materials, bacteria, and algae from a large variety of raw water sources. The ZENON Environmental Inc.-supplied MF unit was operated from October 1, 1999 to November 30, 1999.

4.7.1 Process Description

The pilot unit uses hollow fibers to remove particles greater than 0.1 micron from a feed stream. Individual fibers are bound together in a 'membrane cassette', with each cassette containing a total of 150 square feet of filter membrane surface area. A total of three cassettes are housed in the unit. The membranes are vertically suspended in a 370-gallon feed water tank. Feed water is pumped into the tank and a vacuum pump system draws the feed water through the membranes producing the filtrate (or permeate) stream. Compressed air is continuously pumped into the feed tank at rate of between 12 CFM to 18 CFM. The aeration keeps solids continuously mixed within the tank and reduces solids buildup near the surface of the membranes. The normal hydraulic loading range of the pilot unit is 12,000 gpd to 17,000 gpd (or 28 gpd/sq.ft. to 38 gpd/sq.ft. of membrane surface area).

The ZENON pilot unit is classified as a 'cross-flow with concentrate recycle' MF system. In this configuration, a significant portion of the feedwater stream passes through the membrane and is collected as permeate. The remainder of the feed stream (2 percent to 5 percent of the feed stream) is discharged directly from the system carrying with it solids constituents that have been rejected by the membranes.

When the operating pressure increases to about 18 psi, the membranes need cleaning, which can be accomplished by the simple reversal of the normal flow regime. The 8 second to 10 second cleaning procedure takes typically places every 10 minutes. The operation of the unit is PLC controlled. Periodically the unit needs longer duration cleaning with sodium hypochlorite.

4.7.2 Summary of Investigation Results

The results suggest that the MF treatment process has the potential for significant reduction of Total P concentration. In the absence of a chemical pretreatment the Total P concentration of the feed water (15 µg/L to 30 µg/L) could not be routinely reduced below the threshold limit of 10 µg/L. These findings are in agreement with those conducted by Conestoga-Rovers & Associates' (CRA) "Microfiltration Supplemental Technology Demonstration Project" (CRA Report, May 1998).

4.7.3 Conclusions and Recommendations

In the absence of a chemical pretreatment, the ZENON MF treatment unit could not routinely reduce the Total P concentration of the untreated raw water (South Test Site) below the threshold limit of 10 µg/L. These findings suggest that the ZENON treatment technology alone has limited the potential for full-scale applications. The primary objective is to achieve a 10 ppb or less Total P concentration.

4.8 BENCH SCALE FILTRATION WITH GLASS-SAND FILTER MEDIA (Syracuse University / HSA Engineers & Scientists)

Syracuse University of New York has investigated the filtration characteristics of glass-sand filter media. HSA requested and obtained some of this media for assessing its Total P removal characteristics on actual canal waters.

4.8.1 Process Description

The available glass-sand filter media was packed in two ½" diameter 2-foot high filter columns. The columns were connected in series and operated in the upflow mode. The bench scale filter columns were attached to the outside of the pilot scale clarifier in treatment trailer #1. The actual clarified water was pumped to the bench-scale filter units at an approximate feed rate of 2.45 gpm/sq.ft. of filter area. During the coarse of the bench scale filtration test, the pilot unit was operated with ferric-sulphate coagulant and A-130 coagulant aid.

4.8.2 Scientific Investigation Protocol

As reported by Ray Letterman of Syracuse University, the supplied media was a 50/50 mix of two washed size fractions (0.6 to 1.18 mm and 0.295 to 0.6 mm, respectively). HSA retained CRA to conduct a confirmatory sieve analysis of the size distribution of the glass-sand media. The attached results show that Syracuse University's report and CRA's confirmed results are in close agreement.

Samples for Total P analysis were taken at three distinct locations along the bench-scale treatment process: 1) incoming raw (*i.e.*, clarifier effluent) water, 2) between the two filter columns, and 3) final effluent (*i.e.*, column #2 effluent).

4.8.3 Summary of Investigation Results

The bench-scale filtration results suggest little Total P removal efficiency of the glass-sand packed filter columns. Discrete filtration results showed a nominal (<10 percent) Total P removal efficiency in the first filter column, and essentially no removal in the second column in series. In addition, the initial adjusted hydraulic filter loading of 3.45 gpm/sq.ft. dropped to almost zero in about three hours.

4.8.4 Conclusions and Recommendations

Due to the little Total P removal efficiency and the short filter run, the glass-sand filter media is not recommended for further assessment.

4.9 COATED GRANULAR MEDIA FILTRATION (University of Florida)

The University of Florida (UofF) developed and patented a technique to coat granular filter media with metallic hydroxide precipitate. Bench-scale testing results suggest that the coated filter media have enhanced phosphorus removal characteristics.

4.9.1 Process Description

HSA has collected and delivered water samples, from both the North and South Test Sites to the UofF, where the supplied water was fed to filter columns containing 1) modified sand, 2) modified carbon, and 3) modified olivine granular filter media. Each of these media was coated with a patented metallic

hydroxide precipitate. The two filtration tests took place on July 6, 1999 and September 8, 1999.

Liquid phase samples from both the incoming unfiltered raw water and the filtrate were collected. The collected samples were analyzed for Total P and orthophosphate concentrations for waters from the North and South Test Sites, respectively.

4.9.2 Scientific Investigation Protocol

Activated carbon and olivine sand media were sieved to 30-50 mesh (0.6 mm–0.3 mm). After coating with ferric and aluminum hydroxides, the coated solids were rinsed and dried. The modified granular media was placed into 2-inch diameter and 1-foot high filter columns.

After being delivered to the UofF, the HSA-collected water samples were stored at 4°C for three days. Before pumping to the filter columns, the waters were homogenized and allowed to warm to room temperature. In addition to raw water, four effluent samples were also collected from each of the downflow-operated columns throughout the filtration of 5 gallons of feed water. The collected samples were frozen and sent by UofF to PPB Laboratories (Gainesville, Florida) for analysis.

4.9.3 Summary of Investigation Results

Collected canal water samples from both of the two test sites were introduced to 2-inch diameter filter columns at rates of 7.3 gpm/sq.ft. and 18.2 gpm/sq.ft. The influent Total P concentration of 245 μg/L (North Site) was reduced to 55 μg/L and 7.5 μg/L by the modified carbon and modified olivine media, respectively. The South Test Site water orthophosphate concentration of 48 μg/L could be reduced to 11.5 μg/L by the modified sand, and 6.0 μg/L by the modified carbon media.

4.9.4 Conclusions and Recommendation

Bench-scale testing results suggest that the UofF-patented filter media have the potential for significant Total P reduction. Due to the relatively small-scale study, caution should be exercised before interpolating these data to the design of

pilot or full-scale facilities. Also, cost effective means of backwashing and regenerating the material would need to be developed.

4.10 TESTING OF SUPPLIED COAGULANT AIDS (ETUS Inc. / HSA)

ETUS Inc. supplied HSA with three coagulants for bench-scale testing. Jar test results showed little removal of Total P concentration.

4.10.1 Process Description

The three tested coagulants were:

- Eliminator C500;
- EB-LS500; and,
- EG-1.

ETUS provided HSA with a scientific investigation protocol for tests, which was followed by the HSA field team conducting jar test trials using their coagulant formulation. Jar test analyses on feed waters from both the North and South Test Sites were conducted.

4.10.2 Scientific Investigation Protocol

ETUS provided a detailed investigation protocol for the jar test trial of their coagulants. A summary of this protocol is provided below:

Procedure #1:

1) Take 1 cc of Eliminator C500 sample and dilute it in 1000 mL of distilled water;

2) Take 5 cc of this solution and add it to each of 3 different 1000 mL Everglades water samples;

3) Mix them at 100 RPM for 5 minutes;

4) Take 1 cc of EB-LS500A and add it to 1000 mL of distilled water;

5) Add 20 mg/L of this solution to a beaker containing 1000 mL of Everglades water. Add 25 mg/L to a second 1000 mL beaker of Everglades water. Add 30 mg/L of solution to a third 1000 mL beaker of Everglades water;

6) Mix each beaker for 15 minutes at 1020 RPM;

7) Adjust pH to 6; and,

8) Allow water sample to settle for 30 minutes.

Procedure #2:

1) Take 1 cc of EG-1, dilute with 1000 mL of distilled water;

2) Add 10 mg/L of this solution to a beaker containing 1000 mL of Everglades water. Add 15 mg/L to a second 1000 mL beaker of Everglades water. Add 20 mg/L of solution to a third 1000 mL beaker of Everglades water;

3) Mix each sample at 100 RPM for 5 minutes followed by 15 RPM mixing for 10 minutes;

4) Adjust pH to 6; and,

5) Allow water sample to settle for 30 minutes.

4.10.3 Summary of Investigation Results

Jar test results showed that the raw canal water Total P concentration of 21 µg/L (South Site) and 137 µg/L (North Site) could be reduced to 19 µg/L, and 130 µg/L, respectively. The results suggest that under the conditions tested only nominal removal of Total P concentration would be achieved by ETUS-supplied treatment chemicals.

4.10.4 Conclusions and Recommendation

Chemically assisted sedimentation test results showed that ETUS-supplied treatment chemicals would remove less than 10 percent of the raw water Total P concentration. The coagulants are not recommended for further trials.

4.11 ACTIVATED ALUMINA

HSA conducted on-site filtration tests using activated alumina as filter media to determine the adsorbent and physical filtration performance on Post-BMP waters.

4.11.1 Process Description

The filtration test was operated using a four-inch diameter, 10-foot high filter column. The filter column was packed with 30 inches of granular alumina (effective size 0.8-3.2 mm) and was supplied with untreated raw water.

4.11.2 Testing Summary

Pilot trials were conducted at the North Test Site (Post-BMP) from December 17 through December 22, 1999. The filter was operated in a declining rate mode from a starting filtration point of 2 L/min and was back-washed with filtrate when the effluent flow rate fell below approximately 1 L/min. This corresponds with a filter-loading rate of 6.0 to 3.0 gallons/min/ft^2. Eleven filtrate samples were collected and analyzed for Total P, SRP, and TDP. Raw water quality was obtained from the composite samplers used for the CTSS testing at the North Site.

4.11.3 Conclusion

The average feed Total P concentration to the alumina column was equal to 112 micrograms per liter, and the average filtrate Total P was equal to 99 micrograms per liter. This phosphorus reduction could be attributed to adsorptive and physical filtration. The testing results indicate that filtration with activated alumina at loading rates between 3.0 and 6.0 gallon/min/ft^2 alone cannot reduce Total P concentration in neutral pH Post-BMP waters to 10 ppb.

4.12 RESIDUAL SOLIDS LEACHING STUDY

HSA conducted field trials to determine if phosphorus was releasing from accumulated chemical treatment solids into the surrounding waters.

4.12.1 Process Description

Eight containers were filled with 4 liters of residual solids and 16 liters of clarified effluent water then topped. The residual solids were obtained from two test locations (North and South) and two treatment chemicals (alum and ferric chloride). Two control containers (one from the North and one from the South Test Sites) were filled with only clarified water.

Samples were collected from the water column above the residual solids periodically during the study to determine if the phosphorus concentration in the clarified water increased with time.

4.12.2 Testing Summary

From November 11, 1999 through December 17, 1999, samples of the clarified water were collected and analyzed primarily for TDP.

4.12.3 Results

A total of 27 clarified water samples were collected from the residual solids containers and eight samples were collected from the control containers.

4.12.4 Conclusion

It appears that there is no statistical difference between the initial TDP concentrations and the final TDP concentrations. Therefore, it can be concluded that no phosphorus released from the residual solids into the water column during the six-week study.

FIGURE 4.1
Photograph of:
Krüger Inc. –
Actiflo Process Trailer

FIGURE 4.2
Photograph of:
Infilco Degremont, Inc. – DensaDeg Process Unit

FIGURE 4.3
Photograph of:
ROCHEM Environmental, Inc. – Ultrafiltration Pilot Unit (2 gpm)

FIGURE 4.4a
Photograph of:
F.B. Leopold Company – Dissolved Air Flotation Trailer

FIGURE 4.4b
Photograph of:
F.B. Leopold Company – DAF

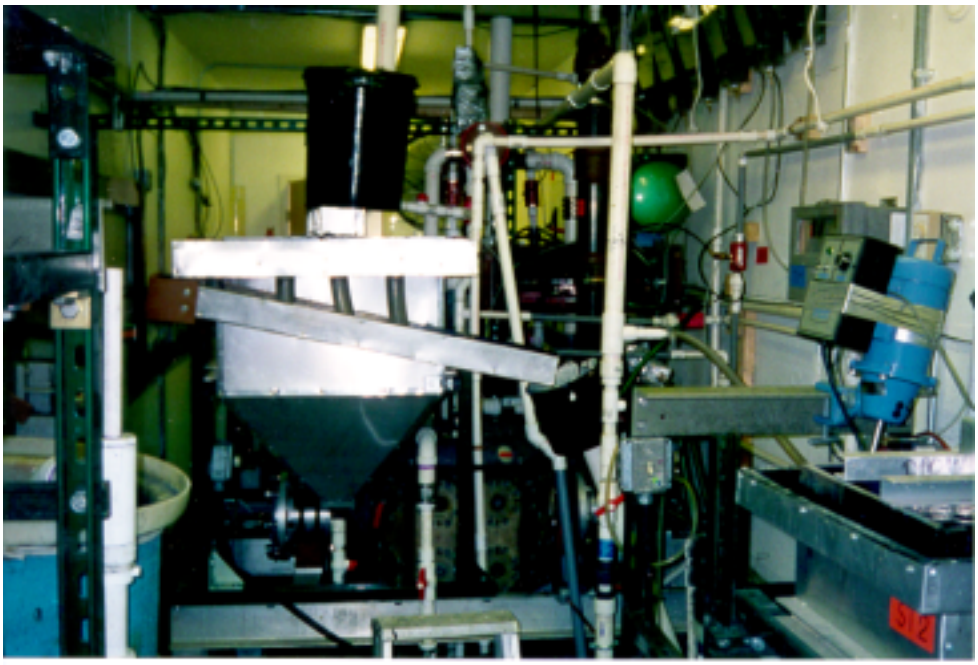


FIGURE 4.5
Photograph of:
Micromag Corporation –
CoMag Process Mobile Pilot Units

Chapter 5

5.0 CONCEPTUAL DESIGN AND PRELIMINARY COST ESTIMATE FOR A FULL-SCALE MICROFILTRATION APPLICATION

5.1 DEVELOPMENT OF HYDRAULIC AND TOTAL PHOSPHORUS DESIGN CRITERIA

The consuliting firms of PEER Consultant and Brown and Caldwell, jointly developed a standard of comparison for all supplemental technology demonstration projects (PEER Consultants/Brown and Caldwell, J.V., November 1997; PEER Consultants/Brown and Caldwell, 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 phosphorus 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.

Generating this synthetic daily time series of inflow and outflow phosphorus information was based upon rescaling historical S5A and S6 flows and phosphorus loadings. Documentation received with this data indicated the following factors were ignored in developing this time series summary:

- BMP make-up water contributions to STA 2 (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 the effect of recently implemented BMPs in the EAA is accounted for by reducing 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 ppb 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 period of record for the data series is from 1/1/79 through 9/30/88. The historical flow weighted mean total phosphorus 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 period of record.

5.2 DEVELOPMENT OF CONCEPTUAL DESIGNS FOR FULL-SCALE POST-BMP AND POST-STA TREATMENT FACILITIES

5.2.1 Analysis of the Baseline Period of Record Data and its Application to the CT-SS Conceptual Design

FIGURE 5.1 provides a graphical representation of the baseline STA 2 inflow data for the 10-year POR and **FIGURE 5.2** shows the corresponding phosphorus concentrations for the same time period. The average flow is equal to 1,424-acre - feet (464 million

gallons per day) of water per day. Also shown on **FIGURE 5.1** are the mean plus 1, 2, and 3 standard deviations of the flow data, respectively.

FIGURE 5.3 provides the graph of the estimated Post-STA 2 effluent flow for the 10-year POR. **FIGURE 5.4** shows the corresponding phosphorus concentration values for this same time period. The average Post-STA flow is equal to 536-acre - feet per day (175 million gallons per day). **FIGURE 5.3** also shows the mean flow plus one, two and three standard deviations, respectively.

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 TP concentrations of 10 and 20 ppb TP with 0%, 10%, and 20% flow diversion (STSOC required) of the 10-year POR flow volume. This approach resulted in a total of 12 full-scale treatment scenarios, shown below.

Location	**Effluent TP**	**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

5.2.2 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 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. The assumptions and the basis for them are summarized below.

***(1) Post-BMP Treatment System*:**

- Flow equalization, chemical treatment, residual solids thickening, and final buffer cell conditioning will occur within the foot print of the existing STA-2;
- 6,000-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 4.5 feet;
- Bypass occurs when the FEB has reached capacity;
- Rainfall and evapotranspiration from FEB have been neglected (Walker, 50-yr POR);
- The phosphorus removal rate within the FEB is 20% (Walker/ Kadlec);
- The full-scale CT-SS system can operate at a peak load of 50 percent greater than its average daily design flow rate for limited time periods (HSA);

- The CT-SS technology coupled with ferric chloride addition will produce an average clarified effluent total phosphorus concentration of at least 0.006 mg/L as P. This concentration was calculated using the Demonstration period clarifier effluent concentrations (ENR Influent Location). Several of the TP concentrations were below the laboratory detection limit (0.004 mg/L). These data were used in the calculations using the detection limit as the TP concentration. This approach is conservative and the actual full-scale system will probably produce filtrates with lower Total P results;
- Raw untreated water would be blended with the CT-SS effluent to achieve the desired discharge concentration (0.01 or 0.02 mg/L as P), STSOC; and
- Full-scale treatment scenarios were based on a scale-up of the CT-SS pilot data.

TABLE 5.1 presents the detailed conceptual design criteria developed for the Post-BMP CT-SS facility designs. These conceptual designs were developed from scale up values from the CT-SS pilot facility as it was successfully operated during demonstration testing.

***(2) Post-STA Treatment System*:**

- "Natural treatment", flow equalization, chemical treatment, residual solids thickening, and final buffer cell conditioning will occur within the framework of the existing STA-2. Based on the pilot data, it was determined that the CT-SS treatment process could treat Post-STA water with an outflow TP concentration of 65 ppb.

- The required size of STA-2 (acres) to provide an effluent TP concentration of 65 ppb was estimated using the exponential relationship between the STA-2 area and the outflow TP concentration represented by, $C=Co*e^{-kA}$, where C is the outflow concentration, Co is the inflow concentration, K is a constant and A is the STA area (Kadlec, Walker). Using the assumed inflow concentration (122 ppb) and the outflow concentration (50 ppb), the exponential relationship becomes, $50=122e^{-kA}$. If the CT-SS plant can treat post-STA water with an outflow concentration of 65 ppb, a 4,540-acre "natural system" is required.

- The Post-STA full-scale conceptual design uses Cell No. 3 and No. 2 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 4.5 feet.

- Bypass occurs when the FEB has reached capacity.

- Rainfall and evapotranspiration from FEB have been neglected (Walker, 50-yr. POR).

- The phosphorus removal rate within the FEB is 20 percent (Walker, Kadlec).

- The full-scale CT-SS system can operate at a peak load of 50 percent greater than its average daily design flow rate for time periods.

- The CT-SS technology coupled with alum addition will produce an average clarified effluent total phosphorus concentration of at least 0.006 mg/L as P. This concentration was calculated using the Demonstration period clarifier effluent concentrations (ENR Effluent Location). Several of the TP concentrations were below the laboratory detection limit (0.004 mg/L). These data were used in the calculations using the detection limit as the TP concentration. This approach is conservative and the actual full-scale system will probably produce filtrates with lower Total P results.

- Raw untreated water would be blended with the CT-SS effluent to achieve the desired discharge concentration (0.01 or 0.02 mg/L as P).

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

TABLE 5.2 presents the detailed conceptual design criteria developed for the Post-STA CT-SS facility designs.

A schematic for the full-scale facility conceptual design is shown on **FIGURE 5.5.**

5.2.3 Post-BMP Full-Scale CT-SS Treatment System Conceptual Design

The Post-BMP conceptual design scenarios were based on using 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 onsite 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 TP 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 four 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

5.2.4 Post-STA Full-Scale CT-SS Treatment System Conceptual Design

The Post-STA conceptual design scenarios were based on using 4,400-acres of STA-2 as a "natural system". The natural system would produce an average effluent TP 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 onsite 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 (USEPA. 1995).

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

Post-STA Conceptual Design Summary		
Effluent TP 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 four 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

5.3 PRELIMINARY COST ESTIMATE FOR THE FULL-SCALE CT-SS DESIGN

FIGURES 5.5 and 5.6 show the layouts of the full scale Post STA and Post BMP facilities, respectively, within the STA 2 framework. Cost estimates were prepared for the 12 full-scale facility scenarios discussed for CT-SS treatment plants treating Post-BMP and Post-STA waters. **TABLES 5.3** and **5.4** provide summaries of the costs estimates for the different STSOC defined treatment scenarios for the Post BMP and Post STA applications, respectively. Each scenario includes capital, operation and maintenance (O&M), replacement, and salvage costs. A 50 percent present worth cost was then calculated based on a using a net discount rate of 4 percent. The 10-year period of record (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). A schematic diagram of the full scale treatment system envisioned for both Post BMP and Post STA applications is provided in **FIGURE 5.7.**

The Basis for Cost Estimates of Full Scale Alternative Treatment (Supplemental) Technology Facilities (August 1999), prepared by B&C for SFWMD, was used to provide various unit costs and is referenced accordingly. These costs were considered as 1998 dollars then converted to 2000 dollars by assuming an average annual inflation rate of 3 percent (Brown and Caldwell, August 1996). Details on the development of costs for the major categories identified in **TABLE 5.3** and **TABLE 5.4** are provided below.

5.3.1 Capital Costs

Land Acquisition. Land acquisition costs for the residual solids disposal sites were calculated at a price of $3,500 per acre. An additional 10 percent more land was allowed for easements, right-of-ways, and buffers (Brown and Caldwell, August 1996).

Influent Pumping Station. B&C (August 1999) included a plot of influent/effluent pumping stations unit costs ($/cfs) against capacity (cfs). FEB and treatment plant influent pump station costs were determined using this cost curve.

Sludge Treatment and Disposal. B&C (August 1996) estimated a base construction cost for sludge treatment and disposal facilities of $20,000 per mgd of average daily design flow. This cost was developed assuming that sludge thickening in settling ponds followed by underground injection on a dedicated land disposal site.

5.3.2 Contingency Costs

Construction Contingencies. A 20 % construction contingency cost line item was applied to the all items (Brown and Caldwell, August 1999).

Engineering, Permitting and Construction Management. Engineering, permitting and construction management costs were assumed to total 15 percent of construction costs (Brown and Caldwell, August 1996).

5.3.3 Operation and Maintenance (O&M) Costs

O&M costs were developed using vendor supplied information and other sources noted below:

Pump Stations. B&C (August 1999) provided O&M costs for two typical pumping stations. Annual O&M costs were based on a flow proportional basis.

Flow Equalization Basin (FEB). The flow equalization basins used for the full-scale designs are previously constructed STAs. Therefore, the annual O&M costs were based on STA O&M costs of $22/acre (Brown and Caldwell, August 1999).

Chemical Costs. Chemical costs were estimated based on the pilot studies chemical dosage. Nominal chemical dosages of ferric chloride (40 mg/L as Fe) for Post-BMP and alum (20 mg/L as Al) for Post-STA application were used to calculate chemical costs. B&C (August 1999) provided costs for ferric chloride and alum at $150 and $180 per dry ton, respectively.

Sludge Treatment and Disposal. The cost of operating and maintaining the sludge treatment and disposal equipment were estimated based on $1,200 per year per mgd of average daily flow treated at the plant (Brown and Caldwell, August 1996).

Electric. Electrical consumption was estimated based on the treatment plant power consumption and a unit cost of $0.065/kWh (SFWMD).

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

Treatment Plant Sampling and Monitoring. It was assumed that sampling and monitoring of the treatment plant would cost approximately $300,000 per year (Brown and Caldwell, August 1996).

5.3.4 Replacement Costs

The following replacement costs items were used (Brown and Caldwell, August 1999):

- FEB pump stations - 25% of costs replaced once at 25 years;

- Treatment plant pump stations – 50% of costs replaced once at 25 years;
- Chemical feed systems – 60% of costs replaced every 10 years;
- Treatment plant equipment – 25% of plant cost replaced at 20th and 40th year.

5.3.5 Salvage Costs

Salvage estimates were prepared considering both salvage value and salvage costs (Brown and Caldwell, August 1996). These costs include demolition costs, restoration costs, and land value. It was assumed that the land purchased for sludge disposal land was dedicated and no land value or restoration costs were assigned (Brown and Caldwell, August 1996). In all cases, demolition and land restoration costs exceeded the land value (negative net salvage value).

5.3.6 Present Worth Analysis

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 are summarized below:

Full-Scale Treatment Scenarios
Present Worth Summary

Application	Treatment Plant Design Average Daily Flow (MGD)	50-Year Present Worth ($ million)
Post-BMP	380	312.2
	270	253.0
	200	210.1
	220	230.4
	150	186.8
	120	164.0
Post-STA	390	341.1
	260	257.4
	190	210.7
	140	175.7
	100	145.3
	80	121.7

5.3.7 Unit Treatment Costs

The present worth cost with respect to gallons treated and phosphorus removed are summarized below:

Application	Treatment Plant Design Average Daily Flow (MGD)	50-Year Present Worth	
		Dollars per million gallons treated ($/mgal)	Dollars per pound of phosphorus removed ($/lb)
Post-BMP	380	112.5	115.5
	270	102.2	108.8
	200	95.9	103.6
	220	92.5	93.4
	150	86.3	88.7
	120	86.3	88.8
Post-STA	390	150.9	298.1
	260	130.0	259
	190	120.7	243.3
	140	113.7	187.5
	100	112.6	181.1
	80	110.2	172.4

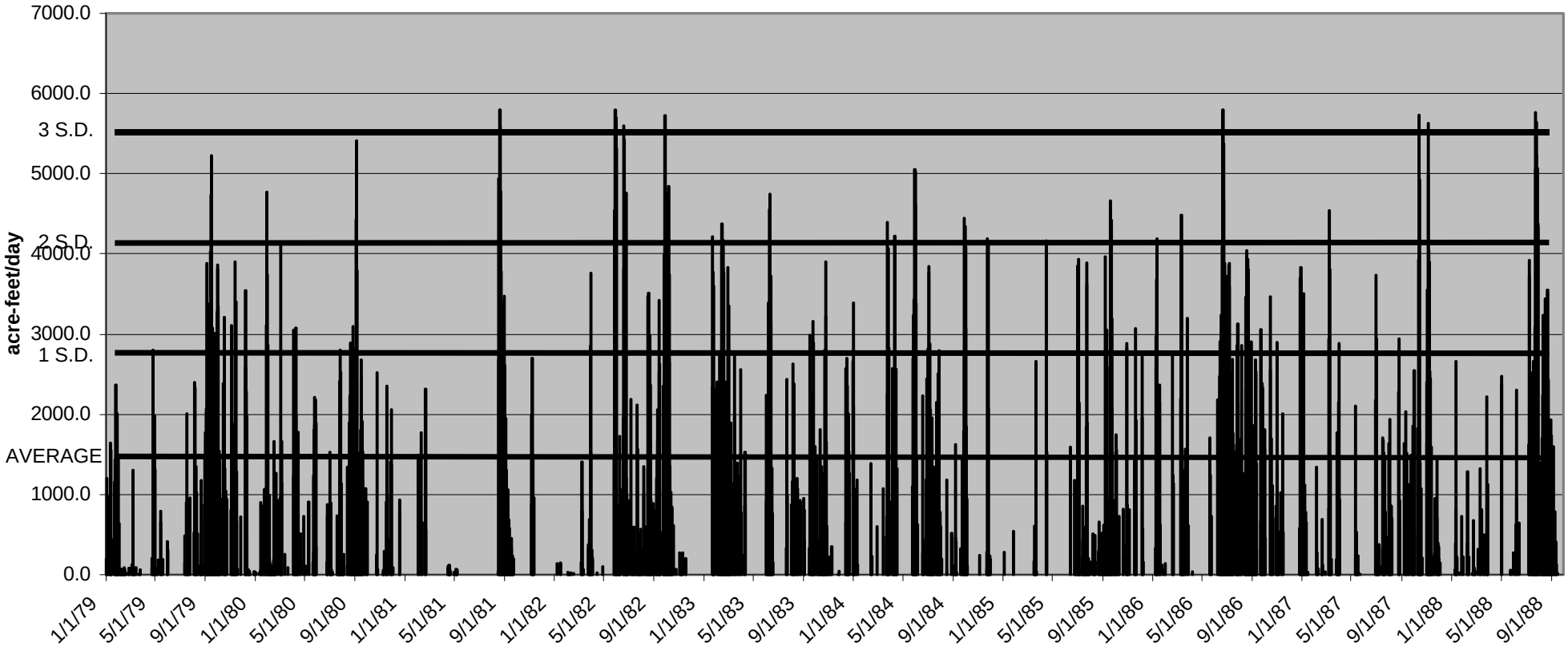


figure 5.1
BASELINE STA 2 INFLOW (POST BMP) DATA

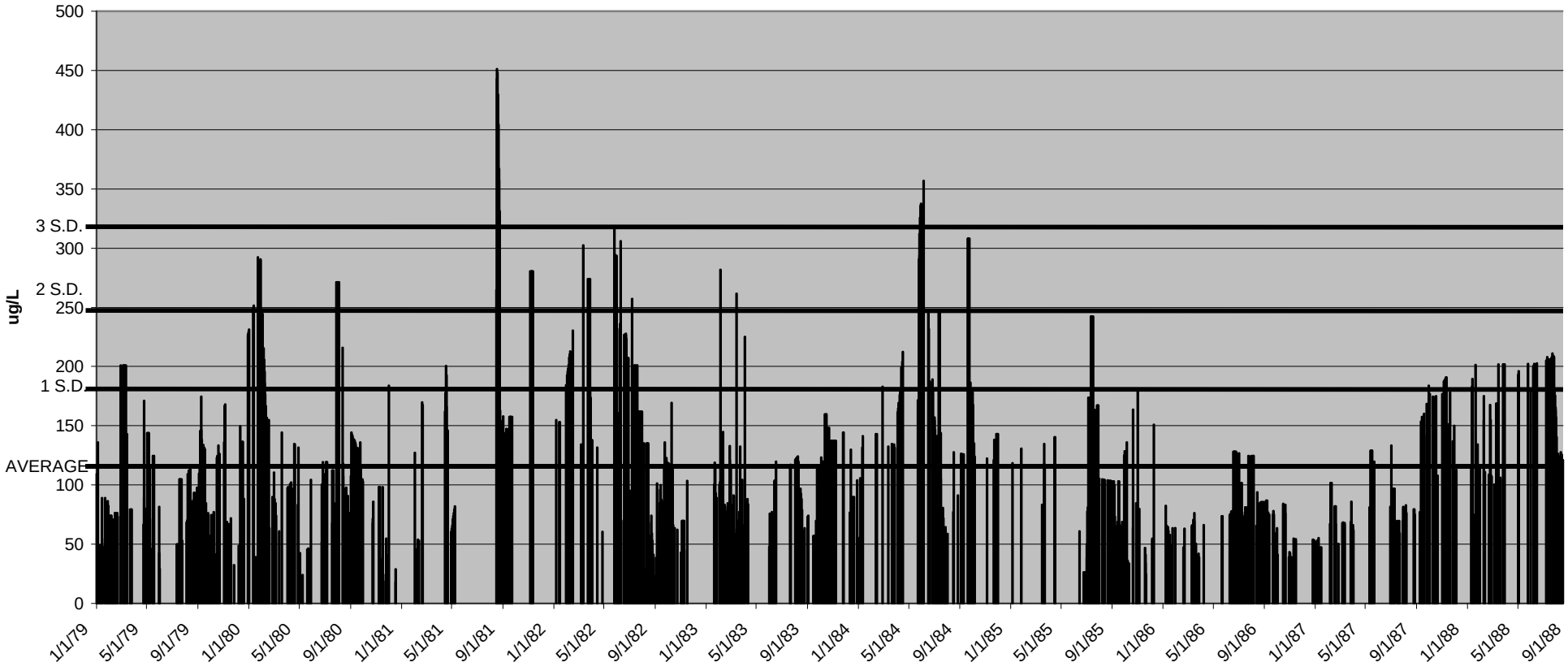


figure 5.2
BASELINE STA 2 INFLOW (POST BMP) TOTAL PHOSPHORUS CONCENTRATION DATA

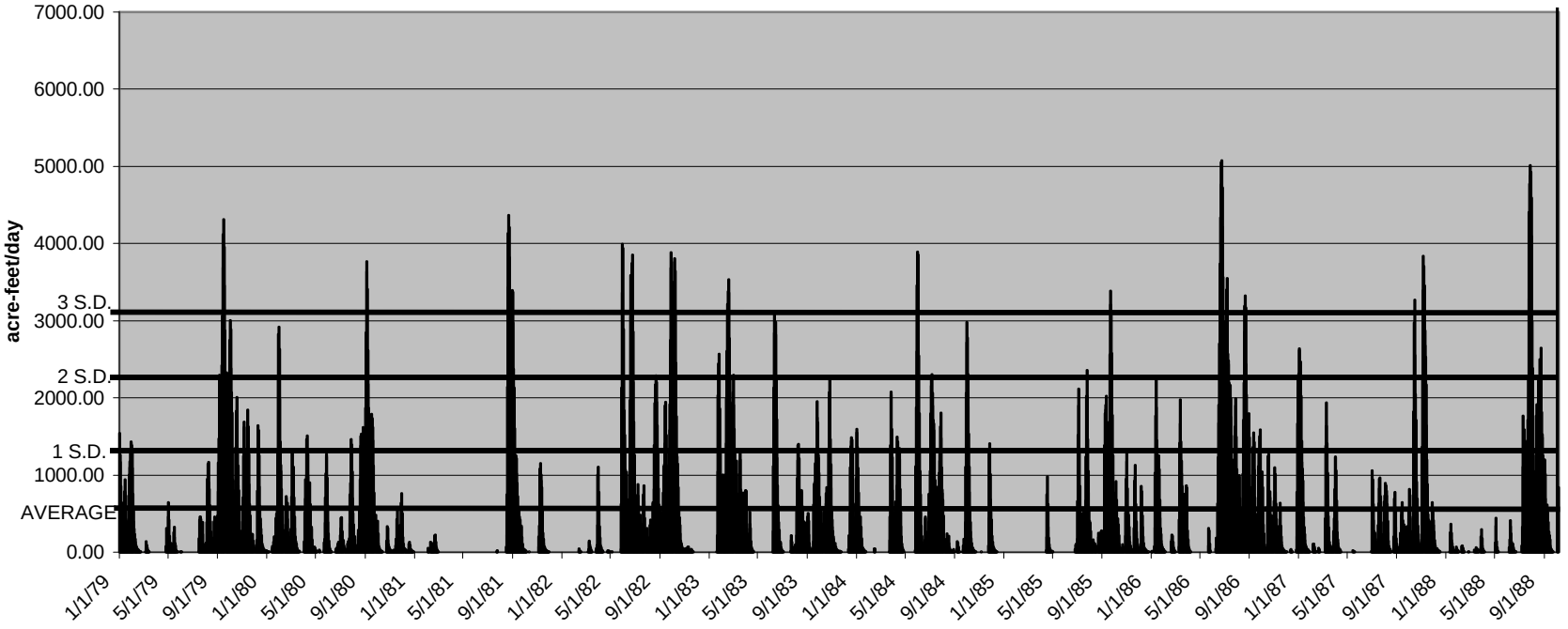


figure 5.3
ESTIMATED BASELINE STA 2 EFFLUENT FLOW (POST STA) DATA

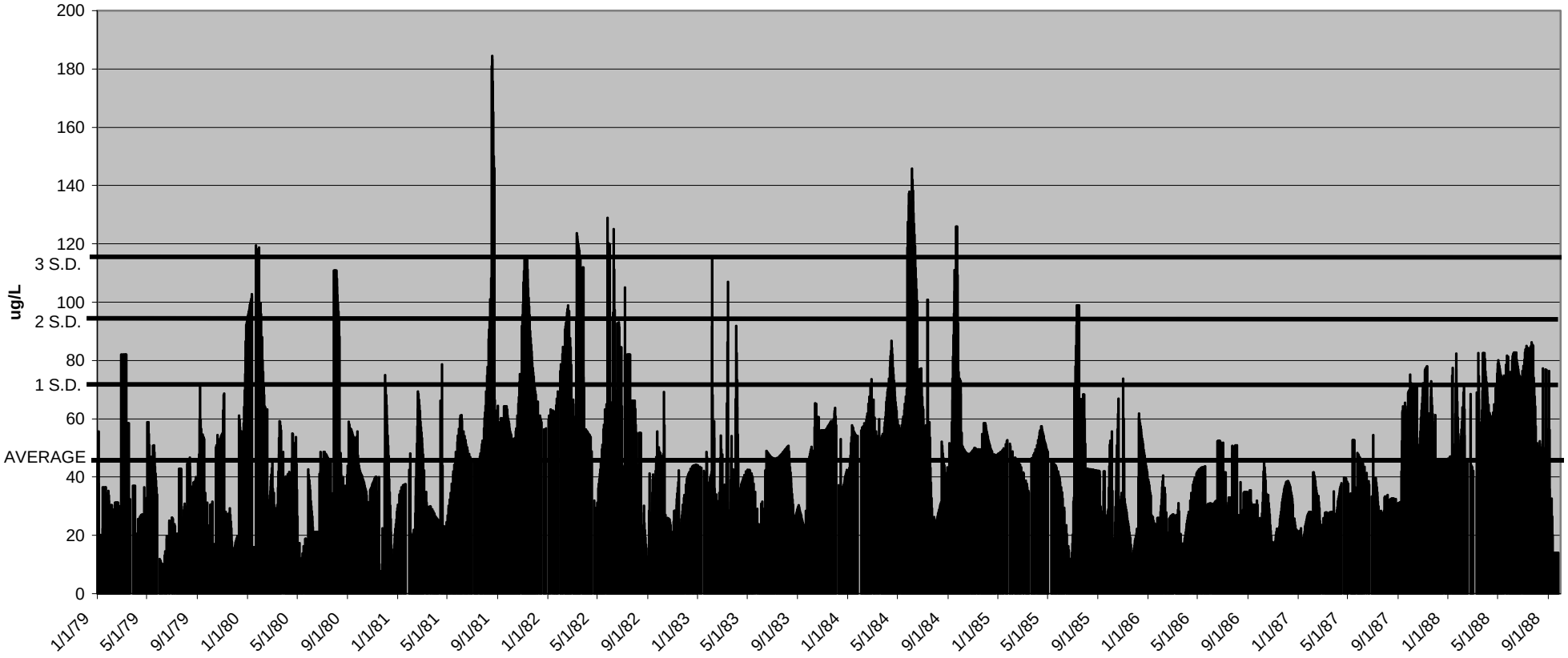


figure 5.4
ESTIMATED BASELINE STA 2 EFFLUENT (POST STA)
TOTAL PHOSPHORUS CONCENTRATION DATA

FIGURE 5.5
POST-BMP CONCEPTUAL DESIGN SCHEMATIC

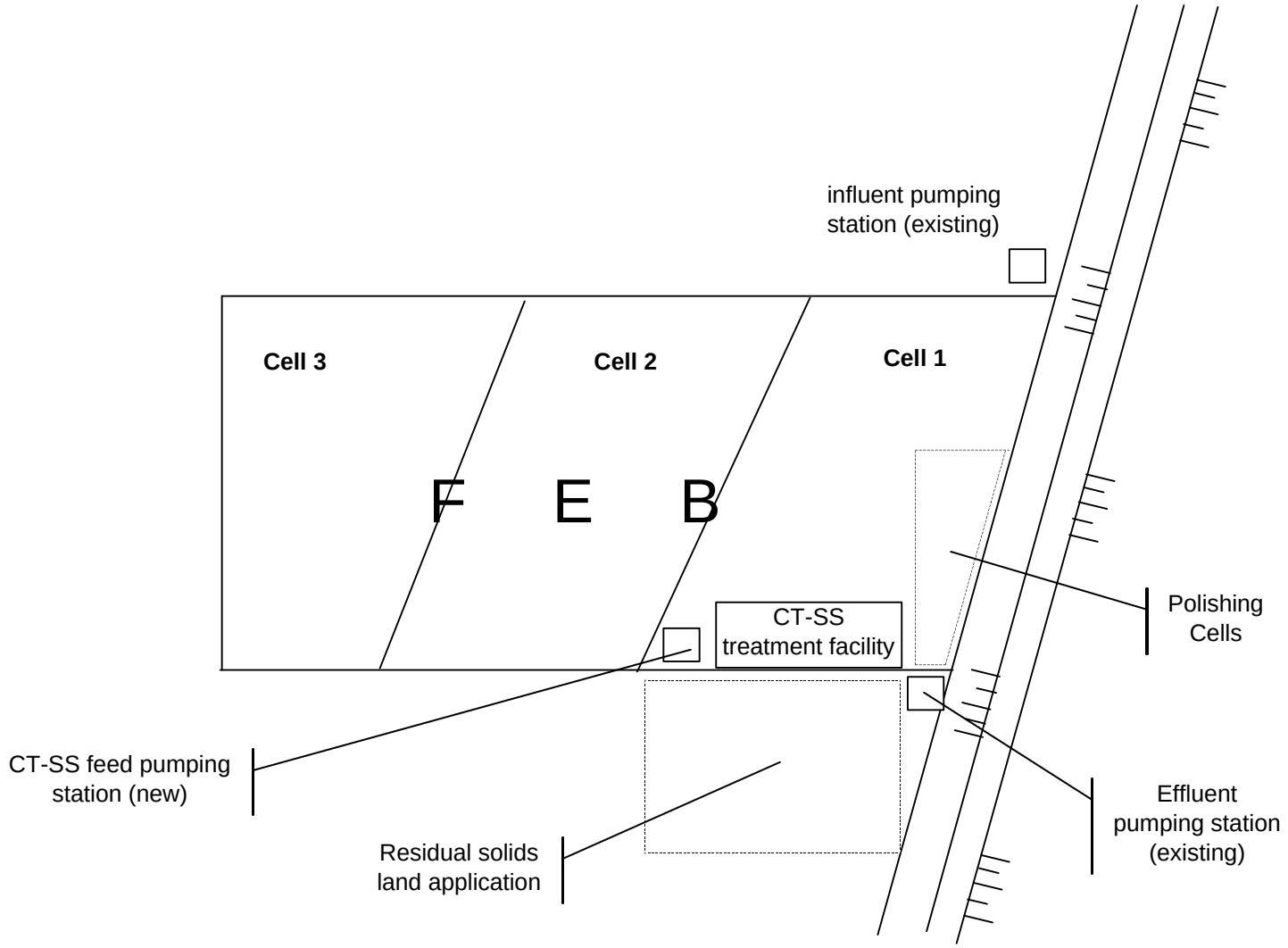


FIGURE 5.6
POST-STA CONCEPTUAL DESIGN SCHEMATIC

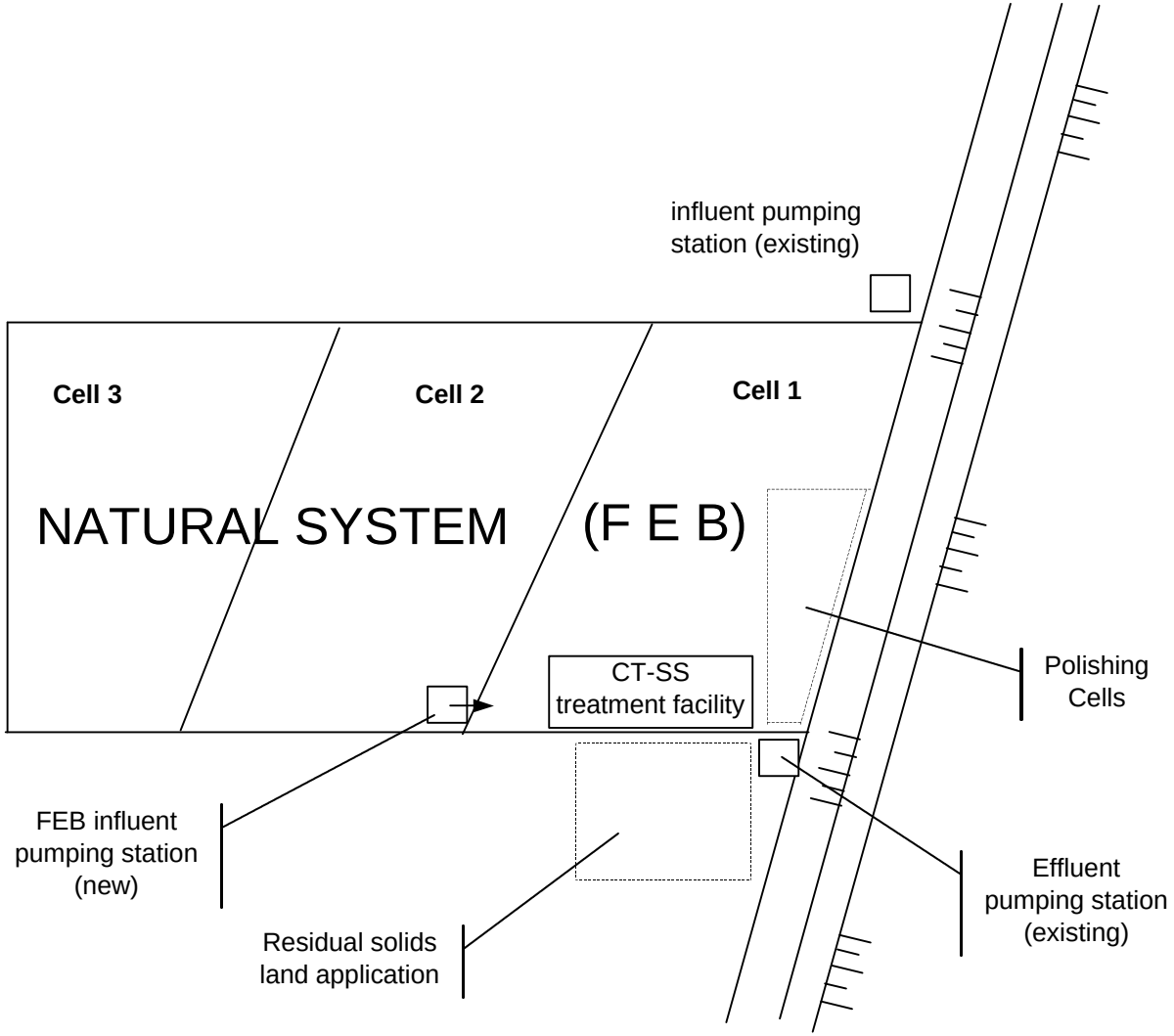


FIGURE 5.7

CONCEPTUAL DESIGN FOR FULL-SCALE POST-BMP AND POST-STA TREATMENT FACILITY

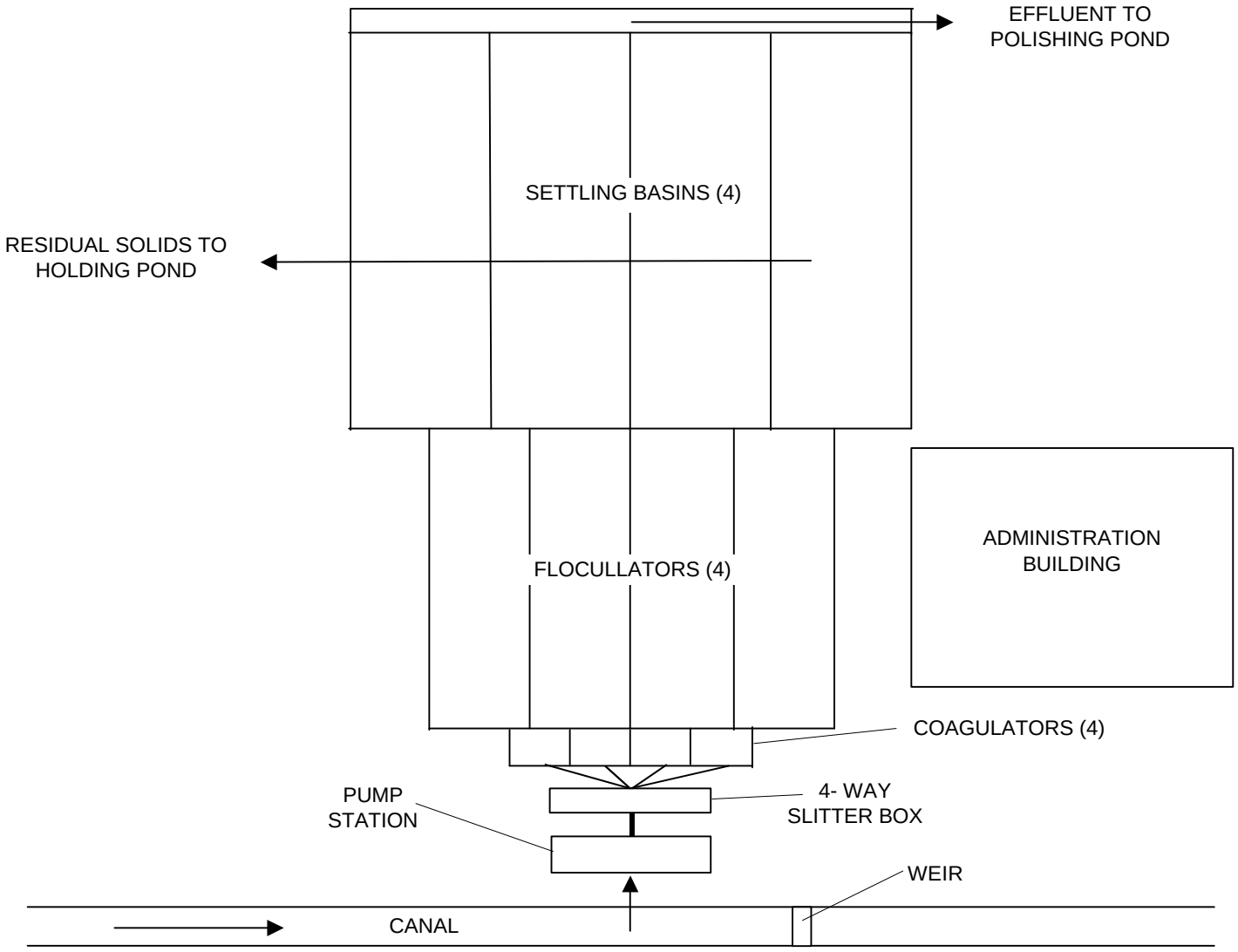


TABLE 5.1
Post-BMP Water Treatment System – Conceptual Design Criteria

Design		Plant Design (Average Day) Hydraulic Loading (MGD)					
Criteria	**Unit**	**120**	**150**	**200**	**220**	**270**	**380**
Feed Characteristics							
Peak Hydraulic Loading	MGD	180	225	300	330	405	570
Average Total Phosphorus Concentration	µg/L	122	122	122	122	122	122
Liquid Phase Temperature Range	°F	68 – 77	68 - 77	68 - 77	68 - 77	68 - 77	68 - 77
Treated Effluent							
Average Total Phosphorus Concentration	µg/L	20	20	10	20	10	10
Flow Equalization							
Surface Area	acres	6,000	6,000	6,000	6,000	6,000	6,000
Usable Depth	feet	4	4	4	4	4	4
Usable Volume	acre-feet	24,000	24,000	24,000	24,000	24,000	24,000
Excavation							
Coagulators	yd^3	214	283	361	389	480	692
Flocculators	yd^3	3,851	4,704	6,403	6,936	8,363	11,971
Clarifiers	yd^3	8,067	9,923	13,443	14,603	17,931	25,091
Flow Control Structure	yd^3	300	300	300	300	300	300
Reinforced Concrete							
Coagulators	yd^3	169	210	255	270	320	432
Flocculators	yd^3	2,095	2,502	3,300	3,548	4,207	5,852
Clarifiers	yd^3	4,169	5,030	6,644	7,171	8,675	11,878
Flow Control Structure	yd^3	200	200	200	200	200	200
Raw Water Pumping							
Design Pumping Capacity	MGD	180	225	300	330	405	570
Coagulation							
Velocity Gadient	sec^{-1}	1000	1000	1000	1000	1000	1000
Usable Volume	mil gallons	0.14	0.17	0.23	0.26	0.31	0.44
Energy Input	KW	513	658	877	965	1,166	1,658
	HP	687,933	882,378	1,176,057	1,294,065	1,563,606	2,223,378
Units	-	4	4	4	4	4	4
Flocculation							
Hydraulic Detention Time	Min	30	30	30	30	30	30
Gt	-	1.8E4-1.4E5	1.8E4-1.4E5	1.8E4-1.4E5	1.8E4-1.4E5	1.8E4-1.4E5	1.8E4-1.4E5
Usable Volume	mil gallons	2.5	3.1	4.2	4.6	5.6	7.9
Surface Area	Sqft	27,855	34,818	46,424	51,067	62,673	88,206
Energy Input	W	23,035	29,531	39,375	43,313	52,369	74,419
	HP	30,889	39,601	52,802	58,082	70,226	99,796
Units	-	4	4	4	4	4	4
Lamella Settling							
Average Usable Tank Depth	Ft	12	12	12	12	12	12
Clarifier loading rate	Gpm/Ft^2	0.14	0.14	0.14	0.14	0.14	0.14
Projected plate area	mil sqft	0.74	0.93	1.24	1.4	1.7	2.4
Surface Area	Sqft	58,905	73,590	98,010	107,745	132,330	186,120
Units	-	4	4	4	4	4	4
Chemical Feed System							
Coagulant Type	-	$FeCl_3$	$FeCl_3$	$FeCl_3$	$FeCl_3$	$FeCl_3$	$FeCl_3$
Average Coagulant Dosage	mg/L as metal	40	40	40	40	40	40
Minimum Coagulant Dosage	mg/L as metal	20	20	20	20	20	20
Maximum Coagulant Dosage	mg/L as metal	60	60	60	60	60	60
Waste Handling and Disposal*							
Usable Depth of Holding Cell	feet	4	4	4	4	4	4
Sludge Discharge Frequency	hr^{-1}	4 - 8	4 - 8	4 - 8	4 - 8	4 - 8	4 - 8
Hydraulic Detention Time	days	3	3	3	3	3	3
Sludge Holding Pond Volume	acre - feet	6.0	7.2	10.0	11.2	13.2	18.0
Sludge Holding Pond Usable Depth	feet	4	4	4	4	4	4
Sludge Holding Pond Surface Area	acres	1.5	1.8	2.5	2.8	3.3	4.5
Area of Farm Land Application	acres	< 100	< 130	< 170	< 190	< 230	< 330

Notes: * *based on: 1,720 lbs solids per million gallons treated @ 4 percent solids content*

TABLE 5.2
Post-STA Water Treatment System – Conceptual Design Criteria

Design Criteria	Unit	Plant Design (Average Day) Hydraulic Loading (MGD) 80	100	140	190	260	390
Feed Characteristics							
Peak Hydraulic Loading	MGD	120	150	210	285	390	585
Average Total Phosphorus Conc.	µg/L	65	65	65	65	65	65
Liquid Phase Temperature Range	°F	68 - 77	68 - 77	68 - 77	68 - 77	68 - 77	68 - 77
Treated Effluent							
Predicted Total Phosphorus Concentration	µg/L	20	20	20	10	10	10
Flow Equalization							
Surface Area	acres	1,500	1,500	1,500	1,500	1,500	1,500
Usable Depth	feet	4	4	4	4	4	4
Usable Volume	acre-feet	6,000	6,000	6,000	6,000	6,000	6,000
Excavation							
Coagulators	yd^3	155	193	259	334	449	692
Flocculators	yd^3	2,563	3,267	4,483	5,891	8,067	12,331
Clarifiers	yd^3	2,731	3,456	4,704	6,403	8,664	13,067
Flow Control Structure	yd^3	300	300	300	300	300	300
Reinforced Concrete							
Coagulators	yd^3	133	157	196	239	303	432
Flocculators	yd^3	1,468	1,814	2,397	3,061	4,071	6,015
Clarifiers	yd^3	1,608	1,698	2,576	3,387	4,446	6,472
Flow Control Structure	yd^3	200	200	200	200	200	200
Raw Water Pumping							
Design Pumping Capacity	MGD	120	150	210	285	390	585
Coagulation							
Velocity Gadient	sec^{-1}	1000	1000	1000	1000	1000	1000
Usable Volume	mil gallons	0.09	0.12	0.16	0.22	0.30	0.45
Energy Input	KW	329	430	614	816	1,118	1,723
	HP	441,189	576,630	823,374	1,094,256	1,499,238	2,310,543
Units	-	4	4	4	4	4	4
Flocculation							
Hydraulic Detention Time	Min	30	30	30	30	30	30
Gt	-	1.8E4-1.4E5	1.8E4-1.4E5	1.8E4-1.4E5	1.8E4-1.4E5	1.8E4-1.4E5	1.8E4-1.4E5
Usable Volume	mil gallons	1.7	2.1	2.9	4.0	5.4	8.1
Surface Area	sqft	18,570	23,212	32,497	44,103	60,351	90,527
Energy Input	W	14,766	19,294	27,563	36,619	50,203	77,372
	HP	19,801	25,873	36,961	49,106	67,323	103,756
Units	-	4	4	4	4	4	4
Lamella Settling							
Average Usable Tank Depth	Ft	12	12	12	12	12	12
Clarifier loading rate	Gpm/Ft^2	0.28	0.28	0.28	0.28	0.28	0.28
Projected plate area	mil sqft	0.25	0.31	0.43	0.59	0.81	1.2
Surface Area	Sqft	19,635	24,585	34,320	46,530	63,690	95,535
Units	-	4	4	4	4	4	4
Chemical Feed System							
Coagulant Type	-	$Al_2(SO_4)_3$	$Al_2(SO_4)_3$	$Al_2(SO_4)_3$	$Al_2(SO_4)_3$	$Al_2(SO_4)_3$	$Al_2(SO_4)_3$
Average Coagulant Dosage	mg/L as metal	20	20	20	20	20	20
Minimum Coagulant Dosage	mg/L as metal	10	10	10	10	10	10
Maximum Coagulant Dosage	mg/L as metal	30	30	30	30	30	30
Waste Handling and Disposal*							
Usable Depth of Holding Cell	feet	4	4	4	4	4	4
Sludge Discharge Frequency	hr^{-1}	4 - 8	4 - 8	4 - 8	4 - 8	4 - 8	4 - 8
Hydraulic Detention Time	days	3	3	3	3	3	3
Sludge Holding Pond Volume	acre - feet	3.2	3.2	5.2	6.0	8.0	12.0
Sludge Holding Pond Usable Depth	feet	4	4	4	4	4	4
Sludge Holding Pond Surface Area	acres	0.8	0.8	1.3	1.5	2.0	3.0
Area of Farm Land Application	acres	< 50	< 60	< 80	< 110	< 150	< 220

Notes: * *based on: 1,145 lbs solids per million gallons treated @ 4 percent solids content*

Table 5.3
Full Scale Cost Estimate Summary

	POST BMP					
	10 ppb effluent			20 ppb effluent		
10-year POR Flow Volume Diversion	0%	10%	20%	0%	10%	20%
Basis of Design - Size / capacities						
STA/"natural system" area, acres	0	0	0	0	0	0
FEB area, acres	6000	6000	6000	6000	6000	6000
Treatment plant, solids thickening, buffer cell area, acres	430	430	430	430	430	430
Total land area (inside STA-2), acres	6430	6430	6430	6430	6430	6430
Residual solids disposal area, acres	1681	1499	1326	1508	1311	1151
Total land area (outside of existing STA), acres	1681	1499	1326	1508	1311	1151
FEB influent PS capacity, mgd	0	0	0	2	0	0
FEB influent PS average flow, mgd	0	0	0	0	0	0
Treatment plant influent PS capacity, mgd	570	405	300	330	225	180
Treatment Plant influent PS average flow, mgd	380	270	200	220	150	120
Capital Costs, $ million						
FEB influent pumping station	0.0	0.0	0.0	0.0	0.0	0.0
Treatment plant influent pump station	14.3	11.2	9.0	9.7	7.3	6.1
Treatment plant	40.1	28.3	21.2	23.1	15.8	12.9
Chemical feed system	1.0	0.7	0.5	0.6	0.4	0.3
Residual solids treatment and disposal	7.6	5.4	4.0	4.4	3.0	2.4
Telemetry	0.1	0.1	0.1	0.1	0.1	0.1
Administrative / sampling & monitoring facilities	0.5	0.5	0.5	0.5	0.5	0.5
Subtotal	63.6	46.2	35.3	38.4	27.1	22.3
Construction contingencies (20 percent)	12.7	9.2	7.1	7.7	5.4	4.5
Subtotal, construction costs	76.3	55.4	42.4	46.1	32.5	26.8
Engineering (15 percent)	11.4	8.3	6.4	6.9	4.9	4.0
Land purchase - solids disposal	6.8	6.1	5.4	6.1	5.3	4.7
Total Capital Cost	94.6	69.9	54.1	59.1	42.7	35.5
Present Worth - Capital Cost	94.6	69.9	54.1	59.1	42.7	35.5
O&M Costs, $ million/yr						
FEB influent pumping station	0.0	0.0	0.0	0.0	0.0	0.0
Treatment plant influent pump station	2.5	1.8	1.3	1.5	1.0	0.8
Chemicals	5.2	4.6	4.1	4.6	4.0	3.5
Maintenance levees	0.1	0.1	0.1	0.1	0.1	0.1
Maintenance FEB	0.1	0.1	0.1	0.1	0.1	0.1
Residual solids treatment and disposal	0.5	0.3	0.3	0.3	0.2	0.2
Electric	0.4	0.4	0.3	0.3	0.3	0.3
Labor	0.7	0.7	0.6	0.6	0.6	0.6
Treatment plant sampling and monitoring	0.3	0.3	0.3	0.3	0.3	0.3
Total Annual O&M Cost	9.8	8.3	7.1	7.8	6.6	5.9
Present Worth - Annual O&M Cost	210.7	178.5	152.7	167.7	141.9	126.9
Present Worth - Replacement Costs, $ million						
Total Present Worth - Replacement Costs	10.4	7.6	5.8	6.3	4.4	3.6
Salvage Value, $ million						
Net Salvage value	24.9	20.5	17.4	18.8	15.6	13.9
Present Worth - Salvage Value	3.5	2.9	2.4	2.6	2.2	2.0
50 - Year Present Worth, $ million						
Capital Cost	94.6	69.9	54.1	59.1	42.7	35.5
O&M Cost	210.7	178.5	152.7	167.7	141.9	126.9
Replacement Cost	10.4	7.6	5.8	6.3	4.4	3.6
Salvage Value	3.5	2.9	2.4	2.6	2.2	2.0
Total	312.2	253.0	210.1	230.4	186.8	164.0
Present worth, $/million gallons treated	112.5	102.2	95.9	92.5	86.3	86.3
Present worth, $/pound P removed	115.5	108.8	103.6	93.4	88.7	88.8

Table 5.4
Full Scale Cost Estimate Summary

	POST STA					
	10 PPB effluent			20 PPB effluent		
10-year POR Flow Volume Diversion	0%	10%	20%	0%	10%	**20%**
Basis of Design - Size / capacities						
STA/"natural system" area, acres	4440	4440	4440	4440	4440	4440
FEB area, acres	1500	1500	1500	1500	1500	1500
Treatment plant, solids thickening, buffer cell area, acres	490	490	490	490	490	490
Total land area (inside STA-2), acres	6430	6430	6430	6430	6430	6430
Residual solids disposal area, acres	911	798	704	623	520	446
Total land area (outside of existing STA), acres	911	798	704	623	520	446
FEB influent PS capacity, mgd	585	390	285	210	150	120
FEB influent PS average flow, mgd	390	260	190	140	100	80
Treatment plant influent PS capacity, mgd	585	390	285	210	150	120
Treatment Plant influent PS average flow, mgd	390	260	190	140	100	80
Capital Costs, $ million						
FEB influent pumping station	11.7	8.8	7.0	5.5	4.3	3.6
Treatment plant influent pump station	14.5	10.9	8.7	6.9	5.3	4.5
Treatment plant	23.5	15.5	11.5	8.5	6.4	5.0
Chemical feed system	0.6	0.4	0.3	0.2	0.2	0.1
Residual solids treatment and disposal	7.8	5.2	3.8	2.8	2.0	1.6
Telemetry	0.1	0.1	0.1	0.1	0.1	0.1
Administrative / sampling & monitoring facilities	0.5	0.5	0.5	0.5	0.5	0.5
Subtotal	58.7	41.4	31.9	24.5	18.8	15.4
Construction contingencies (20 percent)	11.7	8.3	6.4	4.9	3.8	3.1
Subtotal, construction costs	70.4	49.7	38.3	29.4	22.6	18.5
Engineering (15 percent)	10.6	7.5	5.7	4.4	3.4	1.8
Land purchase - solids disposal	3.7	3.2	2.9	2.5	2.1	1.8
Total Capital Cost	84.7	60.3	46.9	36.3	28.0	22.1
Present Worth - Capital Cost	84.7	60.3	46.9	36.3	28.0	22.1
O&M Costs, $ million/yr						
FEB influent pumping station	2.0	1.3	1.0	0.7	0.5	0.4
Treatment plant influent pump station	2.6	1.7	1.3	0.9	0.7	0.5
Chemicals	4.9	4.2	3.7	3.3	2.8	2.4
Maintenance levees	0.1	0.1	0.1	0.1	0.1	0.1
Maintenance FEB	0.1	0.1	0.1	0.1	0.1	0.1
Residual solids treatment and disposal	0.5	0.3	0.2	0.2	0.1	0.1
Electric	0.3	0.3	0.2	0.2	0.2	0.1
Labor	0.7	0.7	0.6	0.6	0.6	0.6
Treatment plant sampling and monitoring	0.3	0.3	0.3	0.3	0.3	0.3
Total Annual O&M Cost	11.5	9.0	7.5	6.4	5.4	4.6
Present Worth - Annual O&M Cost	247.3	193.5	161.3	137.6	116.1	98.9
Present Worth - Replacement Costs, $ million						
Total Present Worth - Replacement Costs	12.0	5.9	4.5	3.5	2.6	2.1
Salvage Value, $ million						
Net Salvage value	20.6	16.5	14.1	12.2	10.6	9.5
Present Worth - Salvage Value	2.9	2.3	2.0	1.7	1.5	1.3
50 - Year Present Worth, $ million						
Capital Cost	84.7	60.3	46.9	36.3	28.0	22.1
O&M Cost	247.3	193.5	161.3	137.6	116.1	98.9
Replacement Cost	12.0	5.9	4.5	3.5	2.6	2.1
Salvage Value	2.9	2.3	2.0	1.7	1.5	1.3
Total	341.1	257.4	210.7	175.7	145.3	121.7
Present worth, $/million gallons treated	150.9	130.0	120.7	113.7	112.6	110.2
Present worth, $/pound P removed	298.1	259.0	243.3	187.5	181.1	172.4